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THE SUSTAINABLE BUILDINGS E-LEARNING PROGRAM

Module 3

SUSTAINABLE BUILDING MATERIALS

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TÜRKİYE SUSTAINABLE BUILDINGS NETWORK

The Türkiye Sustainable Buildings Network was established as part of the “Türkiye Sustainable Buildings Network Project,” which is co-funded by the European Union under the Civil Society Action towards European Green Deal Grant Scheme. The project is coordinated by WRI Türkiye, in partnership with the Zero Energy and Passive House Association (SEPEV) and with the support of the Danish Green Growth Network (DGGN).

The network operates with the aim of supporting climate action in the building and construction sector, promoting green transformation, enhancing the technical knowledge and skills of sector stakeholders, and mainstreaming the concept of sustainable buildings.



As part of this effort, the Sustainable Buildings E-Learning Program has been developed to serve as a comprehensive knowledge resource for all stakeholders in the building sector. The program consists of 10 training modules designed to contribute to the sector's sustainability, energy efficiency, and low-carbon transition goals.

Module 1: Overview of Sustainable Buildings

Module 2: Decarbonization in the Building Sector and the Whole Life-Cycle Approach

Module 3: Sustainable Building Materials

Module 4: Sustainable Construction and Demolition Practices

Module 5: District Heating and Cooling Systems

Module 6: Innovative Building Technologies

Module 7: Financing Instruments for Sustainable Buildings

Module 8: Emissions Trading Systems and the Building Sector

Module 9: Energy-Efficient and Passive Building Design

Module 10: The European Green Deal and the Building Sector

For more information about the Türkiye Sustainable Buildings Network and to access other modules, please visit [the link](#).



MODULE OBJECTIVES

- *Understanding the importance and role of sustainable material use in the building sector.*
- *Presenting definitions of sustainable materials and examples of their application in the building industry.*

*According to the United Nations World Commission on Environment and Development, **sustainability** is defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations World Commission on Environment and Development, Brundtland Report, 1987) (as defined in Module 1: Overview of Sustainable Buildings).*

Sustainable building materials are environmentally friendly or environmentally conscious materials. These materials are primarily derived from renewable rather than non-renewable resources. They are designed to minimize energy consumption during their production and use phases, and do not generate harmful waste or emissions that negatively impact the environment or human health throughout their entire life cycle. [1] (as defined in Module 1: Overview of Sustainable Buildings).

[1] People’s pavilion, BUREAU SLA & OVERTREDERSW, <https://www.arup.com/projects/peoples-pavilion>



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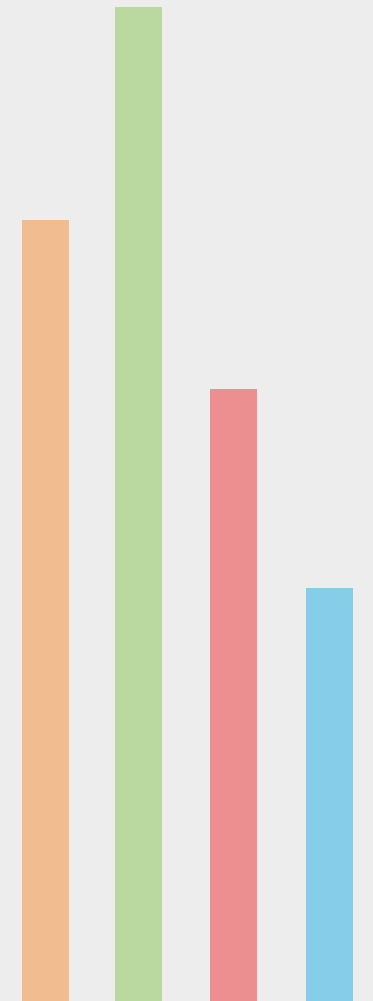
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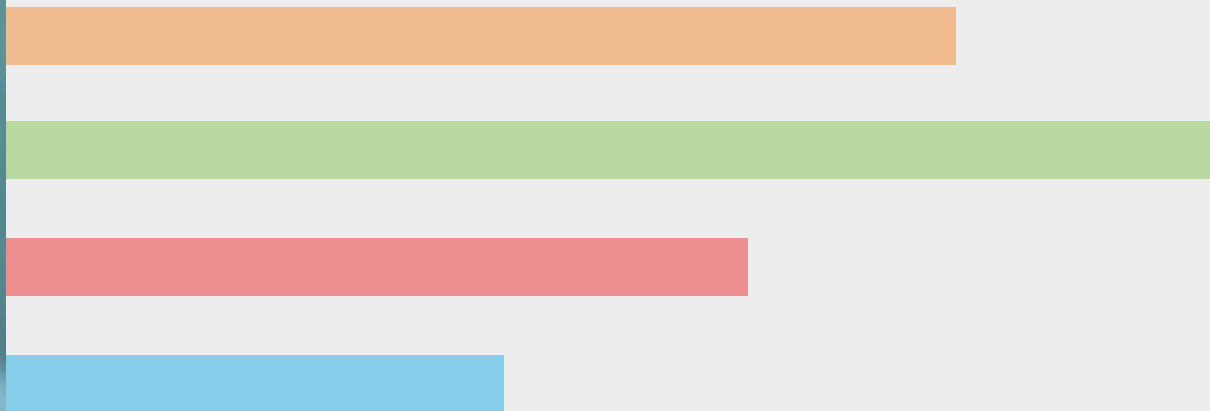
References





Section 1

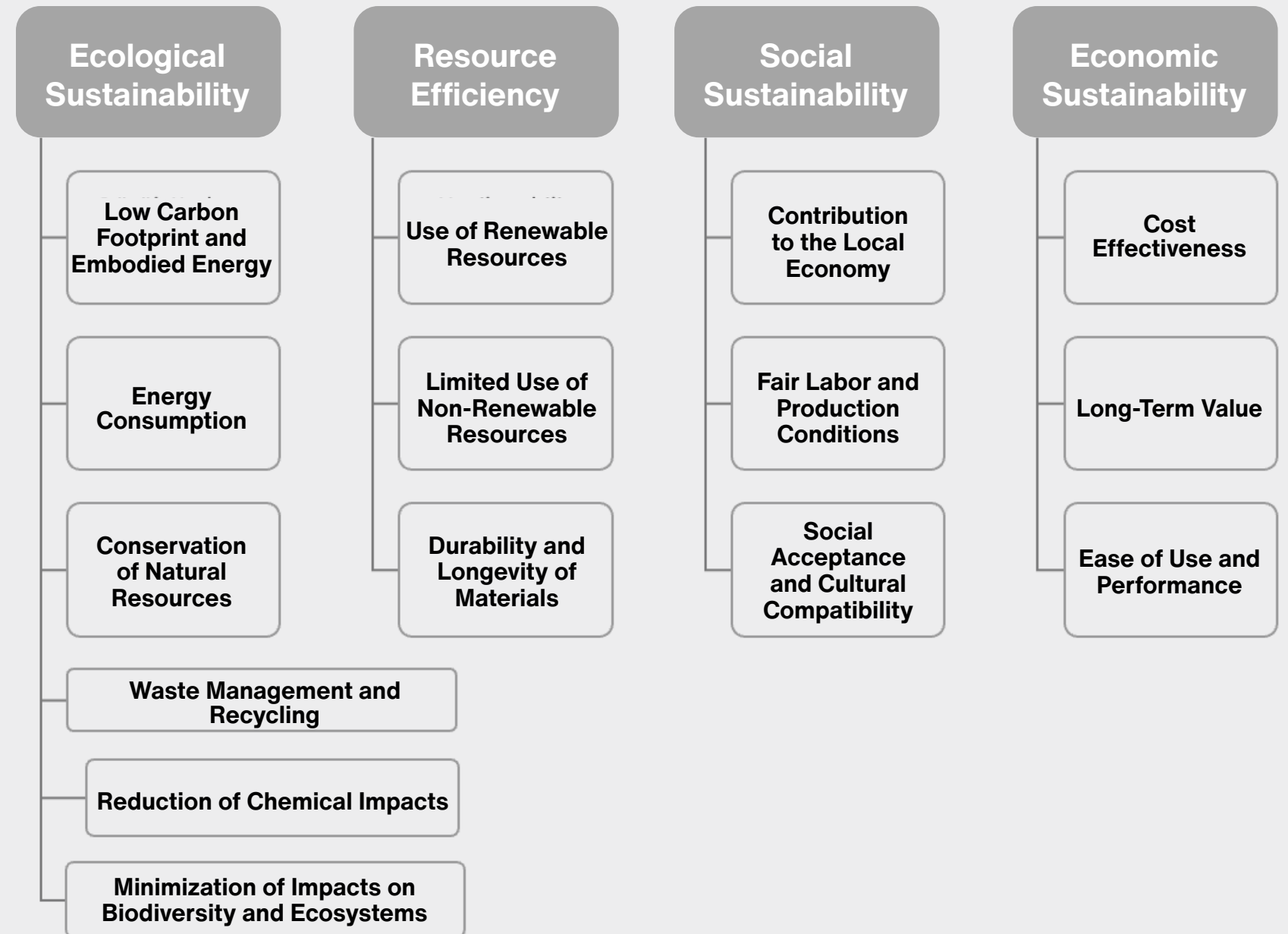
INTRODUCTION TO SUSTAINABLE BUILDING MATERIALS



1.1. Definition and Characteristics of Sustainable Building Materials

Sustainable building materials should possess the following key characteristics:

- They should have low environmental impact and be recyclable.
 - They should use natural resources efficiently and be sourced from renewable materials.
 - They should not harm human health and must ensure fair working conditions.
 - They should be long-lasting, durable, and cost-effective.
 - They should not cause negative impacts on ecosystems or biodiversity.
- [2, 3, 4]



[2] UNEP (2016) *Resource Efficiency: Potential and Economic Implications*. A report of the International Resource Panel. Ekins, P., Hughes, N., et al. ([chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://pure.iiasa.ac.at/id/eprint/13813/1/-Resource_Efficiency__Potential_and_Economic_Implications;_summary_for_Policy-MakersResource-Eff-irp.pdf.pdf](https://pure.iiasa.ac.at/id/eprint/13813/1/-Resource_Efficiency__Potential_and_Economic_Implications;_summary_for_Policy-MakersResource-Eff-irp.pdf.pdf)),

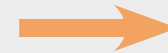
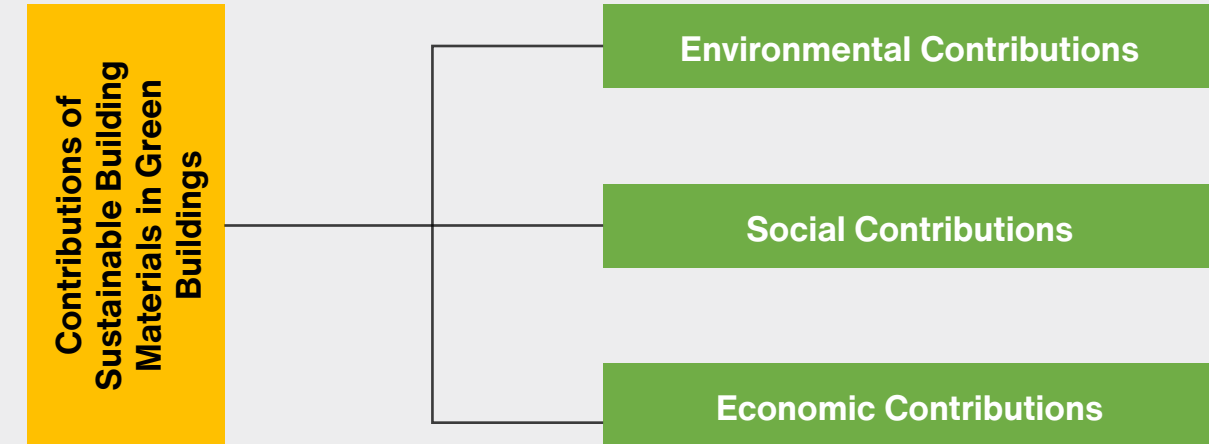
[3] Singha, Kunal & Pandit, Pintu & Maity, Subhankar & Ray, Amal & Kumar, Vikas. (2021). *Advanced applications of green materials in construction applications*. 10.1016/B978-0-12-820484-9.00009-X.

[4] Moghayedi, Alireza & Jeune, Karen & Massyn, Mark & Byron, Paimaan. (2022). *Establishing the Indicators of Sustainable Building Materials*. 10.1007/978-981-16-7160-9_62.

1.2. The Importance of Material Sustainability

Material sustainability refers to the use of materials that are environmentally and human health-conscious, efficient, and reusable, aiming to create long-term positive impacts from environmental, social, and economic perspectives.

In green buildings, sustainable building materials reduce environmental impacts by lowering the carbon footprint and enhancing energy efficiency. These materials contribute to healthier indoor environments by protecting human health and enabling higher quality living spaces through low VOC (volatile organic compound) emissions. Additionally, they promote the use of local materials, generate economic benefits, and support the widespread adoption of sustainable construction practices.



The use of sustainable materials in green buildings provides significant contributions in environmental, social, and economic aspects. These materials play a critical role in saving energy, reducing environmental pollution, and raising awareness about sustainability. They also contribute to local economies through economic benefits and promote the widespread adoption of sustainable buildings. [5, 6]

[5] <https://www.archdaily.com/348692/heineken-wobo-when-beer-met-architecture>,

[6] <https://rarehistoricalphotos.com/wp-content/uploads/2024/05/heineken-wobo-story.jpg>

1.2. The Importance of Material Sustainability



CARBON FOOTPRINT:

Refers to the total amount of greenhouse gases (especially CO₂) emitted into the atmosphere during the production, transportation, use, and disposal phases of a material. Sustainable materials have low carbon emissions during their production processes and minimize their negative impact on the environment.



LIFE-CYCLE ASSESSMENT (LCA):

LCA is an assessment method that examines the environmental impacts of a material throughout its whole life-cycle. This assessment enables the analysis of environmental impacts at all stages from production to end-of-life recycling. **LCAs of sustainable materials** reveal their environmental effects and help in selecting more environmentally friendly alternatives.

(Defined in Module 1: Overview of Sustainable Buildings.)



EMBODIED CARBON:

This is the amount of carbon emitted during all processes involved in the production of a material (extraction, processing, transportation of raw materials, etc.). Sustainable materials should have low levels of embodied carbon. For example, recycled materials contain lower embodied carbon because they are reused, reducing additional carbon emissions from production.



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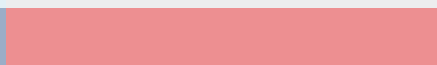
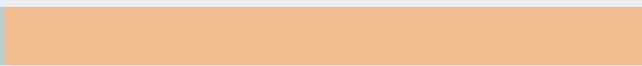
This approach argues that the concept of “waste” should not exist in product design. In other words, the material or product should be fully recyclable at the end of its life cycle and should not harm the natural environment. Sustainable materials should align with this circular economy concept.

(Defined in Module 1: Overview of Sustainable Buildings.)



Section 2

ENVIRONMENTAL IMPACT OF BUILDING MATERIALS



2.1. Life-Cycle Assessment (LCA) of Building Materials

(Reference: Module 2)

LIFE-CYCLE ASSESSMENT (LCA) OF BUILDING MATERIALS [7]

LCA is a valuable tool that enables the comprehensive assessment of the environmental impacts associated with construction materials throughout their whole life-cycles.

- It takes into account the environmental burdens associated with various stages such as raw material extraction, production, transportation, construction, use, and disposal.
- It provides a holistic and systematic approach for evaluating the environmental performance of materials and identifying opportunities for improvement.
- LCA studies measure impacts such as carbon emissions, energy consumption, water use, air pollution, waste generation, and ecosystem depletion.

The Sustainability of Materials Depends on the Following Criteria: [9]

- Resource efficiency
- Energy efficiency (including initial and recurring embodied energy and greenhouse gas emissions)
- Pollution prevention (including indoor air quality)

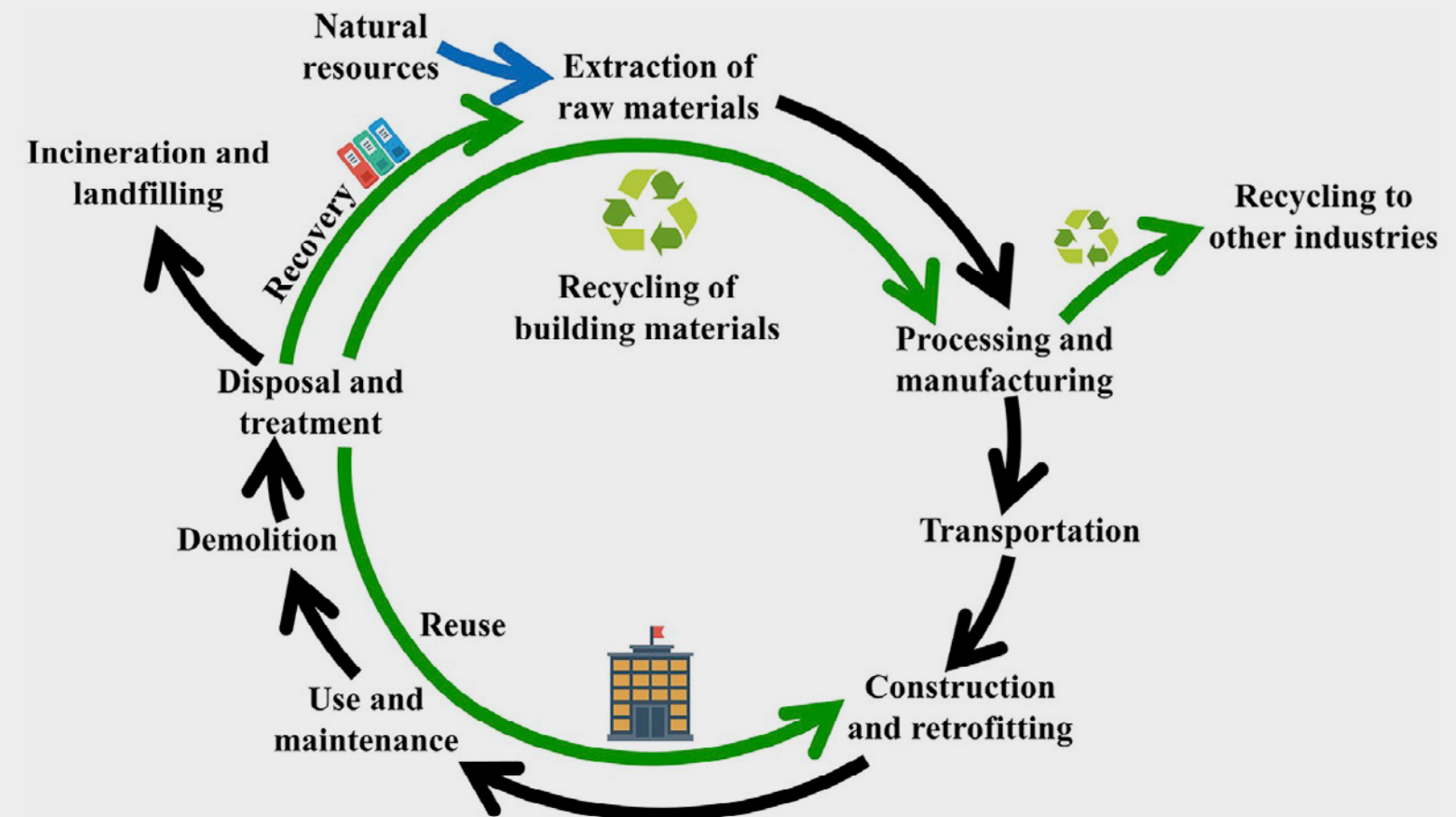


Figure 1. Conceptual Diagram of the Life Cycle of Building Materials [8]

[7] Barbhuiya, S., Das, B. B. (2023). Life Cycle Assessment of construction materials: Methodologies, applications and future directions for sustainable decision-making. *Case Studies in Construction Materials*, vol 19, <https://doi.org/10.1016/j.cscm.2023.e02326>

[8] Huang, B., et al. (2020). A Life Cycle Thinking Framework to Mitigate the Environmental Impact of Building Materials. *One Earth* 3 (5), pp. 564-573, <https://doi.org/10.1016/j.oneear.2020.10.010>

[9] Ding, G., K., C. (2014). Life cycle assessment (LCA) of sustainable building materials: an overview. *Eco-efficient Construction and Building Materials*, pp. 38-62, <https://doi.org/10.1533/9780857097729.1.38>

