In Practice: Operationalizing Life Cycle Assessment for Design Teams

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In the context of ongoing anthropogenic climate change, the building sector bears a significant responsibility to curtail greenhouse gas emissions. To quantify and reduce their environmental impact, building industry professionals are rapidly adopting life cycle assessment (LCA) tools. However, before LCA is adopted in practice as a routine part of the design process, three gaps must be addressed – the knowledge gap of understanding upstream emissions from other economic sectors, the communication gap of effectively conveying LCA study results, and the method gap of matching LCA tools to design team needs. This paper presents a meta-analysis of forty-nine recent LCA studies completed by the Miller Hull Partnership in pursuit of carbon-sequestering design, and describes lessons learned in traversing the knowledge, communication, and method gaps in order to embed LCA in the design process. Our experience demonstrates three possible strategies – the knowledge gap can be closed when practitioners engage with professionals in adjacent sectors in interdisciplinary research; the communication gap can be closed when design teams leverage replicable data collection and visualization tools; and the method gap can be addressed by deliberately framing LCA studies as iterative hotspot analyses rather than retroactive, static performance studies.

INTRODUCTION

Scientist-led organizations such as the International Panel on Climate Change and the United Nations Environment Programme have warned the world of environmental and socioeconomic damage caused by climate change since 1988 (“Climate Change 2014: Synthesis Report” 2015; USGCRP 2017). Thirty years later, members of the IPCC and UNEP have come to a consensus that this damage will become irreversible if average global temperatures increase by 1.5°C above pre-industrial levels (Intergovernmental Panel on Climate Change 2018). This can be averted if annual global greenhouse gas emissions are halved by 2030; however, the global building industry is currently not on track to do its part to meet this goal (United Nations Environment Programme 2019; Global Alliance for Buildings and Construction et al. 2019).

To quantify and curtail buildings’ contribution to global greenhouse gas emissions (39% as of 2019), professionals in the architecture, engineering and construction (AEC) industry can employ whole building life cycle assessment (WBLCA) (Global Alliance for Buildings and Construction et al. 2019). Originally developed for the evaluation of environmental impacts incurred in the lifespan of consumer products, life cycle assessment (LCA) methods have been adopted and standardized for use in the AEC sector to quantify environmental impacts of buildings (EN 15978 - Sustainability of Construction Works. Assessment of Environmental Performance of Buildings. 2011, 2011; ISO 14040 Environmental Management. Life Cycle Assessment. Principles and Framework 2006, 2006; ISO 14044 Environmental Management — Life Cycle Assessment — Requirements and Guidelines 2006, 2006). Although WBLCA can be used to quantify many environmental impacts, the primary focus of this paper is on global warming potential impact category (GWP), also commonly referred to as embodied carbon (Kathrina Simonen 2014).

> In the context of a design project, WBLCA is a versatile tool that can help design teams make informed decisions, document progress towards green building certification, and communicate benefits of new products or construction methods to climate-concerned stakeholders (The Carbon Leadership Forum 2019). WBLCA is recognized and rewarded by multiple green building certification bodies, including LEED, the Living Building Challenge, BREEAM, DGNB, and HQE among others (Bruce-Hyrkäs, Pasanen, and Castro 2018). Established and emerging software tools have recently been developed to ease the implementation of WBLCA, such as Tally for Revit, OneClick LCA, Embodied Carbon in Construction Calculator (EC3), and the Athena Impact Estimator). Continual integration of LCA software with building-information modeling (BIM) software represents a promising direction for adoption of WBLCA; this symbiosis leverages the capacity of BIM to quickly generate material quantity takeoffs for LCA while the design of the building is mutable (Roberts, Allen, and Coley 2020).

