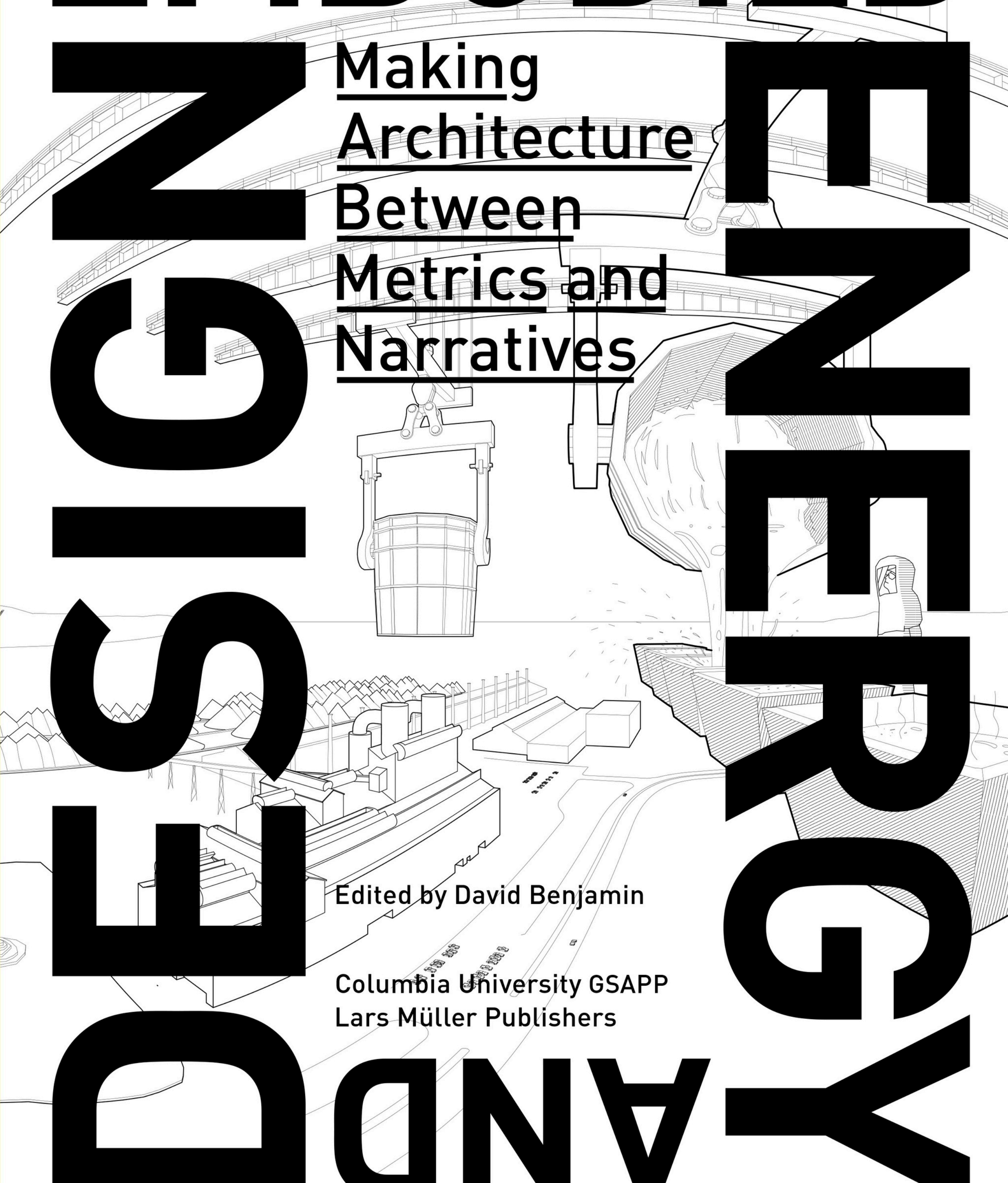

EMBODIED ENERGY AND DESIGN

Making Architecture Between Metrics and Narratives

Edited by David Benjamin

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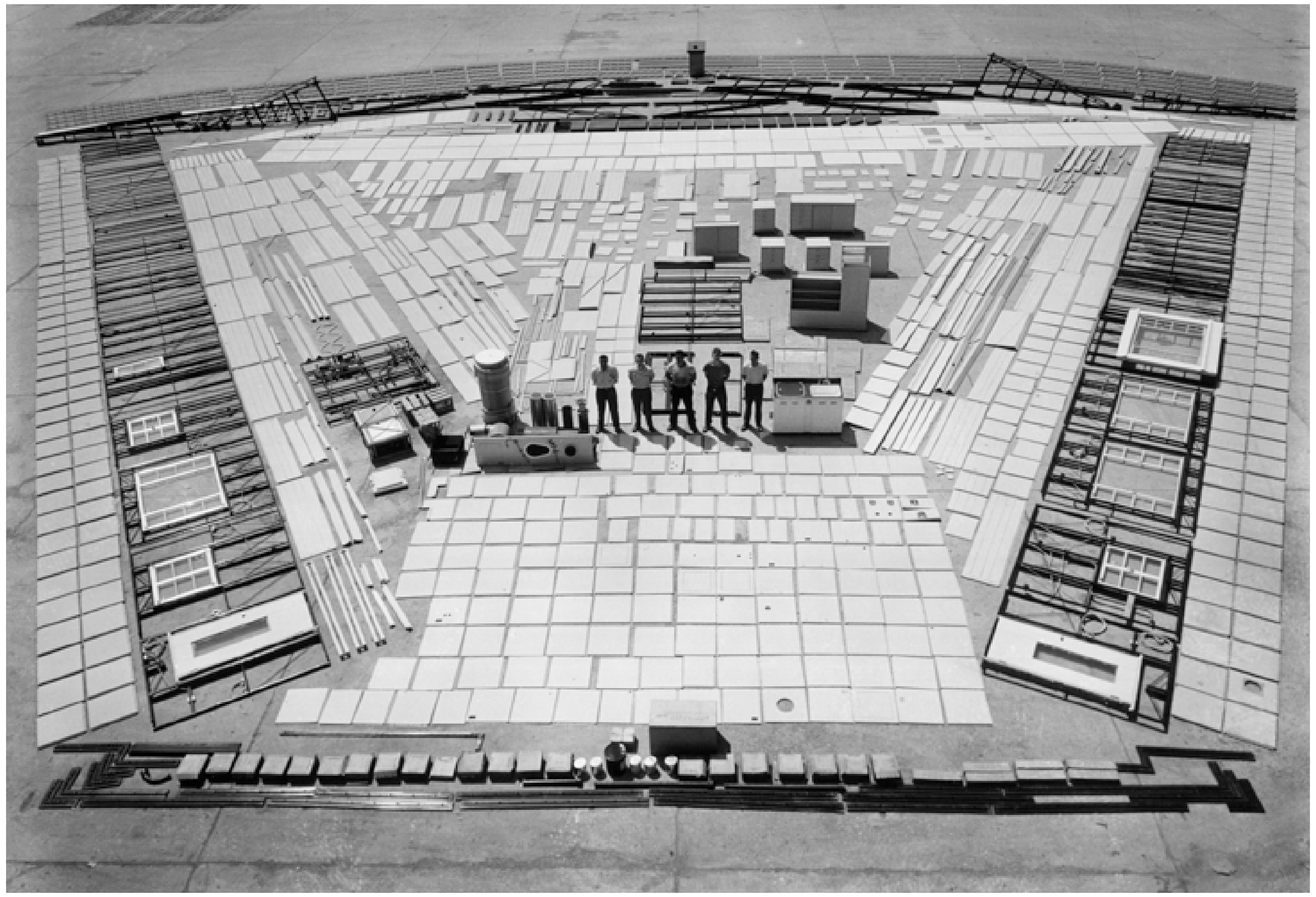

The Lustron Houses were prefabricated, modular homes built after World War II and designed to minimize or even altogether avoid any need for maintenance or repainting.

Getting Beyond Energy: Environmental Impacts, Building Materials, and Climate Change

Stephanie Carlisle

> The carbon record doesn't lie. And what the record tells us is that emissions are still rising: every year we release more greenhouse gasses than the year before, the growth rate increasing from one decade to the next—gasses that will trap heat for generations to come, creating a world that is hotter, colder, wetter, thirstier, hungrier, angrier.
>
> —Naomi Klein

> Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it.
>
> —H. James Harrington

Architecture in the Age of Climate Change

Architecture shapes the environment. Present assessments indicate that buildings account for roughly 30 percent of global greenhouse gas emissions.[1] It is further estimated that an amount equivalent to 60 percent of all existing buildings will be built or rebuilt over the next two decades, making buildings and infrastructure one of the most important causes of global climate change, and one of the greatest opportunities for deep decarbonization.[2] The next decade is a critical window for global emissions reductions, and the effectiveness and cost of mitigation may depend on the extent to which emissions are dramatically curtailed in that time.[3] Decisions that architects make today will have immediate consequences and will bear fruit for decades to come—making architecture vital to protecting the climate, natural resources, and the health and well-being of communities around the planet.

