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What Is Embodied Carbon in the Built World, and How Can It Be Reduced?

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More than 70 countries and 1,200 companies have committed to achieving net-zero emissions by 2050, according to the United Nations. The goal of net zero is to cut carbon emissions to curb climate change to protect the planet and future generations. Human-caused emissions of carbon dioxide and other greenhouse gases are a primary driver of climate change - which, if humans want to mitigate climate impacts to the ecosystem, must be addressed from all perspectives, across all industries.

WHAT IS EMBODIED CARBON?

Embodied carbon in the context of the architecture, engineering, and construction (AEC) industry refers to the greenhouse gas (GHG) emissions released into the atmosphere during the upfront activities necessary to construct or renovate buildings and infrastructure. Reported as carbon-equivalent emissions (CO2e), the total accounting of GHGs emitted during the build phase is called embodied carbon because the environmental impacts associated with building activities are locked in place prior to building operation.

Embodied carbon includes all the upfront activities that are part of construction, as well as any kind of renovation - replacing a roof, fitting-out a tenant space, or simply replacing carpet or repainting - activities that also generate GHG emissions. Before the building systems are operating, a carbon footprint has been formed.

OPERATIONAL CARBON

Energy from fuel-burning activities during building operations can be converted to the metric of operational carbon. Operational carbon, therefore, is the amount of GHG emissions released during the operational, or in-use, phase of a building; for example, it can be calculated from energy bills and reported annually. Operational carbon is the carbon-equivalent emissions associated with the operation phase of the building, including heating, cooling, lighting, and power.

EMBODIED CARBON VS. OPERATIONAL CARBON

Many AEC professionals - everyone from designers and contractors to operators and owners - understand and focus on reducing operational energy costs due to fuel consumption such as oil, natural gas, or electricity. CO2e generated by the use, management, and maintenance of annual building operations currently account for about 28% of annual global GHG emissions.

Relative to operations, CO2e generated by construction activities are accumulated and considered "locked-in" as embodied carbon before the operational phase. Annually, embodied carbon accounts for close to 11% of global GHG emissions, attributed to the ongoing building activity and construction around the globe. Year over year, this is a significant carbon footprint and a big opportunity for the AEC industry to address associated GHGs beyond operational energy.

Stricter building codes, more energy-efficiency equipment and lighting, and more renewable-energy sources will help reduce the operational carbon of buildings. As buildings become more energy efficient, a resulting larger relative percentage of a building's total CO2e impact will be the upfront embodied carbon. As part of the design and renovate process, AEC professionals have the ability to influence and reduce carbon impacts in the built environment. Recognizing the role that embodied carbon plays relative to the total CO2e is key to identifying how the AEC industry can help mitigate the climate crisis by reducing its carbon footprint.

TOTAL CARBON

Measuring the embodied and predicted operational carbon impacts of a building is one way the AEC industry can estimate and quantify the potential environmental impact of a building or other aspect of the built environment in the planning and design phases, long before it is built.

One benefit is the ability to compare and make informed trade-offs between embodied and operational carbon associated with design decisions. For example, imagine you want to compare the total carbon of a window type for a new building design. You could evaluate the trade-offs between double- versus triple-pane insulated glazing units and compare the long-term operational energy and carbon savings of the higher-performing triple-pane window versus the upfront embodied carbon of sourcing more glass and other raw materials necessary to install a triple-pane window. In some cases, the energy savings of the better-performing window over an estimated building lifespan may not offset the embodied carbon of the window itself. The ability to evaluate total carbon impacts of both embodied and operational carbon during the design process can enable optimization and reduction of potential contributions to GHG emissions.

WHOLE-LIFE CARBON

Whole-life carbon expands on the total carbon concept. In addition to the upfront embodied carbon, it includes the ongoing, year-over-year GHG emission impacts associated with an asset's use-phase activities (annual energy consumption, maintenance, repair), as well as the refurbishment, dismantling, salvage, reuse, and demolition activities across an asset's end-of-life phase. This whole-life assessment is often called "cradle to grave" because it is a cumulative accounting of all environmental impacts across the asset lifecycle.

HOW THE AEC INDUSTRY CONTRIBUTES TO GHG EMISSIONS

The built world includes living, working, and recreational spaces made up of buildings, roads, bridges, and transportation and distribution systems (for example, utilities). The everyday operations of these human-made systems affect the world's ecosystem and contribute to climate change. The AEC industry yields significant influence over the planning, design, construction, and operations of the built environment. Notably, the building sector is one of the biggest contributors to GHG emissions, which cause global warming. Given this influence, the AEC industry is poised to adopt more sustainable practices and lead cross-industry decarbonization efforts to reduce its impact on climate change.