Despite its documented versatility and benefits, WBLCA is not yet a ubiquitous process for many architectural firms; a recent survey of 414 AEC practitioners in the EU has found that despite consensus on the importance of LCA, only 27% of respondents use LCA software in practice (Jusselme, Rey, and Andersen 2020). Survey and interview results reveal that common barriers to adoption of WBLCA in the AEC industry include time, cost, lack of regional data availability, lack of harmonization between various certification schemes' LCA requirements, and difficulty in reconciling the timelines of LCA with those of design (Jusselme, Rey, and Andersen 2018; Olinzock et al. 2015; Schlanbusch et al. 2016). One often-cited obstacle is the inherent information mismatch between traditional LCA studies that are conducted retroactively when information about building materials is comprehensive, and the sequence of design; LCA-informed decisions have the potential to be the most impactful during early design, when material quantities and selections are in the greatest state of flux, which complicates the construction of an accurate LCA model.

The Miller Hull Partnership is a mid-size architectural firm with two studios in Seattle, Washington and San Diego, California. Over the course of a year, designers in the firm began to use the Revit plug-in Tally to quantify the global warming potential impact of current and past projects, raising embodied carbon literacy in the pursuit of climate-conscious design. The purpose of this paper is to present a meta-analysis of forty-nine WBLCA studies recently completed by the Miller Hull Partnership to illustrate perceived barriers to adoption of WBLCA in routine practice. To date, the forty-nine buildings which have been analyzed represent a wide range of renovation and new construction work, from office buildings exceeding 500,000 gross square feet of occupiable space to residential cabins just over 1,000 gross square feet in area. Due to the wide variability of these buildings and the scopes of study, the purpose of this paper is not to draw comparative assertions about their performance in terms of GWP, but to document three perceived gaps in the adoption of WBLCA and the proposed solutions in hopes to aid future development of WBLCA software in gathering information for user-centered design (Jusselme, Rey, and Andersen 2020).

The three identified gaps that hinder wide-spread adoption of WBLCA form the structure of the paper, and are:

- The knowledge gap – WBLCA can fall short in describing the environmental impacts of products that are involved in the biogenic carbon cycle; this section discusses the combination of wood-sourcing simulation with early design stage WBLCA studies to quantify the case for sustainably-harvested wood.

- The communication gap – previously identified in user studies, WBLCA results can be difficult to interpret for design teams; this section describes the development of a replicable data visualization process using Tableau to build an internal database of WBLCA studies and aid design teams in data interpretation (Basbagill, Flager, and Lepech 2017).

- The method gap – WBLCA studies suffer from a high degree of uncertainty due to model complexity and lack of regionally-available life cycle inventory data for many building products; this section discusses the adoption of LCA at multiple levels of detail that are appropriate to different design stages, illustrated with two case studies.

Addressing these three identified gaps is the first step towards necessary progress needed to make WBLCA in design useful and ubiquitous.

KNOWLEDGE GAP

WBLCA has proven a powerful tool for architects to deliver on commitments to curb greenhouse gas emissions through climate-conscious material selection and procurement. During design, WBLCA provides project teams with another data point to understand building materials holistically, beyond structural, acoustical, and thermal performance. With the onset of recent structural innovations in mass timber design, architects have become increasingly enthusiastic about the ability of wood to sequester and store carbon over time – suggesting that timber buildings have the potential to be net-carbon sequestering rather than net-emitting over their lifespan (Harte 2017). One potential benefit of designing with wood at a large scale is the promotion of continuous carbon sequestration in the wood building product market, which can occur through incentivizing sustainable forestry practices, although this benefit is not guaranteed when business as usual (BAU) forestry is practiced.

The influence of forestry practices on the lifecycle impact of wood building materials is one example of a "knowledge gap" that can arise due to the limits of currently available WBLCA tools for design teams. As a case study illustrating this knowledge gap, the co-authors selected a Miller Hull mass timber project whose client had requested specific quantifiable data comparing the carbon emission differences between Forest Stewardship Council-certified (FSC) timber and BAU-sourced timber. The design team aimed to investigate whether the reduction in purchased carbon offsets for an FSC-certified mass timber structure, as opposed to a BAU-certified mass timber structure, would justify the anticipated cost premium. Unfortunately, forestry practices are not currently incorporated in WBLCA tools such as Tally or EC3, which presented a gap in practitioner knowledge that could only be bridged through interdisciplinary research with forestry experts.