2.1. Life-Cycle Assessment (LCA) of Building Materials

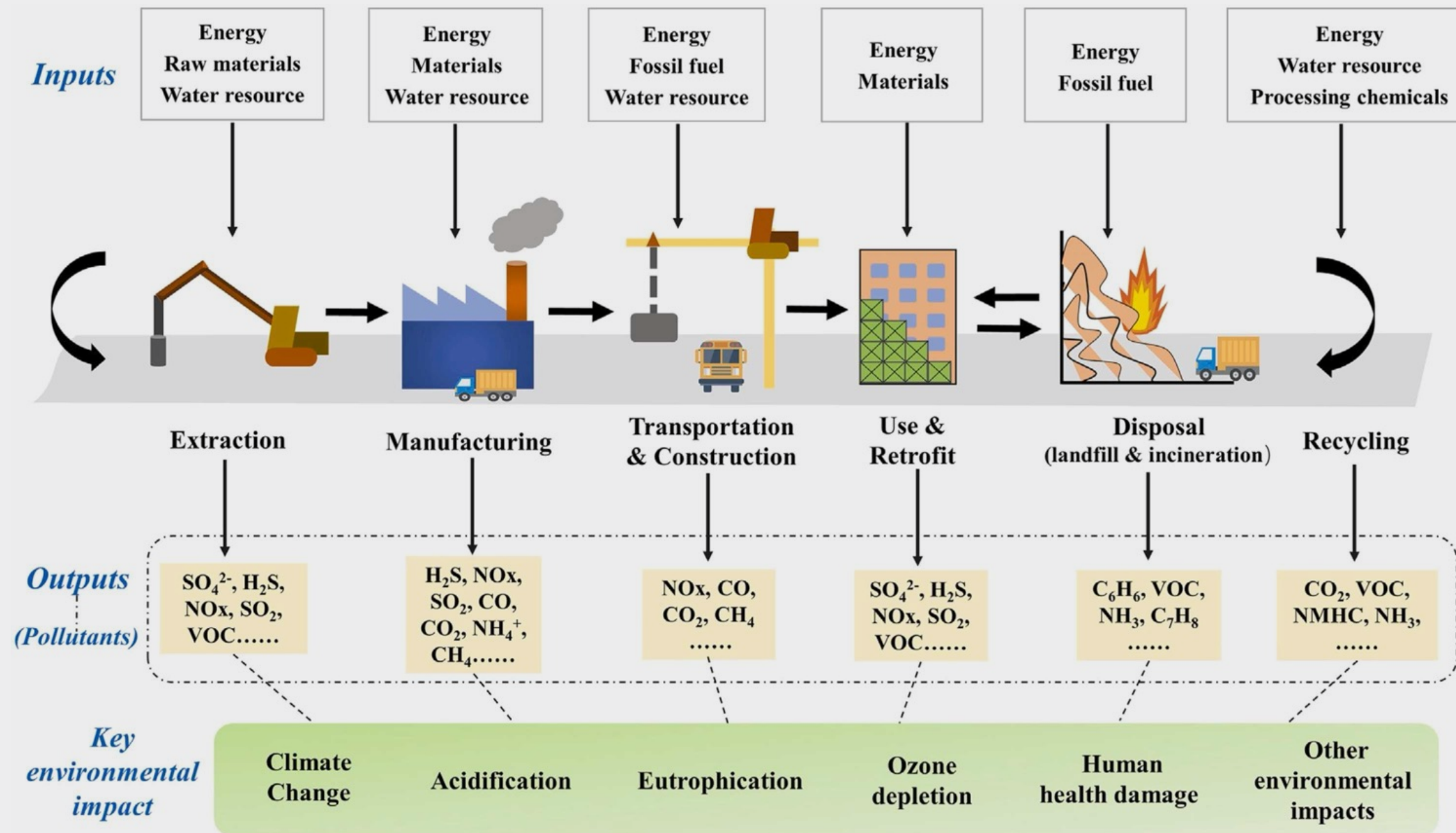


Figure 2. Key Environmental Impacts During the Life Cycle of Building Materials [8]

2.1. Life-Cycle Assessment (LCA) of Building Materials

Standards Used for Determining the LCA of Building Materials

It is generally accepted that the international and draft standards of the ISO 14000 series provide a consensus framework for LCA [10]:

- ISO 14040:2007 (TS EN ISO 14040) – Environmental Management – Life Cycle Assessment – Principles and Framework
(This standard replaces the previous standards related to LCA: TS EN ISO 14041:2003, TS EN ISO 14042:2002, and TS EN ISO 14043:2003.)
- ISO 14044:2006 (TS EN ISO 14044) – Environmental Management – Life Cycle Assessment – Requirements and Guidelines

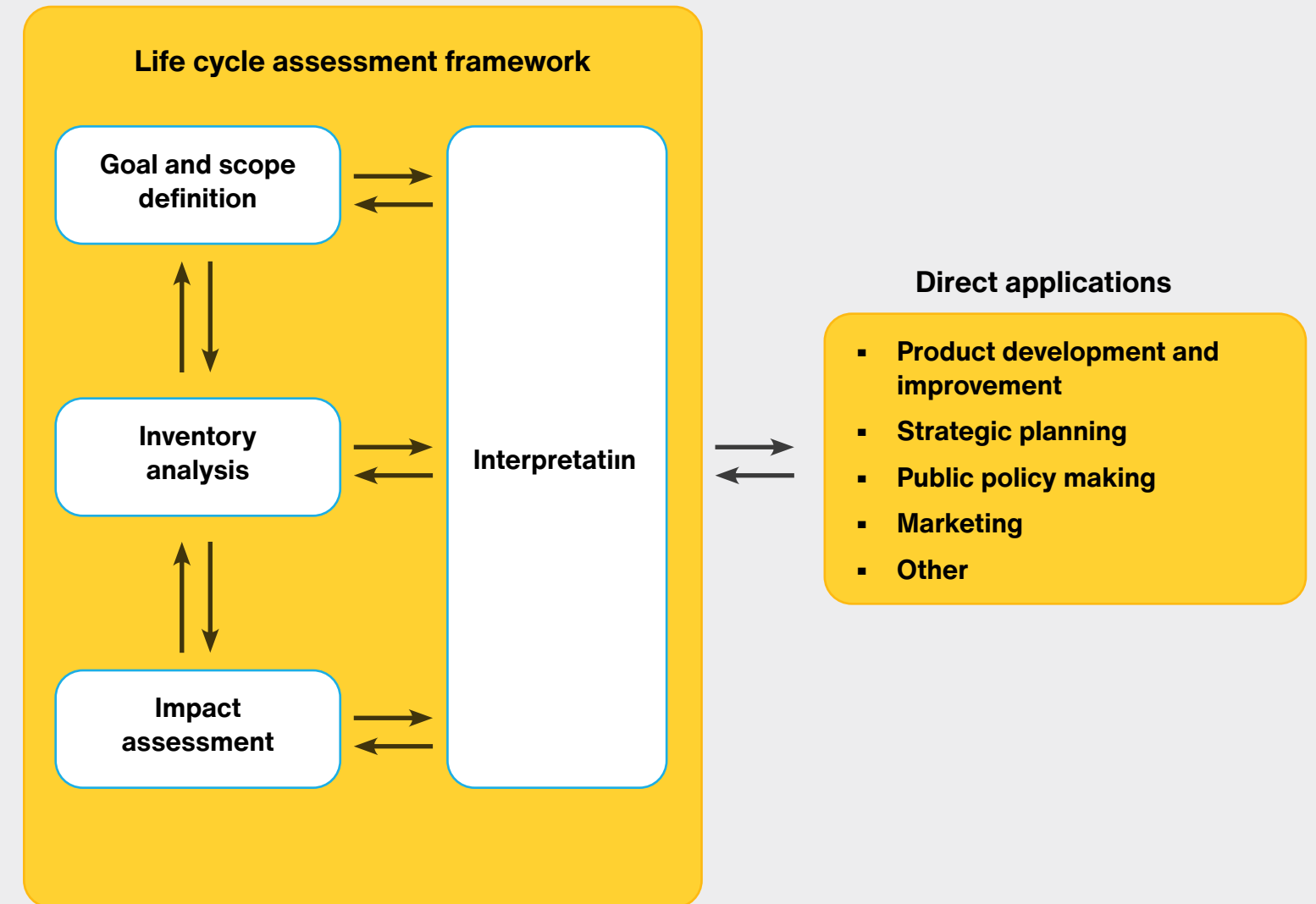


Figure 3. LCA Stages According to ISO 14040:2007 [11]

[10] Rebitzer, G., et al. (2004). Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International*, vol 30, pp. 701-720.

[11] TS EN ISO 14040:2007 Çevre yönetimi - Hayat boyu değerlendirme - İlkeler ve çerçeve (ISO 14040:2006)

2.1. Life-Cycle Assessment (LCA) of Building Materials

Software Used for Determining LCA of Building Materials [12]



BEES (Building for Environmental and Economic Sustainability [13])

- Developed by the Engineering Laboratory of NIST (National Institute of Standards and Technology).
- Measures the environmental performance of building products using the Life-Cycle Assessment approach outlined in the ISO 14040 series standards.
- Environmental and economic performance are combined into an overall performance measure using the ASTM (American Society for Testing and Materials) standard for Multi-Attribute Decision Analysis.
- It is an online platform.



SimaPro [14]

SimaPro Craft ve SimaProSynergy olmak üzere 2 çeşidi vardır.

- Developed by PRé Sustainability.
- Available in two versions: SimaPro Craft and SimaPro Synergy.
- Sphera
- Open LCA
- Umberto
- Ecochain (Mobius and Helix)
- Brightway

[12] Türkiye'nin Döngüsel Ekonomiye Geçiş Potansiyelinin Değerlendirilmesi için Teknik Destek Projesi, EuropeAid/140562/IH/SER/TR, Faaliyet 2.4 – Döngüsel ekonomide izlemeyi desteklemek için yaşam döngüsü analizi eğitimi, Yaşam Döngüsü Analizi (YDA) Nedir?, 27 Kasım 2023.

[13] <https://www.nist.gov/services-resources/software/bees>

[14] <https://simapro.com/>

2.2. Embodied Energy / Embodied Carbon in Building Materials

What is Embodied Energy in Building Materials?

Embodied energy and embodied carbon are interrelated concepts. They refer to the total energy consumption and the greenhouse gas emissions associated with a material throughout its life cycle. Embodied carbon includes the emissions generated during the creation of a building, not during its use. Therefore, it can be described as the carbon footprint of building materials. [15]

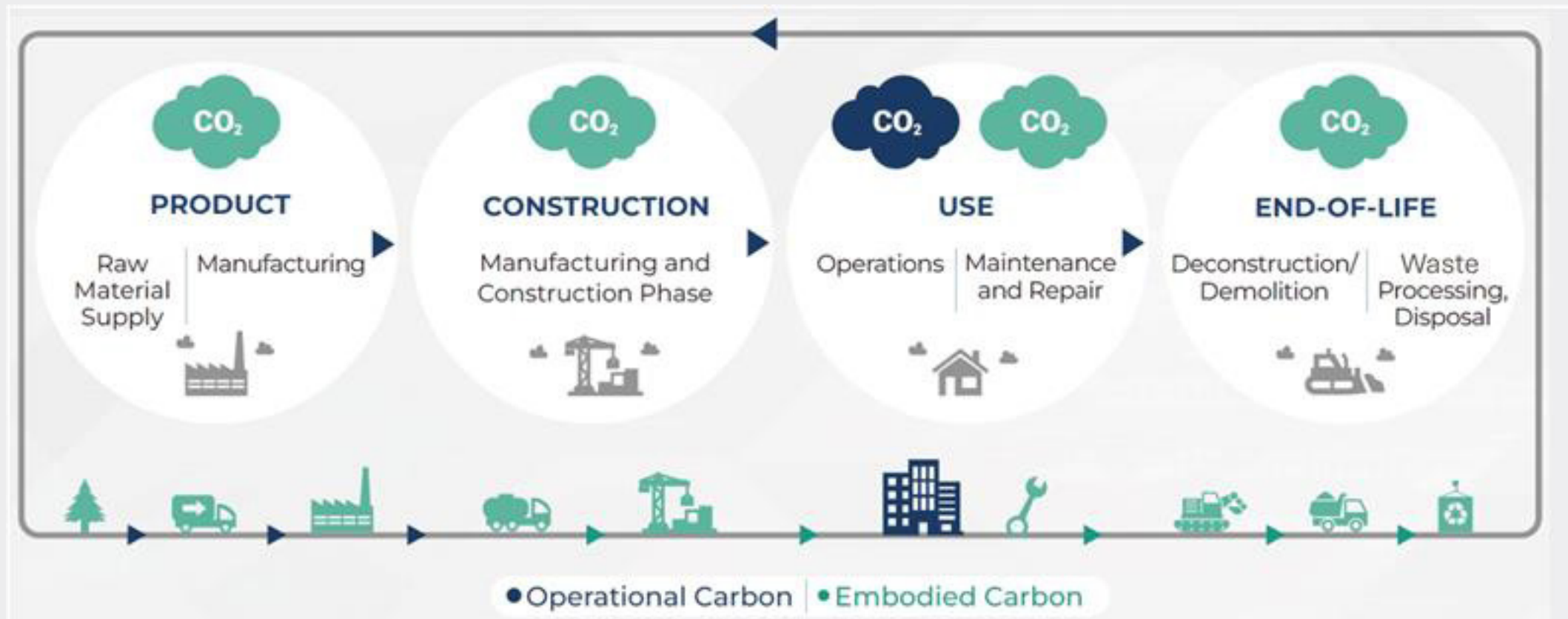


Figure 4. Building Life Cycle Carbon Emissions [15]

Stages Where Embodied Carbon Is Present in Building Materials [16]:

- Raw material extraction
- Transportation to manufacturer
- Production
- Transportation to site
- Construction
- Use phase (e.g., concrete carbonation, but excluding operational carbon)
- Maintenance
- Repair
- Replacement
- Renovation
- Demolition and deconstruction
- Transport to end-of-life facilities
- Processing
- Disposal

[15] Bayraktar, M., Binatlı, B., Üzümoğlu, T. (2023). Türkiye Bina Sektörü Karbonsuzlaşma Yol Haritası. TC Çevre, Şehircilik ve İklim Değişikliği Bakanlığı.

[16] Bringing Embodied Carbon Upfront. Coordinated action for the building and construction sector to tackle embodied carbon. World Green Building Council

2.2. Embodied Energy / Embodied Carbon in Building Materials

The production and use of materials for building construction and renovation account for 11% of global energy and process-related carbon dioxide (CO₂) emissions. [17]

- More than half of emissions associated with building materials come from steel and cement, due to their widespread use and the fact that they are still generally produced through carbon-intensive methods.
- Aluminum, glass, insulation, plastics, and other materials (such as other petrochemical products and copper) are secondary contributors.
- In 2017 alone, steel and cement were responsible for approximately 1.8 gigatons of CO₂ (GtCO₂)—representing 15% of total building-related emissions, including both direct emissions from fossil fuel use and indirect emissions from electricity, heat, steel, and cement production. [17]

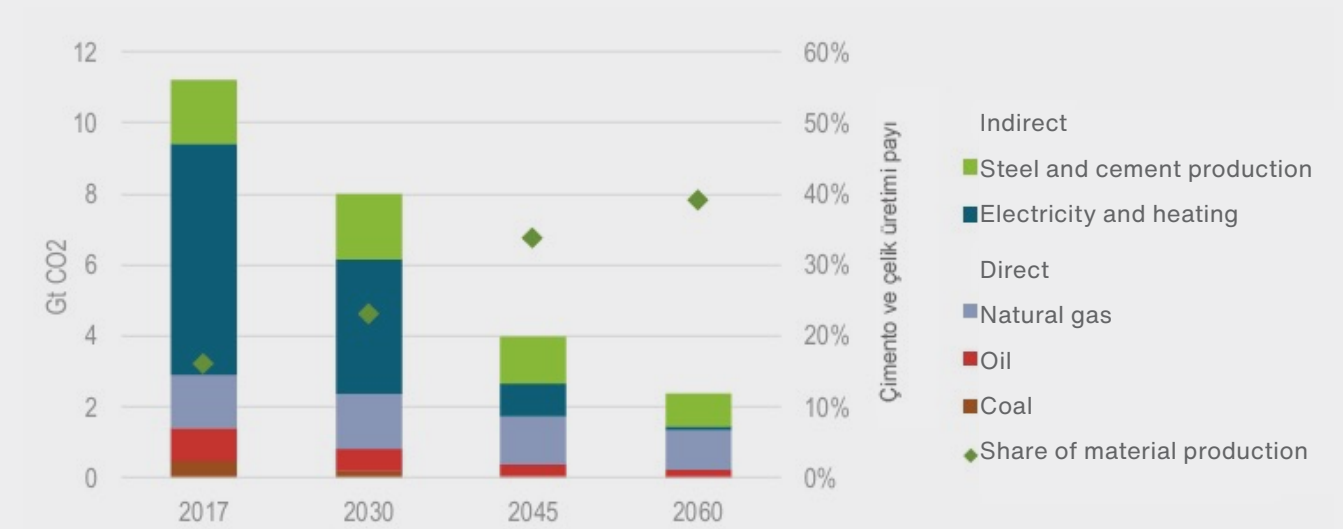


Figure 5. Global building sector emissions and the proportion attributed to emissions from steel and cement production under the Clean Technology Scenario (CTS)



Figure 6. Carbon Reduction Potential by Project Development Stage [21]

2.2. Embodied Energy / Embodied Carbon in Building Materials

Application and Benefits of Life-Cycle Assessment (LCA) for Reducing Embodied Carbon Emissions and Reintegration of Embodied Energy into the System:

- Holistic Perspective
- Comparative Analysis
- Sustainable Design and Decision-Making Process
- Environmental Performance Improvement
- Regulatory Compliance and Certification
- Stakeholder Engagement and Communication
- Life-Cycle Thinking
- Cost Reduction and Resource Efficiency
- Regulatory Compliance and Public Image
- Transparency in the Decision-Making Process [7]

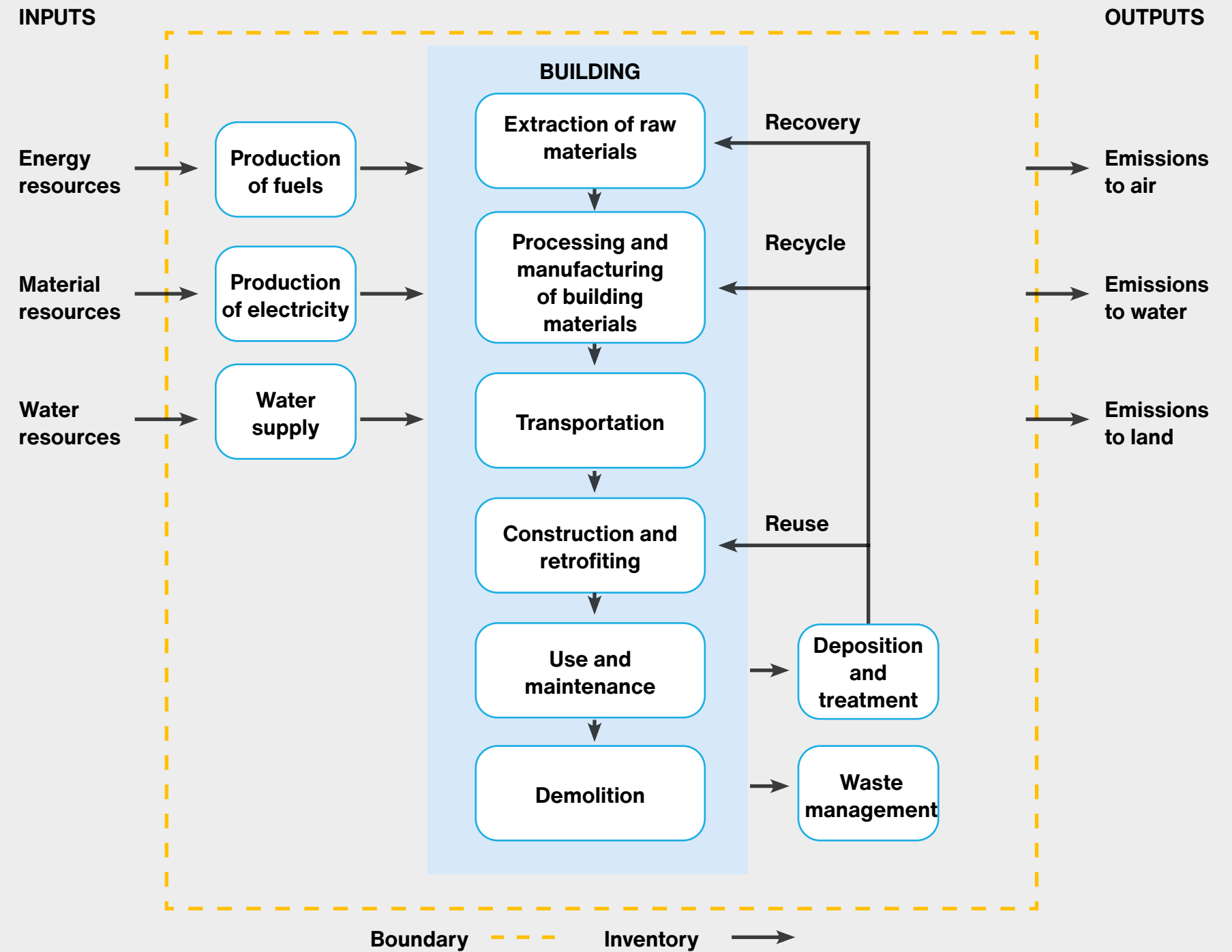


Figure 7. Life Cycle Assessment Application Framework for Building Materials [8]

2.2. Embodied Energy / Embodied Carbon in Building Materials

MATERIAL EFFICIENCY STRATEGIES IN BUILDINGS (Reducing excess material use per square meter of floor area in new constructions):

- Determining building design and structural features during the conceptual design stage in conjunction with the materials to be used.
- Optimizing the properties of the materials used; for example, using high-strength steel and reducing the cement content in concrete.
- Optimizing construction processes for material efficiency; for instance, reducing material waste. Ensuring material procurement is not excessive by keeping the acceptable margin of waste to a minimum through optimization.
- Extending the lifespan of buildings, for example, through adaptive reuse. This helps reduce the need for new material production and consumption by enabling the reuse of existing materials.
- Reuse and recycling of materials contained in structural elements at the end of their service life. [17]

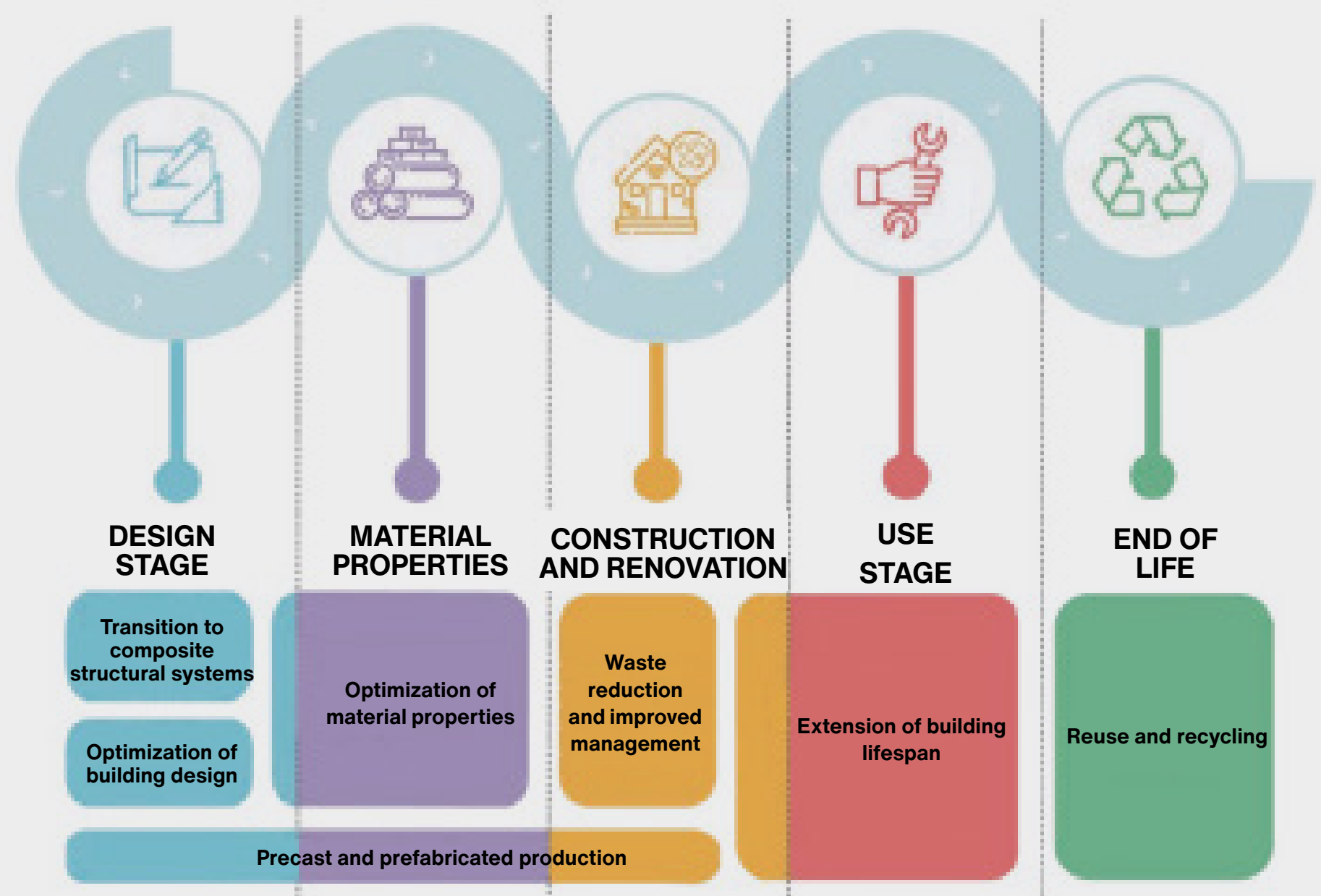


Figure 8. Material efficiency strategies across the building construction value chain [17]

2.2. Embodied Energy / Embodied Carbon in Building Materials

Material efficiency strategies implemented during the design, construction, use, and end-of-life phases can significantly reduce the consumption of steel and cement, which are the primary sources of emissions in the building sector.

