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Via Chicago × Square Roots
Embodied Carbon Calculator
Calculation Methodology, Limitations of Analysis, & Discussion
6 January 2023

Introduction

A 2021 study by Watershed estimates that construction activity accounts for 47% of Square Roots' net corporate carbon emissions. This number represents both a dramatic total, and a clear area for improvement during Square Root's current stage of growth. With a target of reducing construction emissions by 50% on a per farm basis by 2030, Square Roots has tasked Via Chicago with leading the effort to quantify the embodied carbon footprint of each existing farm building and identify actionable strategies for improvement of future farms.

Several carbon calculator tools exist on the market today, with varying degrees of rigor and accuracy.[1] However in order to provide the most accurate embodied carbon data for Square Roots, Via Chicago has found it necessary to develop our own internal program for tabulating embodied carbon in construction. This allows us to produce detailed breakdowns that are closely tailored to the building materials used in a typical farm building, rather than seeing this information get lost in a larger, more-generic program.

The **VC × SQR Embodied Carbon Calculator** applies the reported embodied carbon emissions of different building elements to the overall material quantities tabulated by BIM software to calculate the embodied carbon footprint of the primary building systems (i.e. concrete, steel, wall systems, etc.). The VC × SQR Calculator is focused on these high-impact areas with the goal of accurately quantifying – and clearly summarizing – the carbon footprint of each material or system. This accompanying document outlines our methodology used to arrive at these embodied carbon estimates, the inherent limitations of such an analysis, and key takeaways for Square Roots after our preliminary review.

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[1] EC3 (Embodied Carbon in Construction Calculator) is an open-source Revit plug-in for quantifying embodied carbon in a building. It sources EPDs from a shared central database, however in our experience it can be a somewhat cumbersome tool and not well-suited to the very specific materials a SQR farm is built with. ECOM (Embodied Carbon Order of Magnitude) is a user-friendly carbon calculator provided by SE2050 — a carbon-reduction initiative of the SEI (Structural Engineering Institute.) ECOM does not allow users to save a project for ongoing reference, but it does offer a compelling template for how to present complex information in a clear, graphic format. Tally is a high-end Revit plug-in for embodied carbon measurements and in-depth life cycle analysis (LCA) of a proposed building design. It could become a useful tool in the near future as we compare alternate designs, but carries a high annual cost and likely goes beyond the needs of our immediate analysis.

Calculation Methodology

Embodied carbon is measured using an architectural BIM model – an accurate 3D model of the farm building and structural frame that we create during the design process – paired with manufacturer documentation of the carbon footprint associated with each building material used. Those two datasets are merged in a custom-built Excel file where we process the information and generate an easy-to-read summary of the building's embodied carbon footprint broken down material-by-material. This process allows us to compare the embodied carbon of different SQR farm models (v3, v4, v5) within a consistent framework.

1. **Building Design Data — Revit**

   Information about the quantity of building materials[2] used in a SQR farm comes from Revit – a powerful building information modeling (BIM) software used by the building design and construction industry. By modeling a farm to dimensional accuracy, quantities of the primary building components can be quickly tabulated throughout the design process. Revit requires significant front-end effort and careful accuracy, but the extra effort eventually pays off when we harvest a wide range of data from the final building model.

2. **Embodied Carbon Data — EPDs**

   The amount of embodied carbon per stated building material unit comes from a growing number of Environmental Product Declarations (EPDs). This standardized document is provided by individual manufacturers and industry trade associations and requires independent, third-party review before publication in order to be recognized as reputable. EPDs contain a Global Warming Potential (GWP) value, which is the quantity of embodied carbon per stated unit of material (measured in "CO2e", or *CO2-equivalent*). Taken together, EPDs and GWP allow us to compare "apples to oranges" – or in our case, "the global warming impact of a steel joist versus a sheet of plywood" with a good degree of accuracy.

   EPDs state the amount of embodied carbon produced in each Life Cycle Analysis (LCA) Stage, as outlined in the graphic below. Many EPDs only account for the amount of embodied carbon in the Product Stage (A1-A3), as product manufacturers cannot guarantee the use of their product once purchased by an end user. For consistency, the VC × SQR Calculator only includes embodied carbon found in the Product Stage, even if an EPD provides data on other stages. Therefore whenever "embodied carbon" is cited in this analysis, it refers only to the embodied carbon from manufacturing up to purchase which is a common boundary for this type of initial analysis.

