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Integrating Embodied Carbon Feedback in Early Stage Design Using Dynamo and Insight 360

Aman Singhvi
AECOM

Edward Dalton
AECOM

Learning Objectives

- Discover why embodied carbon simulation is as critical as energy simulation for the Architecture 2030 challenge
- Learn how to estimate during early stage design the impact of embodied carbon simulation on a project's carbon footprint
- Learn how carbon databases and Dynamo libraries can be used to create a basic carbon feedback tool
- Learn about common high- and low-impact materials and where to find additional resources for a carbon-sensitive design

"Designers are the magicians who can orchestrate massive flows of matter and energy"

Description

How "green" is your green building? This session intends to answer this fundamental question and to reveal the "real" carbon impacts of various design decisions on early stage building design. Annually, embodied carbon is responsible for 11% of global greenhouse gas emissions and 28% of global building sector emissions. Currently, architecture, engineering, and construction (AEC) firms mostly focus on reducing operational emissions without much regard for embodied emissions. This talk will focus on the importance of quantifying the impact of material selection at early stage design on EC, and to integrate the results with Insight 360 software. We'll illustrate the fundamentals of EE and EC, and we'll demonstrate through case studies how Dynamo workflows and various carbon databases can be used to provide a visual, high-level carbon feedback to the designer. The intention of this talk is to empower the designers to make better carbon-informed decisions without compromising energy performance for their Architecture 2030 projects.

Speakers



Aman is a New York City based High Performance Design Specialist with over 7 years of research and professional experience in building science and architecture. He holds an M.Des. in Energy and Environments degree from Harvard University Graduate School of Design and has been engaged with multiple projects from small Net-Zero Energy buildings to large master-planning. Aman's professional work also includes development of scripts, tools and UI dashboards to create more efficient, user-friendly workflows for Energy Modeling. Some of his expertise include Whole Building Simulation (energy, daylight glare, CFD), Dynamo, Grasshopper, Insight 360.



Edward is a structural engineer and senior software engineer with 7 years' experience split between three engineering consultancy companies Taylor Thomson Whitting (TTW), Sydney Australia, BuroHappold, London UK and AECOM New York, USA. During his time at TTW, Edward's main role was in the development of in-house software for both drafting and engineering applications. At BuroHappold although his role has been more project/structural design focused he has been key player in setting up creating an in-house object model based in C#. This object model defines a common interface for transferring data (geometry, properties and attributes) between analysis and BIM software as well as creating a program agnostic environment for data processing and manipulation. In his current position at AECOM his role has been much more focused in software development where he manages a small team in the delivery of software solutions including web applications, data management and engineering design.

Contents

Contents	3
Glossary	4
Introduction	6
Macro Embodied Carbon: Our Collective Footprint	7
Global Trends for Changes in Primary Energy Sources	7
GHG Emissions from Fossil Fuels	8
Global Warming Potential (GWP)	9
Construction Industry's share of GWP	9
Embodied Energy and Carbon Footprint of Buildings	10
The 2030 Challenge and AIA 2030 Commitment	11
The 2030 Challenge (Operational Carbon)	11
The 2030 Challenge (Embodied Carbon)	11
AIA 2030 Commitment	12
Environmental Impacts Accounting Frameworks	13
The Life Cycle Assessment Framework	13
Slow Industry Adoption of Current Approaches	14
Embodied Carbon Feedback in Early Stage Design: A Roadmap	15
Embodied Carbon Feedback Tools: Case Studies	16
Datasets and Data Quality	16
Carbon tool 1: Revit + Dynamo	16
Carbon tool 2: Revit + Revit API	17
Embodied Carbon of Common Materials (Resource)	19
Future Work	20

Glossary

Embodied carbon emissions in construction (EC): commonly referred to as “embodied carbon” refers to the GHG emissions associated with the extraction, manufacturing, maintenance, and disposal of a building product.

Embodied energy in construction (EE): It is the sum of energy consumed by all the processes and services associated with the production of a building product, from the mining and processing of natural resources to manufacturing, transport and product delivery and application. This sum, by definition, is considered as if that energy was incorporated or 'embodied' in the product itself.

Greenhouse gases (GHG): are gases that trap heat in the Earth's atmosphere. Commonly these are carbon dioxide, methane, nitrous oxide, and fluorinated gases (such as CFCs, HCFCs, HFCs etc. found in refrigerants).

Net Zero Energy Building (NZEB): A net zero energy building, also known as a zero-net energy (ZNE) building or simply net-zero is a highly resource-efficient building where, the actual annual energy consumed (factored for source energy) is less than or equal to the on-site renewable energy production offset.

Operating carbon (OC): also known as operating emissions, it refers to the GHG emissions that are generated from the burning of fossil fuels used for various operating functions of the building and its occupants such as heating, cooling, power supply, during its service life (or per year).

The definitions below are referenced from ISO 14040/44:2006 – Section (4), (5):

Impact category: Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned

Life cycle assessment (LCA): Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle.

Life cycle impact assessment (LCIA): Phase of life-cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life cycle inventory (LCI): Phase of life-cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life cycle inventory (LCI) database: A database of LCI flows for individual unit processes or for a portion of a product life cycle. In the case of unit process data, the data includes intermediate flows of materials between processes, whereas

system process data is a “black box” that does not specify intermediate flows. LCI databases track hundreds of inventory flows.

LCIA/EPD database: A database of results from LCA studies that does not contain a complete list of LCI flows and instead presents the calculated impact assessment results for a database of products that have previously completed LCAs often leading to published EPDs. These databases are typically based on EPDs and may differ in underlying methodology and assumptions depending on the PCRs that the EPDs are based on.

Product: any goods or service (e.g. transportation, computer software, brick, labor)

Product category rules (PCR): A set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.

Process: Set of interrelated or interacting activities that transforms inputs into outputs

Type III environmental product declaration (EPD): Provides quantified environmental data using predetermined parameters and, where relevant, additional environmental information. (The predetermined parameters are based on the ISO 14040 series of standards. The additional environmental information may be quantitative or qualitative.)

