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DECARBONIZING THE THE BUILT ENVIRONMENT

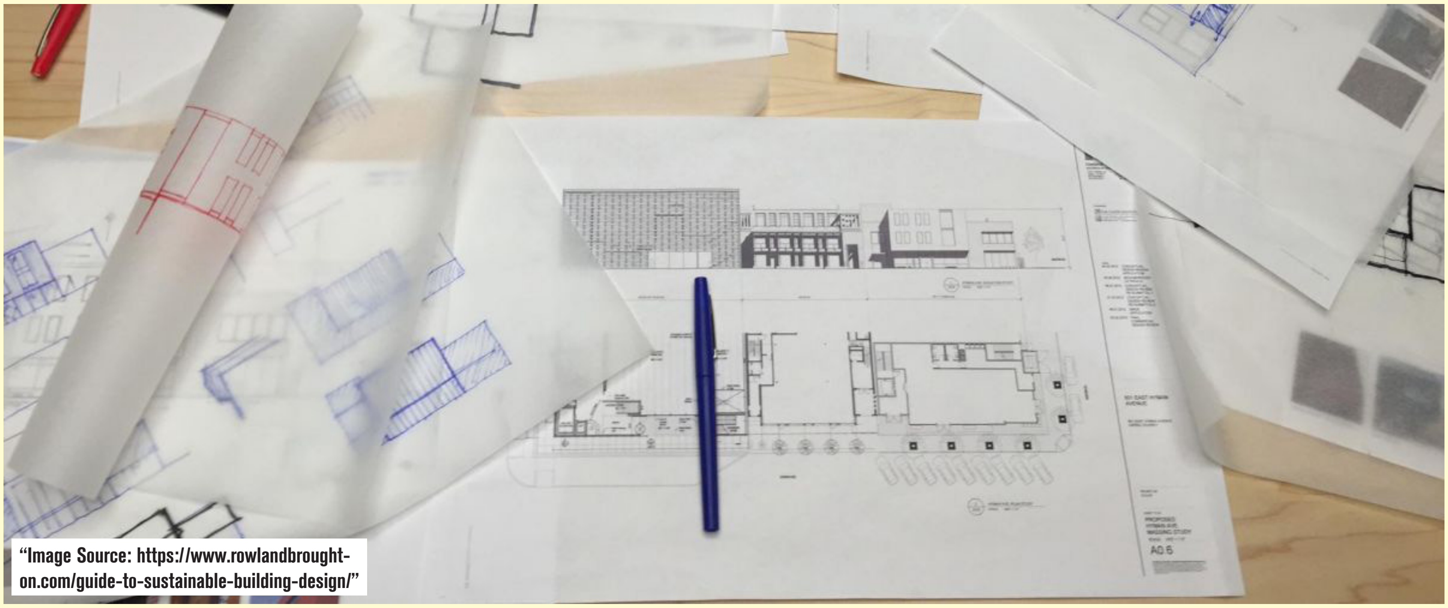
THE CONTRACTOR IS IN THE DRIVER'S SEAT

The design and engineering of new buildings are critical to developing a built environment with a small carbon footprint or achieving Net Zero Energy. Moving from the final approved building model to the construction stage is the next step, and the construction phase offers enormous opportunities for implementing environmental sustainability measures. In previous articles, the role of the supply chain in carbon emissions and strategies for sustainable building design and engineering were reviewed. The construction stage is when the building design's sustainability features become a reality, and the contractor also has opportunities to make decisions about suppliers and construction activities that further support decarbonizing the built environment. Construction is a major element in determining the level of "green" a building's lifecycle achieves.

Recalling the discussion on the role of supply chains in decarbonizing the built environment, it became clear that supply chains are one of the most significant contributors to greenhouse gas (GHG) emissions. Supply chains impact embodied and operational emissions, meaning their impact on GHGs involves activities external and internal to a building. The supply chain is involved in raw materials extraction, manufacturing, transportation of materials and equipment, energy systems designs, waste production, waste recycling-reuse-recycling, building construction, and long-term building maintenance. At every stage of the supply chain are opportunities to minimize greenhouse emissions.

The second article reviews the role of design in decarbonizing the built environment. The design and engineering stage has a direct bearing on a building's level of environmental sustainability achieved through the selection of features like site and building orientation, inclusion of renewable energy systems, application of passive design principles, type of building materials (i.e., windows, insulation, etc.), and maintenance requirements. The building's design also influences the end-to-end supply chain and construction. Two critical strategies for reducing GHG emissions are utilizing Life Cycle Assessment (LCA) for decision decision-making and embracing emerging and advanced technologies in building modeling.

SUSTAINABLE CONSTRUCTION PRACTICES



"Image Source: https://www.rowlandbroughton.com/guide-to-sustainable-building-design/"

Integrative Approach: Bridging Design and Construction

One of the underlying principles of sustainable design and construction is early collaboration. At one time, a team of architects and engineers would present schematics to the construction contractor, who was mostly uninvolved in decision-making during the design stage. Most contractor input came after the building was designed. Today, it is recognized that sustainable building design is a collaborative process that relies on input from architects, engineers, construction contractors and specialists, the building owner, landscapers, and interior designers. Each team member has a different level of collaboration, which can be in person or through the use of shared Building Information Modeling (BIM) and Building Energy Modeling (BEM) software programs.