[2] Materials are tabulated using Revit's *Quantity Schedule* tool.

Life Cycle Analysis
System Boundary Modules

Product Stage			Construction Process Stage		Use Stage					End of Life Stage				Benefits & Loads Beyond the System Boundary
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Raw Material Supply	Transport	Man ufacturing	Transport from Gate to Site	Assembly / Install	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport	Waste Processing	Disposal	Reuse, Recovery, Recycling Potential
					B6	Building Operational Energy								
					B7	Building Operational Water Use During Product Use								

Whenever possible, the analysis utilizes product-specific EPDs rather than industry-average EPDs. Industry-average EPDs aggregate the EPDs of multiple products either throughout a geographical region (such as the USA) or globally, and are often issued by trade groups when individual EPDs are impractical or not yet available. When neither product-specific EPDs or industry-average EPDs are available, the EPD for the nearest product substitute is used.

For all structural components, industry-average EPDs were provided by the Structural Engineering Institute's web-based ECOM tool[3]. As Square Roots begins to partner with national concrete or steel suppliers capable of providing their own EPDs, the accuracy of GWP values used in the Carbon Calculator will improve.

3. **Data Conversion & Calculations**

The building data and embodied carbon data are combined to calculate the embodied carbon of each individual building component, which is organized by construction subsystems and totaled for the full building. Conversion rates are necessary to apply a GWP figure to each material, depending on whether it is measured in square feet, linear inches, cubic yards, kilograms, etc. These calculations are performed in the spreadsheet itself, and are cited on the "Conversion Units" tab for easy reference.

Limitations of Analysis

While the practice of quantifying embodied carbon has been around for a decade or more, practical applications of how to use these findings have only recently been widely adopted and are therefore relatively new. What once required a specialized team of experts, extensive independent research, and a long, costly process is now

[3] Together with the ECOM tool, SE2050 provides a well-cited database of industry-average EPDs for common structural materials such as concrete and steel. These are a useful resource when product-specific EPDs are unavailable.

possible using standard BIM software paired with a growing database of reliable product information. That said, there are limitations to the accuracy of these calculations.

1. **Building Design Data**

    Gathering material quantities from Revit requires diligent building modeling to ensure the carbon calculator's accuracy. This applies to both BIM work created by the architects, as well as any third-party consultants – especially the structural engineer.

    The Carbon Calculator does not calculate the embodied carbon of the entire building; it only tabulates the primary systems determined by Via Chicago and Square Roots. However, it does reflect the vast majority of elements that contribute to the embodied carbon footprint, as extensive industry studies show that other, more minor building elements do not significantly contribute to the overall total. Revit tabulates the quantity of primary material used in the final building and does not take into account any complimentary building components required for installation (e.g. fasteners) or waste generated during construction. As models develop in detail to more accurately represent constructed farms, the accuracy of the carbon calculator will simultaneously increase.

    Site work is a significant part of each new SQR farm. Parking areas, driveways, sidewalks, and loading docks consume a large amount of concrete and asphalt paving. We are currently not accounting for this work when calculating the embodied carbon of the building, because the degree of site work varies considerably between locations and this information is not typically included in the BIM design model.

2. **Embodied Carbon Data — EPDs**

    While the “top line” results of EPDs are not calculated with 100% consistency between material suppliers, they are accompanied by transparent calculation documentation that allows designers to judge the accuracy of the document. Their use is frequently cited as the most objective way to compare products and select low-carbon materials.

    Some experts dispute the accuracy and usefulness of EPDs in calculating embodied carbon, especially when generated by manufacturers and trade associations who stand to benefit from minimizing the GWP of their products. The baseline assumptions (i.e. local power grid, etc.) from which each organization builds its calculations heavily influence the role of embodied carbon contributions. While acknowledging the shortcomings of this documentation, we believe that EPDs currently provide the best baseline tool for estimating the overall embodied carbon of buildings at this time.

3. **Embodied Carbon v. Life Cycle Analysis (LCA)**

    Ideally, embodied carbon emissions would be estimated using a detailed building Life Cycle Analysis. A full LCA is significantly more complicated to perform, as it relies on a variety of inputs from different sources (that do not always align) and involves a wider range of variables due to the uncertainty of how a building will operate over time. The VC × SQR Calculator accounts for LCS stages A1 – A3, which cover the “cradle to mill” stage that is oftentimes responsible for the majority of a building material’s embodied carbon footprint. The Calculator does not account for transport to the building site and installation (stages A4 – A5), performance during the use stage (B1 – B5), or what happens with that material once a building reaches "end of life" (C1 – C4).