Pursuing these strategies to their practical limits results in an additional reduction of 15% in steel use and 17% in cement use by 2060 under the Material Efficiency Variant (MEF) of the Clean Technology Scenario (CTS). (RTS refers to the Reference Technology Scenario.)

Material efficiency strategies include methods to reduce material use per unit of floor area during building construction or renovation, as well as measures that address the impacts of extended building lifespans or increased renovation rates.

1. Structural optimization at the design stage can reduce excess material use and engineering errors by adapting building components according to their functions.
2. Composite structures, which combine different materials in the load-bearing system, facilitate achieving material efficiency goals.
3. Innovative design approaches optimize space utilization and enable the efficient reconfiguration of building elements.
4. Using the most optimized forms of concrete and steel improves material efficiency. High-strength concrete and steel allow for stronger structures using less material by, for example, reducing frame dimensions and cement demand.
5. Reducing the cement content in concrete without compromising its physical properties is another way to enhance material efficiency. For example, optimizing aggregate size can maintain concrete strength while reducing cement demand—a method known as Advanced Concrete Packing. Additives such as plasticizers can improve workability and reduce cement requirements. Since these additives are used in small amounts, their production-related carbon emissions are negligible. Additionally, fillers such as ground limestone, dolomite, basalt, and quartz can be added to concrete to reduce cement content. Increasing the production of industrial materials contributes to improved

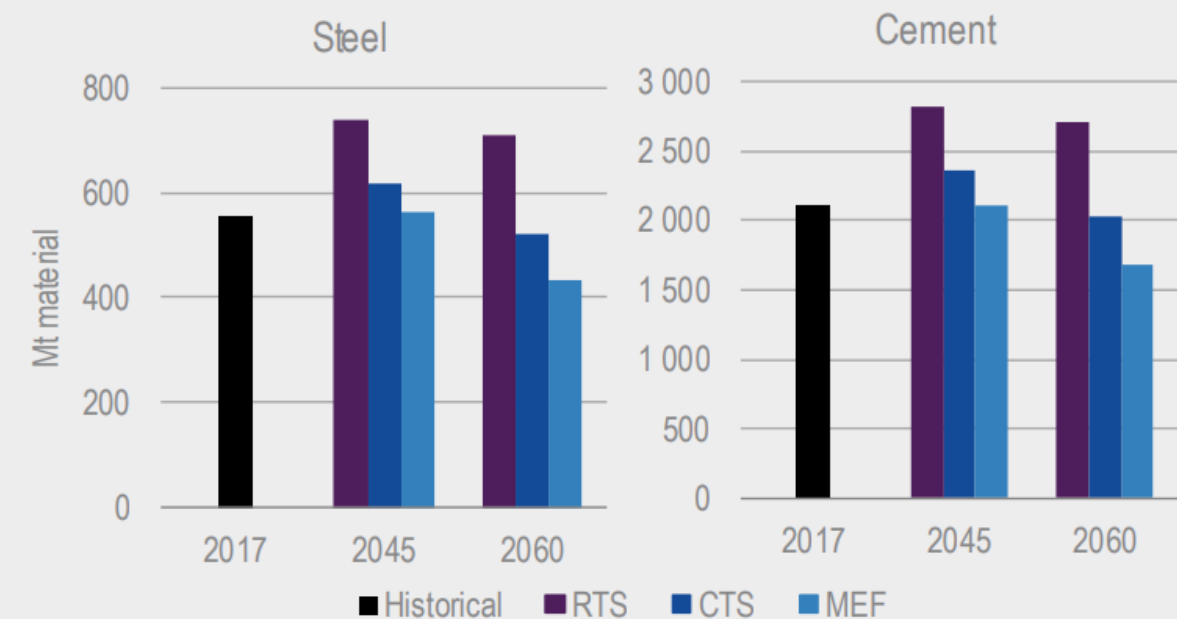


Figure 9. Material efficiency strategies across the building construction value chain [17]

concrete packing. To further reduce emissions, clinker content in cement can be replaced with materials such as ground granulated blast furnace slag or fly ash.

6. Compliance with building specifications is critical to reducing material use. Designers, construction firms, and subcontractors can avoid excessive material consumption by adhering to safety standards. However, practical constraints sometimes necessitate increased material use. Theoretically, improved building design can result in up to 30% savings in steel and 15% in cement.
7. Precast and prefabrication methods are effective strategies to reduce material use through advanced building design and material optimization.
8. Improving construction practices helps minimize material waste.
9. Enhanced modularity, better design, durable materials, and comprehensive improvements extend building lifespans and reduce the need for new construction.
10. Reuse and recycling at the end of the building's life-cycle represent the final category of material-saving potential. [17]

2.3. Waste Reduction and Circular Economy

(For more information on sustainable buildings, see Module 1: Overview of Sustainable Buildings.)

In the context of building materials, the circular economy is an economic model in which materials and products retain their value throughout their useful service life and, after that, are renewed or reprocessed into products of equal or higher quality. [18]

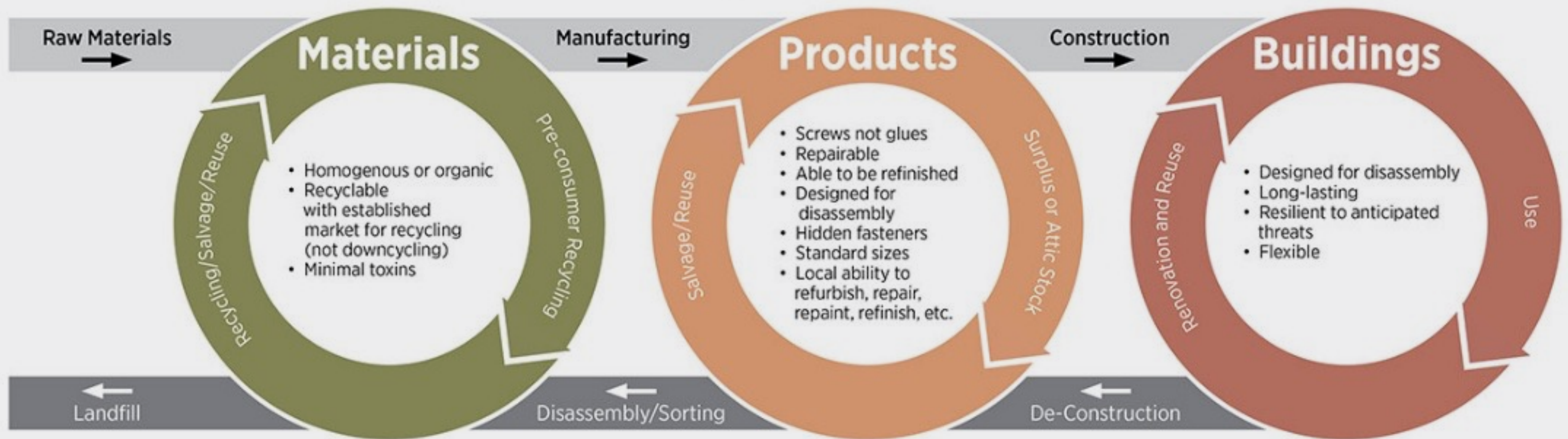


Figure 10. Circular Economy Flows and Strategies [19]

[18] <https://lmnarchitects.com/lmn-research/09-circular-economy-products>

[19] <https://www.usgbc.org/articles/toward-circular-economy-building-materials>

2.3. Waste Reduction and Circular Economy

In a circular economy, materials are either recyclable or compostable. Many solid materials such as metals and untreated wood can be reused, recycled, or composted. Most plastics, however, are not recycled despite

encouraging labels. Moreover, to enable safe and efficient recycling or composting, materials must be free of toxins, as toxic substances make these processes difficult and hazardous.

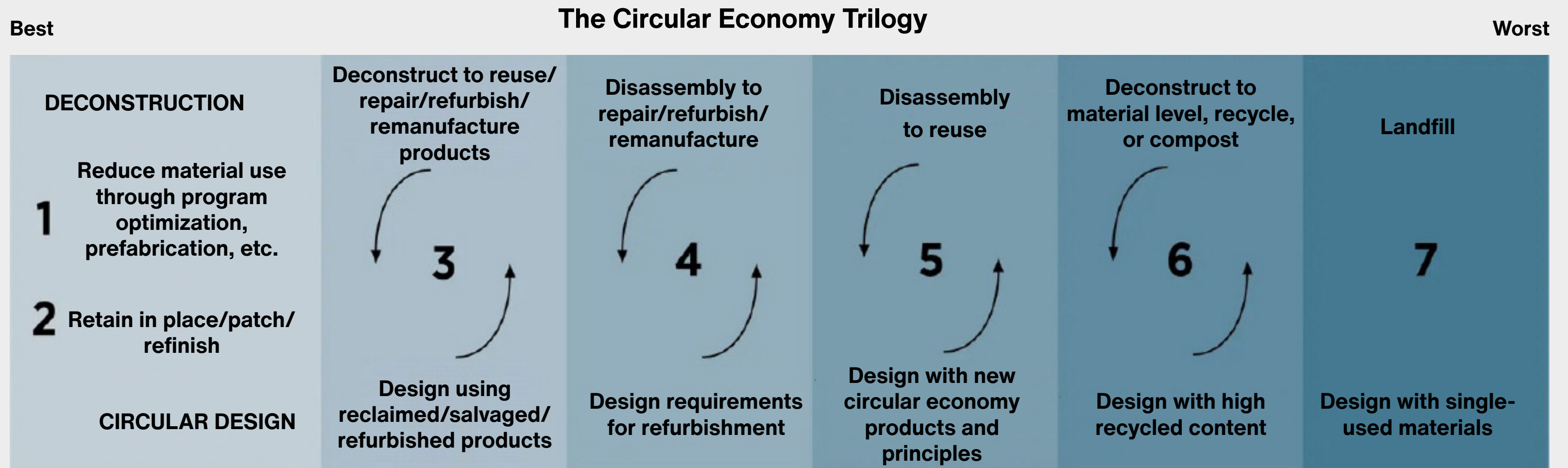


Figure 11. In the Circular Economy, the Design Process Begins with Deconstruction [18]

2.3. Waste Reduction and Circular Economy

Principles for Achieving Circular Economy in Building Materials:

- 1- Designs should be suitable for deconstruction/disassembly, such as by using screws instead of adhesives, concealed fasteners, durable materials with repairable surfaces, and components that can be disassembled for recycling.
- 2- Each design should incorporate at least one recycled material from the outset.
- 3- Materials must be designed for reuse and recycling.
- 4- Resource efficiency should be ensured — for example, by choosing designs that minimize material waste, reducing excess inventory, adopting prefabrication techniques, and implementing lean construction practices.
- 5- Digitization and data management should be implemented to support better material tracking, improved management, and more informed decision-making.
- 6- Work with a demolition team familiar with material reuse. [19, 20]

Benefits of Circular Economy

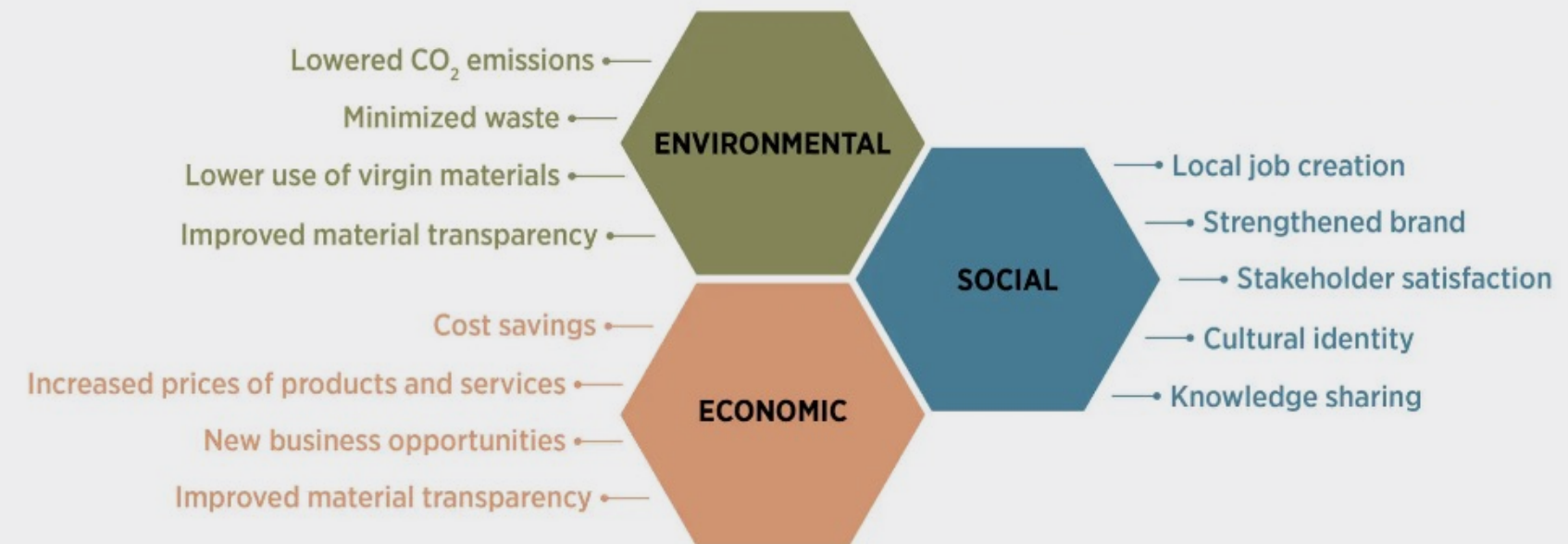


Figure 12. Benefits of Circular Economy [18]

2.3. Waste Reduction and Circular Economy

The construction sector is one of the largest global consumers of energy and raw materials. Within the EU, it contributes to approximately 40% of emissions and generates nearly one-third of all waste. Only about 40% of construction debris is recycled or reused during building demolition. [20]

A circular structure in buildings, in particular, maximizes resource use and minimizes waste throughout the whole life cycle.

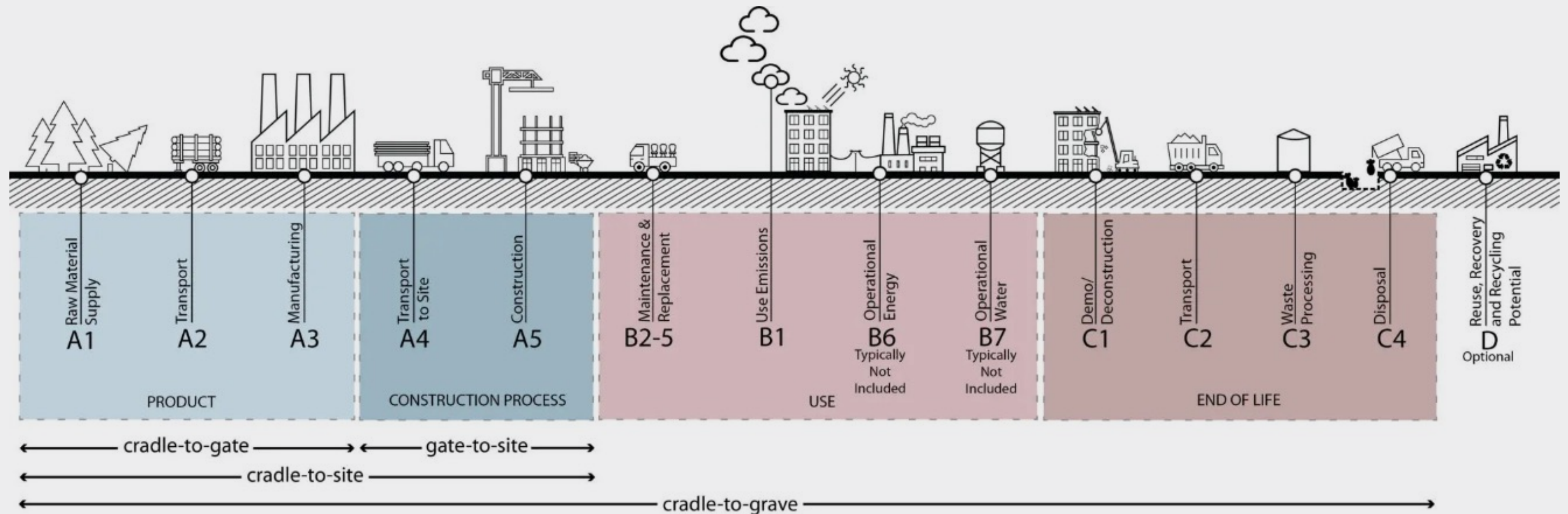


Figure 13. Sources of Embodied Carbon and Its Reduction Through Circular Economy [21]

[21] <https://lmnarchitects.com/lmn-research/07-embodied-carbon-101>

2.3. Waste Reduction and Circular Economy

A large portion of construction and demolition (C&D) debris consists of only a few categories of building products, which should be the initial focus of the circular economy.