As the dangers of climate change become ever more visible and undeniable, architecture needs robust calculations of environmental impact in day-to-day design practice. Undoubtedly, such quantification will add technical complexity to an already challenging creative pursuit, but in fact the architect's tool kit has never been richer or better equipped for those who want to truly understand the impact of buildings on the environment. The integration of architectural design with a rigorous and scientifically grounded exploration of embodied environmental impacts does not need to alienate the concerns, skills, and perspective of architects but instead can build on the strengths of design culture and enrich design practice.

In the face of a fast-moving and imminent environmental crisis, the design community cannot afford to be paralyzed by the seeming complexity of quantifying architecture's carbon and environmental footprint. The baseline for responsible architecture practice has shifted, and we must learn to improve carbon calculations as a matter of course, without questioning our identity as a creative discipline. Much like the responsibilities of managing cost and adher-

1 Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2009* (Washington, DC: US Department of Energy, 2011), 22.
2 American Institute of Architects, "Why the Building Sector?" AIA+2030 Online Series (2016), http://aiaplus2030.org/why/; James H. Williams, Benjamin Haley, Fredrich Kahrl, and Jack Moore, *Pathways to Deep Decarbonization in the United States* (US report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations, revision with technical supplement, Nov. 16, 2015).
3 Intergovernmental Panel on Climate Change, *Climate Change 2014: Synthesis Report: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. R. K. Pachauri and L. A. Meyer (Geneva: Intergovernmental Panel on Climate Change, 2014), 25.

ing to structural principles, the act of calculating environmental impact can become the basis for an innovative and ethical design practice. If architects want to maintain agency over the built environment, there is responsibility that comes with that power.

Energy Is Not an Environmental Impact

Within the study of sustainability, there is a recognition that reductions in energy consumption will not be enough to counter global climate change and that the impact of buildings, construction, and infrastructure extends far beyond the fuels combusted or consumed within a building.

