International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 10 Issue 11, November-2021, Impact Factor: 7.957

The Essential Role of Low-Carbon Building Materials in Achieving Sustainable Development

Chaitanya Korra

University of New Mexico

Corresponding authors: Chaitanya Korra, University of New Mexico, E-mail: chaitanyakorra@gmail.com

ABSTRACT

In the face of a growing environmental crisis, the imperative for sustainable practices has never been more pronounced, particularly within the realms of the construction industry—a sector historically synonymous with significant carbon emissions and environmental degradation. This paper embarks on a comprehensive exploration of the pivotal role that low-carbon building materials occupy in the vanguard of modern construction's shift towards sustainable development. Through an exhaustive analysis, this research meticulously evaluates a spectrum of low-carbon materials, spotlighting not only their potential to drastically curtail the construction sector's carbon footprint but also their capability to forge buildings that are environmentally benign, economically viable, and socially beneficial. Integral to this exploration is innovative procurement strategies that underscore the importance of sustainability from material selection through to construction, along with a thorough examination of the multifaceted challenges and opportunities that accompany the adoption of these materials. The discourse extends to include illuminating case studies that exemplify the successful integration of low-carbon materials in construction projects. These real-world applications serve to demonstrate the multifarious advantages—ranging from economic savings and environmental conservation to the promotion of social equity and well-being—that low-carbon materials offer. Collectively, these insights not only highlight the critical benefits associated with the use of such materials but also propose a strategic blueprint for an industry-wide transformation. This transformation is envisaged to propel the construction industry towards a more sustainable future, aligning with broader global sustainability objectives and contributing to the mitigation of the ongoing environmental crisis.

Keywords: Sustainable Construction, Low-Carbon Building Materials, Embodied Carbon, Carbon Sequestration in Construction, Green Building Certifications, Lifecycle Assessment (LCA), Environmental Product Declarations (EPDs), Circular Economy in Construction, Renewable Resources in Building Materials, Construction Industry Sustainability, Greenhouse Gas Emissions Reduction, Sustainable Material Procurement, Bio-Based Insulation Materials, Cross-Laminated Timber (CLT), Low-VOC Paints and Finishes, Adaptive Reuse and Building Sustainability, Technological Innovations in Sustainable Materials

INTRODUCTION

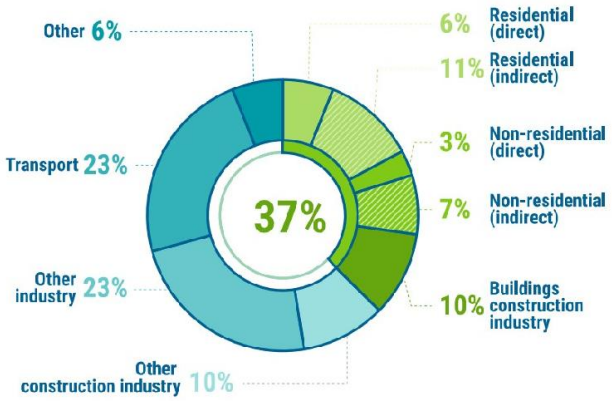
The construction industry, historically a significant contributor to global carbon emissions, finds itself at an inflection point, necessitated by the escalating environmental crisis. This industry, responsible for nearly 39% of global CO2 emissions, with a significant portion attributed to embodied carbon, faces the dual challenge of mitigating its environmental impact while catering to the world's growing infrastructure needs.The transition to low-carbon building materials represents a crucial strategy in this endeavor, promising to redefine the industry's approach to sustainability. Low-carbon building materials represent a class of construction materials designed with a primary focus on minimizing the carbon footprint associated with their production, use, and disposal. These materials are pivotal in reducing embodied carbon—defined as the total greenhouse gas emissions resulting from the extraction, manufacture, transportation, installation, maintenance, and disposal of building materials. By leveraging renewable resources, recycling materials, and employing innovative manufacturing processes that emit significantly lower levels of carbon dioxide, low-carbon materials offer a sustainable alternative to traditional construction materials such as conventional concrete, steel, and wood products.Moreover, the adoption of low-carbon materials is increasingly driven by regulatory requirements, market demand for green buildings, and a growing awareness of the environmental impacts of construction activities.