Introduction

“How did this brick come to be?”

“How much energy did it take to produce, transport and assemble it here?”

“What will happen to it after the building is torn down?”

In today’s fast-paced world of design-deliver-forget, we hardly ever stop to ask questions like these. Even when we do, the answer quickly becomes too vast, overwhelming and impractical for one single stream of thought to conceive. The universe is in perpetual flow of mass and energy, and within the last century itself, these flows and interactions have become far too rapid, complex and multidimensional to fully comprehend the limits of its boundaries or degree of interdependencies.

Nevertheless, these questions help ‘reveal’ the often-ignored realm of mass and energy flows that is put into motion as a result of a simple act of specifying a material for a façade. But most importantly, they help reveal the true environmental impact of our design decisions.

This session will attempt to cover the complex topic of embodied energy (EE) and embodied carbon (EC) in two aspects; **qualitative** and **quantitative**, simplified to fit the time available. It is critical to understand both aspects simultaneously in order to try to comprehend the bigger scales within which our actions may have an impact.

- In the first part, we will briefly cover the concepts, macro trends and current projections of EE and discuss why is there a need for a shift in current approaches.
- In the second part we will discuss a roadmap to generating a high-level embodied carbon feedback tool through two basic embodied carbon tools in Revit, one using Dynamo with add-ins and the other using Revit API.

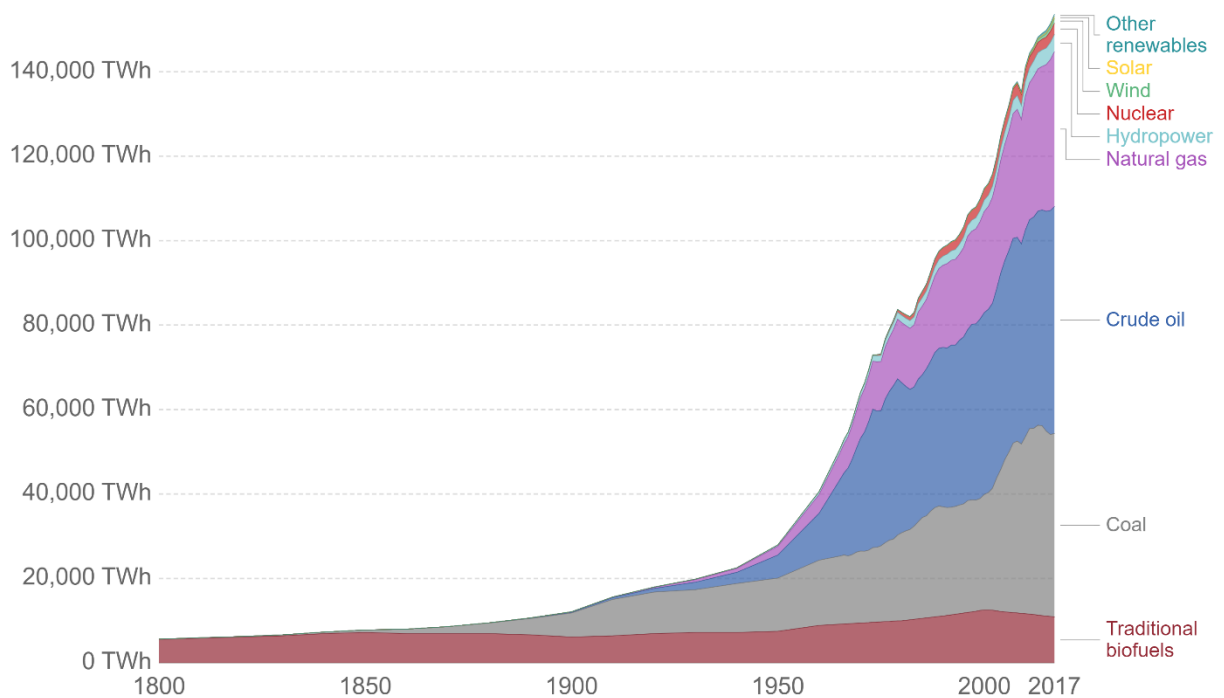
The underlying aim of this industry talk is to empower more designers to make informed design decisions from the early stages of design – right at their drawing board, and to shift the conversation around carbon from numbers and complicated metrics to tangible, real-world impacts.

Macro Embodied Carbon: Our Collective Footprint

Global Trends for Changes in Primary Energy Sources

Every process, whether natural or human-made, requires energy. Due to factors such as rapid urbanization, population growth and the industrial revolution, the world's demand for energy has increased remarkably. To meet this demand of all anthropogenic activities, the sources of primary energies have drastically changed within a short span of only a few centuries (Figure 1).

This shift from biofuel to fossil fuel sources over the years may have proven to be a useful solution to fulfill the growing energy needs but the increased combustion of carbon-rich fuels (has led to rapid release of CO₂ and other Greenhouse gases (GHGs) into the atmosphere. It has also been the primary reason for the environmental imbalance and rapidly changing climate that we are observing today.



Source: Vaclav Smil (2017) and BP Statistical Review of World Energy

CC BY

Figure 1: Global primary energy consumption, measured in terawatt-hours (TWh) per year. Here 'other renewables' are renewable technologies not including solar, wind, hydropower and traditional biofuels.

Source: <https://ourworldindata.org/energy-production-and-changing-energy-sources>, CC by 4.0

GHG Emissions from Fossil Fuels

As noted above, the rise in usage of fossil fuel (primarily coal, oil and gas) about 150 years ago led to increased emissions of CO₂ and other greenhouse gases into the atmosphere.

A greenhouse gas is a gas that absorbs and emits radiant energy within the thermal infrared range. The primary greenhouse gases in Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone. The larger their concentration in the atmosphere, the higher the amount of radiant energy trapped within the atmosphere, this is called **greenhouse gas effect**.

This trapping of heat energy due to higher (naturally imbalanced) concentrations of GHGs is the primary cause of **global warming**, the effects of which are being observed by the world in terms of increased natural disasters, melting glaciers, disruptions of food systems and threat to natural habitats etc. This phenomenon is called **climate change**.