Focusing on embodied carbon is a smart first step in the process toward overall corporate sustainability, but eventually, it will become necessary to look at the topic with a wider lens. Although the Use Stage of a building's life cycle oftentimes makes the largest contribution to total emissions out of any LCA phase[4], embodied carbon is projected to account for nearly half of all construction emissions over the next three decades[5]. This raises important questions about both operational energy efficiency and "end of life" considerations – especially if these farm buildings are expected to become obsolete in less than 50 years.

Discussion

While there is plenty of room for future improvement, the VC × SQR Carbon Calculator provides a detailed breakdown of the embodied carbon in construction for the SQR farm buildings. It is far more accurate than a weight-based or cost-based approach, which is how many companies choose to measure the carbon footprint of their buildings. Having a consistent framework will allow for direct comparison of different farms, and allow SQR to track improvement over time using standard metrics.

High carbon footprint of structural materials. Our initial analysis highlights several areas where design improvements or careful material specification can have a large impact. The modified shipping containers should be one of our first targets for improvement, as these calculations confirm our internal suspicion that the physically heavy containers also carry a heavy carbon footprint. By reducing the amount of steel used in the framing – and choosing a more environmentally responsible alternative to foam insulation – we can dramatically reduce the carbon footprint of 50% of the building. Concrete presents another opportunity, and one that the construction team has already begun to explore. If the grow zones become a slab-on-grade room with a sealed concrete floor this will only increase in importance. Insulated metal panels offer a third avenue for improvement, mainly thru informed material selection and partnering with the most responsible suppliers.

Accounting for miscellaneous building systems and SQR equipment. Our current analysis does not account for the embodied carbon from minor building components such as plumbing fixtures, electrical conduit, PVC piping, etc. We're exploring ways to account for these elements in the overall embodied carbon calculation, although industry research suggests these compose a relatively minor portion of the overall embodied carbon footprint. Similarly, we'll work alongside with the SQR hardware team to determine a strategy for quantifying major pieces of own-provided equipment (such as aluminum grow racks).

Improving reliability of EPDs. As a growing market for sustainable products compels more building material manufacturers to issue their own product-specific EPDs, the accuracy of the VC × SQR Calculator will continue to improve. This increased accuracy can be applied retroactively to the embodied carbon calculations of prior farm versions as well, so Square Roots' understanding of its progress toward reducing carbon emissions will constantly

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[4] As cited in MIT's Department of Civil and Environmental Engineering's "Methods, Impacts, and Opportunities in the Concrete Building Life Cycle" research report R11-01, section "2.2.1 LCA of Buildings."
[5] As reported by BuildingTransparency.org's MaterialsCAN program.

improve. We will also continue to evaluate our broader carbon calculation strategy, as new methods and tools for embodied carbon calculation gain traction in the construction industry.

Establishment of SQR metrics. Both in tracking progress and setting goals of reducing embodied carbon emissions, Via Chicago recommends evaluating farms on an apples-to-apples basis. This is harder than it sounds. Comparing the “Total Embodied Carbon” between farm versions may not provide a useful understanding of progress if the scale of those farms greatly differs (10 grow zones compared to 24, for example). The efficiency of each SQR farm continues to improve at a dramatic pace – comparing the carbon intensity (CO_2e per square foot) of a v3 farm to a v4 farm is somewhat misleading if both buildings include the same square footage but one grows 50% more food. (Put another way, “we just built 1.5 farms in the space of 1 farm.”) Square Roots may consider converting that “Total Embodied Carbon” value of a farm into an “embodied carbon per annual pound of yield” (or a more generic approximation of this approach) so that changes in scale, efficiency, and technology don’t distort understanding of reduced carbon efforts.

Long-term potential for the elimination of a building shell. Although the VC × SQR Carbon Calculator provides a detailed analysis of how the embodied carbon of various building systems compares on the margin, it also provides a much broader perspective on overall building strategy. The most drastic reductions in embodied carbon would come not from improved concrete mixes or insulation specifications, but rather from the elimination of those systems altogether – for instance, through the adaptive reuse of existing structures when building out new farm facilities.

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