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Progressive architects Rowland+Broughton adhere to sustainable architecture design. The company provides a good definition of what sustainable building design means. "Sustainable building design is the holistic application of sustainable architecture, construction, planning, interior design, and landscaping techniques in buildings to reduce negative impacts on the environment. Building sustainability aims to minimize or eliminate excess energy consumption, reduce waste, and create a balance between the man-made and natural." [1]

There are different goals that architects can identify as they design sustainable buildings.

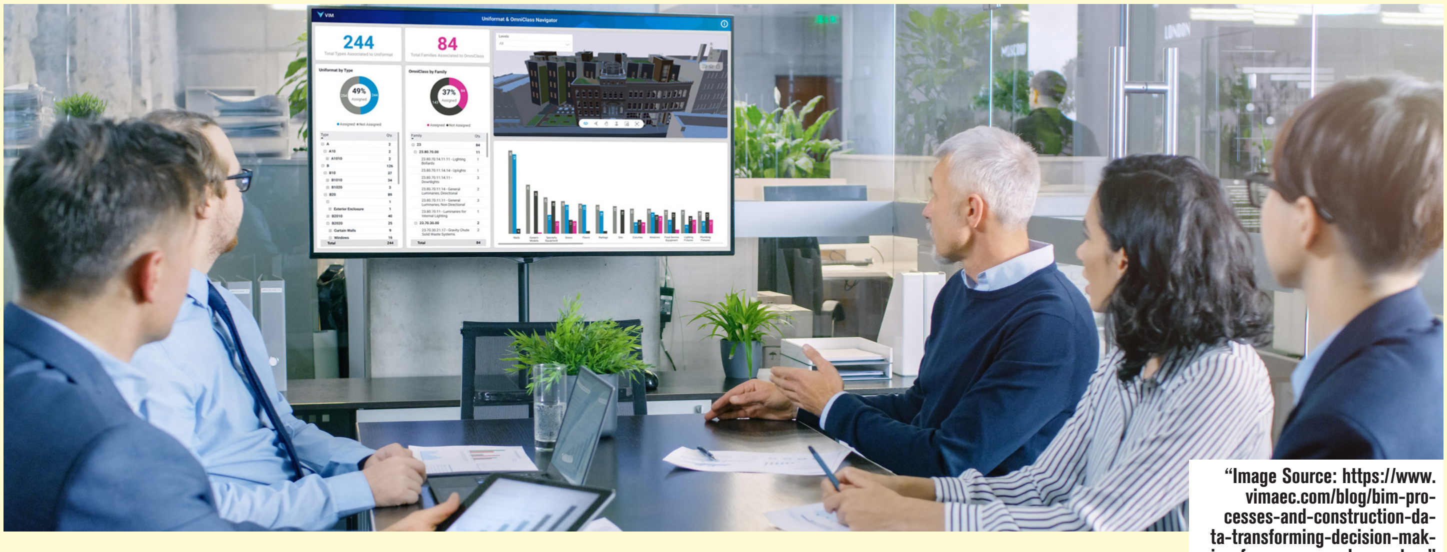
- **Zero Energy Design (ZED) or Net Zero Energy –** total carbon produced is offset by total carbon avoided or taken out of the atmosphere; considers Scope 1, 2, and 3 emissions
- **Carbon neutrality –** building emissions are balanced with carbon removal or emissions avoided
- **3rd Party Certi ication –** building meets strict sustainability standards and earns certification, e.g, (LEED, Living Building Challenge, BREEAM, etc.); it is a holistic approach in which the sustainability design considers the total impacts of the building on carbon emissions and the community of the building's location, i.e., LEED social equity credits related to the responsible sourcing of products and materials [2]

Design and construction concern the how of achieving a pre-determined emissions goal. Early involvement of contractors and other stakeholders in the design phase offers many advantages, including the practical insights of experienced contractors. Some advantages of including the building contractor, subcontractors, major suppliers, and other stakeholders include the following.

- Alignment of expectations among disciplines
- Improved communication about building details, potential sourcing issues, workforce requirements, etc.
- Enables contractor's input on material selection to reduce environmental impact
- Improved documentation
- Early input on the cost-effectiveness of design solutions
- Identification of risks and challenges
- Error minimization
- Brings the contractor on board with sustainable building as a core principle
- Minimizes potential disagreements and misunderstandings between building stakeholders during construction

An integrative approach to building design and construction is necessary for developing an accreditable building life cycle producing low or net zero GHG emissions.