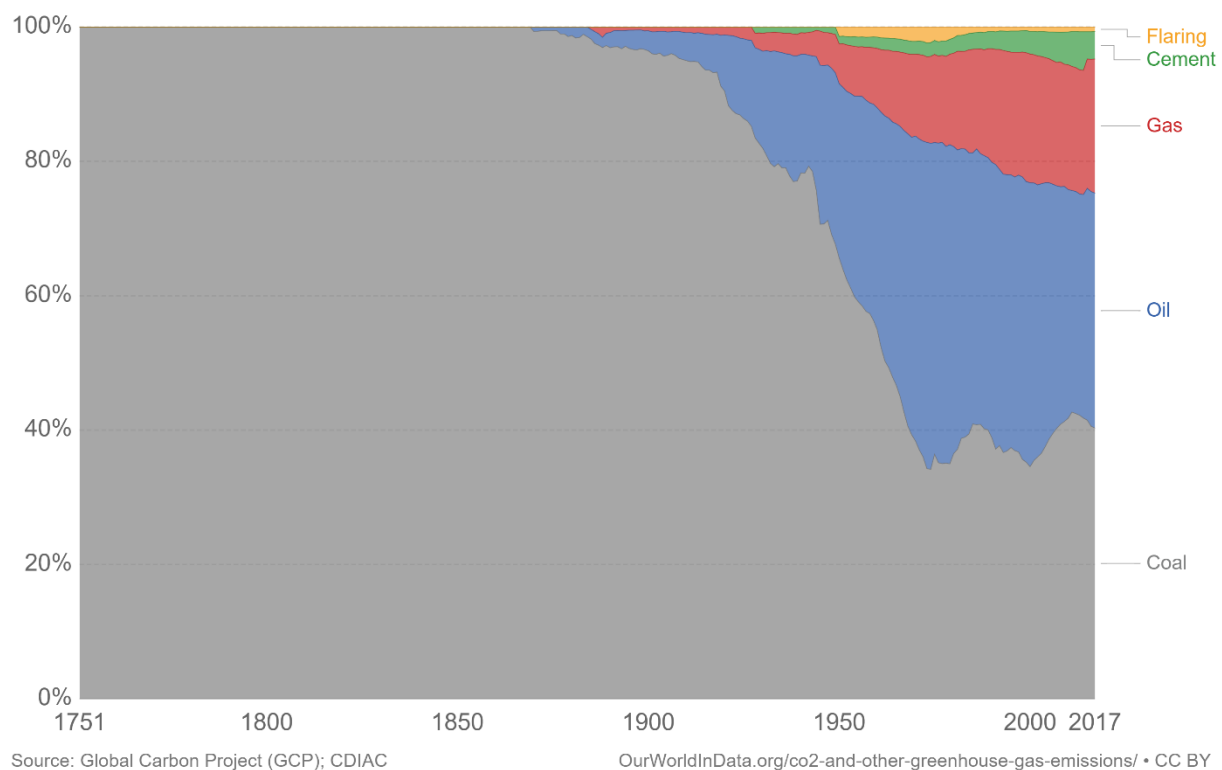


Figure 2: CO₂ emissions by fuel type, World (Relative). Annual carbon dioxide (CO₂) emissions from different fuel types, measured in tonnes per year. Source: <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions>, CC by 4.0

Global Warming Potential (GWP)

The Global Warming Potential (GWP) is a metric to allow comparisons of the global warming impacts of different gases. It is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given time period relative to the emissions of 1 ton of carbon dioxide (CO₂).

The larger the GWP, the more that a given gas warms the Earth compared to CO₂ over that time period. The time period usually used for GWPs is 60 or 100 years. GWP numbers of different gases allow for an across the board comparison of combined emissions and their collective impact. This information is helpful for stakeholders and government etc. to help make policies within high emission sectors.

Greenhouse Gas	GWP over 100 years
Carbon dioxide (reference)	1
Methane	25
Nitrous oxide	298

Construction Industry's share of GWP

The buildings and buildings construction sectors combined were responsible for 36% of global final energy use and 39% of energy-related carbon dioxide (CO₂) emissions in 2017, according to the Global Status Report 2018 by the Global Alliance for Buildings and Construction.

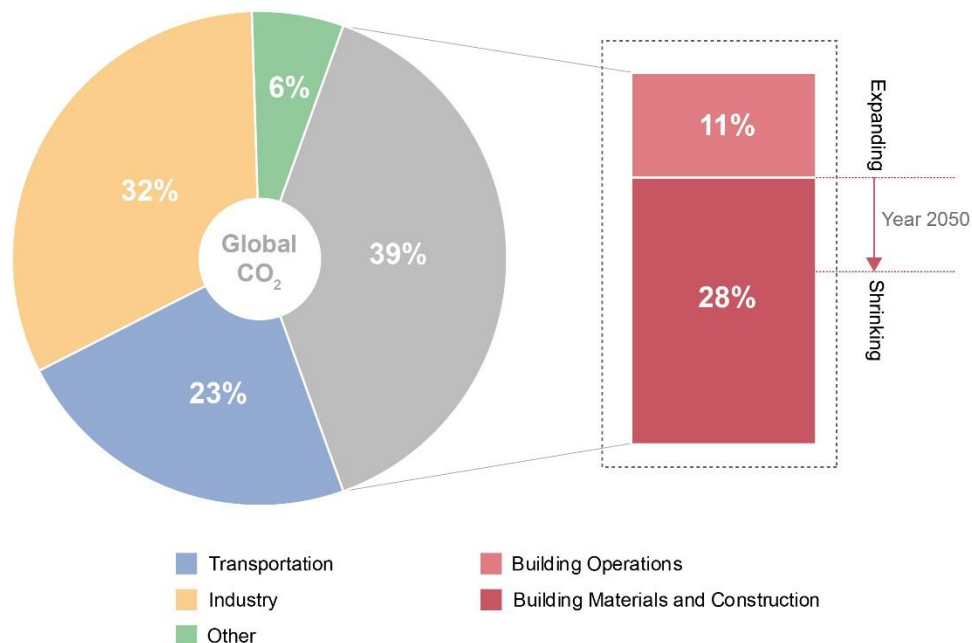


Figure 3: Global share of greenhouse gas emissions by major sectors

Embodied Energy and Carbon Footprint of Buildings

Embodied energy is the sum of all the energy required to produce a building 'product', considered as if that energy was 'embodied' in the product itself. It is an typically accounted using the lifecycle assessment (LCA) framework which aims to find the sum-total of the energy necessary for an entire product life-cycle. Determining the boundary conditions of material life cycle gives the scope of analysis and typically includes these various stages: raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition as well as human and secondary resources.