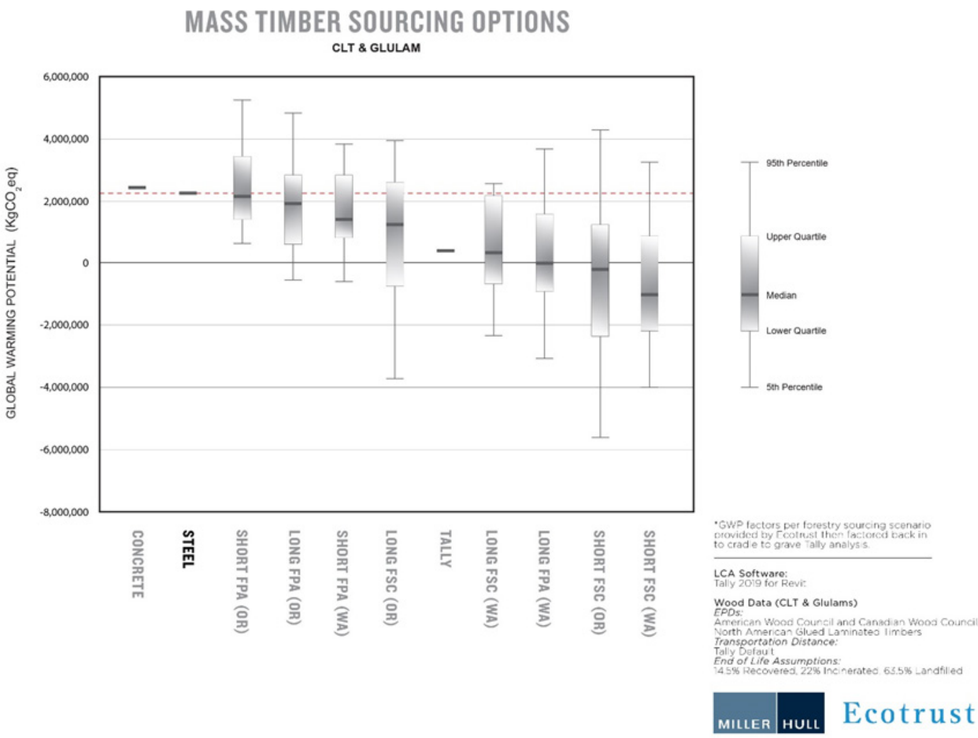


Figure 1: Comparison of alternative structural systems for an office building design, applying factors to reflect varying forestry management scenarios for CLT and glu-lam.

Current WBLCA practice is not scoped to calculate upstream carbon impacts from forestry management because the governing Product Category Rules (PCRs) for wood products have established a net-zero carbon balance between uptake in the forest and biogenic emissions released during manufacturing (FPInnovations 2011). This is a conservative assumption, which indicates that North American forests have sustained a neutral, if not increasing, carbon stock in recent years (U.S. Department of State 2016; Woodall et al. 2015). In addition, forest management certification systems create regulatory frameworks for climate-smart forestry that are formally adopted by 13% of U.S. forests – not accounting for the 290 million acres of family-owned forests who manage their land for purposes other than timber production, including wildlife habitat, land conservation, beauty, and financial investment (Butler et al. 2016; Alvarez n.d.) Although certification systems do not currently require owner-supplied data summarizing greenhouse gas emissions throughout a wood product's lifecycle, it can be hypothesized that certified, climate-smart forestry practices could deliver an embodied carbon benefit for the final wood product, and may outperform the carbon-neutral assumption in wood PCRs.