This paper aims to explore the pivotal role that low-carbon building materials play in the modern construction landscape towards achieving sustainable development. It seeks to provide a comprehensive overview of the types of low-carbon materials currently available, strategies for their procurement and use, and the challenges and opportunities associated with their implementation. Through an examination of case studies and best practices, this research intends to illustrate the tangible benefits of low-carbon materials not only in reducing the carbon footprint of construction projects but also in promoting economic, environmental, and social sustainability. By doing so, the paper aspires to contribute to the discourse on sustainable construction and to encourage further innovation and adoption of low-carbon building materials in the industry.

The Case for Low-Carbon Materials

The case for incorporating low-carbon materials into the construction and building sectors is captivating and multifaceted.The adoption of these materials directly addresses the urgent need for sustainability in the built environment.

Environmental Impact of Building Materials: Building materials significantly influence the environmental footprint of the construction industry. Traditional materials such as concrete, steel, and aluminum are associated with high levels of carbon emissions during their production processes, contributing to global warming and climate change. The extraction of raw materials required for these conventional building components further leads to biodiversity loss, soil erosion, and water depletion. The construction industry can dramatically reduce its environmental impact by transitioning to low-carbon materials. These materials, including mass timber, low-carbon concrete, and recycled steel, offer reduced greenhouse gas emissions during production and can often be sourced more sustainably. Moreover, many low-carbon materials provide additional environmental benefits, such as improved energy efficiency and the potential for carbon sequestration, further mitigating the industry's impact on the planet.



Reference: Share of global greenhouse gas emissions. Source: Buildings & Construction share of energy related CO2 emissions,2020

Role in Achieving Sustainability Goals: Low-carbon building materials are integral to achieving broad sustainability goals within the construction industry and beyond. They not only help to minimize the sector's carbon footprint but also contribute to creating healthier, more resilient built environments. Sustainable materials can improve indoor air quality, enhance building occupants' comfort and well-being, and reduce energy consumption through better insulation and thermal properties. Furthermore, the use of renewable and recyclable materials supports a circular economy, promoting resource efficiency and waste reduction. By adopting low-carbon materials, the construction industry can move towards more sustainable, equitable, and environmentally friendly practices, aligning with global sustainability targets such as the United Nations Sustainable Development Goals (SDGs).

Regulatory and Market Drivers: The shift towards low-carbon building materials is increasingly supported by both regulatory frameworks and market forces. Governments around the world are implementing stricter regulations on carbon emissions and environmental impact, incentivizing the use of sustainable materials through policies, building codes, and green certification programs like LEED and BREEAM. These regulatory measures are complemented by growing market demand for green, sustainable buildings driven by environmental consciousness among consumers, investors, and corporate tenants. Companies are seeking to enhance their corporate social responsibility (CSR) profiles and meet ESG (Environmental, Social, and Governance) criteria, further fueling the demand for buildings constructed with low-carbon materials. Additionally, technological advancements and innovations in material science are making sustainable materials more accessible and cost-effective, enabling wider adoption across the construction industry.

Together, these factors create a strong case for the adoption of low carbon building materials, marking a crucial step towards a more sustainable and environmentally responsible construction sector.

Types of Low -Carbon materials

The exploration of low-carbon materials is pivotal in the architecture and construction fields, promising revolutionary changes in how we build and conceive our living spaces.

A. Innovations in Concrete and Steel

1. **CarbonCure Technologies and the Injection of CO2**
   CarbonCure's groundbreaking technology introduces recycling CO2 into fresh concrete to react with calcium ions in cement to form calcium carbonate, a process that permanently embeds CO2 within the concrete. This not only reduces the carbon footprint by sequestering CO2 but also enhances the compressive strength of concrete, allowing for less cement use and further decreasing emissions. The scalable nature of this technology makes it a potent tool in the battle against climate change, with the potential to transform concrete, one of the most widely used materials on the planet, into a medium for carbon sequestration.
2. **Recycled Steel and Low-Carbon Concrete**
   Recycling steel plays a crucial role in reducing the construction industry's carbon footprint, as it significantly decreases the energy required for steel production, which traditionally involves coal-intensive processes. Recycled steel maintains its structural integrity, offering a sustainable alternative without compromising quality. Similarly, low-carbon concrete mixes that replace a portion of Portland cement with supplementary cementitious materials (SCMs) like fly ash, slag, or calcined clays, reduce the carbon emissions associated with concrete production, pushing towards greener construction methodologies.