To fully understand how the AEC industry contributes to GHG emissions, it is useful to first think about the lifecycle phases of a built asset, such as a building, and the related activities of each:

» **Plan and design:** First, a building must be planned and designed, to be fit for a purpose.

» **Build:** From idea to reality, the build phase is the construction of a building, including procurement and transport of building materials to the construction site for assembly.

» **Operate:** The longest phase, daily operations, often powered by electricity, is necessary for a building to serve its purpose for years, decades, perhaps centuries.

» **Renovate:** Extending its life, a building may be renewed or renovated for an extended operations phase and ultimately be demolished in its final phase.

Greenhouse gas emissions are released primarily during the build and operate phases of a building and are typically caused by fuel-burning activities such as raw-material extraction processes (for example, extraction of iron ore to make steel); manufacturing and transportation of building materials, products, and systems; and on-site construction activities.

Once operating, GHGs are emitted as byproducts of heating and cooling a building. These building activities release various gases - primarily nitrous oxide (N_2O), carbon dioxide (CO_2), and fluorinated gases - for which the cumulation of these gases strengthens the greenhouse effect. The majority is CO_2, and the other gases can be equated to impacts associated with CO_2 by calculating their Global Warming Potential (a method to measure the climate effects of different gases); the combined effects are accumulated as carbon-equivalent emissions (CO_2e).

HOW GOVERNMENTS AND AEC FIRMS CAN HELP REDUCE EMBODIED CARBON

With the world population expected to hit 9.7 billion in 2050, there will naturally be an increase in construction to keep pace with housing, infrastructure, and services for this growth. By 2060, the global building floor area is expected to double in size. And with this estimated increase in construction, there will be an increase in global GHG emissions attributable to the AEC industry. Here's how governments are helping.

GOVERNMENT COMMITMENTS AND REGULATIONS

To mitigate climate change and meet 1.5-degree-Celsius climate targets put forth in the Paris Agreement, CO_2 emissions need to be eliminated from the built environment by 2040. This will take a concerted effort by all governments as well as other stakeholders - working both internally and cooperatively with other countries - and an increase in meaningful corporate commitments and actions.

Around the world, governments are committing to environmental targets, such as net-zero emissions. To meet these commitments, governments are instituting programs and regulations that will require AEC professionals to act and report on carbon impacts associated with designing, building, or renovating the built environment.

For example, the Government of Canada has committed to net-zero emissions by 2050, which means policies will be put in place to decarbonize the operations of government-owned property, mobility, and other programs. Another example is Denmark, which has put forth a set of policies for the phasing of embodied carbon targets to reduce embodied CO_2 emissions and operational CO_2 emissions for buildings. Some jurisdictions are instituting local regulations to decarbonize, such as Marin County, California, which stipulates compliance with low-carbon concrete requirements in construction. These examples are just a few of the growing efforts put forth by regulatory agencies and government organizations around the world to decarbonize the AEC industry.

INFLATION REDUCTION ACT

One policy that will have a significant influence in the United States is the Inflation Reduction Act (IRA). It's the largest federal climate investment in U.S. history, signed into law on August 16, 2022, by President Joe Biden. The IRA's investments in climate and clean energy have the potential to cut GHG emissions in the United States by as much as 40% below its 2005 levels by 2030. This, combined with state action and upcoming federal regulations, puts the nation within reach of its commitment to cut emissions by 50%–52%, per the Paris Climate Agreement, by 2030. Notably, the IRA allocates almost $4.5 billion toward measuring embodied carbon in construction materials and installing low-carbon products in public infrastructure and federal government buildings.

5 WAYS THE AEC INDUSTRY CAN HELP IN REDUCING EMBODIED CARBON

The AEC industry's contribution to GHG emissions is undeniable, and the sector is shifting its focus toward more environmentally responsible building practices. Innovation plays a key role in this shift. By prioritizing the right design strategies and adopting more sustainable construction methods, companies can turn good intentions into positive action.