According to the U.S. Environmental Protection Agency (EPA), materials classified as construction and demolition debris include: Steel, Wood Products, Drywall and Plaster, Brick and Tile, Asphalt Pavement, Concrete, Asphalt Concrete, Carpet, Plastic, Glass, Cardboard, and Organic Materials. [22]

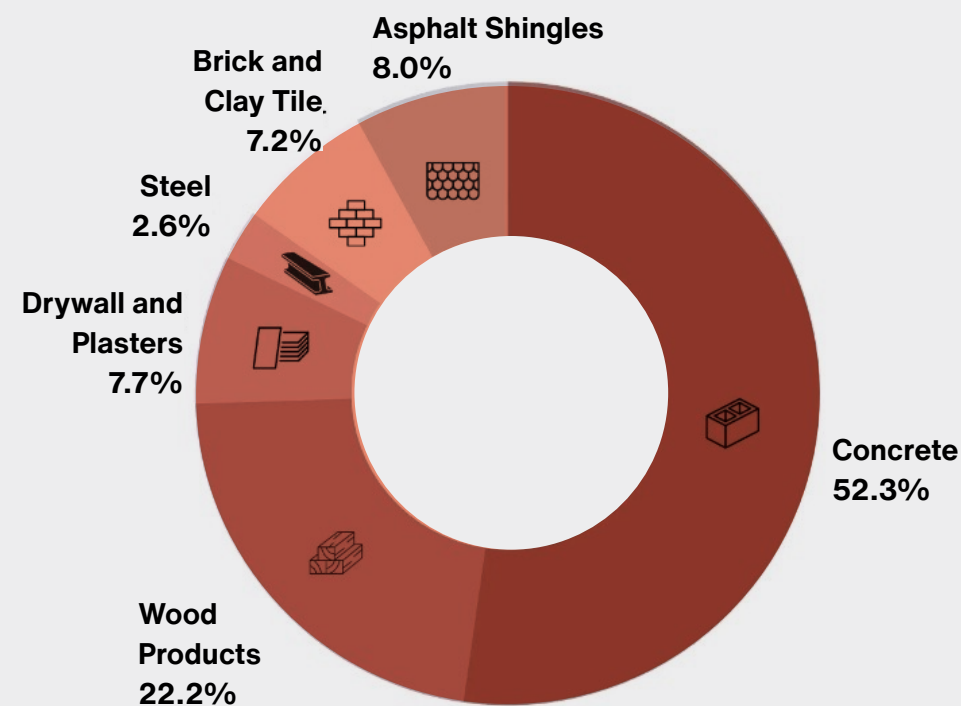


Figure 14. C&D Debris Generation by Source (Thousand Tons) [18]

Debris Management [24]:

- 1- Improved waste identification, on-site separation, and collection
- 2- Improved waste logistics
- 3- Improved waste processing
- 4- Quality management
- 5- Appropriate policy and framework conditions

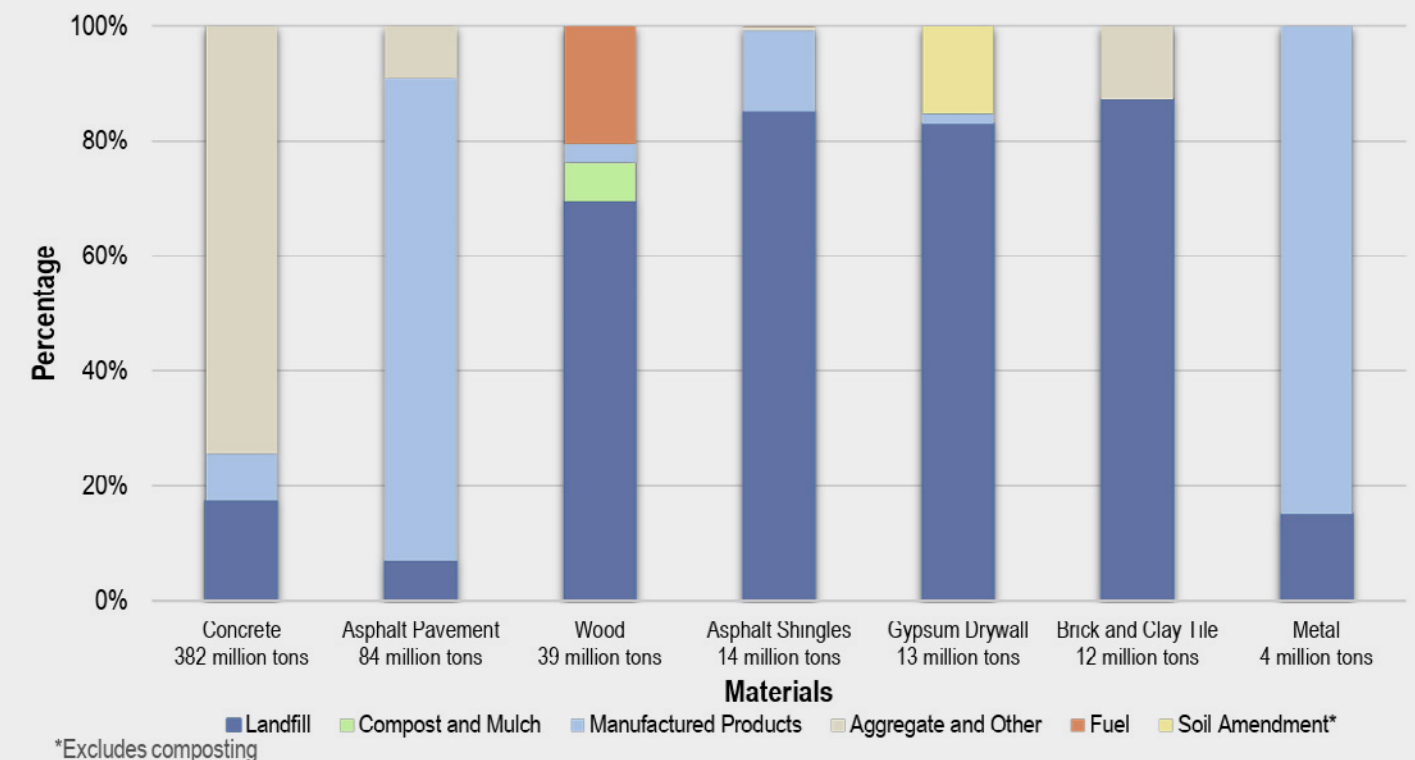


Figure 15. C&D Debris Management by Activity (percent of total generation amount for the material) [23]

[22] Townsend, T., G., Ingwersen, W., W., Niblick, B., Jain, P., Wally, J. (2019). CDDPath: A method for quantifying the loss and recovery of construction and demolition debris in the United States. *Waste Management*, vol 84, pp. 302-309.

[23] *Construction and Demolition Debris Management in the United States, 2015*. U.S. Environmental Protection Agency, Office of Resource Conservation and Recovery, March 2020.

[24] <https://ec.europa.eu/newsroom/growth/items/455097/en>

2.4. Recycled and Renewable Materials

When a particular material or component reaches the end of its life cycle—or the end of the building’s life cycle—the available options include **reuse**, **recycling**, **combustion**, or **landfilling**.

Among these, landfilling is the least desirable option, as it fails to recover the embodied energy in materials and poses a significant risk of soil, water, and air pollution.

Combustion is a method for recovering some of the embodied energy, particularly in materials such as plastics. However, this process can also generate large quantities of gas or toxic waste.

The preferred options focus on reuse of components, followed by recycling, which helps conserve both material and energy resources. [25]

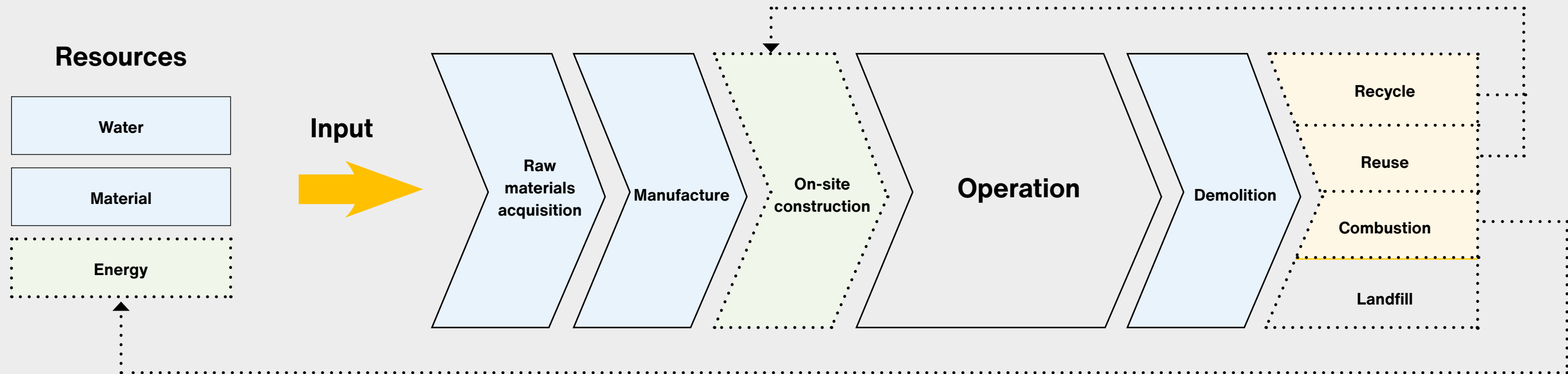


Figure 16. Life Cycle and Recycling of Materials [26]

[25] Maccarini Vefago, L., H., Avellaneda, J. (2013). Recycling concepts and the index of recyclability for building materials. *Resources, Conservation and Recycling*, vol 72, pp. 127-135.

[26] Ng, W., Y., Chau, C., K., (2015). New life of the building materials- recycle, reuse and recovery. *Energy Procedia*, vol 75, pp. 2884-2891.

2.4. Recycled and Renewable Materials

The Cradle-to-Cradle concept: involves two types of material cycles: biological and technical.

The biological cycle is regulated by the biosphere, and the materials within this cycle are designed to undergo biological degradation and eliminate toxic substances.

The technical cycle is governed by the technosphere, and the materials in this cycle require continuous recycling at the end of each life cycle to serve as raw materials for other products.

Both cycles are designed to act as nutrients for the next cycle—under the cradle-to-cradle principle, waste equals food. This definition originates from natural cycles in which no residue is considered waste. [25]

Destination	Savings in energy and CO ₂	Reduction of waste	Same use as previous cycle	Performance in the cycles	Total
Reuse	● ● ●	● ● ●	● ● ●	● ● ●	12
Recycle	● ●	● ●	● ● ●	● ● ●	10
Infracycle	● ●	● ●	● ●	● ●	8
Infrause	●	● ●	●	●	5

Note: ●: low, ● ●: medium, ● ● ●: high.

Figure 17. Qualitative Assessment of the Impact of Recycling Methods on Materials [25]

%	Conventional Landfill	Conventional Recycle	Circular Landfill	Circular Recycle
Total Impacts	100.00	78	57	35
Human Health	54	40	34	19
Ecosystems	25	18	16	10
Resources	21	20	7	6

Figure 18. Impact of Conventional and Circular Use of Materials on Health and Ecosystems [27]

2.4. Recycled and Renewable Materials

Benefits of Using Recycled and Sustainable Materials [28]:

1- Environmental Benefits

- Can reduce greenhouse gas emissions by up to 50%.
- Can reduce waste generation by up to 30%.
- Contributes significantly to resource conservation by using materials that renew faster than they are consumed (e.g., timber, cork).
- Improves energy efficiency, especially during production and disposal phases.
- Materials that require less energy for production, transportation, and recycling (such as locally sourced wood) help reduce the building's carbon footprint.

2- Economic Benefits

- While the initial investment in sustainable materials can be up to 20% higher, significant long-term savings can be achieved, especially in operating costs (e.g., reduced heating and cooling expenses).

3- Social Impacts

- Have positive effects on the health and well-being of building occupants.
- Because they contain low levels of volatile organic compounds (VOCs) (e.g., natural fibers, non-toxic paints), they can reduce indoor air pollution by up to 60%. This has been shown to reduce the incidence of respiratory issues among users.
- Generally, enhance psychological well-being by improving natural lighting and air circulation.
- In regions where local materials are used, they support economic development by creating jobs for local suppliers and workers and encouraging community participation in construction projects.

2.4. Recycled and Renewable Materials

Table 1. Possibilities for Some Building Materials at the End of Their Life Cycles [25]

Material	Element	Cycle				Possibilities at the End of the Life Cycle		
		Technical	Biological	Hybrid	Recycled	Infracycled	Reused	Infraused
Metal	Aluminium Profile	X			X		X	
	Steel Profile	X			X		X	
	Copper – Electric Cable	X			X			
	Copper Plates	X			X			
Plastic	Polyethylene Tube	X				X		
	PET fiber	X				X	X	
	PVC	X				X		
Earth and Stone	Concrete	X						X
	Mortar	X						X
	Brick	X					X	X
	Stone		X				X	X
Wood	Laminated Wood			X			X	X
	Plywood Board			X			X	X
	Hardwood without Toxic Preservative		X		Xa		X	X
	Hardwood with Toxic Preservative			X			X	X
Glass	Tempered Glass	X			X	X	X	
	Laminated Glass	X			Xb	X	X	
Others	Sheep Wool			X			X	
	Cellulose Insulation		X		Xa			

Explanations:

Infracycled: A material that has undergone at least one chemical transformation or change in its physical state. Its original properties are diminished, and it is not required to serve the same function as in its previous life cycle (e.g., plastics derived from petroleum).

Infraused: A material that has not undergone any chemical transformation or change in physical state. Its original properties are diminished, and it no longer serves the same function as in its previous life cycle (e.g., crushed ceramics, bricks, and concrete blocks reused as aggregates in new concrete).

a: Material recycled within the biological cycle. b: The polyvinyl butyral (PVB) interlayer in laminated glass is currently not being recycled. It is sent to landfills.

2.5. Water Use in the Production of Building Materials

Water withdrawal is considered the starting point for water use in buildings. The withdrawn water is used as process water in the production of materials. [31]

There are two types of water use in building construction [29]:

- Embodied
- Direct

The water used in the production of building materials is referred to as **embodied water (also called indirect water)**.

Embodied Water (Indirect Water): Refers to the water used to produce the raw materials of a building throughout the supply chain. Depending on the function, it can be direct (e.g., water used in aluminum production) or indirect (e.g., water used by administrative staff managing the production process).

Embodied water can also be divided into initial and recurrent embodied water.

Initial embodied water is the total of all embodied water used during the early stages of construction.

Recurrent embodied water is the water required for materials during maintenance or throughout the building's service life.

Direct Water: Refers to water used on the construction site, calculated based on daily water usage and the duration of the project.

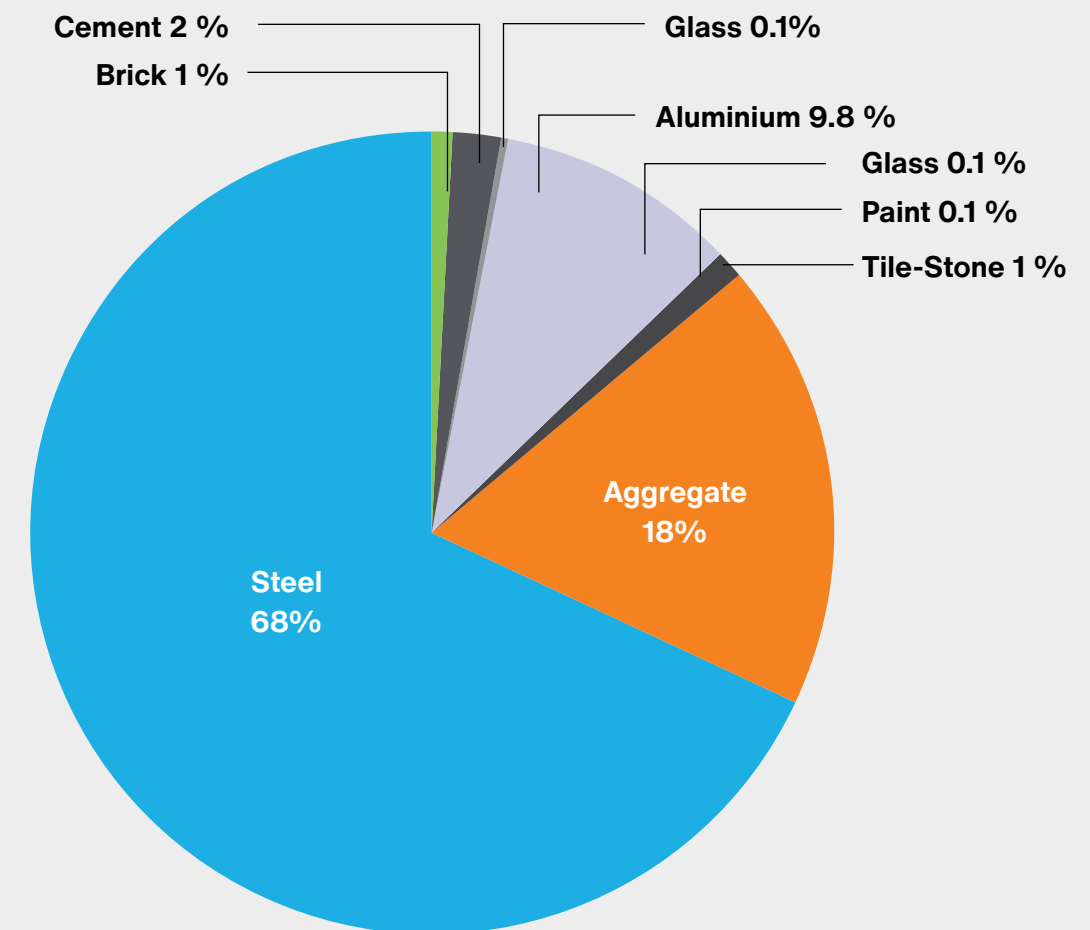


Figure 19. The Contribution of Different Types of Material in Indirect Water Consumption [30]

[29] Mannan, M., Al-Ghamdi, S., G. (2020). Environmental impact of water-use in buildings: Latest developments from a life-cycle assessment perspective. *Journal of Environmental Management*, 261, <https://doi.org/10.1016/j.jenvman.2020.110198>

[30] Heravi, G., Abdolvand, M., M. (2019). Assessment of water consumption during production of material and construction phases of residential building projects. *Sustainable Cities and Society*, vol 51, <https://doi.org/10.1016/j.scs.2019.101785>

[31] Gerbens-Leenes, P., W., Hoekstra, A., Y., Bosman, R. (2018). The blue and grey water footprint of construction materials: Steel, cement and glass. *Water Resources and Industry*, 19, pp. 1-12, <https://doi.org/10.1016/j.wri.2017.11.002>

2.5. Water Use in the Production of Building Materials

These uses form the water footprint of the building. **(For more details, see Sustainable Buildings E-Learning Program Module 1).** In the production of building materials, assessment of blue and grey water footprints is prioritized.

- **The water used during the building construction phase** is defined as the total amount of water used for the extraction, processing, production, and transportation of raw materials for construction (embodied water) as well as the water used in direct construction activities. [29]

Water Consumption Reduction Strategies [30]:

- Life-Cycle Assessment method should be applied in material production. The production of materials with high embodied energy should be reduced.
- Materials with lower indirect water consumption should be used.

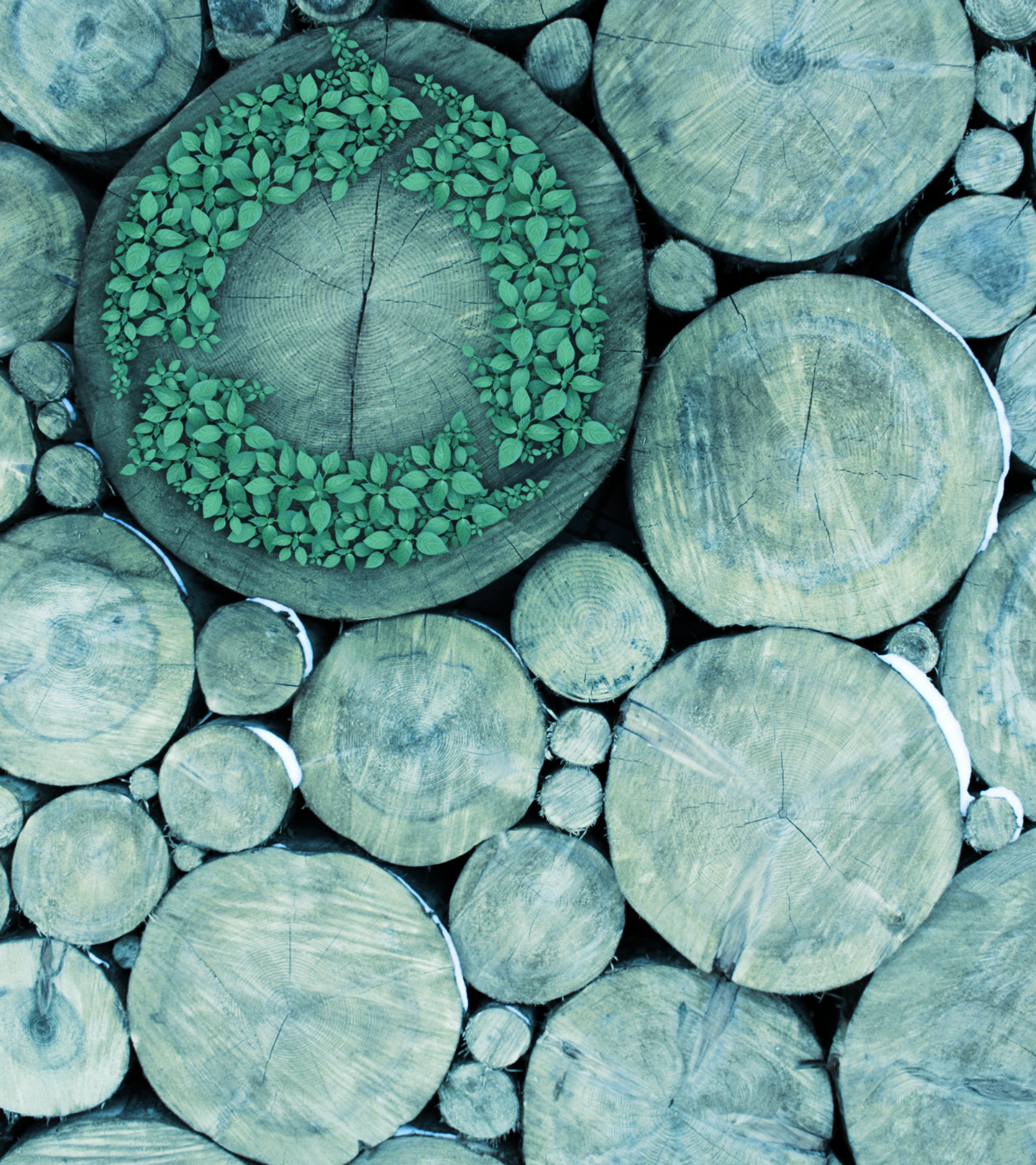
Example 1: Using other façade types such as fiber cement boards, natural stone, and composite panels instead of conventional options can reduce indirect water consumption.

Example 2: In interior architectural components, using aerated concrete instead of bricks, clay blocks, or cement blocks can help reduce indirect water consumption. These blocks contain up to 80% air, significantly reducing the amount of sand, cement, and water needed. Additionally, they can be assembled with thinner cement mortar layers.

- Implementation of water-saving processes in material production

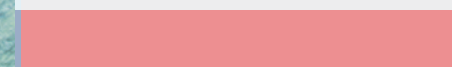
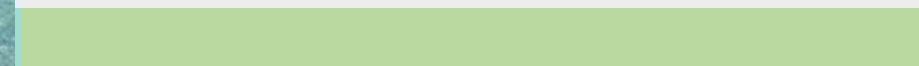
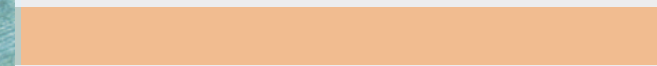
Example 1: One of the key components of indirect water consumption is the water used in steel production processes. Optimizing steel production facilities by applying reduce, reuse, and recycle approaches can significantly lower water consumption.





Section 3

TYPES OF SUSTAINABLE BUILDING MATERIALS



3.1. Natural and Low-Impact Materials



Wood:

Wood is considered the most important renewable resource for a sustainable bioeconomy in the future. Traditionally used in the construction sector, it has recently gained significance as a sustainable alternative to steel and concrete. It also serves as a foundation for the development of new bio-based functional materials [32, 33, 34, 35].