If the embodied energy required during a particular building product's lifecycle is derived from fossil fuel sources, it is called Embodied Carbon or Carbon Footprint of the material and is expressed as carbon dioxide equivalent as discussed previously.

Much of the focus till date has remained on operational carbon rather than embodied carbon, even though the embodied form will make up about half of all carbon emissions from new construction between 2020 and 2050. This is due to the increasing operational efficiency of current buildings and the rise of clean energy sources in the building industry.

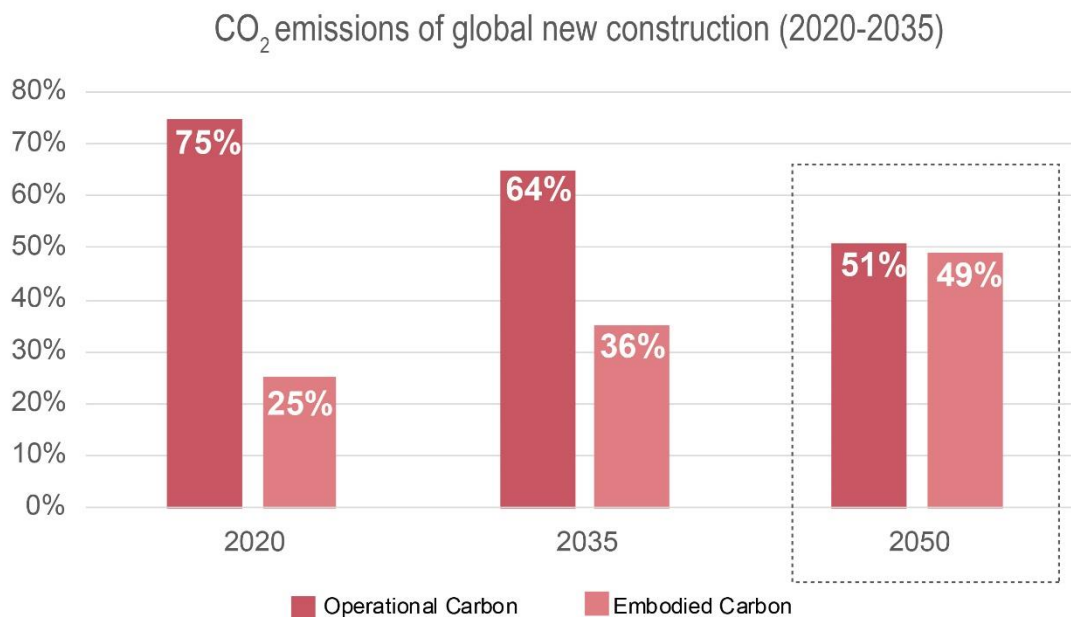


Figure 4: CO₂ emissions of global new construction projections from 2020 to 2050, data source: UN Environmental Global Status Report 2017 and IPCC

The 2030 Challenge and AIA 2030 Commitment

The 2030 Challenge (Operational Carbon)

The 2030 Challenge is an initiative by Edward Mazria and Architecture 2030 asking the global architecture and construction community to adopt a series of greenhouse gas reduction targets for new and renovated buildings.

The following are the targets set by The 2030 Challenge:

- All new buildings, developments and major renovations be designed to meet a fossil fuel, greenhouse gas (GHG) emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type.
- At a minimum, an amount of existing building area equal to that of new construction be renovated annually to meet a fossil fuel, greenhouse gas (GHG) emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type.
- The fossil fuel reduction standard for all new buildings be increased to:
 - 60% in 2010
 - 70% in 2015
 - 80% in 2020
 - 90% in 2025
- Carbon-neutral by 2030 (zero fossil fuel, GHG emitting energy to operate).

The 2030 Challenge (Embodied Carbon)

The 2030 challenge for embodied carbon urges all building sector professionals to reduce their embodied carbon from 60% now to 0% by 2050.

This is a mammoth task, but at the same time requires urgent attention from all stakeholders to plan for, if we hope to achieve this target.