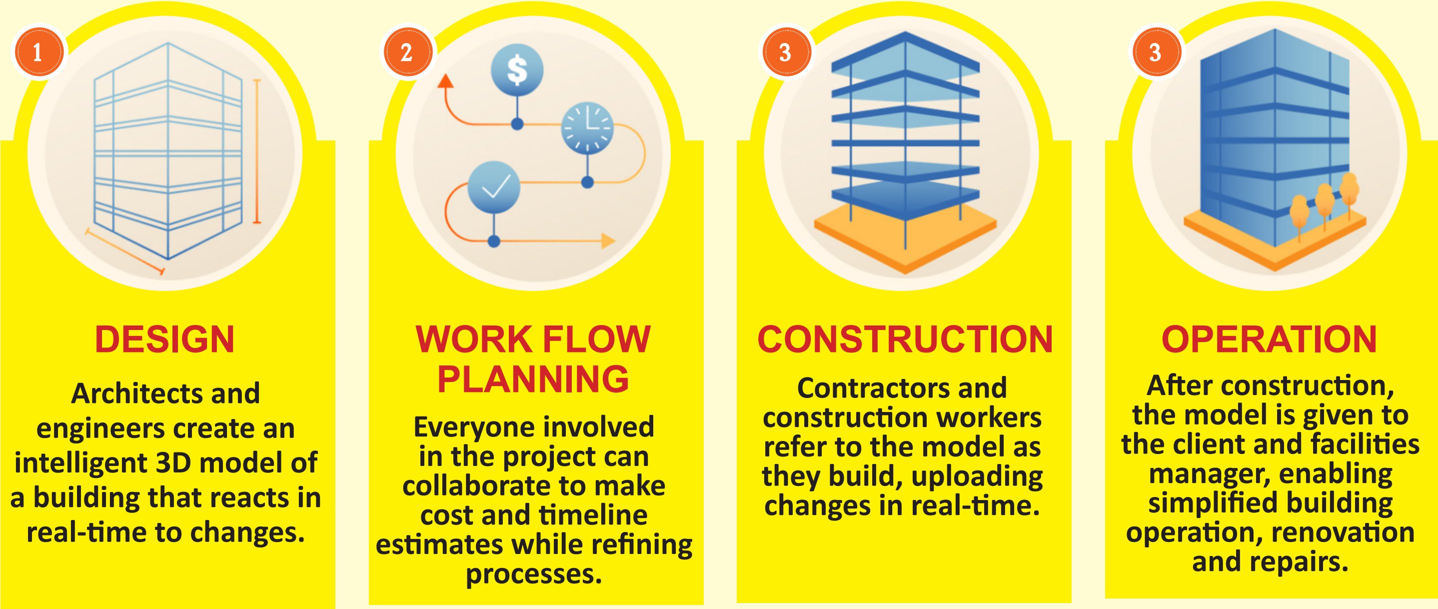
"Image Source: https://www.bigrentz.com/blog/how-to-become-a-general-contractor"



"Image Source: https://www.vimaec.com/blog/bim-processes-and-construction-data-transforming-decision-making-for-owners-and-operators"

Utilizing BIM During the Design Stage

When a Building Information Model (BIM) strategy is used for architectural and engineering building design and the contractor is included in this initial stage, the improved coordination delivers early benefits. For example, BIM enables more accurate materials quantity take-offs for costing. This can reduce waste and ensure efficient use of resources.



Detailed knowledge of the building design from the project's start also enables the contractor to develop a schedule that minimizes embodied GHG emissions. For example, ordering materials is better sequenced to minimize delivery trips to the construction site, and thus, less fossil fuels are burned.

BIM contributes to improved building sustainability because the contractor can use the building model for simulated or virtual walk-throughs. The contractor can suggest improvements that reduce the carbon footprint by providing input on building features like window placement, choice of renewable energy systems, alternative building materials, more sustainable landscaping, etc.

Once the project begins, contractors continue to use BIM to access real-time project information, as discussed in a later section.

Making Sustainable Supply Chain Decisions

Sustainable Construction Supply Chains (SCSC) can significantly impact decarbonization in the built environment. Researchers wrote, “In the context of construction projects, Sustainable Supply Chain Management (SSCM) can offer significant advantages. Implementing SSCM at an early stage of projects can result in long-term cost and time savings, ultimately leading to higher returns on investments and increased cost efficiencies.” Sustainable Supply Chain Management: [3]

1. **Enables the substitution of sustainable materials without compromising functionality**
2. **Promotes the use of technologies for cost-effectiveness**
3. **Reduces costs through supply chain integration**
4. **Integrates economic, social, and environmental supply chain management strategies**
5. **Promotes collaborative interface between suppliers to enhance social and environmental benefits**
6. **Considers the impact of materials sourcing through the supply chain on humans and the environment through sourcing raw material, manufacturing, storage, and transport to the project site**