B. Wood and Composite Alternatives

1. **Cross-Laminated Timber (CLT) from Locally Sourced Wood**
   CLT represents a major innovation in building materials, made by layering lumber in perpendicular layers and bonding them to create strong, structural panels. Utilizing locally sourced wood not only reduces transportation emissions but also supports local economies and sustainable forest management practices. CLT buildings sequester carbon, reducing the overall carbon footprint of construction projects and providing a renewable alternative to traditional building materials like concrete and steel.The use of wood and composite materials in construction offers not just environmental advantages but also enhances human well-being through biophilic design. The natural appearance and warmth of wood contribute to healthier, more comfortable indoor environments. Structurally, materials like CLT provide exceptional strength and flexibility, making them suitable for a wide range of applications from residential to commercial and high-rise buildings.

C. Insulation and Finishing Materials

1. **Bio-based and Mycelium Insulation**
   Emerging as a novel solution, bio-based and mycelium insulation materials offer effective thermal and acoustic performance while being made from renewable resources. Mycelium, the root structure of fungi, can be grown into insulation panels using agricultural waste, providing a compostable and low-embodied-carbon alternative to synthetic insulation materials. These innovations not only contribute to building energy efficiency but also align with principles of circular economy and biodegradability.
2. **Low-VOC Paints and Finishes**
   Volatile organic compounds (VOCs) in paints and finishes can significantly impact indoor air quality and health. The development of low-VOC and VOC-free paints and finishes addresses these concerns, providing safer indoor environments without sacrificing quality or durability. These products are essential for green building certifications and are becoming the standard for environmentally conscious construction projects, reflecting a broader move towards materials that support both ecological and human health.

The shift towards low-carbon materials in construction is supported by innovations across a spectrum of materials, offering viable paths to sustainability without compromising on performance or aesthetics. These materials not only address the environmental impact of construction but also contribute to healthier living spaces and a more sustainable relationship with our planet.

Strategies for Procurement and Use

The strategic procurement and use of low-carbon materials are crucial for advancing sustainability in construction. These strategies not only contribute to the environmental performance of buildings but also support broader sustainability goals.

A. LEED Certification and Material Selection

1. Embodied Carbon Intensity Calculation

Calculating the embodied carbon intensity of materials involves assessing the total greenhouse gas emissions associated with each stage of a material's life cycle, from extraction through manufacturing, transportation, installation, and disposal. This comprehensive approach enables project teams to identify and prioritize the use of materials with the lowest possible carbon footprint. The LEED (Leadership in Energy and Environmental Design) certification system encourages this practice by offering credits for projects that demonstrate a reduction in embodied carbon. Tools like the Embodied Carbon in Construction Calculator (EC3) can be instrumental in this process, allowing teams to compare the embodied carbon of similar products and make informed decisions.

			Materials and Resources	19
Y			Storage and Collection of Recyclables	Required
Y			PBT Source Reduction- Mercury	Required
			Building Life-Cycle Impact Reduction	5
			Environmental Product Declarations	2
			Sourcing of Raw Materials	2
			Material Ingredients	2
			PBT Source Reduction- Mercury	1
			PBT Source Reduction- Lead, Cadmium, and Copper	2
			Furniture and Medical Furnishings	2
			Design for Flexibility	1
			Construction and Demolition Waste Management	2

			Energy and Atmosphere	35
Y			Fundamental Commissioning and Verification	Required
Y			Minimum Energy Performance	Required
Y			Building-Level Energy Metering	Required
Y			Fundamental Refrigerant Management	Required
			Enhanced Commissioning	6
			Optimize Energy Performance	20
			Advanced Energy Metering	1
			Grid Harmonization	2
			Renewable Energy	5
			Enhanced Refrigerant Management	1