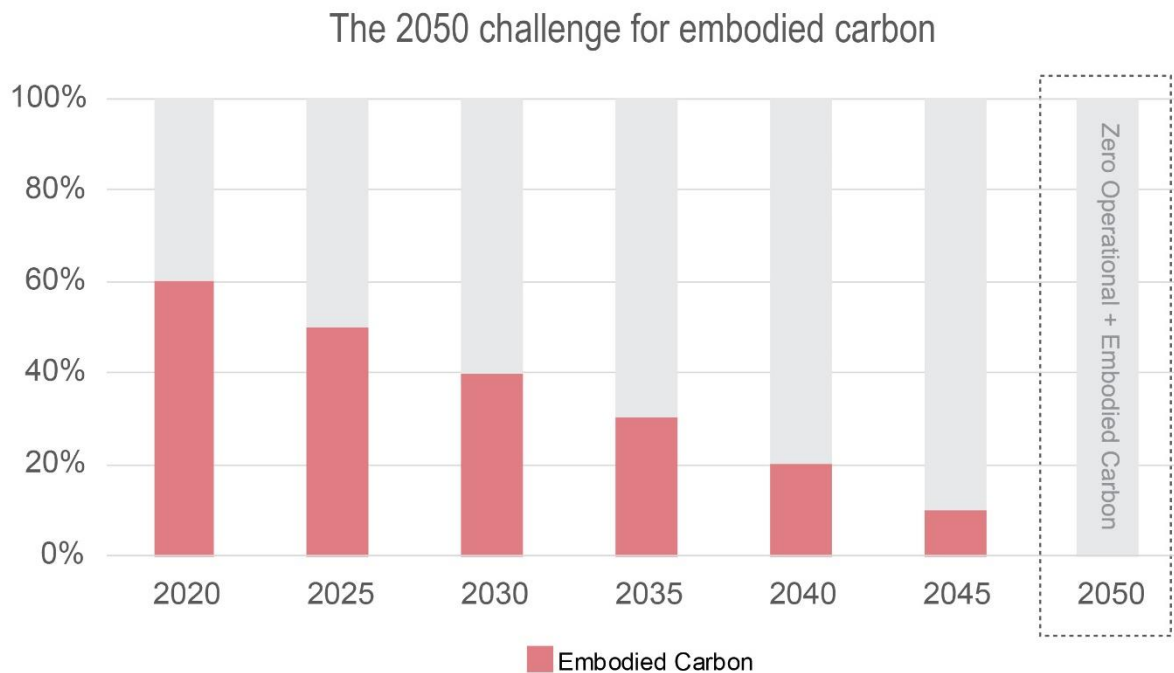


Figure 5: the 2050 challenge for embodied carbon, data source: www.architecture2030.org

AIA 2030 Commitment

The AIA 2030 Commitment is an initiative by the American Institute of Architects that provides a framework to help firms evaluate the impact of project design on energy performance. This framework is intended to help achieve the 2030 challenge targets of zero operational emissions.

Its aim is to transform the practice of architecture in a way that is holistic, firm-wide, project-based and data-driven, so that the all stakeholders in the AEC practice can prioritize energy performance and carbon reductions in the design toward carbon neutral buildings, developments and major renovations by 2030.

Environmental Impacts Accounting Frameworks

The Life Cycle Assessment Framework

Life-cycle assessment (LCA) is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Designers use this process to help critique their products. LCAs can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

Environmental Life Cycle Assessment (LCA) is a standardized method used to quantify environmental impacts of buildings from material extraction and product manufacturing through use and end of life and disposal.

The general LCA framework is described in ISO standard 14044 including a standard list of impact categories and guidance for data quality. Figure 6 shows the journey of a material from extraction to disposal/ recycling based on the life cycle assessment framework.

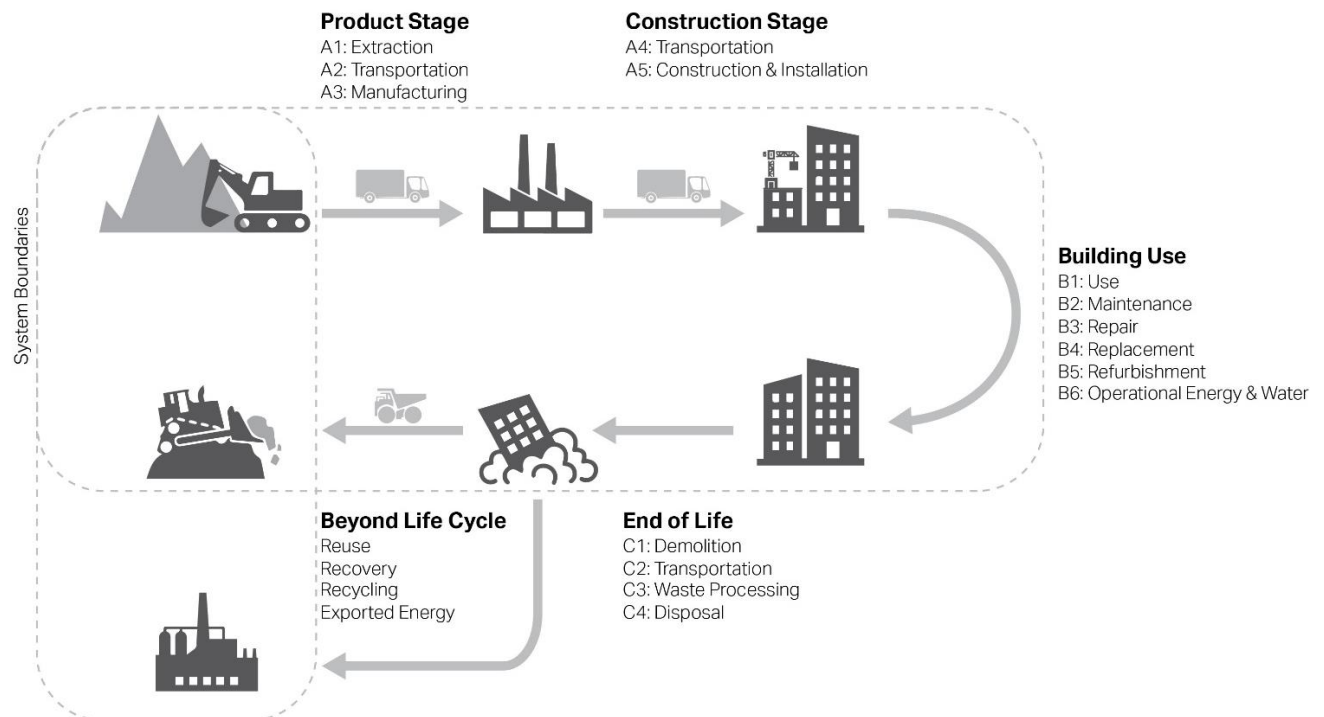


Figure 6: The material lifecycle stages

Slow Industry Adoption of Current Approaches

Even though the LCA methodology, tools and technology has been around for more than three decades, there has been only limited focus on embodied energy. This may be due to a variety of possible factors, some of which are outlined below as food for thought:

- Quantifying entire material and energy flows associated with a building is a task too complicated and time consuming in professional practice
- Lowering only operational energy and operational carbon is a large enough focus for the industry right now
- Inherent complexity of the topic to completely understand all its aspects
- May be perceived as a distraction from design itself
- A lack of consensus on exactly how embodied carbon should be defined and calculated
- Too many different methodologies and references
- The difficulty in obtaining high quality LCI database
- High cost for gathering, organizing and managing product EPD data
- Lack of a common platform for various EPDs and LCI database
- Many open source LCA-related databases only address materials and product; they do not address construction activities or building operations.
- LCI databases require a completely separate task and expertise; they are not integrated into routinely used architecture, engineering, and construction (AEC) tools, methods or best practices

These are meant for open discussion within the industry at large to provoke a conversation regarding how can shift the mindset regarding embodied emissions from merely compliance to urgent global necessity.