For decades, architects and engineers have used embodied energy as a stand-in for resource consumption and environmental impact, extending the domain of architecture over larger systems of global production and manufacturing.[4] Conceptually, this premise is essential for understanding the impact of construction more fully. However, the practicality of our reliance on energy as a broad measure of environmental impacts is less clear. In the face of that uncertainty, architects and engineers still turn to the primary flow that they have historically tracked and to a unit, the megajoule, that has been used for decades as a measure of efficiency and performance. But if the megajoule is not the best indicator of environmental impact, then traditional energy models will be inadequate for gauging architecture's relationship to climate change.

Many architects, engineers, and researchers feel conflicted about the resurgence of embodied energy in contemporary architecture discourse, whether it is used as a metaphor or as a literal modeling practice. This hesitation is not born out of a lack of concern for ecological or social questions: the reality of climate change and its implications for design and construction of the built environment are profound. Indeed, such thinking crops up in any number of design questions, such as: What is the relationship between energy efficiency measures and carbon emissions? Does it make sense to super-insulate a building in a region with a low-carbon energy grid? What are the trade-offs between durable industrial products and bio-based materials? How can the value of building reuse be better articulated and quantified? Where can the biggest contributions be made?

Unfortunately, none of these questions can be sufficiently answered by only calculating embodied energy. *The problem is that energy consumption is simply not equivalent to environmental impact.* Embodied energy is a proxy, like transportation distance or recycled content—a stand-in for a host of relationships and end-point measures that are much more complex and meaningful. Clearly, all megajoules are *not* created equally.

While some environmental impacts are closely tied to fossil fuel combustion and carbon emissions, reducing the richness of material flows and mechanisms of environmental impact into a single unit is overly simplistic. Energy is not just an ability to do work or a fuel stock combusted to produce electricity and heat. Energy sources have context. From an environmental and an economic perspective, it matters a great deal how energy resources are extracted, transported, generated, and consumed.

1

Fig. 1 While burning coal releases large quantities of CO2, coal mining has a much broader environmental impact that is often difficult to measure.

For example, the environmental impact of fossil fuel consumption is not fully captured by its global warming potential. Land use transformation, habitat loss, and water pollution are difficult to quantify and often hidden from sight, but they are no less meaningful than carbon emissions. The effects of coal extraction through mountaintop removal in Appalachia or strip mining in Australia are not fully described by a calculation of the emissions released at a power plant. Deforestation, soil erosion, habitat destruction, disturbance to groundwater levels from pumping operations, disposal of overburden, heavy metal contamination from acid mine drainage, and long-term health issues suffered by nearby communities all extend the scale, scope, and nature of disturbance far beyond direct CO2 emissions.[5] [FIG. 1]

Climate change can even be worsened without any combustion at all. Presently, the Intergovernmental Panel on Climate Change estimates that roughly 15 percent of all carbon emissions are attributed to land use transformation—be it the conversion of wetlands and forests into cities or agricultural land.[6] Architects may be accustomed to specifying wood certified by the Forest Stewardship Council, but they may not have considered the implications of increased cultivation of soybeans for bioplastics, resins, foams, and biofuels.

Energy or carbon assessments alone cannot capture the trade-offs implicit in the very technology supporting energy transformation. The same solar cells, wind turbines, and high-efficiency mechanical, electrical, and plumbing systems that enable the industry to move toward "net-zero" buildings also support the extraction and processing of rare earth metals. Such processes

4 Emmanuel M. Rohinton and Keith Baker, *Carbon Management in the Built Environment* (London: Routledge, 2012), 145.
5 US Environmental Protection Agency, *The Effects of Mountaintop Mines and Valley Fills on Aquatic Ecosystems of the Central Appalachian Coalfields (2011 Final)*, EPA/600/R-09/138F (Washington, DC: EPA, 2011); Pamela Spath, M. K. Mann, and Dawn Kerr, *Life Cycle Assessment of Coal-Fired Power Production* (Colorado: National Renewable Energy Laboratory, 1999).
6 Pete Smith et al., "Agriculture, Forestry and Other Land Use (AFOLU)," in *Climate Change 2014: Mitigation of Climate Change, Working Group III Contribution to the Fifth IPCC Assessment Report*, ed. Ottmar Edenhofer et al. (Cambridge: Cambridge University Press, 2014).

are not abstractly impactful or an allusion to the complexity of globalization. There is a direct relationship between the policy, design, and industry that link a green office building in Seattle to the toxic sludge filling Baotou Lake—the site of the Baogang Steel and Rare Earth complex, a leading global supplier of the dysprosium used in batteries and wind turbines, as well as the tellurium used to produce inexpensive and efficient solar panels. While architects strive to create greener and less impactful building projects, they are also transitively shaping these distant landscapes.

Tracking Impacts across Space and Time

For better or worse, the scale of buildings and construction extends far beyond the building site and the depth of environmental impacts stretches far beyond carbon emissions. Understanding architects and engineers' power to shape both the built *and* natural environment demands that the building and construction industry become far more sophisticated and acknowledge that material and design decisions extend far beyond what has traditionally been defined as the scope and scale of design practice.

Every project that is built carries environmental burdens for terrestrial, aquatic, and atmospheric systems. Design decisions and material choices are inextricably linked to landscapes of extraction, production, manufacturing, and eventual disposal. In order to dig into the complexity of the production, consumption, and disposal of building materials, architects must consider the flows of materials and energy across their full life cycles.