Earth:

Earth is an economical, environmentally friendly, and abundantly available building material—probably one of the oldest known to humanity. Today, earthen structures are drawing increasing interest both for heritage conservation and as a rediscovered eco-sustainable material [36]. Examples of buildings constructed with earth can be seen in the adjacent figures [37].

[32] Goldhahn, C., Cabane, E., & Chanana, M. (2021). Sustainability in wood materials science: An opinion about current material development techniques and the end of lifetime perspectives. *Philosophical Transactions of the Royal Society A*, 379(2206), 20200339.

[33] <https://www.iccsafe.org/building-safety-journal/bsj-dives/the-benefits-of-timber-frame-houses/>

[34] https://www.abodo.co.nz/resources/articles/timber-clad-roofs-simplicity-defined?__geom=%E2%9C%AA

[35] <https://www.havwoods.com/au/sustainability-and-timber/>

[36] Quagliarini, E., D'Orazio, M., & Lenci, S. (2015). The properties and durability of adobe earth-based masonry blocks. In *Eco-efficient masonry bricks and blocks* (pp. 361-378). Woodhead Publishing.

[37] Morel, J. C., Charef, R., Hamard, E., Fabbri, A., Beckett, C., & Bui, Q. B. (2021). Earth as construction material in the circular economy context: practitioner perspectives on barriers to overcome. *Philosophical Transactions of the Royal Society B*, 376(1834), 20200182.

3.1. Natural and Low-Impact Materials



Bamboo:

Bamboo is widely known as a sustainable building material that can be easily grown, harvested in a relatively short time, and reused. Due to its flexibility and pliability, it is particularly suitable for constructing organically shaped buildings. In Indonesia and across Asia, many traditional homes use bamboo as both a structural and non-structural building material [38, 39, 40].



Mushroom (Mycelium):

Mushroom roots provide mycelium, a fungal substance composed of thread-like filaments resembling roots and forming the vegetative part of a fungus. The use of mycelium in construction materials aligns with globally set targets for durability and sustainability, offering an eco-friendly, renewable, and carbon-neutral alternative to commonly used materials such as cement, plastic, and steel [41, 42].

[38] Nurdiah, E. A. (2016). *The potential of bamboo as building material in organic shaped buildings*. *Procedia-Social and Behavioral Sciences*, 216, 30-38.

[39] <https://www.bbc.com/news/business-67402112>

[40] <https://www.buildsoft.com.au/blog/sustainable-solutions-building-with-bamboo>

[41] https://parametric-architecture.com/from-fungi-to-foundations-mycelium-in-construction/?srslid=AfmBOor7JdhNYGxnSFi-IS_k7ZitMtGrRcUy1roMwa_EStdKOCZttTaP

[42] <https://www.certifiedenergy.com.au/emerging-materials/emerging-materials-mycelium-brick>

3.1. Natural and Low-Impact Materials



Hemp:

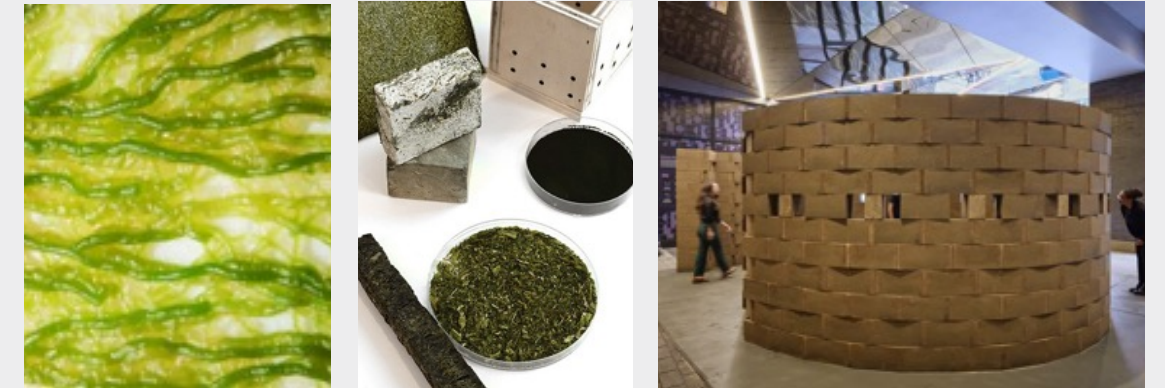
This versatile plant can be transformed into “hempcrete,” a carbon-negative building material that challenges traditional construction methods. Produced by mixing the woody core of hemp stalks with lime powder and water, this innovative material is particularly effective for interior walls and insulation. It has been shown to reduce building energy costs by up to 15% thanks to its excellent insulation properties [43, 44, 45].



Straw:

Straw is a by-product of food production. When grains such as wheat, rice, barley, corn, oats, and rye are harvested, the remaining stalks become straw.

Straw sequesters a significant amount of carbon, so its use as a building material contributes to global emission reduction goals. When densely packed, straw limits oxygen availability, providing fire resistance and eliminating the need for toxic flame-retardant chemicals [46, 47].



Algae:

When microalgae are combined with water, sunlight, and CO₂, they form a material similar to the calcium carbonate produced in coral reefs. When mixed with an aggregate, they create a construction material with a net-zero carbon footprint that offers physical and thermal properties comparable to—or even better than—standard concrete. Compared to traditional concrete, it has the potential to significantly reduce CO₂ emissions [48, 49, 50].

[43] <https://edenhotlimemortar.co.uk/product/hemp-blocks/>

[44] <https://hempfoundation.net/how-hemp-can-transform-the-construction-industry/>

[45] <https://www.archdaily.com/1019891/the-past-present-and-future-of-hemp-in-construction>

[46] <https://www.familyhandyman.com/article/straw-bale-construction/>

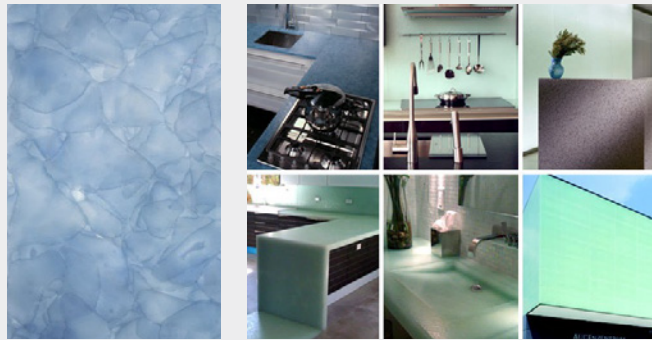
[47] <https://healthymaterialslab.org/blog/building-with-plants-research-on-straw-materials-and-construction>

[48] <https://materialdistrict.com/article/algae-based-concrete-blocks/>

[49] <https://www.advancedsciencenews.com/algae-laden-hydrogels-could-bring-buildings-to-life/>

[50] <https://materialdistrict.com/article/algae-based-concrete-blocks/>

3.1. Natural and Low-Impact Materials



Bio-glass:

Bio-glass is made from 100% recycled glass. It is a silicate-based glass consisting of 45% SiO₂, 24.5% Na₂O, 24.5% CaO, and 6% P₂O₅ by weight. As a Class A bioactive material, bio-glass also exhibits antibacterial properties. It is available in tile and slab forms for use in hard surface designs such as countertops, wall partitions, and flooring [51, 52].



Low-Carbon Concrete:

Low-carbon concrete refers to concrete produced with a smaller carbon footprint than conventional concrete. To reduce emissions, manufacturers can modify production processes and mix designs. These methods may include changing fuel sources, replacing cement content with mineral compounds such as calcined clays or fly ash, and applying carbon capture technologies [53, 54, 55].



Cross-Laminated Timber (CLT):

Cross-laminated timber (CLT) is an engineered wood product composed of kiln-dried, dimensional lumber layers oriented at right angles and then bonded together to form structural panels. The perpendicular arrangement of wood layers gives the panel excellent structural strength in both directions. The CLT building system consists of large, solid wood panels that can be used as walls or floors [56, 57].

DURABILITY AND FIRE SAFETY

Durability:

- Natural materials are generally durable, but their longevity can vary depending on climate conditions and maintenance. For instance, wood and bamboo can last a long time with proper treatment. Materials such as mycelium and algae-based products, however, must be carefully used due to their sensitivity to moisture and mold formation.

Fire Safety:

- Wood and bamboo are combustible materials and thus present fire safety concerns. However, their fire resistance can be enhanced through modern engineering techniques. When these materials are used in construction, compliance with national fire and timber building codes is essential.
- Bio-composite materials and low-carbon concrete generally offer improved fire resistance. Buildings must be designed in accordance with applicable fire safety standards.

[51] Jain, S., Gujjala, R., Azeem, P. A., Ojha, S., & Samudrala, R. K. (2022). A review on mechanical and In-vitro studies of polymer reinforced bioactive glass-scaffolds and their fabrication techniques. *Ceramics International*, 48(5), 5908-5921.

[52] <https://dornob.com/beautiful-recycled-bio-glass-super-strong-surface-material/>

[53] <https://builtoffsite.com.au/news/low-carbon-concrete/>

[54] Althoey, F., Ansari, W. S., Sufian, M., & Deifalla, A. F. (2023). Advancements in low-carbon concrete as a

construction material for the sustainable built environment. *Developments in the Built Environment*, 100284.

[55] <https://civinnovate.com/2024/11/10/low-carbon-concrete-a-greener-future/>

[56] <https://www.naturallywood.com/products/cross-laminated-timber-clt/#:~:text=CLT%20is%20an%20engineered%20wood,structural%20rigidity%20in%20both%20directions.>

[57] Younis, A., & Dadoo, A. (2022). Cross-laminated timber for building construction: A life-cycle-assessment overview. *Journal of Building Engineering*, 52, 104482.

3.2. Recycled and Reused Materials



RECYCLED CONCRETE:

Recycled aggregate concrete (RAC) is an alternative to natural aggregate concrete. Recycled concrete aggregate (RCA) is obtained by crushing old concrete structures. This aggregate is then used in the production of RAC; however, the amount of other construction debris present in the concrete should remain below a few percent.

For example, the British Standard BS 8500-2 (BSI, 2006) defines RCA as recycled aggregate containing a maximum of 5% masonry/fine material, 0.5% lightweight material/asphalt, and 1% other foreign materials [58].

Benefits:

- Recycling used concrete reduces the use of natural resources and minimizes the environmental impact of extracting and transporting new materials.
- Concrete produced with RCA generates fewer emissions compared to concrete made from virgin materials.
- Recycling concrete significantly reduces the amount of waste sent to landfills, which lowers landfill tax costs and offers savings to businesses.
- Recycled concrete can be lighter than newly produced concrete, allowing for a greater volume at the same weight. This can reduce raw material and transport needs, lowering production costs as well [59, 60].

[58] Marinković, S., & Carević, V. (2019). Comparative studies of the life cycle analysis between conventional and recycled aggregate concrete. In *New trends in eco-efficient and recycled concrete* (pp. 257-291). Woodhead Publishing.

[59] <https://www.cemexventures.com/recycled-concrete/>

[60] <https://www.shutterstock.com/tr/image-photo/recovery-recycling-concrete-brick-rubble-debris-2118096518>

3.2. Recycled and Reused Materials



RECYCLED STEEL:

Steel is an iron alloy composed of a combination of metals and non-metals, including carbon, iron, and tin. Like most metals—including aluminum, copper, and brass—steel can be continuously recycled without any degradation in its properties, regardless of its product form.

Benefits:

- The use of recycled steel in new construction projects helps reduce waste and enhances sustainability. It decreases the volume of materials sent to landfills and supports the circular economy. Moreover, producing recycled steel consumes significantly less energy compared to conventional steel production, greatly reducing the carbon footprint of the industry.
- Recycled steel and steel slag can be transformed into valuable construction materials. For instance, steel slag can be used as a cement replacement in concrete, offering both environmental and economic benefits. Thanks to its durable structure, steel slag is preferred for use in fill material, road construction, dams, asphalt paving, concrete masonry, and soil stabilization. Especially in road construction, its mechanical properties can even outperform natural aggregates.
- Structures built with recycled steel are durable and resilient. Additionally, they can be repurposed at the end of their life cycle. This approach supports a closed-loop system that minimizes waste and maximizes efficiency [61, 62, 63].

[61] <https://www.azobuild.com/article.aspx?ArticleID=8693>

[62] <https://www.recyclingdepotadelaide.com.au/scrap-metal-recycling-process>

[63] <https://glescrap.com/blog/stainless-steel-recycling-guide/>

3.2. Recycled and Reused Materials



RECYCLED PLASTIC:

Plastic has become a key material in the construction industry due to its lightweight, durability, and cost-effectiveness. However, these advantages come with significant environmental costs. According to the World Economic Forum, the construction sector accounts for approximately 20% of global plastic consumption. Much of this plastic waste ends up in landfills, oceans, or as microplastics in the environment, causing harm to ecosystems. Thanks to recent research, these plastics can now be recycled and reused in construction applications.

Biodegradable and Recyclable Plastics

One of the most promising developments in sustainable construction is the use of biodegradable and recyclable plastics. These materials are designed to either naturally decompose over time or be reused in new products, helping to reduce the volume of plastic waste sent to landfills.

- **PLA (Polylactic Acid):** PLA is a biodegradable plastic derived from renewable resources such as corn starch or sugarcane. It is already used in packaging and can be adapted for construction purposes such as insulation or non-load-bearing structures.
- **Recycled Plastic Lumber:** Recycled plastic lumber, made from post-consumer plastic waste, offers a durable and environmentally friendly alternative to traditional wood. It is resistant to moisture, decay, and insects, making it an ideal material for decking, fencing, and outdoor furniture [64, 65, 66].

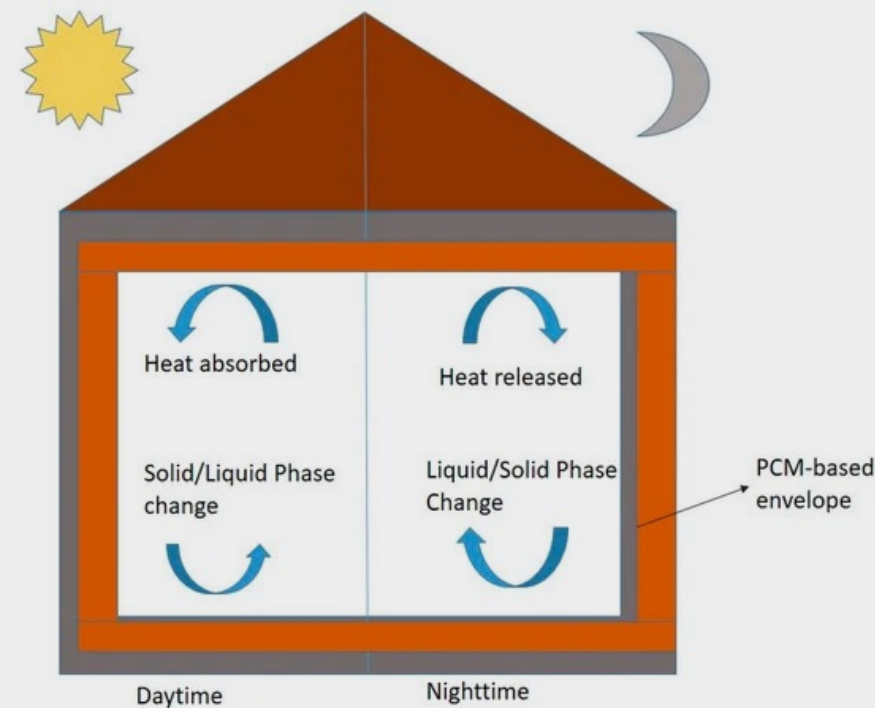
[64] <https://www.4ocean.com/blogs/construction/building-a-greener-future-reducing-plastic-waste-in-construction?srsItd=AfmBOophxEn3ZD9B9qGegnaaSMWW3-bQ9m4o7Jbq6y4V5fMc2cEnKnir>

[65] <https://www.moldplasticinjection.com/news/what-is-polylactic-acid-types-applications-advantages-and-processes-of-pla>

[66] <https://tangentmaterials.com/materials/>

3.3. Phase Change Materials (PCMs)

Phase Change Materials (PCMs) can absorb and release heat at a relatively constant temperature during phase transitions. These materials have a high potential for storing and releasing large amounts of heat per unit volume. By storing heat during the melting/charging phase and releasing it during the solidification/discharging phase, PCMs can effectively manage energy in various applications and help regulate energy demand.



The incorporation of PCMs into building envelopes has proven effective in controlling thermal loads, resulting in significant energy savings. Due to their high latent heat storage capacity during melting and solidification, PCMs are applied to minimize cooling and heating loads through the building envelope, thereby ensuring acceptable thermal comfort [67, 68].

Energy, Economic, and Environmental Impacts:

Heat Storage: PCMs store heat during temperature fluctuations, helping stabilize indoor temperatures. This reduces energy consumption and lowers heating and cooling costs.

Increased Comfort: PCMs reduce temperature variations in buildings, enhancing indoor thermal comfort.

Energy Savings: PCMs reduce energy demand. In particular, heat stored during the day in summer can be released at night, decreasing the need for cooling.

Sustainability: PCMs offer sustainable energy solutions when integrated with renewable energy sources. For example, in a solar-powered heating system, PCMs can store energy during the day for use at night.

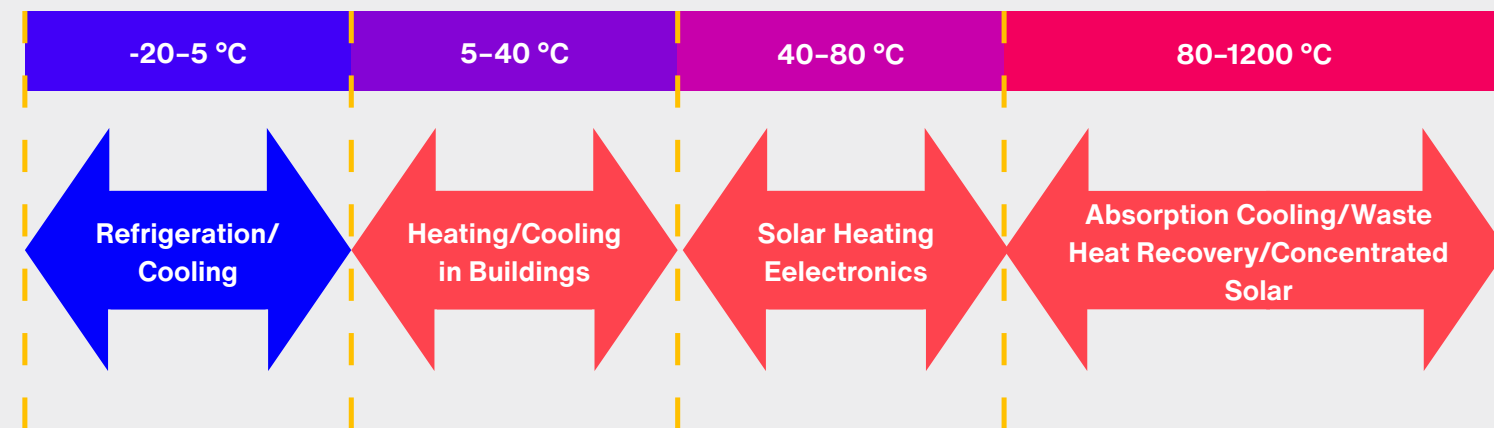
[67] Jha, S. K., Sankar, A., Zhou, Y., & Ghosh, A. (2024). Incorporation of phase change materials in buildings. *Construction Materials*, 4(4), 676-703.

[68] Al-Yasiri, Q., & Szabó, M. (2021). Incorporation of phase change materials into building envelope for thermal comfort and energy saving: A comprehensive analysis. *Journal of Building engineering*, 36, 102122.

3.3. Phase Change Materials (PCMs)

Based on their chemical composition, Phase Change Materials (PCMs) are primarily classified as organic, inorganic, and eutectic materials. Each category has specific operating temperature ranges and thermophysical properties, making them more suitable for particular applications.

PCMs have a wide range of applications across various sectors, including building systems, daily life operations, energy storage systems, microelectronics temperature management, textiles, satellites, telecommunications, transportation, pharmaceuticals, and submarine equipment [69, 70].



In 2009, Charles Sturt University's Thurgoona campus in Albury became the first known site in the world to incorporate PCMs into its concrete floors.

PCMs were also integrated into the campus's plasterboard ceilings. These innovations contributed to the campus receiving a six Green Star rating and a "World Leader" status from the Green Building Council of Australia [71].



Phase Change Materials began to show their true impact in architecture around 2004. During this time, BASF, the world's largest chemical company based in Germany, introduced its Micronal product. This material encapsulated a paraffin wax-based storage medium inside microscopic acrylic polymer spheres. As temperatures rise, the wax within the capsules begins to melt—undergoing a phase change—and absorbs heat in the process. When the temperature drops, the wax solidifies again and releases the stored heat.

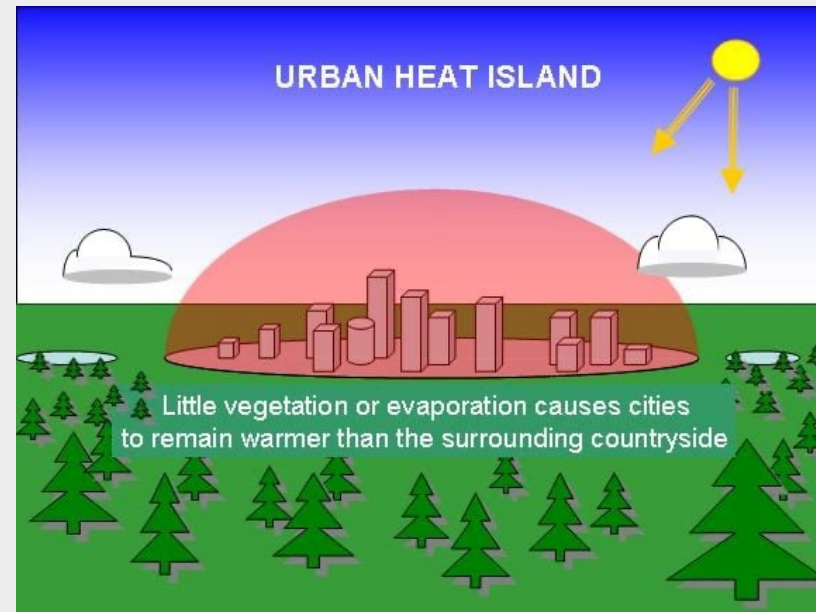
[69] Du K., Calautit J., Wang Z., Wu Y., Liu H., A Review of the Applications of PCMs in Cooling, Heating and Power Generation in Different Temperature Ranges, *Applied Energy*, C 220, S 242- 273, 2018.