1. Make Data More Transparent

A key to better understanding embodied carbon's role in the built world is transparency of the environmental impact of materials and processes used in all upstream activities. Providing transparent data, with measured and verified environmental impact, gives AEC professionals the opportunity to make better decisions about how and with what they're building. For example, embodied carbon can be reduced by comparing data for building products and choosing lower embodied carbon products or carbon-sequestering materials. Furthermore, if AEC professionals demand more transparent data - asking manufacturers to report metrics and measurement of environmental impact, for example - they could drive change and foster industry transformation, ultimately accelerating decarbonization of the AEC industry.

2. Implement Design-Optimization Tools

There are many resources available to help AEC professionals understand the environmental impact of building materials and compare material data sources to make informed decisions. There are design optimization tools specific to product and material data, which can aid an AEC professional in exploring, comparing, and selecting building materials. These tools help make sense of the data available and can be used to evaluate various environmental factors associated with the building products and materials, as part of the comprehensive evaluation for other design criteria, such as performance, durability, maintenance, and aesthetics. As one part of a designer's toolkit, optimization tools can leverage material data transparency to enable informed design decisions, empowering the AEC industry to consider sustainability as part of the design and build process.

For example, by comparing material data, designers and contractors can choose more sustainable materials for their projects, such as concrete mixes that have lower embodied carbon, more sustainably manufactured steel, and recycled or carbon-sequestering materials such as wood. Many design-optimization tools enable this process by quantifying the CO2e of materials and products.

Integrating these capabilities into building information modeling (BIM) workflows can help streamline this exploratory process for AEC professionals. Building Transparency is a U.S.-based organization that not only manages a robust and growing dataset on embodied carbon data for materials but also helped developed BIM-connected solutions that are transforming the toolbox used by AEC professionals to enable the design optimization of sustainable building materials. Below are a few software solutions that enable design optimization to reduce embodied carbon:

Carbon Insights

The Carbon Insights feature provides architects the ability to conduct early-phase embodied-carbon analysis of building exterior walls. Carbon Insights is a cloud-based service that leverages material embodied carbon data from Building Transparency's Embodied Carbon in Construction Calculator (EC3) dataset.

Embodied Carbon in Construction Calculator (EC3)

EC3 is a free, open-access tool that helps measure embodied carbon in building materials - a hidden contributor to carbon emissions. The cloud-based tool includes a searchable global database of thousands of building products, pulling third-party-verified data from Environmental Product Declarations (EPDs). Leveraging this database, EC3 can assess and benchmark embodied carbon of building material quantities from construction estimates and/or BIM models. Architects, engineers, and contractors can input their project-specific data and then compare the carbon intensity from available materials. This open and transparent database will continually improve as both Building Transparency and EC3 users continue to add more EPDs to the dataset. With EC3 data, AEC professionals can make more informed choices, opting for materials that have a lower environmental impact.

TallyLCA

TallyLCA is a plug-in that enables architects to conduct Life Cycle Assessments (LCAs—analyses of the potential environmental impacts of products or services during their entire life cycle) of their BIM data. Intended to be used in early-phase design to make building-system design decisions, Tally enables cross-category and cross-system LCA comparisons based on a customized dataset. This gives architects the power to conduct LCAs to make major building-system decisions during the design and planning phase and, later in the procurement phase, optimize for embodied carbon of the system by comparing specific products of a category or system using EC3. While TallyLCA assesses whole-life carbon of building systems, EC3 calculates embodied carbon impacts associated with specific products, a decision that can be made later in the procurement phase.

TallyCAT

Tally Climate Action Tool, currently in beta, is a plug-in that enables real-time data connection between a model and the EC3 tool. This enables embodied carbon assessment of building products and materials while designing with BIM and supports the specification for low-carbon materials during procurement.

3. Use an Environmental Product Declaration (EPD)

Not all product and material data are equal. Therefore, to ensure a quality and fair comparison of two materials, referencing third-party-verified data that's been vetted by a scientifically based and globally accepted methodology is critical. An EPD reports environmental data based on an LCA of the individual material that was independently verified according to International Standards Organization (ISO) 14040 and ISO 14044. ISO sets the global baseline and benchmark for EPD data - not only for the AEC industry but also for all material data.

An EPD provides transparent data about the environmental impact associated with the making of, and sometimes the use of, a material or product. When it comes to understanding impact and making choices, a material EPD is similar to a food nutrition label, which displays the ingredients and health effects of that food item. This information can be used to inform decisions about designing with that material.