When an engineer is refining a structural concept or specifying steel members, her decisions may have a direct impact on the air quality in Tangshan, the largest steel-manufacturing city in China. The environmental impact associated with that steel production is not felt by building occupants, but the 5.5 million people around the world who die prematurely every year from breathing polluted air are very real. But if not steel, then what? Cement production makes up nearly 5 percent of global carbon emissions, a number slated to rise precipitously in coming decades.[7] Commercial forestry carries landscape impacts as well but also provides an ecosystem service in the form of biogenic carbon sequestration.

In truth, material evaluation and comparison in design is never as simple as substitution or selection. How can so much information be managed without a clear model and method? How do we keep the multitude of impacts in mind as we expand the complexity and nuance of design? If architects cannot describe or measure the full impacts of buildings, how can they reduce them?

Life Cycle Assessment and Environmental Impact

While embodied energy hides such interconnections within a single unit, there is an alternate framework that allows for a systems-based approach to measuring and describing environmental impact. In use for more than three decades, life cycle assessment (LCA) is a quantitative methodology that tracks the material, chemical, and energetic flows in a product system over its full life cycle, connecting the inventory of materials and processes to their impacts on aquatic, terrestrial, atmospheric, and human systems.

7 Manfred Fischedick et al., "Industry" in Edenhofer et al., *Climate Change 2014*, 739; Global Carbon Project, *Global Carbon Budget: Data* (2016), www.globalcarbonproject.org/carbonbudget/16/data.htm; Ecofys and ASN Bank, *World GHG Emissions Flow Chart 2010* (2013), www.ecofys.com/files/files/asn-ecofys-2013-world-ghg-emissions-flow-chart-2010.pdf.

8 ISO 14040:2006 and ISO 14044:2006, *Environmental Management: Life Cycle Assessment: Principles and Framework* (International Organization for Standards, 2006).

9 R. H. Crawford, *Life Cycle Assessment in the Built Environment* (London: Spon Press, 2011).

10 Kathrina Simonen, *Pocket Architecture: Life Cycle Assessment* (London: Routledge, 2014).

11 Henrikke Baumann and Anne-Marie Tillman, *The Hitch Hiker's Guide to LCA: An Orientation in Life Cycle Assessment Methodology and Application* (Sweden: Studentlitteratur AB, 2004).

12 Roderick Bates, "Life Cycle Assessment at the Speed of Design," *Building Energy* 35, no. 2 (2016): 44–46.

LCA models draw from international, peer-reviewed databases of materials and processes that translate inventory data (material and energetic inputs and outputs) into natural resource, environmental, and human health impacts across a number of standardized categories, such as global warming potential (GWP), ozone depletion, acidification, and eutrophication.[8] The results allow designers to trace the discrete environmental impacts of specific materials and processes through each life cycle stage: material extraction, manufacturing, transportation, construction, use, and end-of-life, including demolition, disposal, and recycling.[9]

The collection of inventory data and the characterization of environmental impacts is not the work of architects but rather a collective enterprise of chemists, engineers, ecologists, biologists, climate scientists, toxicologists, and industry—a body of knowledge that is constantly improving in quality, scale, and scope.

LCA provides an analytical framework to model complex product systems, identify environmental impacts, and improve manufacturing and construction processes.[10] LCA was initially developed as a tool for incremental improvement, supporting design iteration with a direct link between materials or processes and the environmental impacts that they may produce. LCA practice has developed significantly since the first multi-criteria model was built in the late 1970s to evaluate trade-offs between energy, water, and material resource consumption and pollution from glass and plastic bottles.[11] In the last thirty years, the method has been used to evaluate the full life cycle of environmental impacts for sophisticated products and services such as consumer electronics, biofuels, textiles, and agricultural production.

Still, a building is not just a difficult product. A building is a complex and dynamic system with hundreds of materials and processes coming together not just at the point of construction but continuously, in bits and starts, over its full life cycle. While structural materials will likely remain in place for the full life of a building, coatings, finishes, equipment, and hardware are periodically replaced. Roofing assemblies outlive their useable life and are repaired or replaced; cladding is upgraded as performance or aesthetic sensibilities change. Some building types—like commercial office buildings—may be reconfigured with a new fit-out every five to ten years, sending thousands of pounds of gypsum, flooring, plastics, and sheet metal to the scrapyard or the landfill. Life cycle assessment provides an ordering framework for this complexity—allowing materials to be placed in context and in time.

There are three main challenges to conducting life cycle assessments of whole buildings and architectural assemblies: inventory, resolution, and iteration. In the past five years, significant progress has been made in the development of tools and databases that support architects in conducting LCA during the design process, addressing all three of these challenges.[12] Inventory, the collection of discrete material quantities, is greatly improved through tools such as Tally, a plug-in for Revit that makes use of building information modeling (BIM) workflows that support simultaneous design development, documentation, and analysis—allowing for greater collaboration among team members from various disciplines and skill sets. A conceptual shift from discrete, scaled drawings to multifunctional and collaborative modeling allows for even schematic designs to carry intelligence and nuance, connecting design intent with technical data. Such integrated workflows allow for LCA to be conducted by designers as an integrated and iterative practice, with LCA models gaining resolution natively as building design progresses.

At the same time, the building material databases underlying tools such as Tally, Quartz, and Athena have become more robust and represent a fuller spectrum of architectural materials and techniques. Developed expressly for use by architects and engineers, LCA tools nest individual materials into nuanced assemblies that allow designers to compare results for hundreds of concrete mixes, glazing assemblies, cladding options, or waterproofing systems—rather than merely comparing simple materials like concrete, steel, wood, or cement. New tools presently in development aim to make the practice even more accessible and balance the ease of modeling with the resolution of results. [FIG. 2]

Quantifying and tracking all of the material flows across a building's full life is a daunting and complicated task. But architects revel in complexity. The contemporary narrative of the discipline assigns value according to architects' ability to manage complexity and open-endedness in a practice that demands both technical acuity and artistic vision. So what explains the resistance from both academia and practice to the modeling and quantification of environmental impact?