Reference: LEED v4 BD+C scorecard

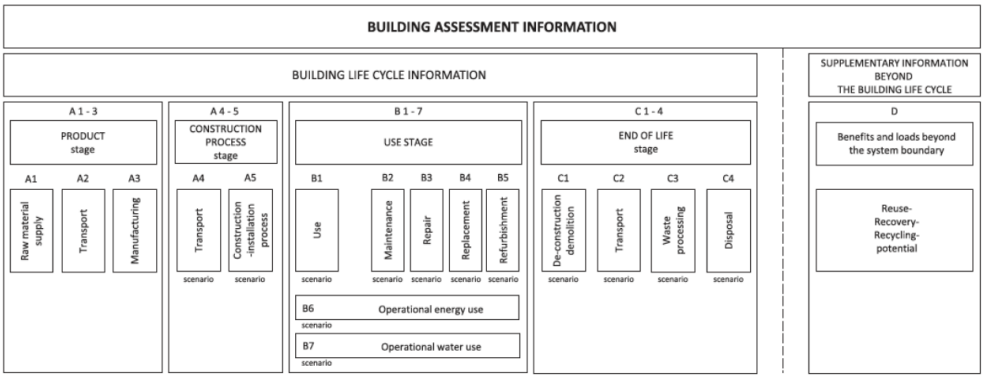
2. Verification and Reduction Strategies

Verification of embodied carbon reductions is critical to ensure that the calculated improvements align with reality. This process often involves third-party certification or validation of environmental product declarations (EPDs) which detail the carbon impact of materials. Reduction strategies may include optimizing material use through efficient design, selecting alternative materials with lower carbon footprints, and incorporating recycled or renewable resources. LEED provides a framework for recognizing these efforts, and motivating project teams to pursue innovative solutions that contribute to carbon reduction.

B. Sustainable Sourcing Practices

1. Importance of Transparency and Environmental Product Declarations (EPDs)

Transparency in material sourcing is fundamental to achieving sustainability objectives. Environmental Product Declarations (EPDs) play a key role in this process by offering a standardized way to communicate the environmental impact of products, including their embodied carbon. EPDs are based on a life cycle assessment (LCA) and provide a comprehensive overview of a product's environmental performance. By prioritizing materials with EPDs, project teams can make more informed choices that support sustainability goals. Furthermore, the demand for EPDs encourages manufacturers to assess and improve their products, driving the industry towards more sustainable practices.



Reference: Building life cycle stages from BS EN 15978:2011

2. Case Study: Salesforce Tower Chicago's Material Strategy

Salesforce Tower Chicago exemplifies sustainable sourcing practices through its material strategy, achieving significant reductions in embodied carbon. The project team prioritized the use of materials with verified low carbon footprints, leveraging EPDs to guide their selection. One of the key strategies was the use of low-carbon concrete, which incorporated innovative additives to reduce the cement content without compromising strength. Additionally, the project utilized recycled steel, further contributing to its embodied carbon reduction. This approach not only resulted in a 19 percent reduction in embodied carbon compared to a baseline but also demonstrated the feasibility and benefits of sustainable material procurement in large-scale projects. Salesforce Tower Chicago serves as a compelling example of how transparent

sourcing practices and strategic material selection can align with both LEED certification goals and broader sustainability objectives.

These strategies for the procurement and use of low-carbon materials underscore the importance of thoughtful material selection in reducing the environmental impact of construction projects. By embracing these practices, the construction industry can make significant strides towards sustainability and contribute to the global effort to combat climate change.

Challenges and Solutions

A. Data and Transparency Issues

Challenges: A major hurdle in adopting low-carbon materials is the lack of comprehensive, standardized data on the environmental impact of construction materials. This gap makes it difficult for project teams to make informed decisions. Additionally, the construction industry has been slow in adopting digital tools that could enhance data sharing and transparency.

Solutions: Advancing the development and use of environmental product declarations (EPDs) is crucial. EPDs provide detailed information on the environmental impact of products, including their carbon footprint. Standardization of EPDs across industries would enable easier comparison and selection of low-carbon materials. Furthermore, investing in digital platforms for sharing and analyzing construction material data could significantly improve transparency and decision-making.

B. Collaborative Efforts Among Stakeholders

Challenges: The fragmented nature of the construction industry, with its many independent contractors and suppliers, often hampers efforts to adopt sustainable practices. A lack of alignment on sustainability goals across stakeholders can impede the procurement of low-carbon materials.

Solutions: Building strong collaborative networks among all stakeholders—developers, architects, contractors, suppliers, and regulatory bodies—is key. Joint sustainability workshops and shared goal-setting sessions can align stakeholders' objectives. Implementing project delivery methods that encourage collaboration, such as Integrated Project Delivery (IPD), can also foster a shared commitment to using low-carbon materials.