To bridge this practitioner knowledge gap regarding life cycle embodied carbon impacts of wood products dependent on variable forestry practices, the project design team collaborated with Ecotrust, a nonprofit organization with a background in sustainable forestry practices. Recent work from David Diaz at Ecotrust aimed to analyze the life cycle impacts of two forestry management constraints in the Pacific Northwest: State Forest Practices Act (FPA) and Forest Stewardship Council (FSC), and two forestry management scenarios: max sustained timber yield (long rotation) and max net present value (short rotation) (Diaz et al. 2018). A total of eight management scenarios were simulated using a remote sensing dataset of 67 properties in Washington and Oregon state.

The design team collaborated with Diaz to apply embodied carbon factors derived from these scenarios to the project WBLCA, specifically to investigate the possible variability in embodied carbon sequestered by cross laminated (CLT) and glue laminated timber products. Using lifecycle global warming potential (GWP) impacts generated by the Revit plug-in Tally to evaluate WBLCA impacts of the structural design, default GWP impacts for wood products were augmented with newly-applied factors provided by Diaz. The resulting box and whisker chart in figure 1 illustrates the scale of possible GWP variability for the design of the load-bearing structure, assuming different management scenarios for all wood in CLT and glue-laminated products, with the exception of the Tally default baseline scenario which represents the carbon-neutral forestry assumption in current LCA practice. The delta between each management scenario and the Tally baseline scenario supports the idea that most forestry practices do not operate in a state of carbon balance, and in fact have a significant impact on the resulting WBLCA.

While the study results helped to close this practitioner knowledge gap despite data limitations (management scenarios are informed by forestry practices across 67 properties in Washington and Oregon only), it is important to note that the intent was not to quantitively rank management scenarios

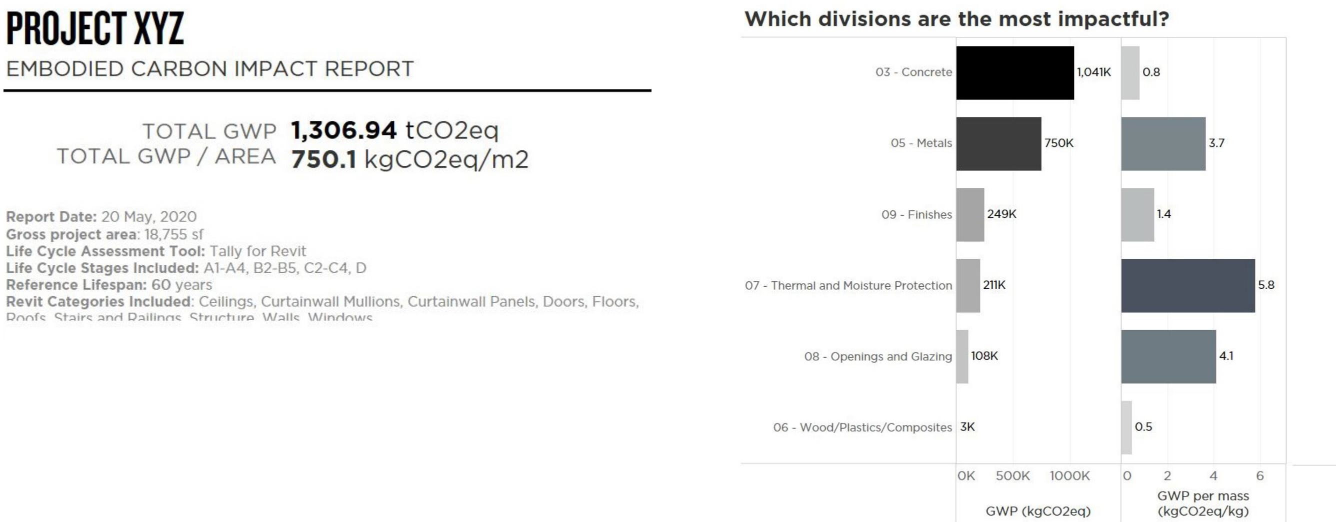


Figure 2 (above and opposite): Sample project-level dashboard to describe embodied carbon impacts, generated using Tally for Revit and Tableau Desktop.