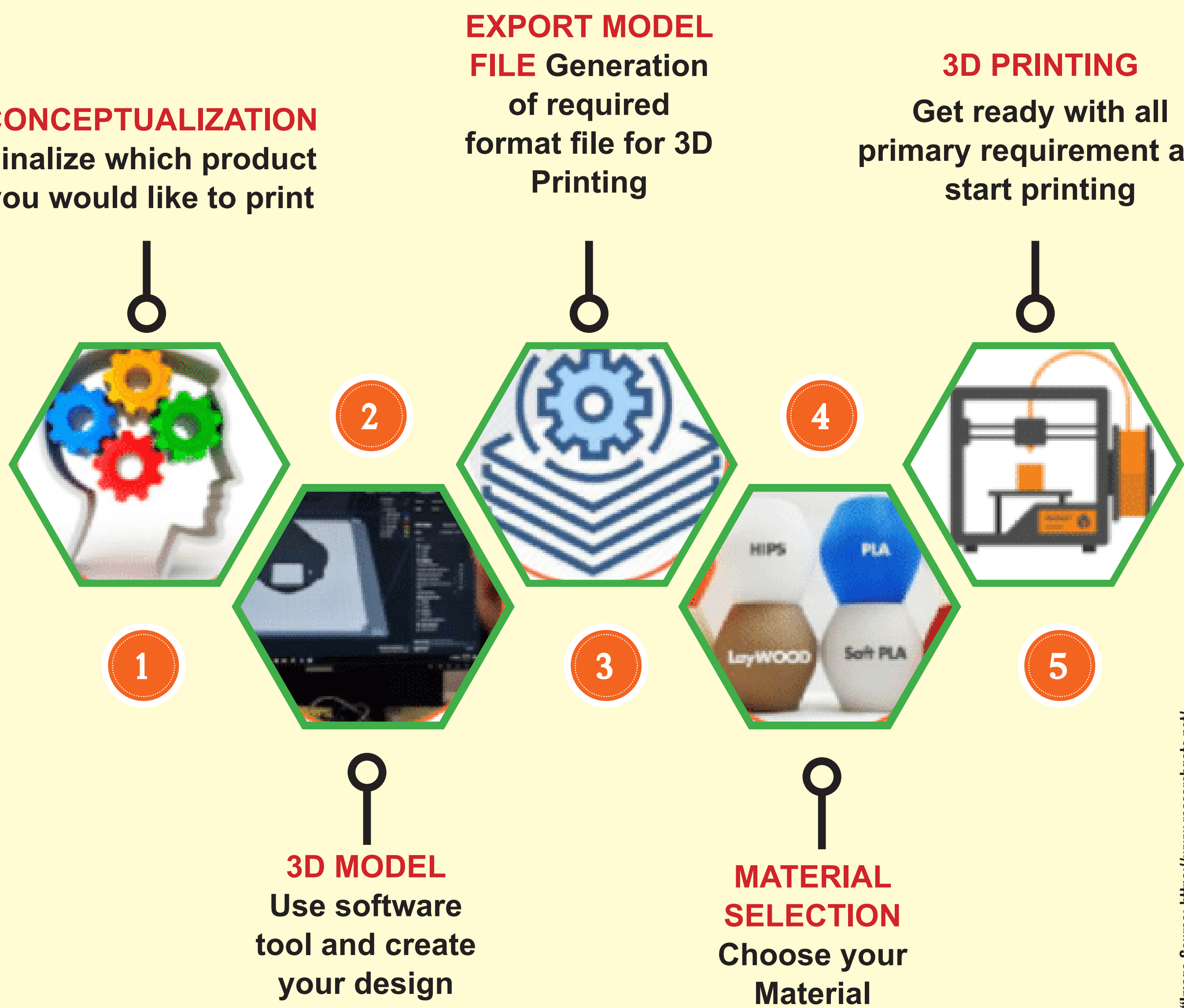
The contractor’s supply chain decisions based on the use of sustainable materials have a direct impact on carbon emissions during the building’s life cycle. For example, using recycled and repurposed materials contributes to the circular economy by reducing waste and greenhouse emissions.

Contractors decide about the suppliers of renewable energy systems, like solar panels and wind turbines, and building elements like LED lighting, windows, temperature control devices, etc. They can select suppliers with low carbon footprint and adhere to environmental sustainability practices. Selecting materials produced by a manufacturer that minimizes waste in their supply chains using smart manufacturing technologies directly affects carbon emissions. A manufacturer using the Industrial Internet of Things (IIoT) can reduce energy usage and waste by creating production lines that automatically adjust production output based on demand changes. IIoT is used for smart manufacturing, smart power grids, connected logistics, and smart digital supply chains. [4]

Waste Management and 3D Printing

The role of 3D printing in building design was included in the discussion on building decarbonization in the design phase. 3D printing can create more sustainable structures, reduce material waste, and enable innovative designs. During construction, decisions about sustainable materials are increasingly considering 3D printing. With 3D printing, only the exact amount of material needed is used to produce the final product, directly affecting the amount of waste generated.

3D printing is called additive manufacturing. In article 2 on the role of design in building decarbonization, 3D printing was mentioned as one of the innovations in materials that the building team can consider to reduce the size of the building's carbon footprint. The 3D printing process is already used in supply chains, and its utilization is expected to grow significantly. The Building Association predicts 3D printing will revolutionize the construction industry in the near future, explaining, "3D printing in construction, also known as additive manufacturing, is a process that involves creating three-dimensional objects by depositing layers of material one on top of the other. Instead of traditional construction methods that often require assembling parts on-site, 3D printing allows for the creation of entire structures in a single, continuous process." [5]



"Image Source: https://www.researchgate.net/figure/3D-Printing-process-flow_fig3_346875574"