C. Technological and Material Innovations

Challenges: Despite the potential of low-carbon materials to revolutionize the industry, the pace of research, development, and approval of new materials can be slow. Regulatory bodies may be hesitant to approve new materials without extensive testing, delaying their market entry.

Solutions: Increasing investment in research and development of sustainable materials is essential. Partnerships between academic institutions, industry players, and government agencies can accelerate innovation. Encouraging pilot projects to test new materials in real-world settings can provide the necessary data to gain regulatory approval. Additionally, creating fast-track approval processes for materials with proven low-carbon benefits could expedite their adoption.

D. Case Study: Gensler's Adaptive Use Projects

Challenges: Gensler faced the challenge of repurposing existing1960s-era telecom building in downtown Denverstructure to meet modern needs and sustainability goals. This required overcoming the preconception that new construction is preferable to adaptive reuse and addressing the complexities of integrating modern systems into older buildings.

Solutions: Gensler demonstrated that adaptive reuse could significantly reduce embodied carbon emissions by preserving the structural elements of buildings. By retaining the concrete and steel framework of the 12-story, 230,000 SF vacant telecom building, Gensler reduced embodied carbon emissions by 68% compared to new construction. The project emphasized the importance of creativity in design and the potential of existing buildings to contribute to sustainability goals. Gensler's approach included comprehensive assessments of buildings' potential for reuse, integrating sustainable materials in the renovation process, and applying modern design principles to enhance the functionality and energy efficiency of the space.

These examples highlight that while challenges to implementing low-carbon materials in construction are significant, they are surmountable with focused effort, innovation, and collaboration. By addressing these challenges head-on, the construction industry can make substantial progress toward sustainability and significantly contribute to global efforts to combat climate change.

Economic and Environmental Benefits
The use of low-carbon materials can lead to cost savings over the lifecycle of a building. Although initial investments may be higher, the operational costs, including energy consumption, maintenance, and eventual decommissioning, can be significantly lower. This shift also opens new markets and business opportunities, encouraging innovation and job creation in green technologies.

Incorporating low-carbon materials substantially reduces the carbon footprint of construction projects, directly contributing to the mitigation of climate change. It also lessens the depletion of natural resources, reduces waste, and often leads to improved land and water management practices. The cumulative effect is a significant contribution towards global sustainability goals and a healthier planet.

Health and Well-being Improvements
The adoption of low-carbon materials often correlates with healthier building practices, such as the use of non-toxic, natural materials that improve indoor air quality. Buildings designed with natural light, improved ventilation, and materials that do not emit volatile organic compounds (VOCs) contribute to a better indoor environment. This can lead to improvements in the health and well-being of occupants, including reduced illness and enhanced mental health, productivity, and comfort levels.

Social Equity Considerations
By prioritizing materials that are locally sourced and produced, the construction industry can support local economies and communities, providing jobs and fostering economic development in often underprivileged areas.Also, Buildings constructed with low-carbon materials tend to have better indoor environmental quality, which is particularly important in low-income housing projects. This approach addresses health disparities by ensuring all communities have access to high-quality, healthy living environments.

Sustainable construction practices raise awareness about environmental issues and the importance of sustainability in the broader community. Educational programs and community involvement in green building projects can empower individuals and foster a culture of sustainability.

Regulatory Impacts and Future Directions
Governments worldwide are recognizing the importance of sustainable construction in achieving national and international environmental targets. Increasingly stringent regulations on carbon emissions and building standards are driving the adoption of low-carbon materials. These regulations not only mandate certain practices but often provide incentives for exceeding baseline sustainability measures. And as the industry continues to evolve, we can expect to see an increase in the innovation and use of sustainable materials. Future directions may include the development of new materials with even lower carbon footprints, advanced recycling technologies, and the integration of smart technologies to further reduce energy use and emissions. The industry is moving towards a more holistic understanding of sustainability, where economic, environmental, and social factors are considered in concert, leading to a more resilient and equitable future.

The impact of low-carbon materials extends beyond the construction site, influencing economic trends, environmental conservation, social well-being, and regulatory landscapes. By embracing these materials and the principles they represent, the industry plays a crucial role in shaping sustainable, healthy, and equitable communities for future generations.