[70] Douvi E., Pagkalos C., Dogkas G., Koukou M. K., Stathopoulos V. N., Caouris Vrachopoulos Y. M. G., PCMs in Solar Domestic Hot Water Systems: A Review, *International Journal of Thermofluids*, C 10, S 100075, 2021.

[71] <https://www.architectureanddesign.com.au/features/features-articles/the-state-of-phase-change-materials-in-australian>

3.4. Cool Roofs and Reflective Materials

While urbanization accelerates economic development in many ways, it also gives rise to a number of environmental problems. One such issue is the increase in temperature caused by dense built environments, known as the urban heat island (UHI) effect.

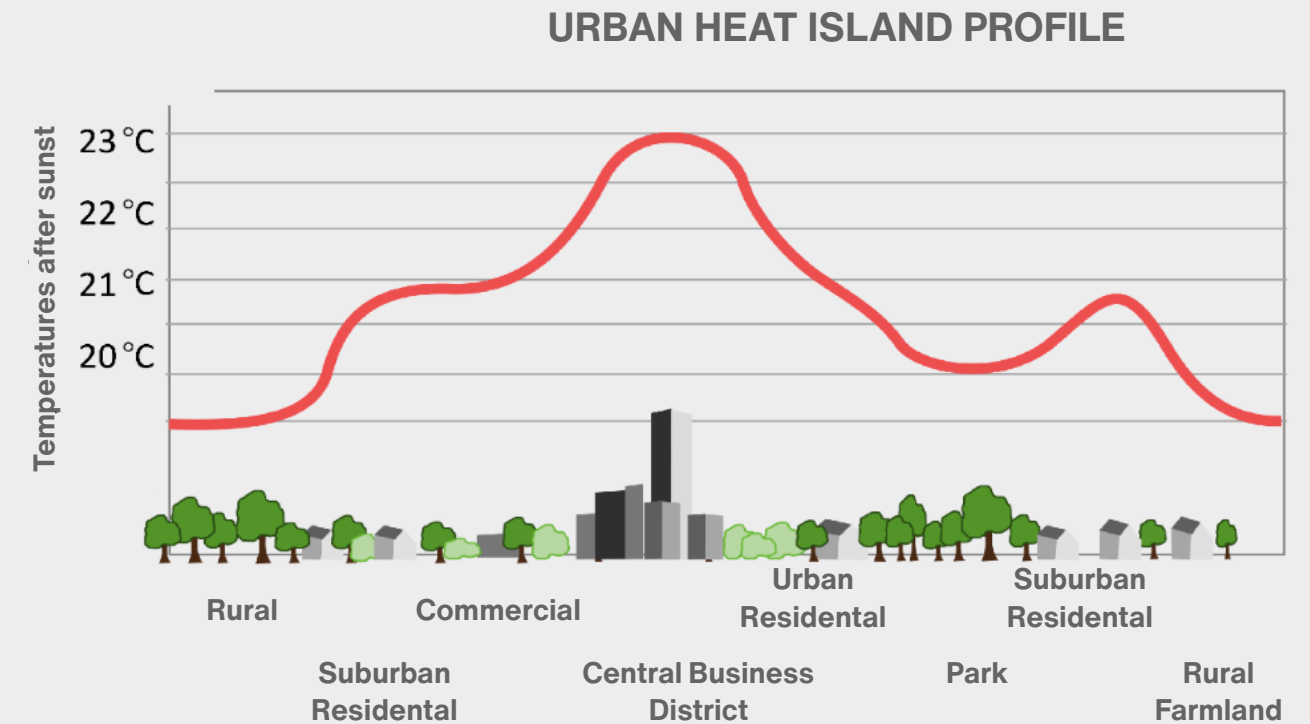


What Is the Urban Heat Island Effect?

The urban heat island effect is a significant form of **anthropogenic** (human-induced) climate change caused by urbanization and industrialization. It has a major impact on urban climate. Urban areas, where buildings are densely packed and green spaces are limited, become “islands” with higher temperatures compared to their surroundings. These zones of elevated temperatures are referred to as heat islands [72].

[72] <https://www.rff.org/publications/explainers/urban-heat-islands-101/>

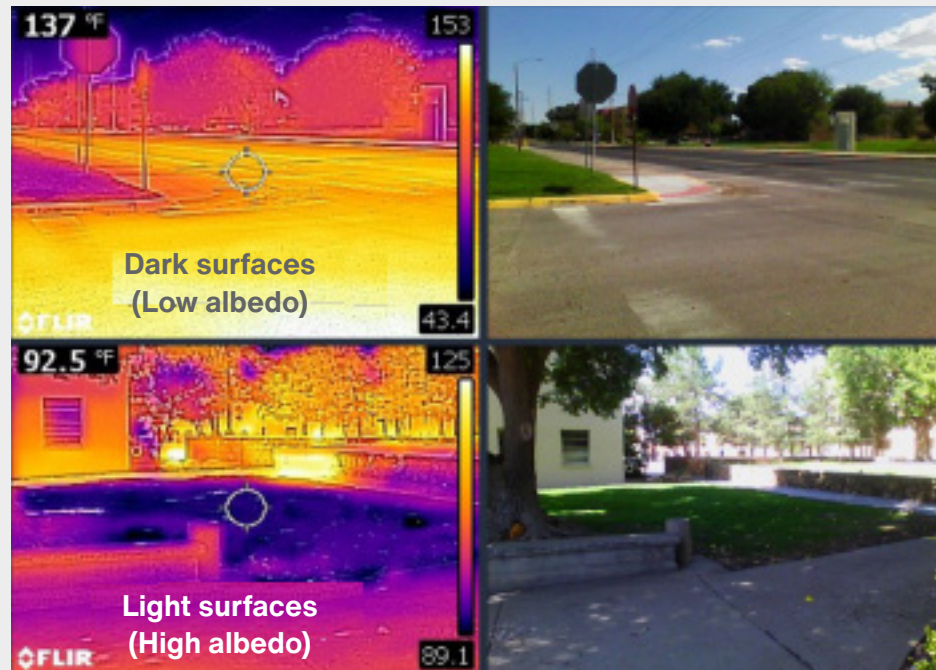
[73] <https://www.metlink.org/fieldwork-resource/urban-heat-island-introduction/>



Urban heat islands can occur year-round, but extreme summer conditions have the most pronounced effects on quality of life and energy consumption in cities.

Studies estimate that heat islands can increase daytime temperatures in urban areas in the United States by approximately 0.5°C to 4°C, and nighttime temperatures by 1°C to 2.8°C [73].

3.4. Cool Roofs and Reflective Materials



Low-Albedo, Heat-Absorbing Materials:

Dark-colored surfaces (low albedo) absorb more solar energy compared to lighter and more reflective surfaces (high albedo). The energy absorbed is eventually released as heat that can be felt. This is why a dark surface exposed to the sun feels hot to the touch.

Urban environments typically contain a higher proportion of heat-absorbing materials. The temperature difference between high- and low-albedo surfaces can be observed using an infrared camera [74].

[74] <https://www.heat.gov/pages/urban-heat-islands>

[75] <https://www.epa.gov/heatislands/using-cool-roofs-reduce-heat-islands>



Cool Roof Applications

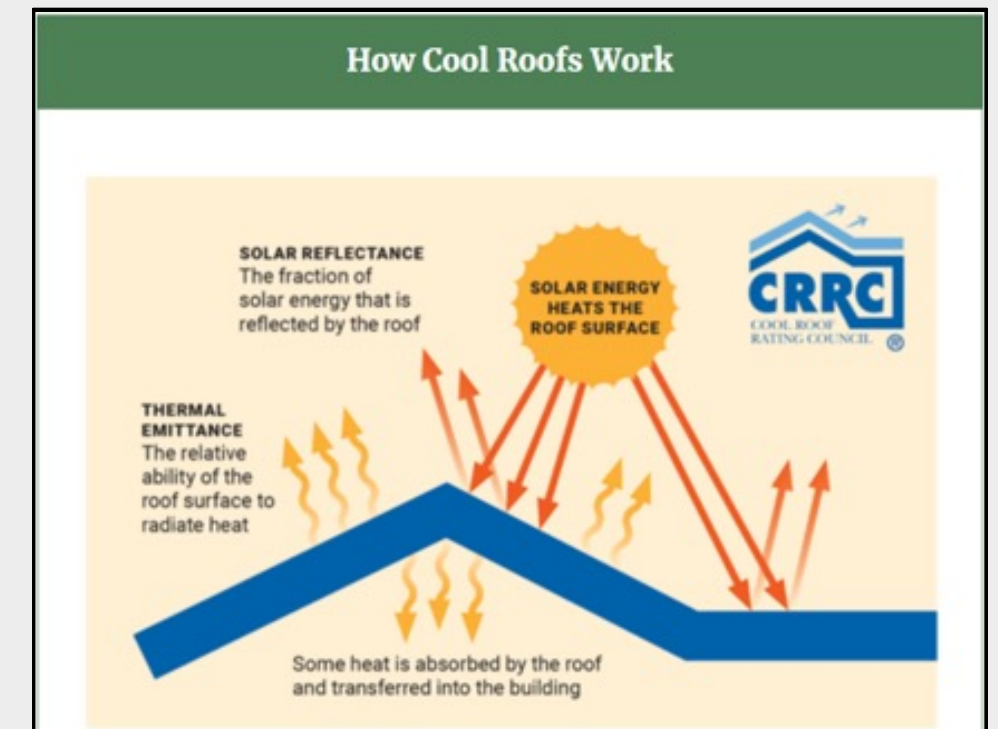
Designing your building's roof as a cool roof involves using materials or coatings that reflect a significant amount of sunlight and heat away from the building. This reduces roof surface temperatures, enhances occupant comfort, and lowers energy demand [75].



A higher solar reflectance rate means more solar energy is reflected from the cool roof surface.

Products for Different Roof Types:

- Asphaltic membranes coated with reflective granules
- Ceramic tiles (such as terra cotta)
- Liquid-applied roof coatings in light or cool colors
- Liquid-applied membranes in light or cool colors
- Roof aggregate in light or cool colors (e.g., gravel)
- Single-ply membranes with light or cool color pigments [75]



3.4. Cool Roofs and Reflective Materials

Using Cool Pavements

In sidewalks, parking lots, and roadways, using paving materials that stay cooler than conventional surfaces—by reflecting more solar energy and increasing water evaporation—not only cools the surface and surrounding air but can also reduce stormwater runoff and enhance nighttime visibility [76].



Effects of Permeable Pavements:

- Reduced stormwater runoff and improved water quality
- Lower roadway noise
- Increased safety
- Improved nighttime visibility



Light-colored slag, a byproduct of iron and steel production, enhances reflectivity, structural integrity, and environmental durability when integrated into concrete.

[76] <https://www.epa.gov/heatislands/using-cool-pavements-reduce-heat-islands>

3.5. Composites in Sustainable Construction



Recycled Bio-Based Composites: Recycled bio-based composites are made from environmentally friendly materials derived from natural sources (e.g., plant fibers). These composites are produced using waste or recycled materials and typically consist of fibers combined with bioplastics or natural resins.

Bioplastics: While conventional plastics are derived from natural gas, petroleum, or plants, most bioplastics are created through a chemical reaction that transforms sugars extracted from plants or other organic materials into key chemical compounds used in plastic polymers. When abundant bio-based alternatives are used instead of fossil-based feedstocks, bio-based plastics offer a unique potential for carbon neutrality—restoring the environmental reputation of plastics [77, 78].

[77] <https://bioplastics.org.au/resources/faq/#toggle-id-1>

[78] <https://euoplas.com.vn/en-US/blog-1/can-bioplastic-be-genetically-modified>

3.5. Composites in Sustainable Construction



Steel Fiber Reinforced Concrete (SFRC) is increasingly adopted in both precast and in-situ concrete structures, allowing partial or complete replacement of traditional reinforcement. This reduces construction time and labor costs associated with placing conventional reinforcement. SFRC also helps reduce shrinkage-related cracking and enhances the durability of concrete structures.

The fiber dosage in concrete typically ranges between 0% and 2% of the total concrete volume [79].

Environmental Impacts

- **Waste Management:** The use of recycled materials reduces waste volume and contributes to the conservation of natural resources.
- **Carbon Footprint:** Bio-based composites have a lower carbon footprint compared to traditional construction materials, which helps reduce greenhouse gas emissions.
- **Energy Efficiency:** Their production processes generally consume less energy, thereby helping to minimize environmental impacts.

Contributions to Circular Economy

- **Resource Efficiency:** Recycled bio-based composites promote more efficient use of resources.
- **Longevity:** The durability of these materials extends the lifespan of construction projects and reduces the need for frequent renovations.
- **Economic Benefits:** The adoption of innovative materials can create new job opportunities and contribute to economic growth.

3.6. Innovative Insulation Materials

Cellulose

Cellulose is a natural polymer found in the cell walls of plants. It is typically produced from recycled paper or wood fibers.

Energy Savings: Cellulose insulation helps save energy due to its low thermal conductivity.

Thermal Comfort: Cellulose can regulate humidity, providing a comfortable indoor environment.

Health Conditions: Being a natural material, it contains no chemical additives, which improves indoor air quality.

Recyclability: Cellulose is fully recyclable and biodegradable.

Low Energy Consumption: Its production process requires less energy compared to traditional insulation materials [80, 81, 82, 83].

Aerogels

Aerogels are lightweight, high-performance insulation materials with a high porosity rate.

Energy Savings: They provide excellent thermal insulation, contributing to energy savings.

Thermal Comfort: Aerogels minimize temperature fluctuations, enhancing indoor comfort.

Health Conditions: Generally, they do not contain chemical additives, which improves indoor air quality.

Recyclability: Some aerogels are recyclable, but their production processes can be complex.

Low Energy Consumption: The manufacturing process may consume more energy compared to traditional materials, but their performance is high [80, 81, 82, 83].

Sheep Wool

Sheep wool is a natural insulation material obtained from sheep fleece.

Energy Savings: It reduces energy consumption due to its high heat retention capacity.

Thermal Comfort: Sheep wool enhances indoor comfort through its temperature-regulating ability.

Health Conditions: As a natural material, it does not contain allergens or toxic chemicals.

Recyclability: At the end of its lifespan, it can be composted or recycled.

Low Energy Consumption: Its production process consumes low energy [80, 81, 82, 83].

[80] International Energy Agency (IEA). (2020). *Energy Efficiency 2020*.

[81] United Nations Environment Programme (UNEP). (2018). *Sustainable Building and Construction: A Global Perspective*.

[82] <https://www.usgbc.org/>

[83] <https://www.ellenmacarthurfoundation.org/>

3.6. Innovative Insulation Materials



Cotton

Cotton is a natural fiber derived from plants grown using sustainable farming methods.

Energy Savings: Cotton insulation provides good thermal insulation and helps save energy.

Thermal Comfort: Cotton improves indoor comfort by absorbing and regulating moisture.

Health Conditions: It is a healthy insulation option as long as it is not chemically treated.

Recyclability: Cotton is biodegradable and recyclable.

Low Energy Consumption: The production of cotton insulation may consume less energy compared to other materials [80, 81, 82, 83].

Recycled Clothing (Denim Jeans)

This insulation material is produced by recycling old clothes.

Energy Savings: Recycled clothing helps save energy due to its low thermal conductivity.

Thermal Comfort: It provides comfort indoors through its insulation properties.

Health Conditions: Being made from natural materials, it can be a healthy option.

Recyclability: Used clothing is recyclable and can be turned into new products.

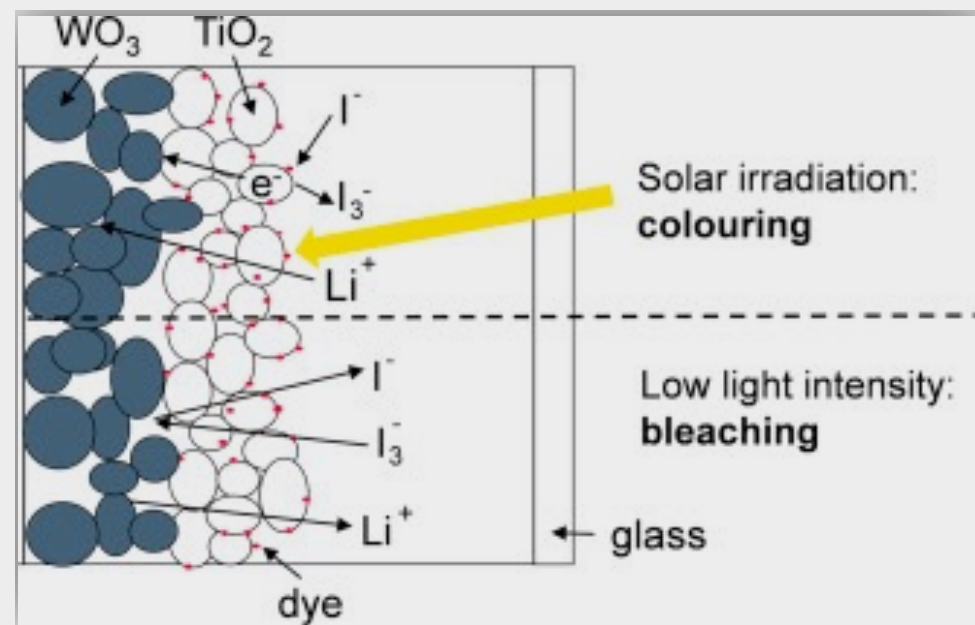
Low Energy Consumption: The production process requires less energy compared to new materials [80, 81, 82, 83].

3.7. Smart Glass Technologies

Smart glass technologies play an important role in sustainable construction and energy efficiency. These materials help reduce environmental impact by saving energy and enhancing indoor comfort.

Photochromic Glass Coating: A glass coating material that automatically darkens when exposed to ultraviolet (UV) rays. It darkens when exposed to sunlight and becomes transparent again in the shade or indoors.

UV rays in sunlight activate the photochromic components of the glass. UV light changes the structure of the molecules (e.g., WO_3 and TiO_2) inside the glass. This change causes the glass to darken and thus absorb more light, protecting the eyes. When sunlight disappears or UV light decreases, the photochromic molecules return to their original form and the glass becomes transparent again. This feature provides energy savings both indoors and outdoors, as photochromic glasses prevent excessive solar heat and reduce the need for air conditioning [84, 85].



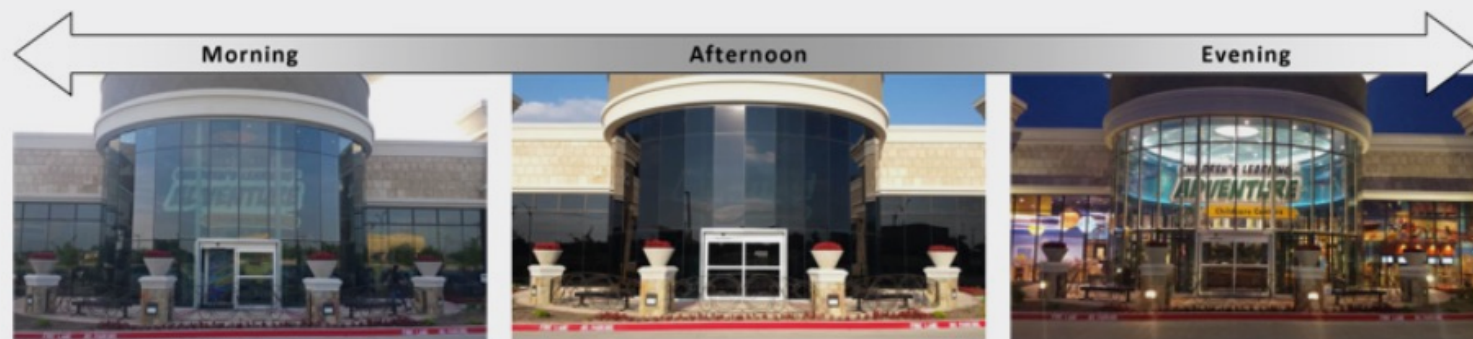
[84] <https://windows.lbl.gov/high-performance-windows>

[85] <https://smartglassnordic.com/index.php/en/products-en/photochromic-film>

3.7. Smart Glass Technologies

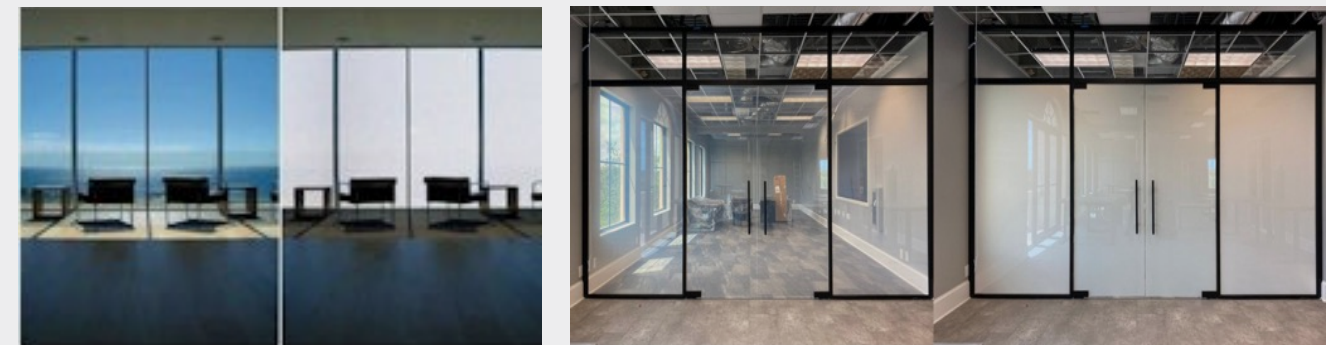
Thermochromic Glass Coating: A type of glass coating that changes color depending on temperature changes. It becomes opaque within a certain temperature range.