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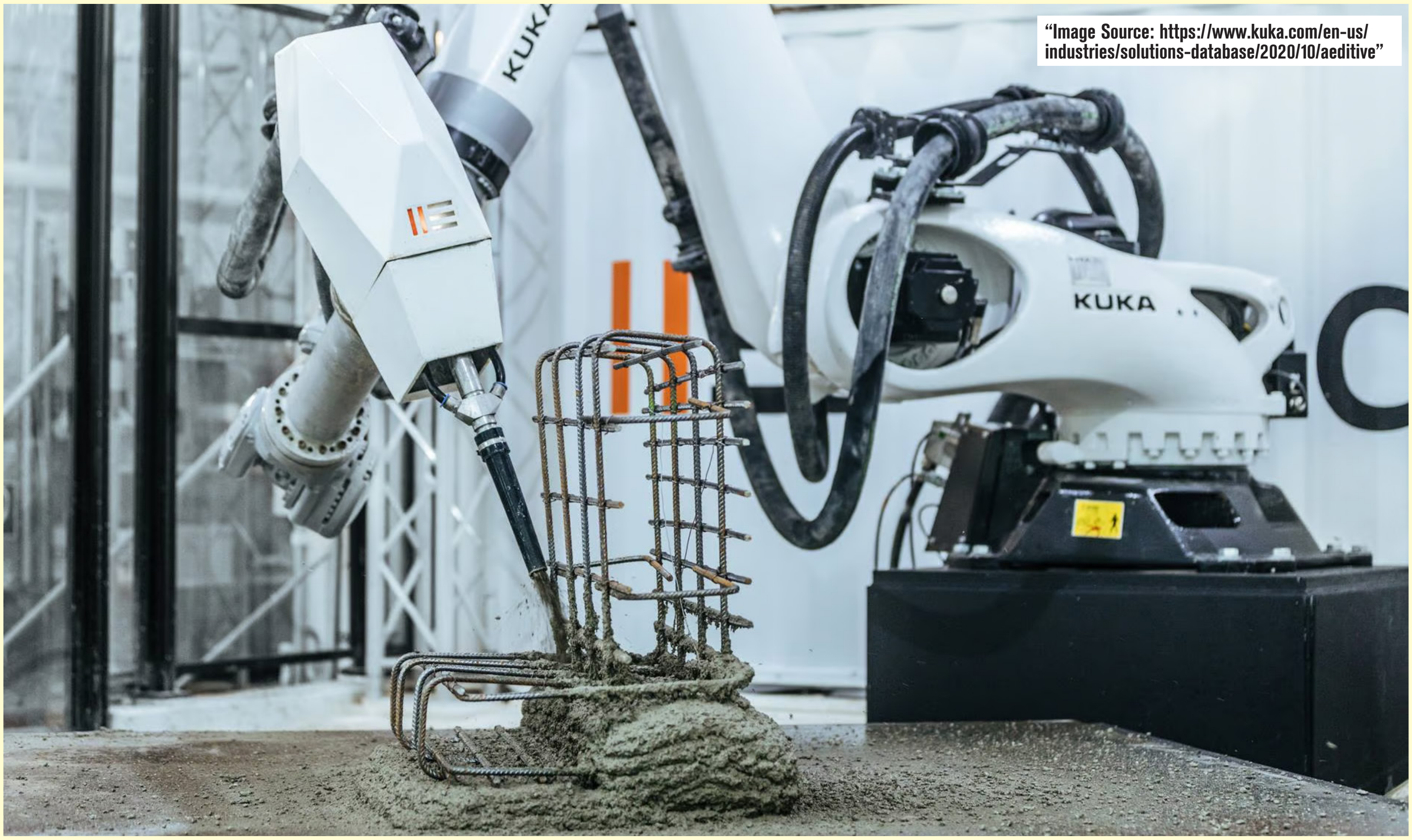
The Builders Association touts the many benefits of 3D materials printing. It can significantly increase the speed at which buildings are constructed, reducing carbon emissions because materials transport and other fuel-burning activities are reduced. 3D printing allows for reduced waste because it is a precise process, so it requires only a precise amount of materials. Another benefit is that some construction 3D printers can use recycled materials. During the design phase, a team of architects, engineers, and contractors have more flexibility in areas like building exterior and interior shapes, meaning they can maximize opportunities to reach energy utilization goals.

Researchers at Singapore's Architectural Intelligence Research Lab (AIRLAB) estimate that using print casting for construction materials has the potential to reduce product-related energy consumption by between 4-21 percent, with much of the reduction coming from the reduced transportation of raw materials. [6]

3D concrete printing is one of the most important areas of materials innovation for building structures. Manufacturing one ton of concrete releases .8-.9 tons of carbon dioxide, which accounts for approximately 8% of global CO_2 emissions and 25% of all industry carbon emissions. To remain below the Paris Agreement of two degrees warming target, emissions from cement will have to be reduced by more than 20% in the next 10 years, taking into account a projected 20% increase in cement production to consumption to meet economic development needs. [7]

The practicality of developing and using 3D-printed concrete in formwork is advancing and has become a leading digital fabrication technology in the industry. The 3D materials are used in off-site manufacturing and on construction sites. A 3D printer deposits material layers, one on top of the other, to create a three-dimensional form. Robotic arms form and place materials. It is a highly efficient process that significantly shortens the time it takes to construct a building.