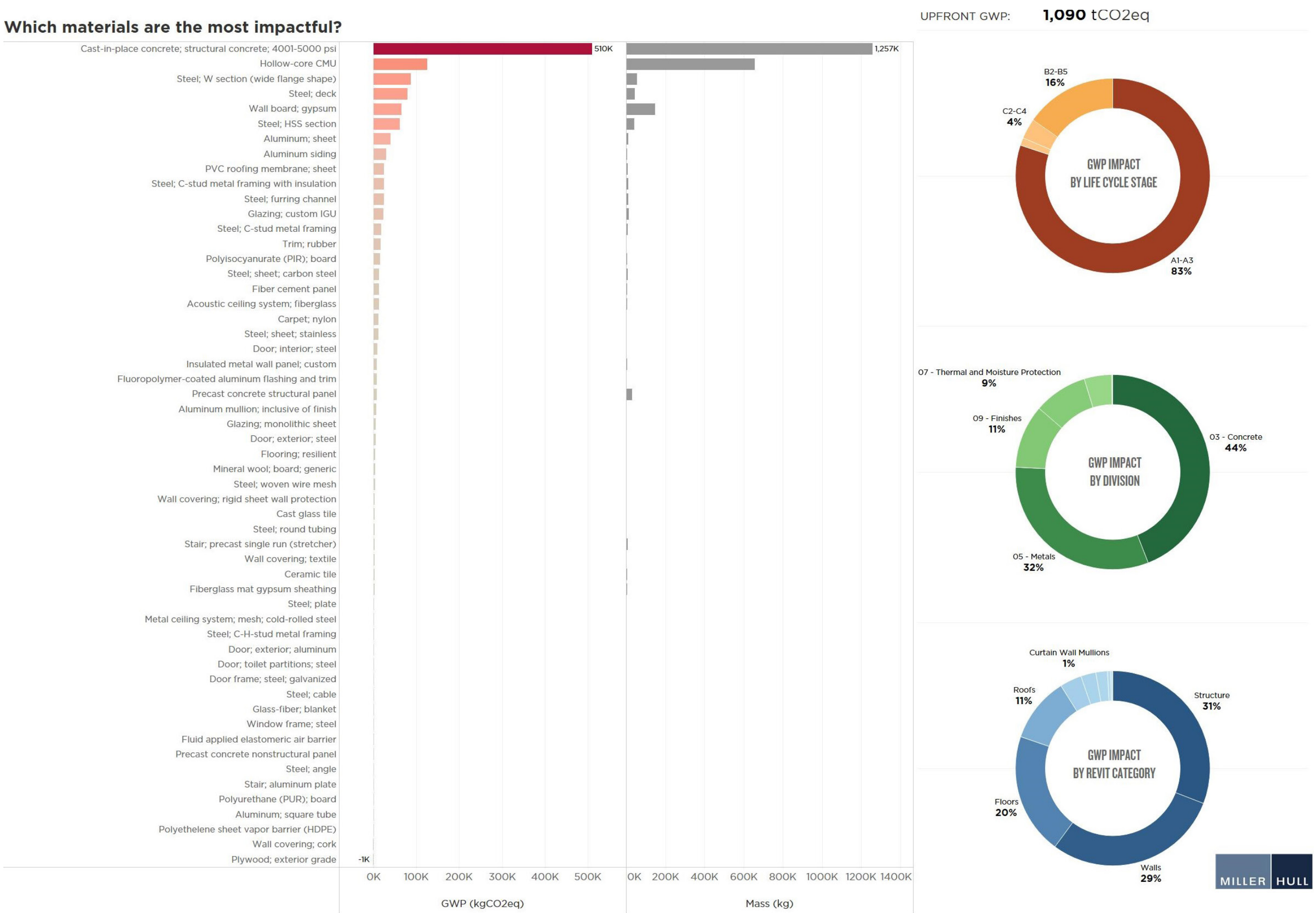
based on GWP. Instead, the intent of this study was to demonstrate the sensitivity of WBLCA results to upstream forestry practices. In the context of a meta-analysis of building designers' adoption of WBLCA, this case study illustrates the current limitation of WBLCA in addressing biogenic carbon, which may be seen as a barrier by design teams and require interdisciplinary collaboration with professionals upstream in the building material supply chain.