4. Ensure Design Collaboration and Data Access

Enabling easy collaboration and access to common data during early-phase planning through to detailed design and procurement also helps the AEC industry reduce embodied carbon emissions. For example, when all stakeholders are working in the cloud and using a tool such as BIM on their projects, everyone has access to and is informed by the same information. Embodied carbon associated with building materials and products is one of many forms of data that can be integrated into BIM and inform the decision-making process. When stakeholders evaluate and compare products and material selections before procurement to determine the best building practices and materials for the environment, it leads to more sustainable outcomes.

5. Reuse, Repurpose, and Upgrade Existing Building Stock

Existing buildings are an important resource because the embodied carbon emissions are already embedded and locked in place for many years. Avoiding demanding more raw materials and resources is one part of the solution. Seeking opportunities to repurpose and reuse existing building stock will minimize landfill waste and demand for new resources. This reduces embodied carbon that otherwise would have been attributed to building new structures.

2 EXAMPLES OF REDUCED EMBODIED CARBON IN THE BUILT WORLD

A growing number of AEC firms are doing their part to offset global carbon emissions, and it all starts with how they're designing and building. Using a variety of methods to decarbonize their buildings, these firms understand that embodied carbon is a key metric that must be measured and reduced.

Mass Timber for Creative Multiuse in San Francisco

1 De Haro is the first building in San Francisco to use cross-laminated timber (CLT) and the first multistory building of its type in California. What makes this 134,000-square-foot project unique is its mass-timber structure. Using a combination of CLT and glue-laminated timber (GLT), global design practice Perkins&Will created a building that's more lightweight, sustainable, and aesthetically appealing than a traditional steel or concrete building.

Perkins&Will used TallyLCA to measure the embodied carbon and discovered a massive savings in the CLT system over a comparable concrete and steel building - more than 3,500 metric tons of CO2, to be exact. Additionally, thanks to using prefabrication methods of mass timber, the embodied carbon sequestered in the structure will offset 15 to 20 years of operational energy use.

Reducing Microsoft's Footprint in Redmond, WA

When Microsoft redeveloped its 500-acre headquarters in Redmond, WA, it was committed to going beyond designing for building energy efficiency. It looked for ways to reduce the associated carbon footprint of every single building material. The company knew that building new came with a hidden environmental impact: embodied carbon.

With 17 new buildings and 2.5 million square feet of new workspace, project stakeholders understood the importance of reducing embodied carbon to meet Microsoft's stated environmental targets. To this end, they used the EC3 tool to reduce embodied carbon by as much as 30%. Using EC3, Microsoft was able to prioritize reductions in key areas where the new building materials would otherwise have had high embodied carbon emissions.

WHAT DOES THE FUTURE HOLD FOR THE AEC INDUSTRY AND EMBODIED CARBON?

There's a paradigm shift happening in the AEC industry: Design professionals are taking on a new role that prioritizes climate-change initiatives and assumes more responsibility for how their projects in the built environment impact the planet.

Fortunately, architects and designers have access to more data and more design-optimization tools to make informed decisions about the materials and products going into our buildings and infrastructure. Today, the AEC industry can evaluate and choose environmentally responsible building materials, more than ever before. With this new way of working and access to common data, AEC professionals can be more discerning about the manufacturers they work with and from whom they select materials, such as giving preference to those that exhibit the most product transparency.

By working with businesses that disclose the environmental impacts of their products, design professionals can make sound choices that help reduce embodied carbon as well as other environmental considerations. Possessing a better understanding of how building products interact with the environment, through transparent data, enables them to go a step further by eliminating harmful substances and practices altogether. Early planning and evaluation of materials for environmental attributes such as embodied carbon can drive the greatest sustainable impact.

Governments around the world are beginning to incentivize or implement building regulations to help reduce embodied carbon. AEC professionals and firms alike are beginning to make stronger commitments to reduce their carbon footprint in the built environment. The effects of climate change affect everyone - and everything - on Earth, and the movement toward building for a more sustainable, cleaner future is growing. Data is key to understanding the effects of embodied carbon in the built environment, but it's not just about gathering the data; it's also about understanding what it means and how it affects every structure and every product.

With these forces of change, the AEC industry is poised to standardize and connect material and product data for embodied carbon with data from authoring tools such as BIM. Combining built-environment data in this way enables AEC professionals to make informed design decisions and empowers them to make more sustainable material selections.

Technology is already a key enabler of climate change mitigation, and when properly harnessed, it has the power to drive the planet toward a net-zero economy. And it could happen even sooner than anticipated. With the right powerful tools and a growing awareness of embodied carbon in construction, a more sustainable tomorrow is well within reach.

About the Author

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