There is ongoing research on the type of materials that produce the best cement, technologies to strengthen the bonding of layers, and advancing smart robot-controlled formwork. In assessing the sustainable effect of 3D printed materials, the researchers wrote,

“Image Source: https://www.sciencedirect.com/science/article/pii/S2666165923000698#sec11”

The building and construction industry significantly impacts the generation of solid waste, energy consumption, water depletion, and anthropogenic CO2 emission, accounting for approximately 40%, 40%, 12%, and 8%, respectively…. because of the building and construction industry's remarkable reliance on non-renewable resources, promoting sustainability by improving construction methods and materials is imperative. Sustainability, which encompasses economic, social, and environmental outcomes, must be considered holistically.

The researchers developed a model for cement production based on Life Cycle Assessment (LCA) principles. First, the design process considers the functional aspects that can reduce materials consumption and the materials with the right properties that support the building. The best materials alternative is selected, and the manufacturing process is assessed. Alternatives include adjusting robot speed or using renewable energy, whichever achieves the lowest environmental impact. [9]

EMISSION REDUCTION STRATEGIES

Proactive Approaches in Construction

The importance of the role of 3D printing in the concrete industry to reduce GHG emissions is stressed because concrete manufacturing produces such a high amount of emissions, and concrete is essential to the built environment. There are many other ways contractors can proactively reduce project emissions during construction., [10][11]

- Identify opportunities to increase energy efficiency as the project progresses and in consultation with the engineers, like swapping materials for various elements, especially when new material innovations become available
- Select suppliers that operate with proven environmental sustainability principles
- Plan ahead for the most efficient delivery of materials that utilizes the least amount of fossil fuels to minimize the carbon impact through load planning, delivery scheduling, and type of transportation (truck, ship, rail)
- Manage the onsite use of energy through strategies like avoiding unnecessary equipment operation (establish a no idling policy), using energy-efficient lighting or other equipment, insulating construction trailers, etc.
- When possible, utilize renewable energy sources to power lighting and equipment during construction
- Use project management tools to construct the building in a minimal timeframe without jeopardizing quality or safety, i.e., using prefabrication materials
- Use new technologies when applicable

As discussed, waste management during construction is also critical to reducing carbon emissions, and it should not need to wait for broader use of technologies like 3D printing.

On our St. Pete Pier project in St. Petersburg, Florida, we were tasked with choosing a metal material for the doors that wouldn't rust near seawater. We chose aluminum, which has a lower carbon footprint than steel and it won't have to be replaced as often as other metals that corrode. (Photo Credit: City of St. Petersburg)

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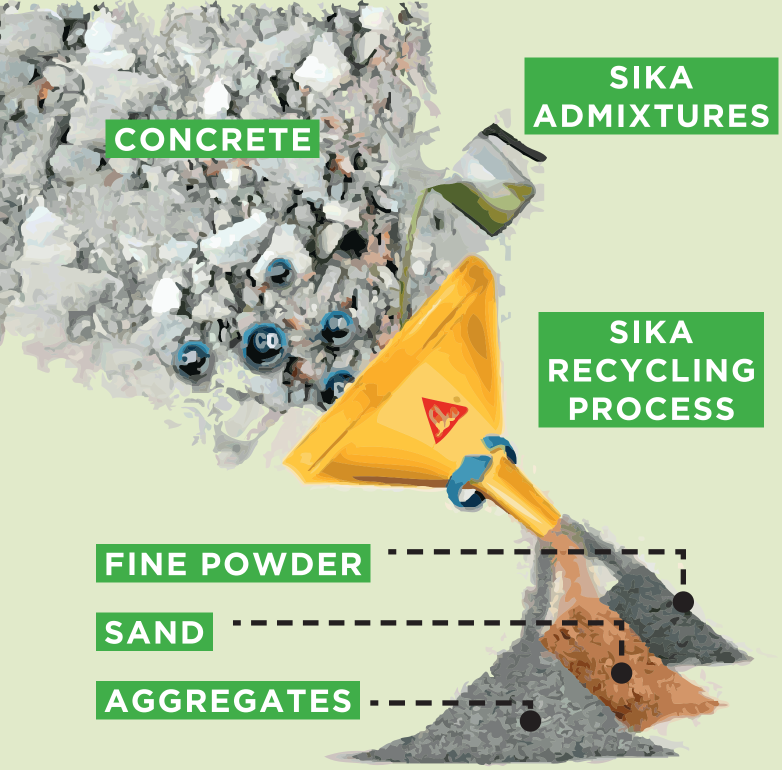
Waste Management and Recycling During Construction

Embedded building materials are estimated to account for 28% of emissions related to construction. Waste management during construction and focusing on the end-of-life recycling and reuse of materials can significantly reduce global GHG emissions. End-of-life recycling and reuse means being able to recover materials and reuse them at the point the building is renovated or deconstructed. This approach supports working towards a circular economy.

As previously discussed, the best time to plan for waste management is during the building design stage. Embedding Life Cycle Assessment (LCA) in design through BIM establishes waste management as a principle from the beginning and directs the choice of building components and materials. Putting waste management strategies into practice during construction or demotion is how waste is diverted from landfills. Even the ideal LCA-based design is only effective at diverting waste when the contractor ensures materials are not wasted or are diverted from landfills.