Embodied Carbon Feedback in Early Stage Design: A Roadmap

In order to address certain issues discussed in the previous section on potential barriers for mass adoption of embodied emissions accounting, there needs to be a new type of intervention or approach.

The following are identified as potential elements to increase adoption of carbon accounting (as well as awareness):

- **Simplify definitions to scores:** Shift from complicated definitions and metrics to simple numbers (e.g.: a normalized carbon score)
- **Simple workflows:** Develop simple workflows and tools which are easy to setup and automatically pull certain information from the 3D model as well as map it to the database
- **Open source database:** Advocating for creation and use of more open source databases so that the adoption range increases to a broader user group
- **More intuitive comparisons:** Convert the units of embodied carbon to metrics form other industries for an intuitive comparison and thought-provoking insights on the impacts of their design decision (e.g.: converting the final embodied carbon emission number from Kg CO2 EQ to number of trees needed to offset in a year)
- **Live tool:** Making the tool operate in real-time and be responsive to any 3D model change events

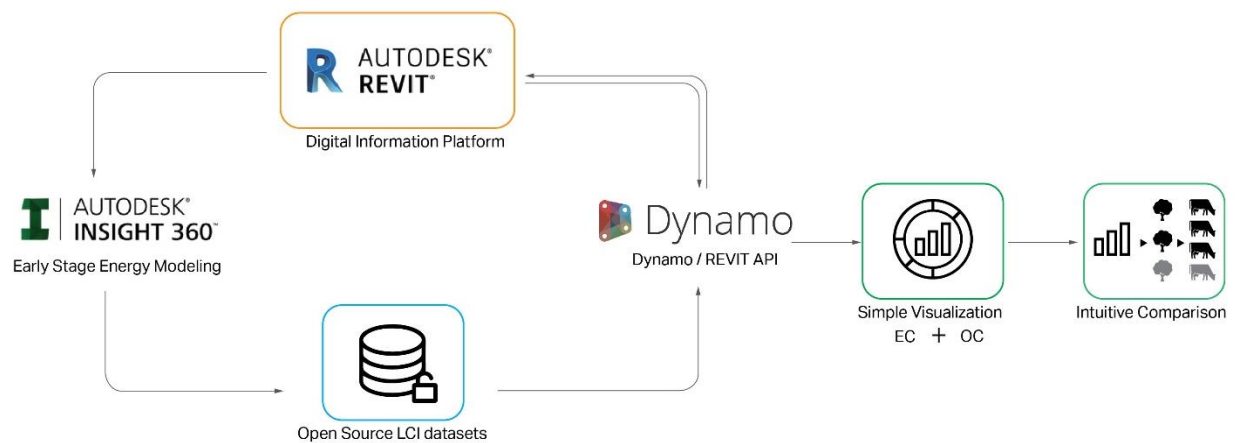


Figure 7: Proposed technical workflow of an early stage embodied carbon tool

Embodied Carbon Feedback Tools: Case Studies

Using simplified roadmap and framework discussed previously, two high level carbon feedback tools were developed to work within Revit models in real-time.

In both tools, energy modeling results from Insight 360 were integrated to also provide an estimate of the total carbon footprint (Embodied Carbon + Operational Carbon).

The second tool was developed using Revit API to overcome some recent changes within the dynamo interface and to advance some of the ideas mentioned in this handout.

The step-by-step process for each tool is mentioned here and this will be elaborated using a live case study in the talk session.

Datasets and Data Quality

Sources of information, number of samples available, creation methodologies, boundary conditions and geographic regions are some of the important criteria that are factored into the equation when assessing the quality of a dataset.

A high-quality dataset is critical when carrying out detailed LCA or when modeling for LEED compliance. It is highly recommended to follow the guidelines mentioned in ISO14044 and EN15804 when selecting a dataset for these kinds of applications.

In the case of this tool and its intended function, precise calculations are not required. This tool is more intended to be a comparative tool rather than precise LCA calculator. It is designed to work with open source data to only provide a high-level feedback to the designers at their “drawing board”.

Having said that, the purpose of these embodied carbon feedbacks is also to serve as a precursor to a more robust LCA analysis, to be carried out in the later stages of the design, using industry standard tools and methodologies available for AEC professional practice.

Carbon tool 1: Revit + Dynamo

Below are the steps based on the above-mentioned framework that were executed to develop this tool. Please note: These are to be elaborated using a case study during the session.

- Step 1: Bring excel DB to dynamo
- Step 2: Import Revit instances into dynamo by selected categories
- Step 2: Map Revit material to DB material (manually)
- Step 3: Get density information from the material's structural asset
- Step 4: Get instance volume by material
- Step 5: Multiply material density by volume to get mass
- Step 6: Multiply mass volume to the corresponding material impact category from the DB
- Step 7: Calculate embodied carbon
- Step 8: Get EUI and fuel breakdown from Insight 360 analysis and multiply by building life
- Step 9: Convert site operation energy to source energy and operational carbon
- Step 10: Report cumulative number/ visualize in Mandrill add-in for dynamo

Carbon tool 2: Revit + Revit API

Below are the steps based on the above-mentioned framework that were executed to develop this tool. Please note: These are to be elaborated using a case study during the session.\

- Step 1: Bring excel DB to Visual Studio
- Step 2: Import Revit instances through Revit API
- Step 2: Initially map Revit material to DB material by using keyword search
- Step 3: Get density information from the material's structural asset
- Step 4: Get instance volume by material
- Step 5: Multiply material density by volume to get mass
- Step 6: Multiply mass volume to the corresponding material impact category from the DB
- Step 7: Calculate embodied carbon
- Step 8: Get EUI and fuel breakdown from Insight 360 analysis and multiply by building life
- Step 9: Convert site operation energy to source energy and operational carbon
- Step 10: Report cumulative number/ visualize in a stand alone Revit API window
- Step 11: Create live-link to Revit (on material change)
- Step 12: In a second Revit API graph, compare the Embodied Carbon to other industry metrics such as number of trees needed in a year etc.

