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MBUILD

APPLICABILITY OF SIMPLIFIED LIFE CYCLE ASSESSMENT METHODS IN SUPPORTING EARLY-STAGE STRUCTURAL DESIGN DECISIONS

ARNOLD MUYENGA

Supervision: Jens Minnert THM

Co-supervision: Christian Baier THM

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U.PORTO THM TECHNISCHE HOCHSCHULE MITTELHESSEN UC Universidad de Cantabria

MBUILD

ERASMUS MUNDUS JOINT MASTER IN SUSTAINABLE DESIGN, CONSTRUCTION AND MANAGEMENT OF THE BUILT ENVIRONMENT

✉ mbuild@fe.up.pt

🌍 www.mbuild.eu

Edited by

FACULDADE DE ENGENHARIA
DA UNIVERSIDADE DO PORTO

Rua Dr. Roberto Frias
4200-465 Porto
PORTUGAL
☎ +351-22-508-1400
✉ feup@fe.up.pt
🌍 www.fe.up.pt

TECHNISCHE HOCHSCHULE
MITTELHESSEN

Wiesenstraβe 14
D – 35390 Gießen
DEUTCSHLAND
☎ +49-641-309-0
✉ info@thm.de
🌍 www.thm.de

UNIVERSIDAD DE CANTABRIA

Avda. De los Castros, s/n
39005 Santander
ESPAÑA
☎ +34-942-20-10-18
✉ informacion.general@unican.es
🌍 https://web.unican.es

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ABSTRACT

Life Cycle Assessment (LCA) is increasingly being positioned as a tool for guiding early-design decisions before they become costly to reverse, yet conventional LCA somewhat requires sufficient design detail that may not exist sufficiently until a project has reached its construction stage. This thesis investigates whether simplified, BIM-integrated LCA methods can close that gap reliably enough to be relied on at early design stages, using Germany's HOAI Leistungsphasen framework and its ÖKOBAUDAT environmental database as the regulatory and data context for the investigation.

A single case study building, Snowdon Towers, a composite reinforced concrete and steel mixed-use structure, was assessed at two design-resolution stages, corresponding to Leistungsphase 3 and Leistungsphase 2. Using three BIM-integrated screening tools: One Click LCA, Tally, and Carbo Life Calculator. A one-factor-at-a-time sensitivity analysis isolated three candidate sources of deviation from a detailed-design reference dataset: member-sizing assumption, quantity estimation method, and emission-factor dataset granularity.

Results show that geometric simplification produces only modest deviation. Emission-factor dataset choice, by contrast, produced deviation several times larger than either other factor, and explained most of the spread observed across the four tool conditions tested. Two conditions, both drawing on product- or region-specific data, remained within a pre-specified 15 percent applicability threshold; two conditions relying on generic, internationally sourced data exceeded it substantially. A further, isolated test found that substituting manufacturer-specific data for generic data increased, rather than decreased the calculated result and thus complicating the common assumption that generic environmental databases are uniformly conservative relative to product-specific alternatives.

These findings indicate that early-stage LCA applicability is governed primarily by dataset selection as opposed to design-stage data resolution. Simplified methods are shown to be defensible for informing early structural design decisions well before detailed design, provided the dataset under use is verified as appropriate to the project's material and regional context. For German practice specifically, tools connected to ÖKOBAUDAT consistently outperformed generic alternatives, suggesting that the infrastructure needed to support earlier, more reliable assessment already exists within the national certification landscape, even where current guidance does not yet distinguish between dataset-appropriate and generic-default tool configurations.

This thesis contributes a controlled, single-variable comparison across multiple BIM-integrated LCA tools, a tested hypothesis between German design-stage terminology and international Level of Development classifications. The findings are drawn from a single building and material combination and should be extended to other structural typologies before being generalized further.