Waste management during construction includes waste minimization and identifying materials that can be recycled, reused, or repurposed. Waste minimization strategies include ordering the right amount of materials, consistently using BIM to ensure materials are measured correctly, and the correct materials are used, and having a policy requiring segregating and saving any materials that can be recycled or reused, like bricks, concrete chunks, drywall pieces, etc. During demolition, major materials that can be recycled include items like steel, doors, rebar, wood, etc. Another consideration in LCA and the circular economy is minimizing carbon emissions associated with transporting construction waste to recycling plants.



"Image Source: https://www.sika.com/en/knowledge-hub/reco2ver-concrete-recycling.html"

There are carbon emissions associated with each waste composition. A study on recycling the most common waste materials found that each type of construction waste varied considerably. The major types of materials recycled are concrete and mortar, brick, steel, and wood. From a circular economy perspective, recycling steel and wood delivers environmental benefits by reducing the need to produce the materials. Recycling brick and mortar produces more carbon emissions because, currently, the materials are mainly used as filling materials. The study found that concrete recycling led to the most significant emission reduction in the transportation stage to the recycling plant, followed by steel and wood. Steel recycling produced the largest amount of GHG emissions reduction during recycling, followed by brick, wood, concrete, and mortar.[12] This demonstrates just one area of complexity when striving to develop a circular economy.

There is an effort to find ways to utilize construction waste better. A good example is a study that proposes a sustainable building design and construction framework that enables designing buildings with the principle of upcycling off-cut wood in mind. Off-cut wood is an irregular piece of wood that commonly accumulates during construction. The framework includes a material reclamation system in which 3D scanning is used to record the specifications of the materials in a database, followed by using a design and assessment system before construction to optimize the building. During construction, there should be minimal off-wood waste.[13]

"Image Source: https://www.nature.com/articles/s44296-023-00002-8/figures/6"

A literature review of 26 articles on minimizing construction-related carbon emissions found 56 carbon minimization measures the researchers sorted into nine categories. [14]

- Material transport
- Waste transport
- Materials and equipment
- Waste
- Materials
- On-site office
- On-site lighting
- On-site transportation of material and equipment
- Construction methods

ROLE OF COMMISSIONING IN SUSTAINABLE CONSTRUCTION

“Image Source: https://meadhunt.com/commissioning-brings-energy-savings-to-existing-buildings/”

Building commissioning is a systematic process of ensuring a building project achieves energy performance goals or design intentions. It is a collaborative team effort that begins with project planning, so the team includes the owner, who defines the building’s requirements. Other team members are architects, engineers, contractors, operations and maintenance staff representatives and others. The owners' and designers' roles in sustainable construction are crucial to minimizing GHG emissions. The owner’s project requirements and the building’s architecture and engineering establish building performance expectations. Establishing a goal of achieving building certification promotes developing and completing a project with the lowest carbon emissions possible or Net Zero Energy.

Commissioning of an entire facility drives the choice of contractor and subcontractors, systems installed, and many other factors influencing environmental sustainability. The commissioning process is a comprehensive evaluation of the building envelope, systems, and other components to ensure they were developed, installed, and tested against performance targets and are operating as designed and planned. Energy efficiency optimization is one objective, so the commissioning process assesses the energy performance of components like lighting, electrical system, and the HVAC system and features like ventilation, humidity levels, temperature control, plumbing, and more.

The commissioning process also evaluates the building envelope, which includes the roof, walls, doors, and windows. Commissioning also considers building occupants' health and comfort by evaluating air quality and natural lighting. In other words, commissioning is a holistic process.

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Some of the benefits of building commissioning include the following.

- Determines the building meets expected energy efficiency targets incorporated during design and construction
- Evaluates materials sustainability, i.e., VOC emission content
- Establishes baseline energy performance metrics for comparison during ongoing operations
- Identifies potential issues that can lead to excessive maintenance and repair costs
- Identifies additional opportunities to minimize carbon emissions or improve the comfort of building occupants
- Establishes a coordinated assessment of different components as a functional system
- Assists with the development of a maintenance plan
- Provides all essential documentation

There is New Construction Commissioning (NCCx), Existing Building Commissioning (EBCx) and Ongoing Commissioning (OCx). Focusing on New Construction Commissioning, the process contributes to environmental sustainability by optimizing energy and water use while maximizing human comfort and safety. According to the Whole Building Design Guide (WBDG), "The cost of not commissioning is equal to the increased costs of correcting design and construction deficiencies later, plus the costs of inefficient operations. For example, in mission-critical facilities, the cost of not commissioning can be measured by the cost of downtime and lack of appropriate facility use."[15]

Building Commissioning requires a detailed and team oriented process.

"Image Source: https://www.wbdg.org/building-commissioning"

The commissioning process is guided by a chosen building performance rating system that certifies a building meets environmental and social standards. Rating systems like LEED, LBC, and BREEAM establish standards for planning, designing, constructing, and operating an environmentally sustainable building.

The commissioning process is guided by a chosen building performance rating system that certifies a building meets environmental and social standards. Rating systems like LEED, LBC, and BREEAM establish standards for planning, designing, constructing, and operating an environmentally sustainable building. Per the WBDG quoted earlier, "A building certified to these rating systems can include highly efficient gas, water, power and lighting systems, solar photovoltaics, and other energy and resource technologies. From an Owner's perspective, investment in these and other sophisticated building technologies must be accompanied by rigorous design and construction quality assurance and performance verification measurement, which are provided holistically through the commissioning process."