Has climate change shaken our confidence? Or is our love of complexity reserved only for geometry, cultural context, economics, logistics, and semiotics? Are architects waiting for a more prescriptive approach to lowering embodied carbon? The practice of life cycle assessment has been around for three decades; still, architects struggle with assessing the environmental impacts of their projects—whether the embodied impacts of building materials or the global warming potential of operational energy. A common explanation offered by academics, policy makers, and sustainability-minded architects is that LCA is simply too complicated, too time-consuming, and too intimidating to be embraced widely, despite the presence of tools and technology available to facilitate it.[13] Surveys of practitioners also point to the lack of demand from clients as a key barrier to use of LCA.

While we are far from a reality in which every architecture office engages in iterative energy modeling, the conversation surrounding evaluation and prediction of operational energy has a different tone. Is this because kilowatt-hours are more easily converted to cost, a unit that building owners feel deeply invested in? Is it simply that energy is a far more tangible and quantifiable flow? Is it because calculating energy consumption has long been required of architects and is enshrined in building code?

When asked to make the jump from energy to carbon—from cost to environmental impacts—does our collective hesitation reflect a subconscious suspicion of the science of climate change? Does it reflect a collective guilt over the magnitude of carbon emissions tied to the concrete, metals, and plastics used on each and every project? Or does carbon accounting seem like one more concern among many, a distraction from design? These are emissions that we cannot even bring ourselves to properly calculate, let alone reduce or offset.

Fig. 2 Even small construction elements—such as aluminum window frames—are composed of a large number of parts, each embodying significant carbon emissions.

13 Maureen A. Olinzock, Amy E. Landis, Christi L. Saunders, William O. Collinge, Alex K. Jones, Laura A. Schaefer, and Melissa M. Bilec, "Life Cycle Assessment Use in the North American Building Community: Summary of Findings from a 2011/2012 Survey," *International Journal of Life Cycle Assessment* 20, no. 3 (2015): 318–31; Joyce Smith Cooper and James A. Fava, "Life Cycle Assessment Practitioner Survey: Summary of Results," *Journal of Industrial Ecology* 10, no. 4 (2006): 12–14.

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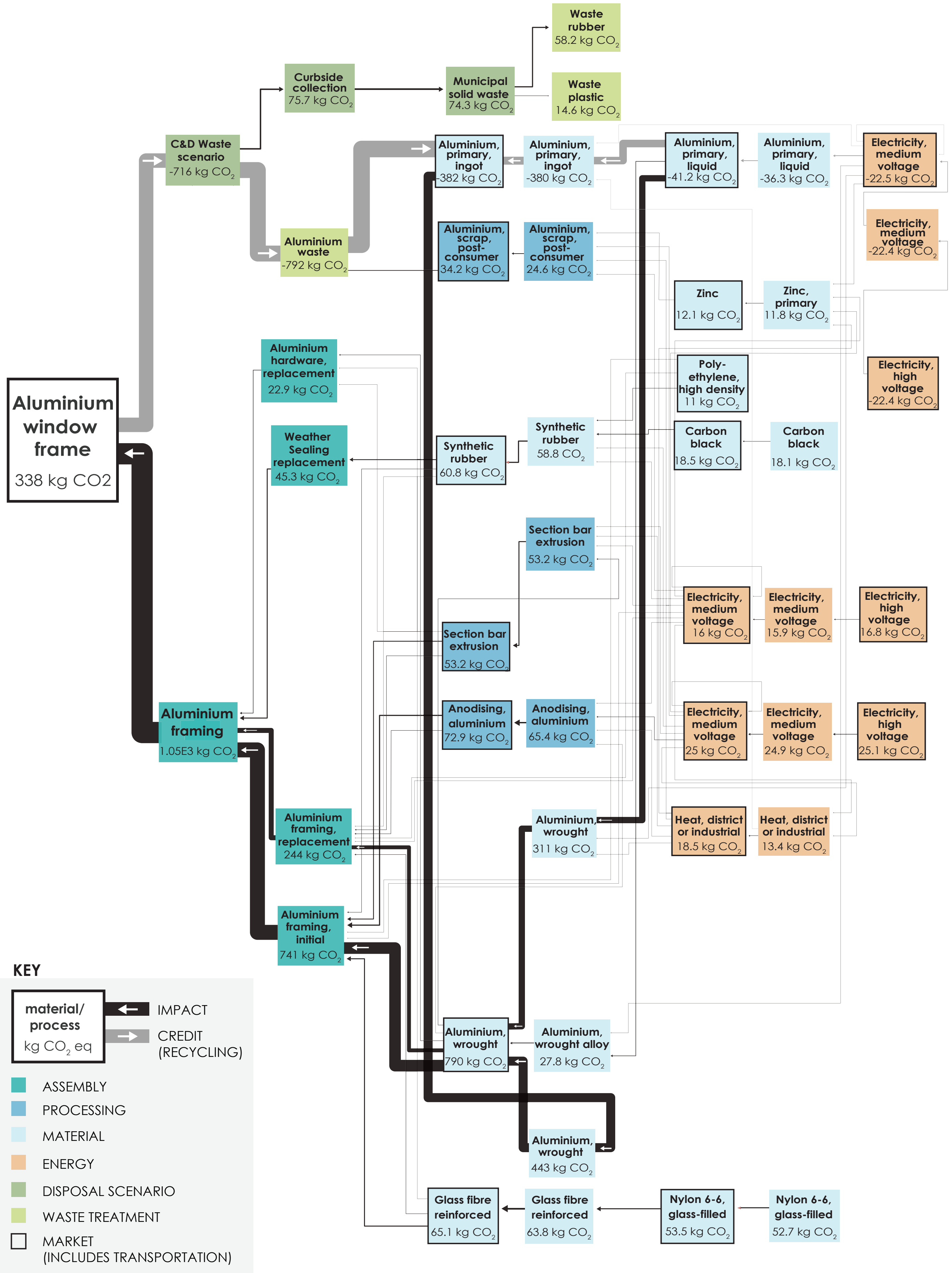