Case Studies
A. First United Bank's Mass Timber Branches
First United Bank's decision to construct its branches using mass timber technology marked a pioneering move towards sustainability in the banking sector. The Fredericksburg, Texas, branch became the first in the state to be built entirely from cross-laminated timber (CLT) sourced from southern yellow pine, a local and rapidly renewable resource. This choice not only reduced the carbon footprint associated with the construction but also showcased the aesthetic and biophilic benefits of mass timber, creating a warm and inviting atmosphere for customers. The success of this project led to the construction of additional mass timber branches, reinforcing First United Bank's commitment to sustainability and serving as a model for the financial industry.

B. Salesforce Tower Chicago: Embodied Carbon Reduction
Salesforce Tower Chicago achieved a remarkable 19% reduction in embodied carbon compared to a baseline scenario, setting a new standard for skyscrapers in urban environments. This reduction was accomplished through strategic material selection, including the use of low-carbon concrete and recycled steel. Furthermore, the project's focus on sustainable sourcing practices, guided by rigorous environmental product declarations (EPDs), exemplified how transparency and

informed decision-making can significantly impact a building's carbon footprint. The project stands as a testament to Salesforce's dedication to sustainability and its influence on the construction industry.

C. Microsoft's Campus Modernization: Carbon and Material Transportation

Microsoft's campus modernization project in Redmond, Washington, illustrates the importance of considering all aspects of a project's carbon footprint, including material transportation and construction activities. By closely monitoring these factors, the project team identified that construction activities contributed significantly more to the project's overall embodied carbon than initially estimated. This insight led to the exploration of alternative transportation methods and fuels to reduce on-site carbon emissions. The project underscores the critical role of comprehensive carbon accounting and innovative carbon reduction strategies in large-scale modernization efforts.

These case studies highlight the diverse strategies and benefits associated with the use of low-carbon materials in construction. From the pioneering use of mass timber and the strategic reduction of embodied carbon in skyscrapers to the comprehensive carbon management in campus modernization and the innovative approach to adaptive reuse, these examples provide valuable lessons for the industry. They underscore the importance of commitment, innovation, and collaboration among all stakeholders in driving the construction industry towards a more sustainable future.

CONCLUSIONS

As we stand on the cusp of a sustainability revolution in the construction sector, the transition to low-cararbon building materials presents an unparalleled opportunity to align industry practices with global sustainability goals. The findings of this research underscore the multifaceted benefits of low-carbon materials, highlighting their pivotal role in shaping a sustainable, resilient, and equitably built environment.

The future of construction with low-carbon materials is promising and is expected to be characterized by increased innovation, regulation, and market demand for sustainable buildings. Technological advancements will likely lead to the development of new materials and the improvement of existing ones, making low-carbon options more accessible and cost-effective. Regulatory frameworks will evolve to not only mandate the use of sustainable materials but also to incentivize practices that go beyond the minimum requirements. Consumer and investor demand for green buildings will continue to grow, pushing the industry towards more sustainable practices. As digital tools and platforms become more prevalent, the ability to track and verify the sustainability credentials of materials will improve, facilitating more informed decision-making.

Call to Action for the Construction Industry

The construction industry stands at the forefront of the fight against climate change and the pursuit of sustainable development. To capitalize on the opportunities presented by low-carbon materials, the industry must:

1. **Embrace Innovation and Collaboration**: Engage in research and development, form partnerships across sectors, and participate in knowledge-sharing initiatives to drive the advancement of sustainable materials.
2. **Prioritize Transparency**: Adopt and support the use of environmental product declarations (EPDs) and other tools that enhance the transparency of material sourcing and production processes.
3. **Adopt and Advocate for Supportive Policies**: Work with governments and regulatory bodies to develop policies that support the use of low-carbon materials, including incentives for their adoption and guidelines for their implementation.
4. **Educate and Train**: Invest in education and training for all stakeholders in the construction process, from architects and builders to suppliers and clients, to ensure they have the knowledge and skills to effectively utilize low-carbon materials.
5. **Lead by Example**: Implement sustainable practices in projects, demonstrate the feasibility and benefits of low-carbon materials, and share success stories to inspire broader industry change.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