COMMUNICATION GAP

Through the process of running WBLCA studies, the co-authors found that it is crucial to establish a replicable data visualization process to ensure that project teams are encouraged to use WBLCA at critical points in design, extract actionable data from study results, and allow it to inform their decision making. To date, communicating LCA results within the AEC industry both at the building and component level has not been standardized. WBLCA results performed by the Carbon Leadership Forum with the use of Athena Impact Estimator take the form of written reports with appendices to document assumptions and takeoffs (The Carbon Leadership Forum and The Center for International Trade in Forest Products 2020); reports obtained from the Revit-plug in Tally have a standard set of normalized bar charts to describe the allocation of various impacts to life cycle stages, CSI divisions, and building elements; and results from the Embodied Carbon in Construction Calculator (EC3) are entirely in-browser, with a set of key Sankey and box and whisker diagrams to aid users in interpreting the GWP impacts of selected materials as well as their relative burden within the building project. Having used Tally to quantify embodied carbon impacts of projects currently in design, the co-authors have identified the following issues with existing means of communicating LCA study results: (1) lack of standardization across WBLCA tools that is a barrier to using multiple WBLCA methodologies, (2) information density that can discourage team members from interpreting results during the design process rather than retroactively due to perceived complexity, and (3) lack of contextual benchmarks to aid interpretation. These identified barriers are corroborated by the experience of other practitioners surveyed on the usability of LCA tools in the AEC industry (Jusselme, Rey, and Andersen 2020).

In order for WBLCA tools to become proactive (used during design to inform decision-making and reduce embodied carbon expenditures) rather than retroactive (used post-design to document compliance with the original intent), WBLCA communication methods need to accommodate the rhythm of design.

The co-authors developed a replicable workflow using Excel outputs from Tally, Tableau Prep and Desktop to consistently interpret WBLCA results and present project teams with an embodied carbon report which prioritizes data visualization. First, members of the design team use Tally to make material assignments and calculate material takeoffs in the Revit environment. Excel results from the WBLCA study are compiled with those from previous WBLCA studies using Tableau Prep; this allows those who are unfamiliar with WBLCA benchmarks to contextualize their results within the firm portfolio, beyond comparison to established benchmarks such as the Embodied Carbon Benchmark Study and the Database of Embodied Quantity outputs (K. Simonen et al. 2017; MIT Building Technology Program n.d.). Tableau Desktop is used to visualize key metrics for embodied carbon reduction – GWP of each project segmented and ranked by division to support the writing of performance specs, GWP of each project segmented and ranked by Tally material definition to identify "hotspots" within the design that would be the most consequential if altered, and a series of three pie charts that document the allocation of emitted GWP across life cycle stages, divisions and



Revit categories (fig. 2). In the development of this dashboard template, the team became aware that each visualization has a duplicate purpose – to communicate study results, and to act as a gateway to quality assurance of the model. In particular, communicating material quantities via a mass histogram alongside the GWP impact histogram helped project teams identify modeling mistakes early.