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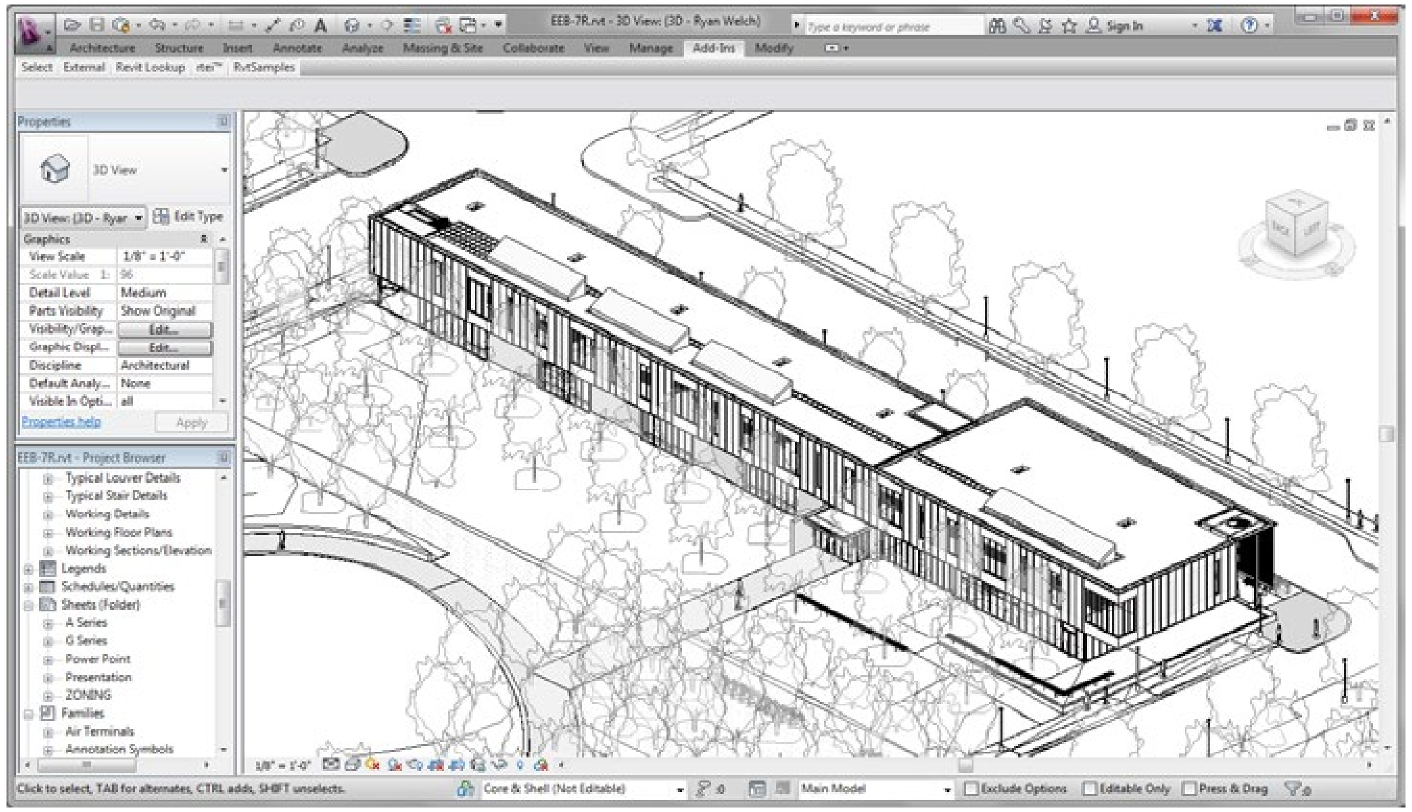