It is important to understand that commissioning is not a single event. It is an ongoing commitment to maintaining building environmental sustainability performance. Building certifications are periodically renewed.

CASE STUDIES: PUTTING INTENT INTO ACTION

Many building projects have incorporated sustainable practices, and many of them have been commissioned or certified. Following are a few examples.

"Image Source: https://www.usf.edu/administrative-services/facilities/documents/leed-chowdhari-info.pdf"

The Chowdhari Golf Center in South Florida pursued LEED V3 New Construction (NC) certification. Five prerequisite categories had to be met before the building project team could design and construct the building to achieve credits in the five categories, plus two more, for eventual certification. The seven categories are Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design, and Regional Priority. The LEED-certified building uses low-flow plumbing fixtures that reduce water use by more than 20%, and native, drought-tolerant plants in landscaping meant no permanent irrigation system was necessary. More than 25% of construction materials were extracted and manufactured within 500 miles of the project, reducing transportation-related emissions.

More than 10% of the materials are made with a combination of post-consumer and pre-consumer recycled content, and paints, sealants, and adhesives contain low or no VOCs. There is an energy-efficient HVAC system with energy recovery. The building has bike racks encouraging human-powered transportation and is on a campus shuttle route.[16] There is a highly insulated building shell with low-E glass and an attic with spray foam icynene insulation. The construction team adhered to a strict indoor air quality plan.[17] Lighting and mechanical control systems give people more control over their indoor space.

"Image Source: hhttps://www.dezeen.com/2020/12/22/kamp-c-completes-two-storey-house-3d-printed-one-piece-onsite/"

In 2020, Kamp C built the first 2-story house in Europe 3D printed on-site. It is a first of its kind because the whole building envelope was printed onsite instead of printing components in a factory. A fixed COBOD 3D concrete printer was used, demonstrating the future of environmentally sustainable construction strategies for many buildings. This particular building is two-story and has 90 square meters (969 square feet). The wire-mesh reinforcement is minimal, and formwork became redundant. It is estimated that there was a savings of 60% in material, time, and budget. It took only three weeks to build the house. [18]

An example of using a holistic approach to energy reduction is found in Ferguson Headquarters 3, a plumbing supplies distributor's building. Located in the Newport News city center at Oyster Point, the building design is transformational. The light-filled open floor space encourages workforce collaboration; some spaces are available for community reservations.[19] Early energy modeling during building design achieved a significant energy consumption reduction in current and future emissions. The holistic approach included a building orientation that maximizes daylighting and views while reducing solar gain and material use in the interior. The exterior glass has a low solar heat gain coefficient. The HVAC system has a thermal storage system to shift electric demand during day and night demand periods, an energy recovery ventilator to transfer heat between the exhaust and outdoor air streams, variable volume air distribution systems, and high-efficiency operations. It is estimated there is a pEUI reduction of 73%.[20] The building earned a Three Green Globes rating for New Construction in December 2020. [21]

"Image Source: https://www.clarknexsen.com/project/ferguson-headquarters-3/"

“Image Source: https://www.procore.com/jobsite/skanskas-journey-to-sustainability-leadership-in-construction”

Skanska is a global sustainability construction company that integrates sustainability at each stage of a building project, from land acquisition to building operations. The project Täby Park in Sweden is a new neighborhood built on a previously developed horse race track property. Close to the Stockholm city center and next to a shopping mall, the modern neighborhood began seeing residents move in during 2020. The project was built with sustainability as an important feature as a pilot project for Citylab Action, a certification system for sustainable neighborhoods. This demonstrates the importance of certification systems in promoting sustainability in construction. Existing buildings were recycled, and the soil and rock masses were saved onsite and reused during construction. A walking and cycling system was built so cars are less used. [22]

“Image Source: https://group.skanska.com/projects/246528/Taby-Park”

COLLABORATION: A UNITED EFFORT TO REDUCE GHG EMISSIONS

Decarbonizing the built environment through sustainable design, construction, and operations is complex. It depends on continued innovations in materials and energy systems, building owners requiring energy efficiency, and contractors making decisions about suppliers and construction activities adhering to sustainability principles, like minimizing waste. In addition, people must first be willing to accept the importance of reducing GHG emissions to meet Paris Agreement goals.

This points to the importance of green building rating systems that define how a building can reduce greenhouse gas emissions and improve occupant comfort. The commissioning process is a key strategy for ensuring a building meets scientifically proven guidelines and, importantly, the building continues to operate with reduced GHG emissions or is Net Zero. It is also a key strategy for continuing to decarbonize the built environment.

Two sectors that have proven to be the biggest drivers of decarbonizing the built environment are governments and universities. The private sector is contributing through the development of sustainable materials and processes and sustainable architectural designs and building engineering. But there is agreement that it needs to step up progress. All professionals need to continue learning and adapting sustainable practices in their areas of expertise.

Meeting certification requirements requires collaboration between all professionals involved in the built project. The first three articles have discussed supply chains, building architecture and engineering, and construction. The next article dives into building operations and maintenance as the discussion continues exploring each stage of the building life cycle.

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