METHOD GAP

When rolling out a firm-wide process for embodied carbon analysis in design, logistics such as staffing and periodic check-ins must be established to ensure portfolio-wide consistency and accuracy. The WBLCA process at Miller Hull has evolved from a single dedicated modeler in Athena to over a dozen project team members running Tally at different stages in design. The evolution of this process has confirmed that disseminating expertise to project teams creates accountability and leadership that often leads to increased adoption of embodied carbon reduction strategies.

In addition to upskilling staff, it is important to develop a framework that prescribes unique purpose to LCA at different stages in design. Some projects require a retroactive WBLCA during the construction administration phase to document reductions, while others may require early systems comparison in schematic design – in both cases, it is important to communicate expectations and guidelines for how WBLCA can adapt to best serve each project stage. Once staffing and WBLCA goals have been established, it is imperative to communicate that missing and uncertain data is inherent in current practice. WBLCA software users can unintentionally underestimate the sensitivity of study results to material substitutions or simple modeling errors.

Previously, in a typical project timeline, only one WBLCA study was developed to document reduction targets retroactively. However, this approach does not allow for effective quality control and may result in baked-in modeling errors. An effective WBLCA process must include room for iterative analysis to allow users to critically interpret their results with the design team (in accordance to the interpretation step of an LCA study documented in ISO 14040) (ISO 14040 Environmental Management. Life Cycle Assessment. Principles and Framework 2006). The WBLCA method gap which acts as a barrier to wide-spread adoption of WBLCA tools during design can be addressed through the cultivation of this iterative process that can accommodate multiple study purposes at different times throughout the design schedule. The following

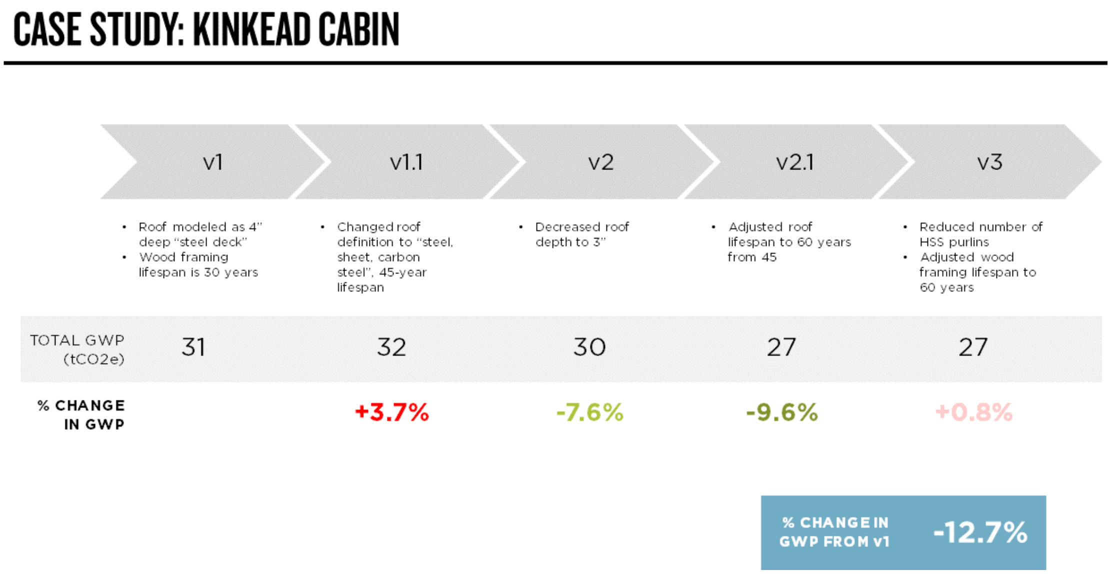


Figure 3: Diagram of the multiple WBLCA studies that informed case study 2 during design, quantifying change in total GWP after each design and Tally model adjustment.

section describes two case study projects that used this iterative process to operationalize LCA during design.