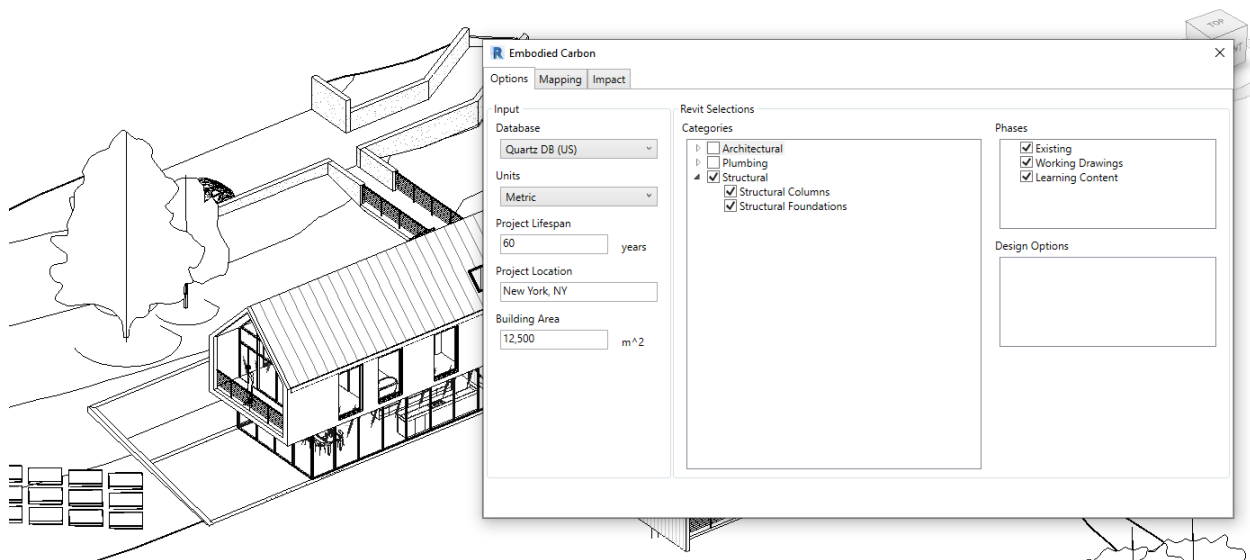


Figure 8: Tool 2 - Inputs Tab and automatic model identification

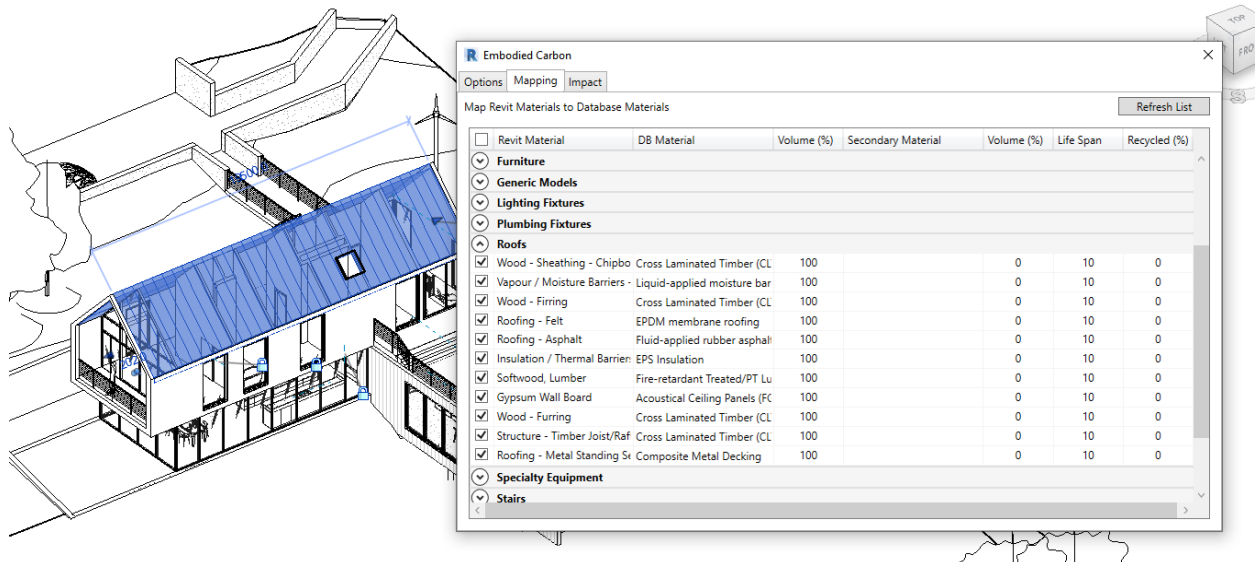


Figure 9: Tool 2 - Material mapping tab and automated database material search functions