Keywords: BIM, Life Cycle Assessment, Structural elements, Early-design, ÖKOBAUDAT

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

GHG – Greenhouse Gas Emissions

LCA – Life Cycle Assessment

BIM – Building Information Modelling

HOAI - Honorarordnung für Architekten und Ingenieure

OFAT – One-factor-at-a time

OCL- One Click LCA

CLC – CarboLifeCalculator

1

INTRODUCTION

1.1. BACKGROUND AND MOTIVATION

Global climate commitments and the urgent transition towards a circular economy have fundamentally reshaped building sector priorities, necessitating a shift from qualitative sustainability goals to quantitative environmental metrics. The early integration of environmental assessments remains challenging as the current lack of quantitative data at the design conceptual stage greatly limits the ability to compare alternatives D'Amico & Pomponi (2020). The construction sector dominantly contributes to the global environmental burden with the building industry being responsible for approximately 42 percent of global primary energy use and 39 percent of Greenhouse Gas Emissions (GHG), a scale of impact that has made Life Cycle Assessment (LCA) a central methodology for evaluating and reducing the environmental performance of buildings across their full life cycle (Kumar et al., 2025). The same body of research identifies a mismatch between when LCA is methodologically reliable and when its findings can still meaningfully influence a project. A systematic literature review of 274 papers on LCA in the building design phase of which 108 were subject to detailed analysis, found that LCA is generally applied late in the design process, at a point where it is too late to influence design outcomes in a substantial way (Roberts et al., 2020). These findings are represented across wider literature and form the starting point of this thesis: If LCA is supposed to help people make better early design decisions, but it's only used after those decisions are already fixed, then it's not doing the job it was created to do.

A closely related strand of research has responded to this problem not by abandoning LCA at its early stages but by simplifying it. Basbagill et al. (2013) demonstrated one of the earliest responses to this challenge, introducing a Building Information Modelling (BIM) based LCA method combined with a sensitivity analysis specifically to guide early-stage design decisions, showing that targeting small number of high impact material and component choices early in a project can yield significant reductions in embodied carbon without requiring the full data resolution of a conventional detailed-design LCA. This method exemplifies the premise this thesis investigates which is that a simplified LCA approach deliberately built around the data constraints of early design instead of treating them as a deficiency to be tolerated, may be more useful in practice than a LCA applied too late to matter.

The past decade has seen this simplification agenda expand exponentially. A recent systematic review covering 56 studies on early-stage LCA integration found growing adoption of BIM, artificial intelligence, and parametric modelling as mechanisms for streamlining LCA. This concluded that simplified and computational LCA tools can improve both accessibility and real-time decision-making during early-stage design, all this while noting that data scarcity, lack of standardization and interoperability issues remain persistent barriers to their adoption (Kumar et al., 2025). Another, literature review of BIM-LCA workflows identified more than 50 relevant BIM-LCA case studies in the published literature, underscoring both the volume of methodological development in this space and the continuing absence of consensus on which simplification strategy is appropriate at which design stage (Obrecht et al., 2020). This literature establishes that simplified LCA methods exist and are widely argued to be beneficial but it does not establish with precision how applicable these methods actually are once real design stage

data constraints are imposed nor how their accuracy changes as a design moves from concept toward completion.

1.2. PROBLEM STATEMENT

This gap can be stated as an applicability problem rather than a methodological one. It is well established in the literature that simplified LCA methods can, in principle, be constructed to function with limited early-design data (Basbagill et al., 2013), (Kumar et al., 2025). It is less well established how reliably such methods perform when applied to structural components specifically, using the data realistically available, standardized points in a real design process. Reviews of the field have also observed that the appropriate level of simplification is itself stage-dependent: screening-level LCA is generally considered suited to the pre-design or conceptual phase, while more detailed simplified methods become appropriate only once a design has progressed further, with Level of Development (LOD) commonly used as a proxy for this transition LOD 305 TO 350 is identified as the point at which more precise, material-based impact assessment becomes possible, while LOD 400 and above is associated with the resolution needed for procurement and certification purposes (Kumar et al., 2025).

This creates a specific testable problem, without a clear and quantified account of how simplified LCA accuracy changes across defined design stages for structural components specifically, practitioners and researchers have no reliable basis for deciding which simplified method, if any, is defensible at which point in a project and organizations risk either applying methods too crude to be trusted or withholding LCA entirely until a stage at which per Roberts, Allen and Coley (2022), it can no longer meaningfully affect the design. Structural components are an important test case for this problem because the choice of structural system and grid decisions made very early in design has a reasonable and irreversible influence on a building's total embodied carbon, meaning if simplified LCA cannot be made applicable at this stage for structural elements, its value elsewhere in the building is also diminished.