REFERENCES

[1]. Abergel, T., Dean, B., &Dulac, J. (2017). Global Status Report 2017: Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Alliance for Buildings and Construction.
[2]. Ali, Y., &Nsairat, S. F. A. (2009). Developing a green building assessment tool for developing countries – Case of Jordan. Building and Environment, 44(5), 1053-1064.
[3]. Churkina, G., Organschi, A., Reyer, C. P. O., Ruff, A., Vinke, K., Liu, Z., Reck, B. K., Graedel, T. E., &Schellnhuber, H. J. (2020). Buildings as a global carbon sink. Nature Sustainability, 3(4), 269-276.
[4]. Ding, G. K. (2008). Sustainable construction—The role of environmental assessment tools. Journal of Environmental Management, 86(3), 451-464.
[5]. Guggemos, A. A., & Horvath, A. (2006). Decision-support tool for assessing the environmental effects of constructing commercial buildings. Journal of Architectural Engineering, 12(4), 187-195.
[6]. Hammond, G. P., & Jones, C. I. (2008). Inventory of Carbon & Energy (ICE). University of Bath, UK.
[7]. Lehmann, S. (2015). Low carbon construction systems using prefabricated engineered solid wood panels for urban infill to significantly reduce greenhouse gas emissions. Sustainable Cities and Society, 19, 38-48.
[8]. Pomponi, F., &Moncaster, A. (2017). Embodied carbon mitigation and reduction in the built environment – What does the evidence say? Journal of Environmental Management, 203(Pt 1), 687-698.
[9]. Ramesh, T., Prakash, R., & Shukla, K. K. (2010). Life cycle energy analysis of buildings: An overview. Energy and Buildings, 42(10), 1592-1600.
[10]. Röck, M., Saade, M. R. M., Balouktsi, M., Rasmussen, F. N., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., & Passer, A. (2020). Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation. Applied Energy, 258, 114107.
[11]. Sturgis, S., & Roberts, G. (2010). Redefining Zero: Carbon profiling as a solution to whole life carbon emission measurement in buildings. RIBA Publishing.
[12]. Thormark, C. (2002). A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential. Building and Environment, 37(4), 429-435.
[13]. Venkatarama Reddy, B. V., &Jagadish, K. S. (2003). Embodied energy of common and alternative building materials and technologies. Energy and Buildings, 35(2), 129-137.
[14]. Wu, P., & Low, S. P. (2010). Project management and green buildings: Lessons from the rating systems. Journal of Professional Issues in Engineering Education and Practice, 136(2), 64-70.
[15]. Zabalza Bribián, I., Aranda Usón, A., &Scarpellini, S. (2011). Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. Building and Environment, 46(12), 2510-2520.
[16]. Anderson, J., Shiers, D., & Steele, K. (2009). The Green Guide to Specification: An Environmental Profiling System for Building Materials and Components. Wiley-Blackwell.
[17]. Moncaster, A. M., & Symons, K. E. (2013). A method and tool for 'cradle to grave' embodied carbon and energy impacts of UK buildings in compliance with the new TC350 standards. Energy and Buildings, 66, 514-523.
[18]. Junnila, S., Horvath, A., & Guggemos, A. A. (2006). Life-cycle assessment of office buildings in Europe and the United States. Journal of Infrastructure Systems, 12(1), 10-17.
[19]. Ortiz, O., Castells, F., &Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23(1), 28-39.
[20]. Passer, A., Ouellet-Plamondon, C., Kenneally, P., John, V., & Habert, G. (2016). The impact of future scenarios on building material selection: The role of exergy. Building and Environment, 105, 212-222.
[21]. Stephan, A., Crawford, R. H., & de Myttenaere, K. (2013). Towards a comprehensive life cycle energy analysis framework for residential buildings. Energy and Buildings, 55, 592-600.
[22]. Dixit, M. K., Fernández-Solís, J. L., Lavy, S., &Culp, C. H. (2010). Identification of parameters for embodied energy measurement: A literature review. Energy and Buildings, 42(8), 1238-1247.
[23]. Chau, C. K., Leung, T. M., &Ng, W. Y. (2015). A review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on buildings. Applied Energy, 143, 395-413.
[24]. Balouktsi, M., Lützkendorf, T., & Habert, G. (2018). Comparison of environmental assessment methods for buildings: A cognitive mapping approach. Building and Environment, 133, 53-65.