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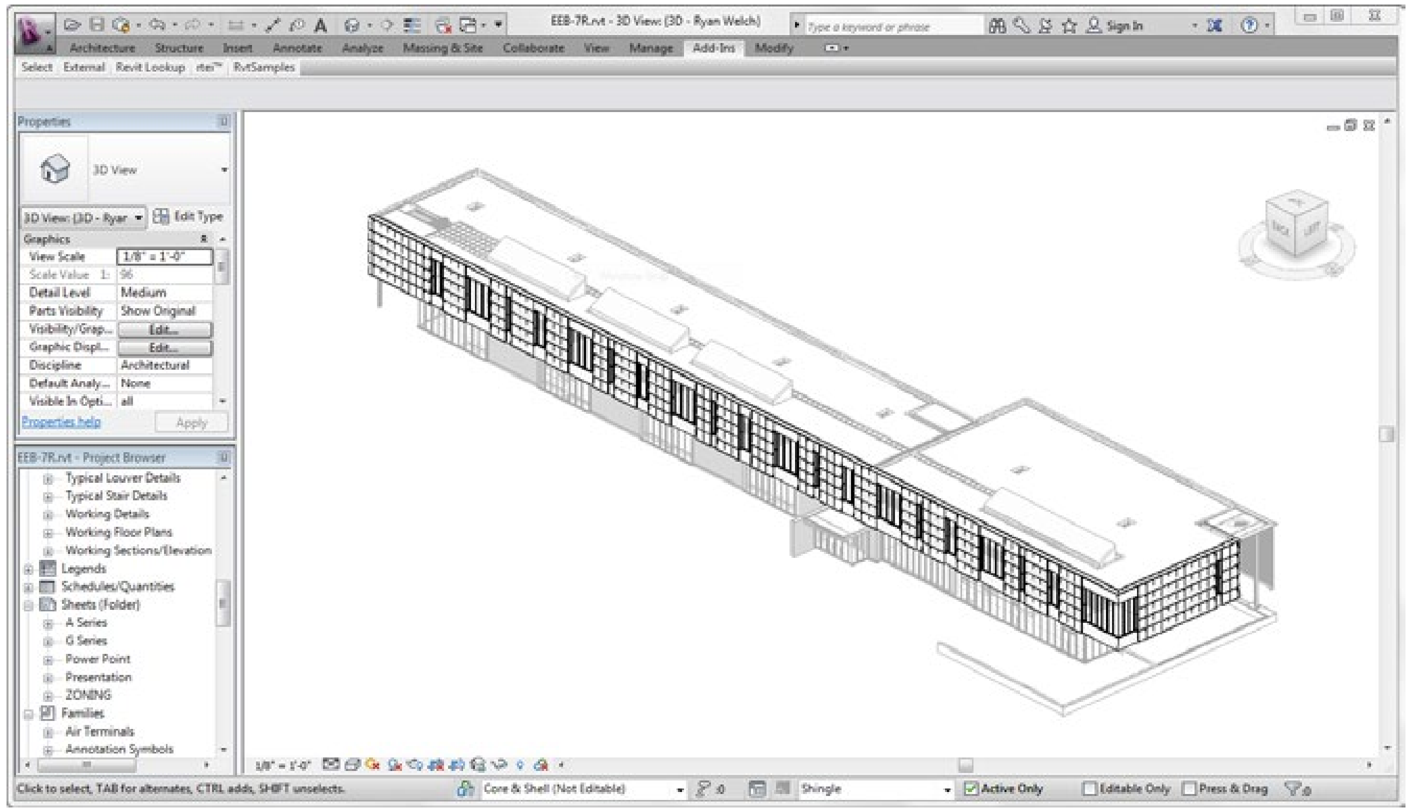

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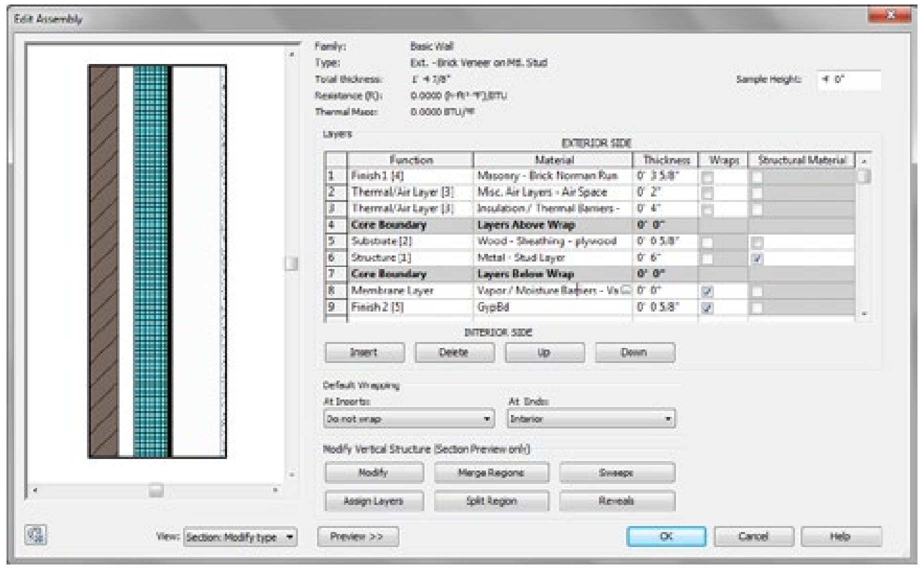

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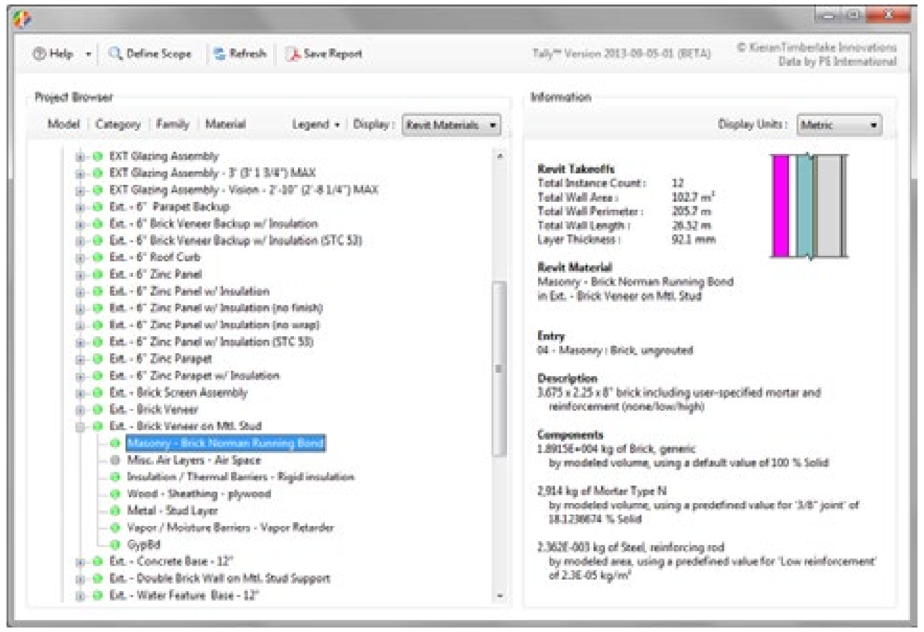