Germany offers a well-suited empirical setting in which to test this applicability question. Its construction sector operates under a standardized, legally defined sequence of design service phases (the HOAI Leistungsphasen), a mandatory federal environmental dataset (OKOBAUDAT), and a certification landscape (BNB, DGNB, QNG) that already requires LCA reporting, meaning the infrastructure to test a simplified method against a realistic detail-design baseline already exists, and any findings on applicability carry direct practical relevance to an active regulatory context.

1.3 RESEARCH QUESTION

By evaluating how these streamlined frameworks navigate the inherent data limitations of the conceptual phase, the research assesses the extent to which they can genuinely influence foundational choices such as structural layout, and material selection (Kanyilmaz et al., 2023a). (Roberts et al., 2022) also concluded that application of screening LCAs reduces the time spend conducting an assessment but at the same time will increase the level of uncertainty.

The research question addressed by this thesis is:

To what extent are simplified Life Cycle Assessment methods applicable to supporting early-stage structural design decisions, and how does their accuracy change as a design of a model progresses through successive stages?

This may be addressed through four sub-questions (SQ):

SQ1: What data on structural components is available at successive early design stages, and how does this affect the choice of simplified LCA method that can be applied?

SQ2: How large is the deviation between results produced by a simplified LCA method at any given early stage and a full, detailed design LCA treated as a baseline?

SQ3: Which structural system assumptions, quantity estimation or how specific and detailed the emission factor data contributes most to this deviation?

SQ4: Under what conditions can a simplified LCA method be considered applicable and reliable enough to meaningfully inform.

1.4 SCOPE AND DELIMITATIONS

The objective of this study is to evaluate the practical application of simplified LCA methods specifically within the context of early-stage design of structural models.

Component scope: Only structural components are to be considered for all design stages that is early-stage to detailed-design stage (including structural frames, foundations, columns, beams, slabs, load bearing walls). Envelope, MEP and finishes are excluded.

Method scope: The thesis evaluates simplified LCA methods of the type namely: parametric, single-indicator and BIM-integrated screening approaches instead of proposing an entirely new method. After review and evaluation, a specific method shall be considered for results purposes.

Lifecycle scope: A cradle-to-practical completion (EN 15978 modules A1-A5), consistent within the design phase focus of the research question, though the core case study narrows this further to modules A1-A3 as its primary boundary.

Contextual scope: The German regulatory and data environment (HOAI, OKOBAUDAT) is used as a core application example. However, should be noted that the findings are not assumed to generalize automatically to other national data infrastructures, though the underlying applicability question is treated as internationally relevant.

Design stages assessed: An early conceptual stage, a preliminary design stage and a detailed-design stage, corresponding to the HOAI framework.

1.5 THESIS STRUCTURE OVERVIEW

Chapter 2 reviews the literature on simplified LCA methods for early-stage design, placing this thesis against the applicability gap identified above. Chapter 3 develops the design- stage data availability framework used to structure the core concept and work, grounded in the German HOAI system. Chapter 4 sets out the research design, method selection and analytical approach. Chapter 5 presents the case study and the comparative datasets assembled at each design stage. Chapter 6 reports the resulting accuracy and sensitivity analysis. Chapter 7 discusses the findings against the literature reviewed in Chapter 2 and considers under what conditions simplified LCA methods can be considered applicable. Chapter 8 concludes by answering the research question and finally Chapter 9 sets out recommendations for practice and future research.

2

LITERATURE REVIEW

2.1. LCA FUNDAMENTALS AND THE CASE FOR SIMPLIFICATION

This chapter reviews the body of literature supporting the application of simplified Life Cycle Assessment (LCA) methods to early-stage structural design decisions. It is supported by 35 peer reviewed sources collected for this thesis, all indexed in Scopus and/or ScienceDirect, with publication years spanning from 2013 to 2026. The span of years was considered as such because this is where most relevant information can be identified. The chapter is organized into seven sections,