CASE STUDY 1

The first project to adopt the full LCA workflow in design was a 100,000 square foot, steel framed building on the University of Washington campus. Due to the project delivery method (progressive design build), timely implementation of LCA was critical to ensuring reduction strategies were incorporated into the design. During the schematic design phase, a comparative analysis of three alternative structural systems was developed to support the team in their pursuit of a sustainably-sourced CLT structure. The comparison study quantified a significant embodied carbon reduction in the hybrid CLT structure option compared to a full steel and concrete structure, and supported the team's decision to secure CLT from a local supplier. During the design development phase, a cladding comparative analysis was run to assist the team in selecting the most cost and carbon efficient system. Ultimately, the team selected an aluminum siding system which resulted in a 23% GWP reduction and significant cost savings over the alternate panelized fiber cement system. Due to the aluminum system's high recycled content and reduced assembly weight, the cost and carbon goals for this study aligned and made for a simple pitch back to the owner and contractor. Finally, during the construction documents phase, the team ran a WBLCA study as part of the firm-wide effort to create an internal embodied carbon benchmarking database, but was also used as a hotspot analysis for optimization opportunities in writing project specifications for material procurement. The timely implementation of these three types of LCA studies made it possible for the project team to make informed decisions about carbon at different resolutions in design.

CASE STUDY 2

The second case study WBLCA process was conducted in the spring of 2020 on a steel-frame residential cabin approximately 1,500 square feet in size. At the time of the first Tally WBLCA study, the project was in the schematic design phase. Initial study results indicated a high GWP contribution from the steel deck material assigned to the roof membrane and steel HSS members used as purlins; subsequent revisions to the Tally model and rapid follow-up allowed the team to reduce the overall GWP impact of the project by 13% through a combination of model and design changes. First, the definition of the roof membrane was redefined as a more representative material definition, steel sheet. At this stage, the architect-engineer team made the decision to decrease the depth of the steel sheet roof, which led to a commensurate decrease in the number of HSS purlins; the team also adjusted material lifespan assumptions within the study to match the expected durability of steel sheet and wood framing members inside the wall assemblies. In this case, using WBLCA during schematic design allowed the design team to make a decision that was both cost and carbon-effective. It's important to note that both design changes and altered WBLCA assumptions had a significant role to play in the modeled GWP reduction; this reflects the sensitivity of WBLCA results to both types of model inputs (fig. 3).

From the perspective of WBLCA implementation during design, this process underlined the importance of performing WBLCA early to quantify the embodied carbon impacts of structural design decisions that would have otherwise not been quantified. Using the BIM-integrated WBLCA tool paired with a data visualization flow established using Tableau, the team was able to iterate through multiple versions of the study within the span of one week. Future implementations of this process would benefit from clearer documentation of study scope and an incremental approach to making design changes before result interpretation – conflating design and model assumptions into one study "version" renders it impossible for users to correctly attribute GWP reductions or increases to their cause.

CONCLUSION

After over a year of synthesizing and interpreting data, the co-authors have formulated strategies to overcome three common gaps in current LCA practice; the knowledge gap, the communication gap, and the method gap. These three gaps were approached as learning opportunities for calibrating, testing, and refining resulting datasets that are sensitive to nuanced or missing material data and hidden modeling errors. The solution for overcoming these obstacles has been to remain critical about results – seeking external industry expertise when it is needed, creating a framework for effective result communication, and running iterative studies at different resolutions to inform critical design decisions. As with any developing field of expertise, it is important to disseminate knowledge internally to staff members as well as externally to industry networks. With this collective knowledge, the AEC industry can begin to move the dial on climate-conscious design and advocate for local policy and adjacent sectors to follow suit. Without transformation of the AEC industry to climate-smart design and broad integration of WBLCA within design processes, manufacturers will not be incentivized to provide emissions data and compete on the basis of embodied carbon reductions within the building material market. To conclude, raising the bar on climate-conscious design is a collaborative effort between LCA and AEC professionals, whose collective expertise is needed to deliver accurate and actionable results during building design.

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