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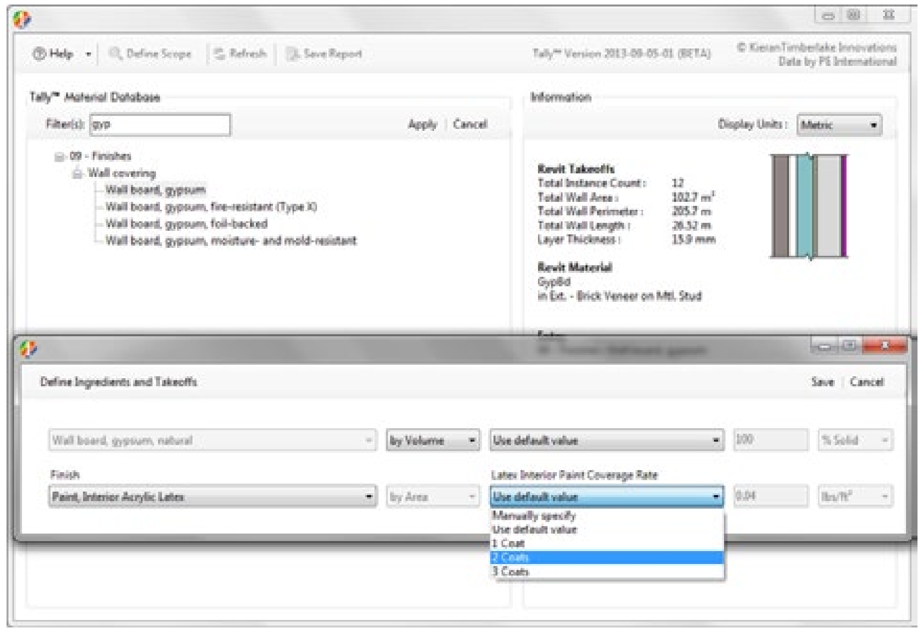

Figs. 3–7 **Tally is a plugin for Revit that allows designers to measure the environmental impacts of building, at the scale of an entire structure as well as in order to compare individual design choices.**

Life Cycle Assessment as a Creative Practice

Instead of sidestepping environmental modeling, architects should take advantage of the newly available power and integration provided by LCA-enabled tools to expand their design agency. In order to fully embrace these possibilities, architects will also need to tap into their imaginative potential and see environmental modeling as more than just a way to make buildings less bad. When life cycle assessments are billed as sustainability metrics or as a means to secure LEED points, architects miss the creative potential of such investigations.

While LCA is a practice based on hard science, it also supports deep thinking about materials and places. Life cycle assessment provides architects with a means and method to explore a richer narrative about the full history of materials—the mechanisms of their production as well as the landscapes of power, labor, energy, extraction, and transformation that they perpetuate. A close examination of materials does not limit design: it empowers and grounds creative practice.

Beyond simply supporting material selection, LCA equips designers to explore the deep relationships that link landscapes of production, consumption, and disposal. If LCA lends a quantitative and data-rich hand to design imagination, then designers have ample opportunity to enrich LCA practice through experimentation in the art of data interpretation, visualization, and communication. [FIGs. 3-7]

Addressing climate change and other environmental impacts is not the work of any single discipline. It is a collaborative pursuit, an active conversation—the work both of big ideas and millions of small actions. Architects do not need to reinvent the science of risk analysis or the characterization of environmental impacts. They do not need to transform themselves into amateur toxicologists or ecologists. What architects need to do is actively collaborate with industries and practitioners who are more experienced at conducting such assessments to make flows of materials and chemicals up and down the supply chain more transparent and comprehensible. They need to join the conversation. In doing so, architects must also bring to the table their considerable skills and expertise, their understanding of how things get built, their creativity and problem-solving abilities, their great talent at translating complex systems into accessible stories.

Climate change has made it abundantly clear that measuring environmental impacts matters. But to address climate change in any real way—in a way that systematically overhauls structures of power and production, and radically rethinks how we use and manage resources globally—requires a shift in social behavior and in the culture of our thinking.[14] It requires us all to become more educated and articulate in explaining climate change and in our understanding of the relationship between our actions and large-scale impacts.

By modeling full material systems, life cycle assessment may prove to have richer narrative potential than more reductive embodied energy calculations. From a global warming perspective, embodied carbon is far more important than embodied energy. Unlike simple calculations of embodied energy, a single LCA model has the ability to distinguish between specific environmental impacts. While the wide range of impact categories can be overwhelming, models that reveal connections between design elements and their environmental impact, and then allow designers to explore trade-offs, are more useful than those that reduce those environmental impacts into megajoules. In truth, the numbers themselves are not really the point. When investigations of environmental impact are integrated into design, the goal is not simply to hit a baseline but to cultivate a practice of iteration, exchange, and exploration.

14 Naomi Klein, *This Changes Everything: Capitalism vs. the Climate* (New York: Simon & Schuster, 2014).