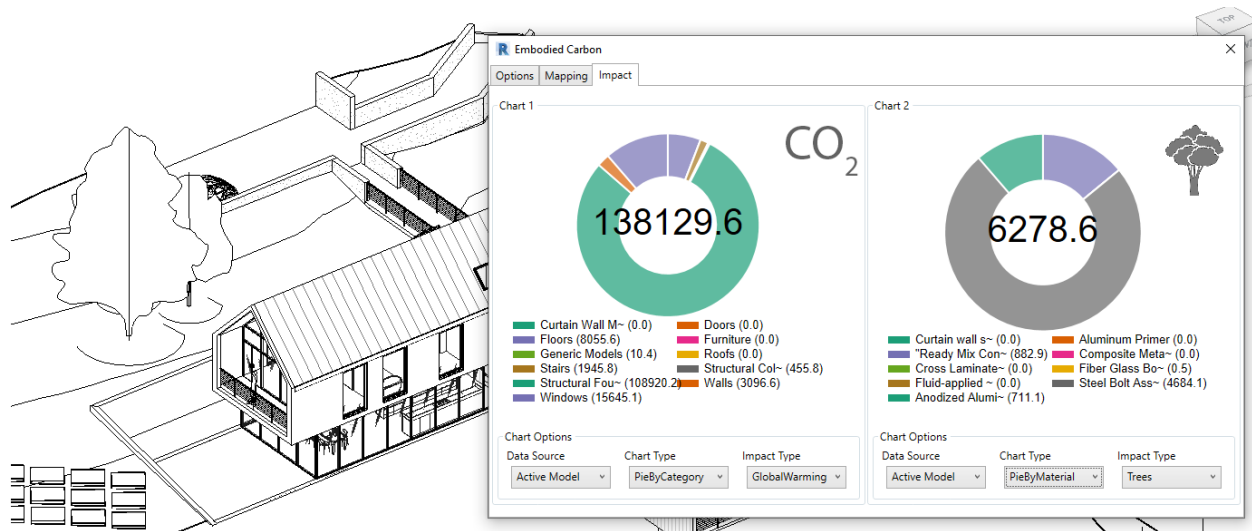


Figure 10: Tool 2 - Dynamic visualizations and real-time comparisons to other metrics (trees)

Embodied Carbon of Common Materials (Resource)

The Carbon Smart Materials Palette is one of the best initiatives for providing a visual material palette to the architects and designers. It currently lists some high-impact materials and carbon smart materials which can be clicked for more information and detailed comparison.

Other publicly available data are also good to get an initial idea on these material types and their impacts but most of them do not provide a visual palette ready for designers.

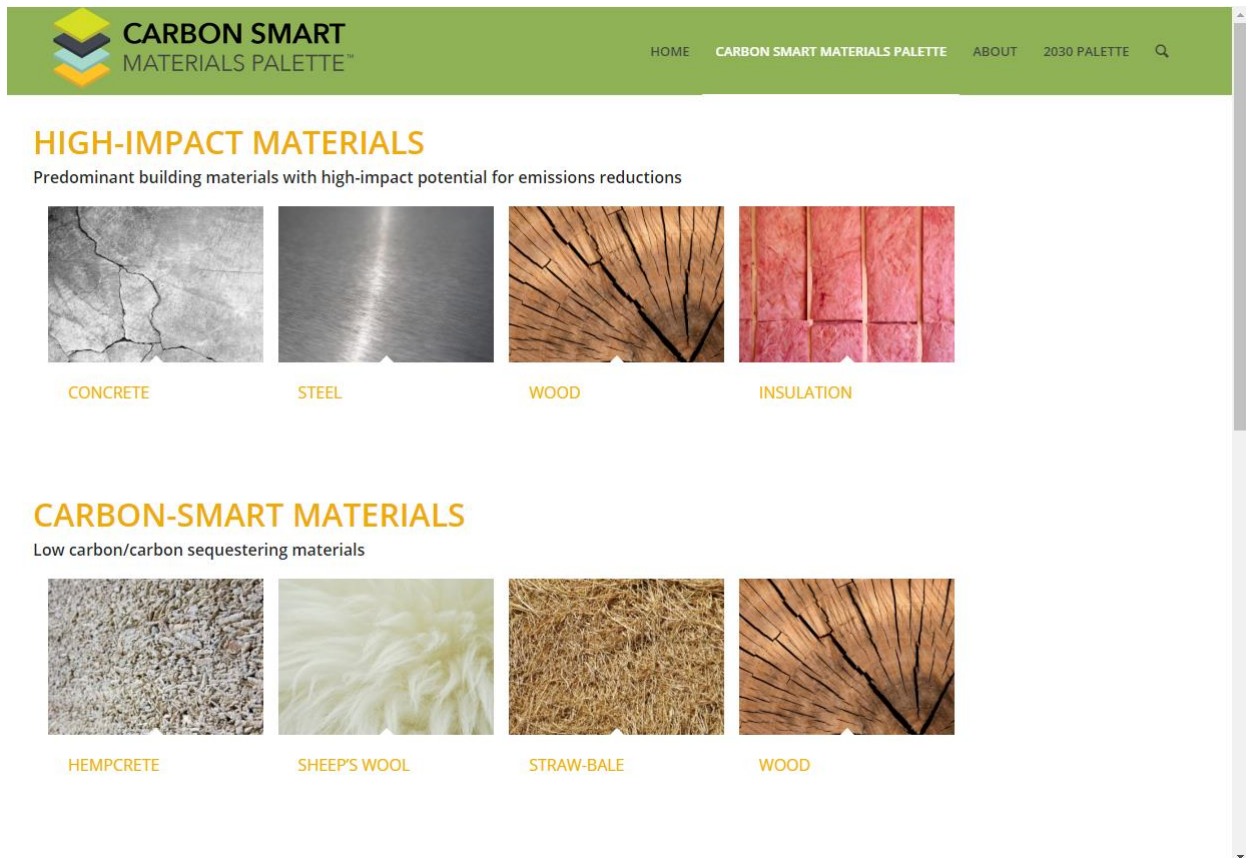


Figure 11: Source: <https://materialspalette.org/palette/>

Future Work

This talk is intended to provoke a conversation to shift the mindset around Embodied Carbon calculations and empower firms and stakeholders to integrate simple, but visually powerful, real-world embodied carbon comparison feedbacks in early stages of design.

Potential expansions of this work may benefit in these directions:

- Automated energy use intensity to operational carbon conversion and integrating within early stage design as a visual feedback to the designer alongside the EUI number.
- Connecting multiple open-source databases into the Dynamo/ excel or Revit API interfaces to provide a robust range of materials and to narrow down uncertainty.
- Using Autodesk Forge to create more efficient cloud-based tools