When the temperature of the glass exceeds a certain threshold, the thermochromic components (e.g., VO_2) inside the coating are activated. As the temperature increases, the molecules in the glass change their structure, and this change causes the color of the glass to darken or lighten. When the temperature decreases, the thermochromic molecules return to their original form and the glass regains its original color [86, 87].



Electrochromic Glas: Electrochromic glass is a type of glass that changes color with electric current. The user can control the transparency level of the glass.

On the inner surface of the glass, there is a film or coating with electrochromic properties. This material undergoes a chemical change when electric current is applied. When an electric current is applied to the glass, the electrochromic material allows the movement of ions. This process causes the color of the glass to change. Generally, the glass darkens and absorbs more light [88].



The relationship between smart glass technologies and sustainability:

By filtering solar radiation, it reduces the heating of indoor spaces, thus lowering energy consumption related to the use of air conditioning systems. In addition to reducing the greenhouse gas emissions from the building due to this drop in energy use, it also improves indoor comfort for users.

[86] Aburas, M., Soebarto, V., Williamson, T., Liang, R., Ebendorff-Heidepriem, H., & Wu, Y. (2019). Thermochromic smart window technologies for building application: A review. *Applied Energy*, 255, 113522.

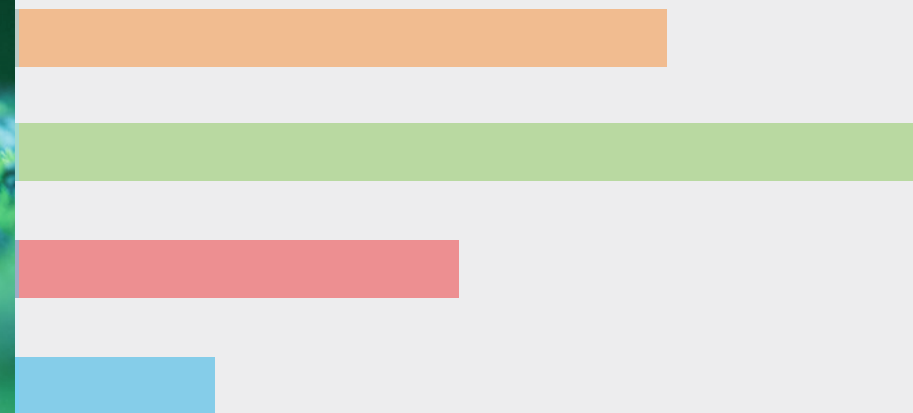
[87] <https://avdiscovery.com.my/>

[88] Taher, R., Abdelkader, W. A., & Fahim, A. A. M. A. (2022, December). Sustainable Building: To Achieve Thermal Comfort in Highly Glazed Buildings Using Smart Glass. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1113, No. 1, p. 012021). IOP Publishing.



Section 4

ECONOMIC AND SOCIAL ASPECTS OF SUSTAINABLE BUILDING MATERIALS



4.1. Economic Benefits of Sustainable Building Materials

Cost-effectiveness refers to achieving the lowest total cost in the process of obtaining and using a material, taking into account its availability, quality, and performance.

Cost-effectiveness is evaluated by considering stages such as the production, transportation, processing, service life, and recycling of the material.



The economic impact of using sustainable materials in the stages of raw material extraction, production, and transportation can be considered as follows:

- 1. Raw material extraction:** Sustainable materials are generally those that are extracted with less energy consumption, have lower environmental impacts, and consume fewer natural resources. In the long run, this results in lower costs because as natural resources begin to deplete, extracting them becomes more expensive. In addition, companies involved in the sustainable material supply chain can often protect themselves from price fluctuations by signing long-term contracts.
- 2. Production stage:** Sustainable materials may consume less energy and generate less waste during production. This reduces production costs. Although initial investment costs may be high, in the long term, as energy and waste management costs decrease, the total cost also decreases.
- 3. Transportation:** In the transportation processes of sustainable materials, the aim is also to reduce environmental impacts. More efficient transport methods are used. Moreover, transporting materials over long distances can increase carbon emissions, which may result in additional costs in the long term due to regulatory measures [89].

4.2. Market Trends in Sustainable Building Materials

The use of sustainable materials in buildings is gaining rapidly increasing importance in today's market. The construction sector is associated with high energy consumption and environmental impact; therefore, the use of sustainable materials helps buildings become environmentally friendly, energy-efficient, and resource-effective structures. The use of sustainable materials not only reduces environmental impacts but also provides long-term economic benefits by helping to reduce operating costs.

Buildings constructed with sustainable materials can obtain green building certifications due to their environmentally friendly features, which can increase demand for such projects. Moreover, such structures are preferred by consumers and businesses as awareness grows. The increase in the number of sustainable building projects in the market also increases the demand for these materials.

- **Wood:**
 - Certified Wood
 - Cross-Laminated Timber (CLT)
- **Recycled Materials:**
 - Recycled Steel
 - Recycled Glass
 - Recycled Concrete
- **Biological and Natural Materials:**
 - Bamboo
 - Hemp
- **Insulation Materials:**
 - Wool Insulation
 - Foam Glass Insulation
- **Green Roofs and Walls:**
 - Green Roofs
 - Green Walls (Vertical Gardens)
- **Solar Panels and Renewable Energy Systems:**
 - Solar Panels
 - Wind Energy Systems
- **Biological and Organic Paints and Coatings:**
 - Biodegradable Paints
 - Natural Wood Coatings



4.2. Market Trends in Sustainable Building Materials

<p>Contribution to Human Health</p> <ul style="list-style-type: none"> ▪ Indoor Air Quality: Materials with low VOC (Volatile Organic Compound) emissions improve indoor air quality, which helps prevent respiratory diseases. ▪ Protection from Harmful Chemicals: Sustainable materials do not contain toxic or harmful chemicals, thus protecting human health. 	<p>Contribution to Local Economies</p> <ul style="list-style-type: none"> ▪ Local Production and Employment: Materials sourced from local resources increase demand for local labor and create regional employment. ▪ Supporting the Local Economy: Procuring sustainable materials from local producers revitalizes local economies and supports regional development. 	<p>Equity and Justice in Society</p> <ul style="list-style-type: none"> ▪ Sustainable materials enable the construction of low-cost and high-quality housing, allowing low-income groups to access healthy living spaces. ▪ Structures built with these materials support healthy and equitable living conditions for all segments of society.
<p>Raising Public Awareness</p> <ul style="list-style-type: none"> ▪ Widespread Adoption of Environmentally Friendly Behavior: The use of sustainable materials encourages the adoption of environmentally friendly habits within society. ▪ Education and Awareness: The use of these materials raises public awareness about environmental sustainability and fosters greater environmental consciousness. 	<p>Promotion of Fair Working Conditions</p> <ul style="list-style-type: none"> ▪ Social Responsibility: Ethical and fair working conditions are prioritized in the production of sustainable materials. Workers' rights and safety are given importance. ▪ Prevention of Child Labor: Companies that produce sustainable materials have policies aimed at preventing child labor and other human rights violations. 	<p>Social Solidarity and a Culture of Sharing</p> <ul style="list-style-type: none"> ▪ Social Awareness: The construction of green buildings and the use of sustainable materials promote a collective approach within society based on environmental responsibility. ▪ Community-Oriented Projects: These types of projects not only help protect the environment but also bring local communities together and encourage shared purpose.

4.3. Impacts of Building Materials on Health

The selection of non-toxic, low-VOC materials is crucial for improving indoor air quality, preventing allergic reactions, and minimizing negative impacts on overall health. VOCs (Volatile Organic Compounds) are organic chemicals that, when released into the air, can cause respiratory issues, headaches, allergic reactions, and, in the long term, serious health problems such as cancer. Especially in new buildings or renovated interiors, the concentration of VOCs tends to be high, which can lead to conditions like “sick building syndrome.” Low-VOC materials do not contain—or contain significantly less of—such harmful chemicals, thus helping to protect user health. These materials also stand out for their environmentally friendly properties [90].



- **Paints and Varnishes:**
 - Water-based paints
 - Organic paints
- **Floor Coverings:**
 - Bamboo flooring
 - Natural linoleum
 - Solid hardwood floors
- **Insulation Materials:**
 - Cotton insulation
 - Bio-based insulation materials (felt, coconut fiber, hemp)
- **Building Materials:**
 - Natural stones (granite, marble)
 - Certified sustainable wood (FSC)
- **Furniture and Interior Products:**
 - Low-VOC MDF and particleboard
 - Natural textile fabrics (organic cotton, wool, bamboo)
- **Cleaning Products:**
 - Natural cleaning agents (lemon juice, vinegar, organic compounds)

4.4. Certifications and Labels for Sustainable Building Materials



Forest Stewardship Council (FSC) Certification: This certification ensures that forests are managed in a way that preserves biodiversity, benefits local communities, and supports economic sustainability. It sets essential environmental standards to prevent deforestation, protect wildlife habitats, and maintain ecological balance [91, 92, 93, 94].



[91] Johansson, Johanna. (2012). Challenges to the Legitimacy of Private Forest Governance – the Development of Forest Certification in Sweden. *Environmental Policy and Governance*. 22. 10.1002/eet.1591.

[92] Heredia, Aide & López Serrano, Pablito & Molinier, Matthieu & Wehenkel, Christian. (2023). Evaluation of forest cover loss in properties in the Sierra Madre Occidental, State of Durango, Mexico, certified by the Forest Stewardship Council. *Trees Forests and People*. 4. 100454. 10.1016/j.tfp.2023.100454.

[93] <https://connect.fsc.org/document-centre>

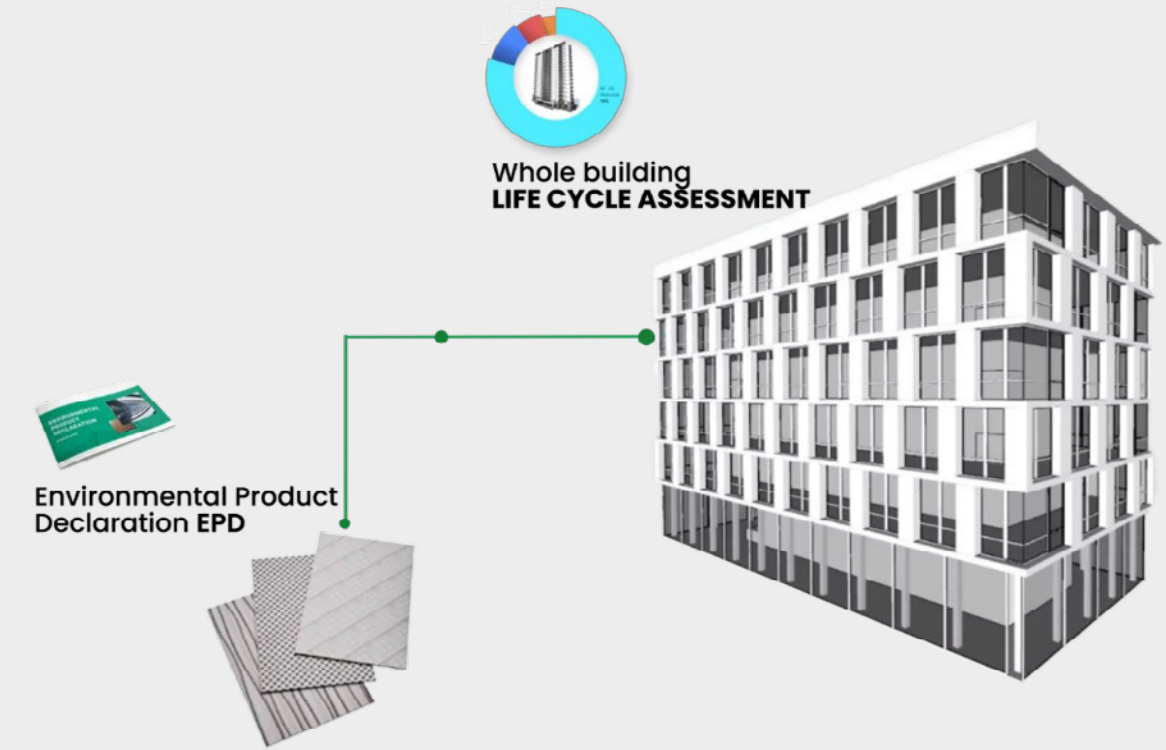
[94] <https://starprintvn.com/what-is-a-fsc-certificate-forest/>

4.4. Certifications and Labels for Sustainable Building Materials

Environmental Product Declarations (EPD) are documents that present the results of Life-Cycle Assessments of products based on standardized parameters defined under ISO 14040. These documents aim to provide detailed information on the environmental performance of building materials and structural products and are developed in accordance with ISO 14025 [95].

EPDs evaluate and declare aspects such as raw material extraction, energy consumption, material and chemical content, emissions to air, water, and soil, and waste generation related to the product. In this way, it becomes possible to determine the ecological footprint of the assessed products [96].

An Environmental Product Declaration (EPD) is an independently verified and registered document that reliably communicates transparent and comparable information about the life cycle and environmental impacts of products [97].



The Relationship Between EPD and LCA in Buildings

[95] Yılmaz, F. Ş. (2014). *Sürdürülebilir Çevre için Mimari Aydınlatma Sistemi Tasarımında Kullanılabilecek bir Yaklaşım. (Doktora Tezi). İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul*

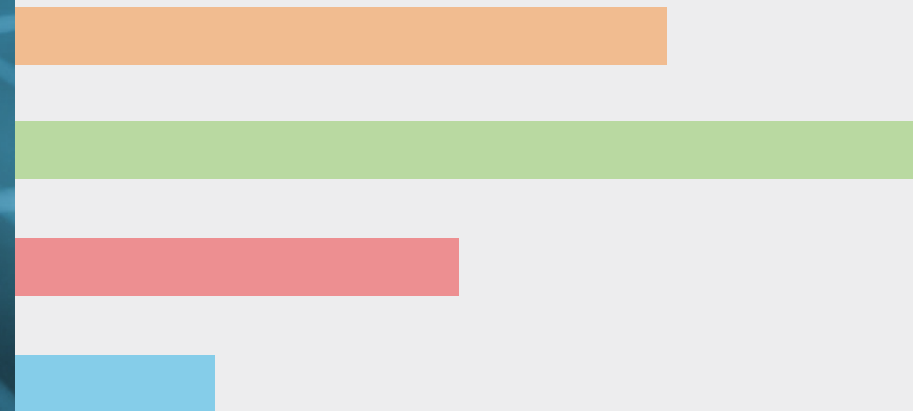
[96] Çevresel Ürün Beyanları Bilgilendirme Sistemi İnternet Sayfası <http://www.epdturkey.org>

[97] Görsel: <https://oneclicklca.com/en/resources/articles/what-are-environmental-product-declarations>



Section 5

SELECTION OF SUSTAINABLE BUILDING MATERIALS



5.1. Criteria for Selecting Sustainable Materials

The selection of sustainable materials is critically important for reducing environmental impacts and using resources efficiently. The key factors to be considered in this process and their relation to sustainability are listed below.

Key Factors to Consider in the Selection of Sustainable Materials



Embodied Energy

Embodied energy is the total amount of energy consumed throughout the entire life cycle of a material, including its production, transportation, installation, and disposal phases. In sustainable material selection, materials with low embodied energy should be preferred. This reduces energy consumption and minimizes environmental impact [98].



Recyclability

Recyclability refers to the capacity of a material to be reused or recycled at the end of its service life. In sustainable material selection, recyclable materials should be prioritized. This helps reduce waste and contributes to the conservation of natural resources [99, 101].



Carbon Footprint

The carbon footprint is the total greenhouse gas emissions released into the atmosphere during the life cycle of a product or service. Sustainable materials should have a low carbon footprint. This is an important step in combating climate change. Materials derived from renewable sources generally have a lower carbon footprint [99, 100].



Non-Toxicity (Non-VOC)

Non-toxicity means that a material does not contain components harmful to human health or the environment. VOCs (Volatile Organic Compounds) are typically considered harmful chemicals. Sustainable materials should include non-toxic components and have low VOC content. This improves indoor air quality and protects human health [99, 102].

[98] <https://cove.inc/blog/carbon-reducing-embodied-carbon-early-design>

[99] <https://www.epa.gov/>

[100] <https://naeco.com/en/news/how-can-we-reduce-the-carbon-footprint-in-the-logistics-area-of-our-company/>

[101] <https://www.terracastproducts.com/planters-from-recycled-materials-all-about-recycled-plant-pots/>

[102] <https://www.homedit.com/flooring/carpet/low-voc-carpets/>

5.2. The Role of Building Information Modeling (BIM) in Material Selection

Building Information Modeling (BIM) allows designers to create detailed digital models containing information about the materials used in construction. This information is linked to databases that provide data on material properties such as embodied energy, recycled content, and environmental impact. BIM tools like Tally, One Click LCA, and SimaPro facilitate the Life-Cycle Assessment (LCA) of buildings. LCA tools assist designers in evaluating the environmental impacts associated with construction materials, including raw material extraction, production, use, and disposal. This enables informed decisions considering sustainability and resource efficiency related to material selection and construction methods [103, 104].



Material Selection & LCA

Importance of BIM in Material Selection for Construction Projects

BIM offers many advantages in material selection and tracking:

- 1. Data-Driven Decision Making:** BIM provides data on the physical and performance characteristics of materials, helping engineers and architects make more informed choices.
- 2. Cost Analysis:** Material costs and budget estimates can be calculated more accurately through BIM models, allowing better project budget management.
- 3. Time Management:** Material procurement timelines and construction phases are integrated with BIM, aiding timely project completion.
- 4. Sustainability:** BIM plays a significant role in sustainable material selection. Criteria such as energy efficiency and recyclability can be assessed through BIM models.
- 5. Risk Management:** Potential issues in material selection (toxic components, incompatibilities, etc.) can be detected early with BIM, reducing risks during the project process.

For more information on innovative building materials, you can refer to Module 6: Innovative Building Technologies.

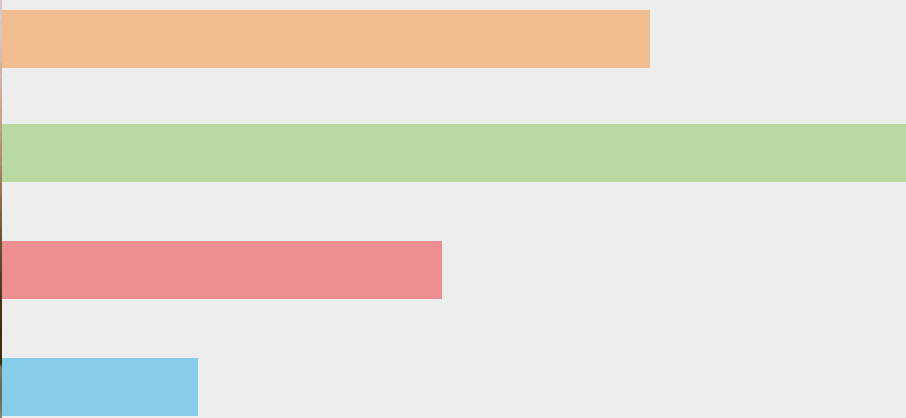
[103] <https://medium.com/@bimexperts/role-of-bim-in-sustainable-building-design-e13c88aa89b2>

[104] <https://lupitertechnologies.medium.com/bim-based-material-selection-to-reduce-life-cycle-cost-89a3b11ce695>



Section 6

REGULATORY AND POLICY FRAMEWORKS

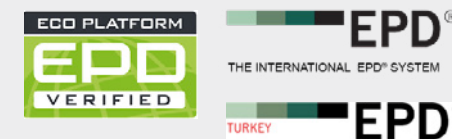


6.1. National and European Regulations

In the European Union, sustainability performance in buildings is defined by a series of standards (CEN/TC 350) developed by the European Committee for Standardization (CEN). According to these standards, building sustainability is based on three main pillars: environmental, social, and economic. Türkiye also follows the regulations in the EU [105].

- **EN 15804 – TS EN 15804+A2/AC (2021):** Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.
- **ECO Platform:** Established in the EU in 2012. Its purpose is the widespread adoption of LCA in buildings and that all construction materials have an Environmental Product Declaration certificate. [105, 106]
- **EU Construction Products Regulation (CPR):** With the latest amendment in 2024, manufacturers are required to prepare a performance declaration in accordance with the necessary articles in the regulation and to apply the CE mark to their products accordingly. The CE mark is the only mark that shows compliance of the declared performance of the construction product regarding essential characteristics covered by harmonized standards or European Technical Assessments. Türkiye is also subject to this regulation. [105, 107]
- **EN 15978:2011 – TS EN 15978 (2012):** Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

Environmental Product Declaration (EPD): It is obtained by conducting an LCA of a product prepared in accordance with EN 15804 and ISO 14025 standards, following ISO 14040/44 standards. It is a declaration that states the material has a transparent production policy from an environmental perspective [108].



Conducting LCA of materials.

EPD Certificate:
Environmental Product Declaration

ISO Standards:

- **ISO 14040:2007 – TS EN ISO 14040 (2007):** Environmental management – Life cycle assessment – Principles and framework
- **ISO 14044:2006 – TS EN ISO 14044 (2007):** Environmental management – Life cycle assessment – Requirements and guidelines
- **ISO 14025:2006 – TS EN ISO 14025 (2008):** Environmental labels and declarations – Type III environmental declarations – Principles and procedures

[105] <https://yalova.csb.gov.tr/bina-ve-yapi-malzemelerinde-surdurulebilirlik-standartlari-ve-yasal-cerceve-haber-107230>

[106] <https://www.eco-platform.org/the-mission.html>

[107] Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 (Amended), 02011R0305 – EN – 17.11.2024 – 003.001.

[108] <https://erketasarim.com/epd-belgesi>

6.2. . National and European Certifications



HPD (Health Product Declaration): The Health Product Declaration is a standardized report that provides detailed information on the health impacts of building materials. It is an open-source standard used to assess and disclose the chemical contents of building products, guiding manufacturers and building professionals toward designing healthier environments. [108, 109]



Product Health Declaration -The Global GreenTag PHD-: This is a rating tool aligned with the material health transparency tool used by progressive manufacturers who fully disclose product contents and subsequently rate the health of the product in use. It drives transparency to uncover chemical hazards in products used in workplaces and homes. It is officially recognized under five core WELL features of the WELL Building Standard and is also acknowledged by LEED v4.0 and v4.1 as well as the Green Star rating tools of the Green Building Council of Australia. [110]



M1 Emission Classification of Building Materials: A product classified as M1 has been tested for low emission levels, and the majority of building materials fall under this classification scheme. An M1-classified product supports the goals of the EU Taxonomy. The M1 classification focuses on emissions from building materials and furniture into indoor air, setting limit values for volatile organic compounds (VOCs), formaldehyde, and ammonia emissions, as well as the acceptability of odors. [111]



Recycled Content Certificate: Throughout the supply chain, this certificate independently verifies the percentage of secondary raw materials in a product based on systematic audit evaluations of the chain of custody. The certification assessment focuses on the traceability of non-hazardous waste materials from recovery to their inclusion in the final product. [112]

[109] <https://www.hpd-collaborative.org/>

[110] <https://www.globalgreentag.com/service-phd.html>

[111] <https://ymparisto.rakennustieto.fi/en/emission-classification-of-building-materials>

[112] <https://www.tuvsud.com/en/themes/corporate-sustainability/sustainable-products/recycled-content-certification>

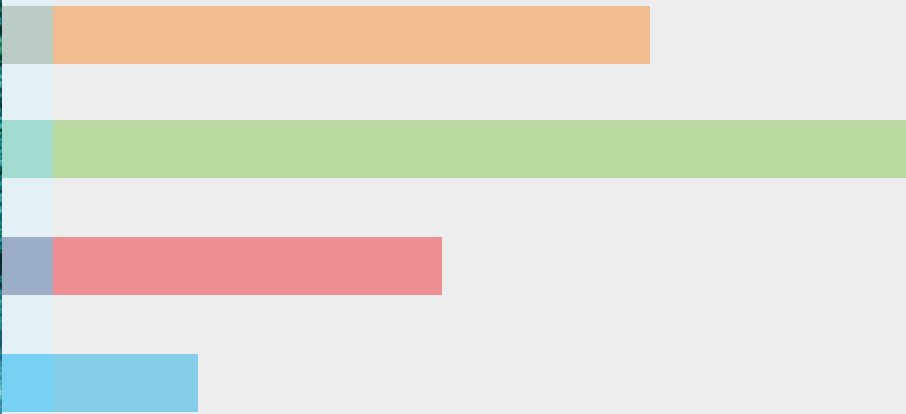
6.3. Incentives and Subsidies for Sustainable Materials

- **European Green Deal:** The European Union (EU) announced the European Green Deal in 2019 to combat climate change and promote sustainable development. This deal includes various strategies for the use of sustainable materials.
- **Horizon Europe:** It is the EU's research and innovation program. Through the Research and Innovation Fund it provides, it can finance projects aimed at the development and use of sustainable materials. It supports innovative solutions and technologies.
- **LIFE Programme:** The EU's LIFE Programme, which provides funding for environment and climate action, supports projects on the use of sustainable materials and waste management. Through the Environment and Climate Action Fund, it offers grants for sustainable projects in the areas of environmental protection and combating climate change.
- **EU Circular Economy Action Plan:** With this Plan, action plans have been developed aiming to optimize material use and reduce waste in line with targets. Grants and incentives are provided for innovative projects.
- **Ecodesign Directive:** This directive promotes the use of sustainable materials at the design stage in order to minimize the environmental impact of products.
- **Erasmus+ Programme:** It provides funding for educational and awareness-raising projects on the use of sustainable materials through education and awareness initiatives.
- **Green Building Certifications:** Green building certifications such as LEED and BREEAM both monitor the use of sustainable materials and, in some countries, provide financial incentives for projects that hold these certifications.



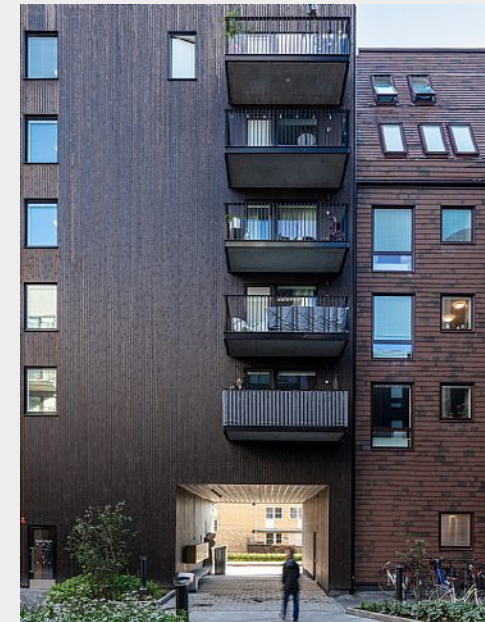
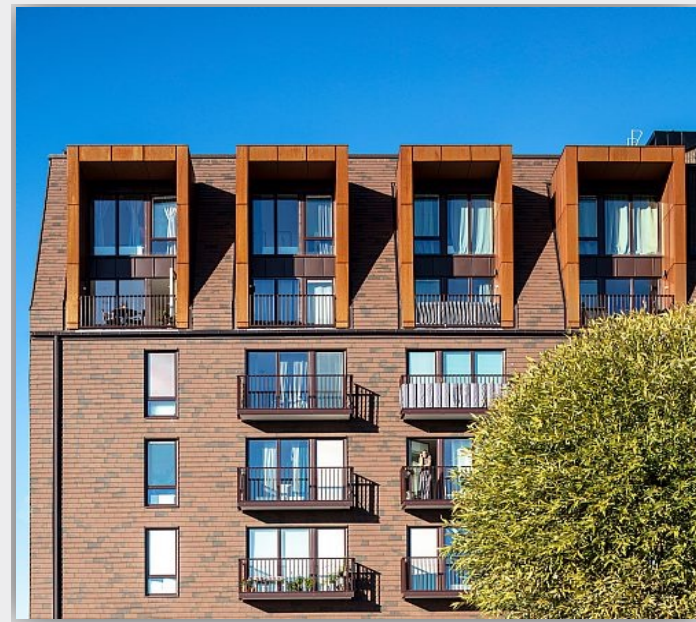


Section 7
**CASE
STUDIES**



7.1. Case Study 1 – Timber Structures

Gråalen, Norrtälje Harbour



In Norrtälje, located one hour northeast of Stockholm, C.F. Møller Architects designed the Gråalen neighborhood as part of the redevelopment of the Norrtälje Harbour.

The neighborhood consists of approximately 140 homes distributed among eight buildings, four of which feature cross-laminated timber (CLT) frames. The project includes a parking level, a youth center, and housing adapted for individuals with disabilities.

The neighborhood is designed to accommodate people and families at different life stages, with diverse lifestyles and backgrounds [113].

Architect: C.F. Møller Architects	Total Area: 30,000 m ²
Location: Norrtälje, Sweden	Number of Buildings: 8
Construction Year: 2015 - 2022	Total Number of Homes: ~ 140

[113] <https://www.cfmoller.com/p/Graaalen-Norrtalje-Harbour-i3309.html#>

7.1. Case Study 1 – Timber Structures

Residential Tower Antwerp



Architect: C.F. Møller Architects	Total Construction Area: 7.500 m ²
Location: Västerås, Sweden	Building Area: 2.400 m ²
Construction Year: 2016 - 2019	Number of Floors: 9



Kajstaden – Tall Timber Building is a significant landmark for sustainable construction and a reference project demonstrating that a shift toward climate-conscious architecture is possible.

The building is nine stories high and includes a raised ground floor and a double-height top floor. The use of high-precision technology with CNC-milled solid wood and laminated timber components results in airtight and energy-efficient homes without the need for unnecessary wall materials.

Research shows that timber-framed buildings contribute positively to human health and well-being. The lightweight nature of the material allows for fewer deliveries to the construction site and creates a more efficient, safe, and quieter work environment during construction.

Screwed mechanical joints were used, making the building demountable and enabling the materials to be recycled.

When solid timber is used, total carbon dioxide savings are estimated at 550 tons of CO₂ [114].

[114] <https://www.cfmoller.com/p/Kajstaden-Tall-Timber-Building-i3592.html>

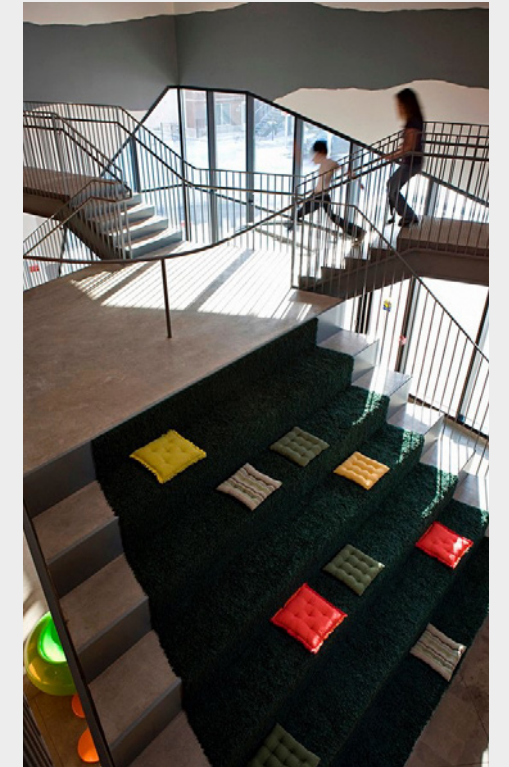
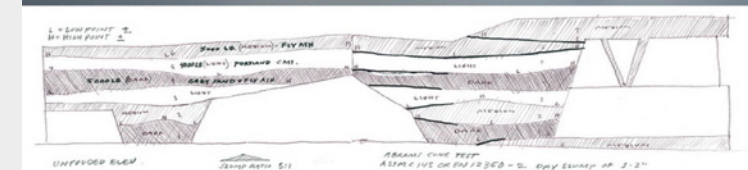
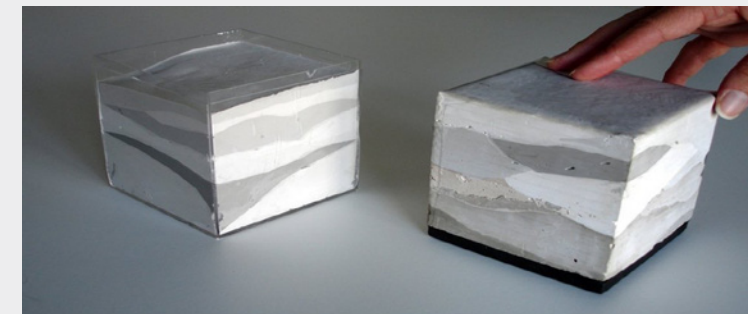
7.2. Case Study 2 – Recycled Concrete

SOS Children’s Villages Lavezzorio Community Center, Illinois, Chicago, Architect: Studio Gang (2008)

The SOS Children’s Village in Chicago is a residential complex designed to create stable foster care families and reunite children in foster care with their siblings. The village consists of 12 family homes, 4 duplexes, a director’s house, an administrative building, a playground, and a community center. A home has been built for approximately 100 children.

The building’s southwest corner is constructed with various concrete mixes, including fly ash, Portland cement, and slag aggregates. The concrete was poured in horizontal bands with color changes to showcase its fluid nature. This resulted in a design that directly expresses the use of the material. This external feature resembles geological stratification, where the varying shades of gray in irregular horizontal lines represent different concrete densities.

The concrete materials of varying densities were donated from construction sites, and because they are exhibited as part of the building itself, they make the structure iconic [115, 116].

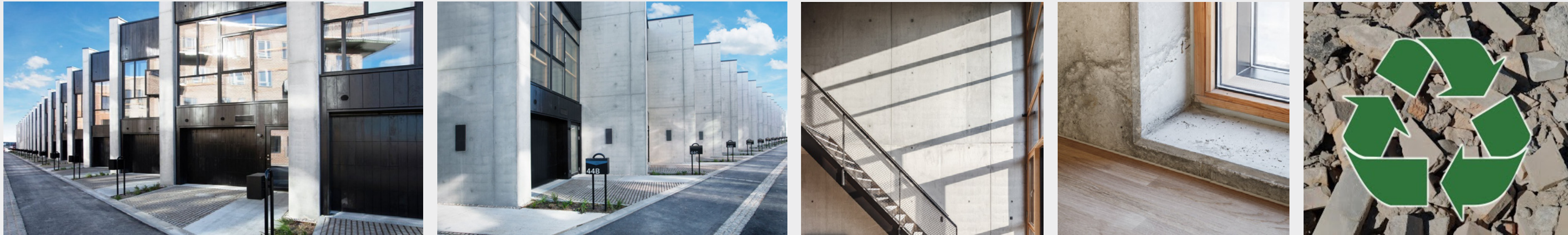


[115] <https://www.re-thinkingthefuture.com/materials-construction/a4311-10-examples-of-recycled-concrete/#3097d04b2818fa5257ea5576febcca6a6b7bcf4c#246348>

[116] <https://www.archdaily.com/28636/sos-children%25e2%2580%2599s-villages-lavezzorio-community-center-studio-gang-architects>

7.2. Case Study 2 – Recycled Concrete

“Upcycle Studios” - Lendager Group – Ørestad, Copenhagen, Denmark (2018)



This project aims to maintain a circular economy and reduce carbon footprint while addressing the housing shortage in Denmark.

By developing a new recycling technique, approximately 850 tons of concrete from the construction of the Copenhagen Metro were recovered and reused in the structure [117]. This example of recycling played an effective role in reducing CO₂ emissions.

The design adopts general sustainable strategies, taking a social and urban perspective with a focus on creating new employment opportunities. Additionally, surplus wood materials from a Danish flooring company were used in the project and integrated into recycled glass façade components [118, 119].

[117] <https://lendager.com/project/upcycle-studios/>

[118] <https://urbannext.net/upcycled-studios/>

[119] <https://www.betonvecimento.com/surdurulebilirlik/beton-geri-donusum-icerigi>

7.3. Case Study 3 – Zero Waste Construction

The Bullitt Center, Seattle, USD



Figure 20: The Bullitt Center, Seattle, USA [120]

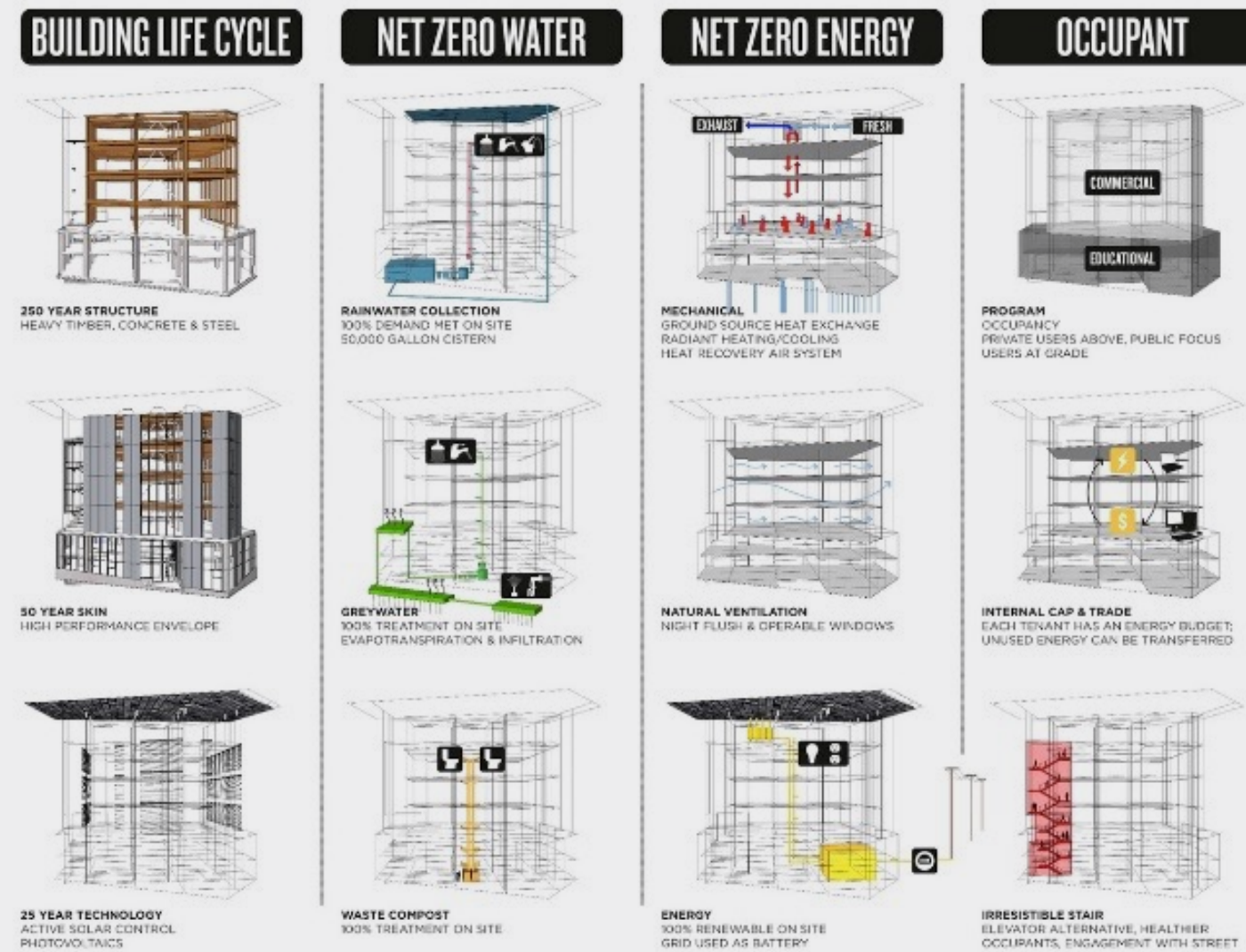


Figure 21: Building Features [120]

- It is recognized as the greenest commercial building in the world.
- In 2015, it was awarded the “Living Building” certification (Living Building Challenge) by the International Living Future Institute. It is the largest commercial living building in the world. [121]

Architect: Miller Hull Partnership
Location: Seattle, Washington, USA
Year of Construction: 2013
Area: 4645 m ²

[120] <https://www.archdaily.com/363007/the-world-s-greenest-commercial-building-opens-in-seattle-today>

7.3. Case Study 3 – Zero Waste Construction

Building Features [121, 122, 123, 124]:

- The steel used in the building consists of 83% recycled material, meaning that a total of 496 tons of recovered metal was incorporated into the construction. As a result, the environmental footprint of the project was significantly reduced.
- A timber structural system certified by the Forest Stewardship Council (FSC) supports the building atop a reinforced concrete foundation. This certification ensures that the wood was sourced from responsibly managed forests. To minimize the use of timber, small cross-sectional pieces were laminated together to form strong wooden supports, eliminating the need for large timber components.
- All wood materials were sourced locally within a 1,000 km radius, and all steel and concrete materials within a 500 km radius.
- The wood used in the structure stores approximately 545 metric tons of CO₂.
- The building avoids the use of 362 potentially toxic chemical compounds commonly found in conventional construction materials.
- A rainwater harvesting system allows the building to meet all of its water needs independently, with a storage capacity of approximately 190 liters.



Şekil 22. Strüktürel Malzemeler [124]

- Greywater is treated and reused for irrigation of the rooftop garden and landscaped areas. Collected wastewater is also treated and composted into organic fertilizer.
- Vacuum toilets efficiently and odorlessly compost human waste on-site, with no need for removal for up to 18 months.
- Photovoltaic panels on the roof supply the building's electricity.
- Radiant heating, a heat pump, and heat recovery ventilation systems have been employed.

[121] <https://www.usgbc.org/education/sessions/living-proof-bullitt-center-three-years-later-10406582>

[122] <https://bullittcenter.org/>

[123] <https://www.arkitera.com/haber/dunya-uzerindeki-en-cevreci-ticari-yapi-bullitt-center/>

[124] <https://bullittcenter.org/building/building-features/tall-timbers/>

7.3. Case Study 3 – Zero Waste Construction

The Edge Office Building

The project received a BREEAM “Outstanding” certification for New Construction with an overall score of 98.36%, by employing both innovative smart technologies and a holistic approach to sustainability. [125]

Architect: PLP Architecture	Year of Completion: 2015
Location: Amsterdam, the Netherlands	Area: 40,000 m ²

Building Features [126]:

- A daily waste management system, which enables the collection, weighing, and recording of waste generated by each occupant, is used to further minimize the building’s footprint.
- **Exhaust air from the offices is reused in the atrium area. This air is discharged through the roof, and during this process, the residual heat is recovered by passing it through a heat exchanger installed at the top.**



Figure 23. The Edge Office Building [125]



Figure 24. The Edge Office Building Gallery [125]

- Rainwater collected on the roof is used for flushing toilets and for irrigating the green terraces inside the atrium as well as other landscaped areas surrounding the building.
- **Biodegradable materials (such as wood) have been selected for the interior finishes.**
- The building is oriented to optimize the benefits of natural daylight and solar radiation.
- **A smart lighting system has been implemented.**
- A total of 6,000 m² of solar panels have been installed across the façades, the roof, and the rooftops of University of Amsterdam buildings for remote energy feeding. This enables the building to support external energy sources as well.

[125] <https://www.archdaily.com/785967/the-edge-plp-architecture>

[126] <https://www.ekoyapidergisi.org/dunyanin-en-yesil-binasi-the-edge>

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CONGRATULATIONS!

*You have successfully completed
Module 3. Now, reinforce your learning by
taking the test and challenging yourself!*

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