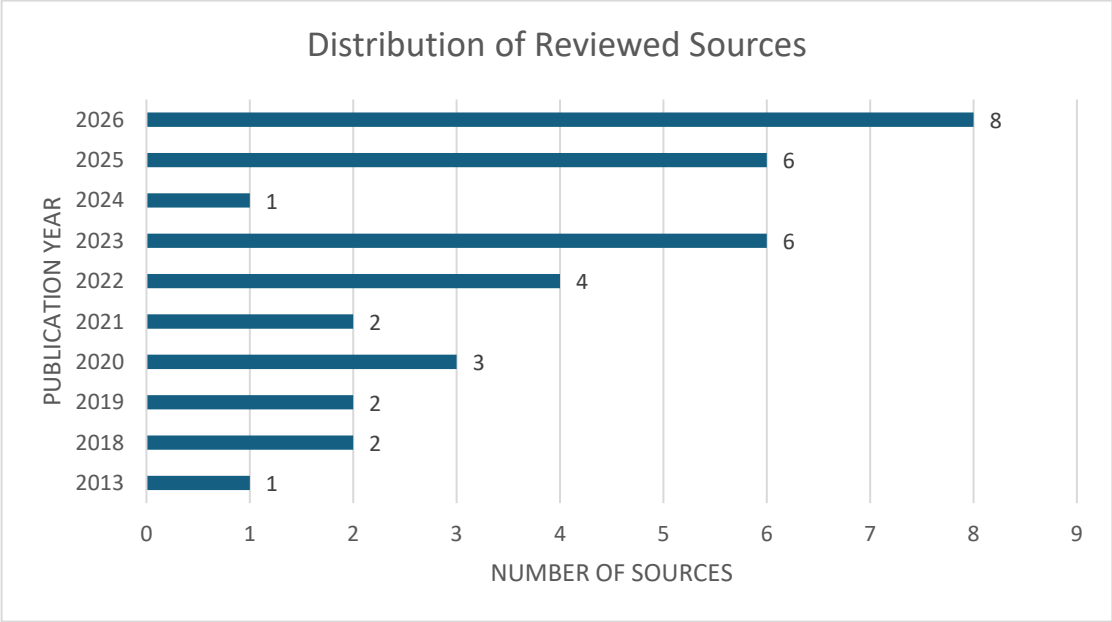


Figure 2.1 Distribution of the 35 reviewed sources by publication year, showing a marked increase in research output on early-stage and simplified LCA methods since 2023.

As figure 2.1 illustrates, more than half of the sources reviewed in this chapter were published in 2023 or later, with eight sources published in 2026 alone at the time of writing. This distribution is itself an evidence-based finding, indicating that simplified early-stage LCA for structural design is a rapidly intensifying research area.

Life Cycle Assessment is standardized internationally through IOS 14040 and ISO 14044 which establish the four-phase structure common to all LCA studies: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation. For construction works specifically, this general framework is further specified by EN 15804 (as amended by EN 15804+A2) which establishes the Product

Category Rules governing Environment Product Declarations for construction products, and by EN 15978, which extends the assessment to the level of the whole building or component assembly.

Roberts et al., 2020 provides a more comprehensive systematic account of how LCA is actually applied within the building design process, reviewing 274 papers of which 108 were subject to detailed analysis. Their central finding was that LCA is generally applied late in the design process once design decisions have already been effectively fixed. Basbagill et al., 2013 responded to these findings seven years earlier, by developing one of the first BIM-based LCA methods that were combined with sensitivity analysis specifically intended to guide early-stage design decisions rather than to report on a finished design. Their approach illustrated that targeting a small number of high impact material and component choices, rather than attempting a fully resolved inventory, could still yield meaningful reductions in embodied carbon and environmental impact, establishing simplification as a design-support strategy.

This case for simplification has since been generalized and extended. (Kumar et al., 2025) in a review covering 56 studies on early-stage LCA integration, found that simplified and computational LCA tools improve both accessibility and real-time-decision-making during early-stage design, while cautioning that data scarcity, lack of standardization, and interoperability issues remain persistent during the said stages and also significant adoption barriers. Their review defines Level of Development as the variable that governs which simplification strategy is appropriate at which point in a project: screening-level methods for pre-design and conceptual stages, more resolved simplified methods once a design has progressed toward LOD 300, and full detailed assessment only once fabrication-level information exists.

2.2 TYPOLOGIES OF SIMPLIFIED LCA METHODS

The literature does not converge on a single simplified LCA method but instead investigates several distinct typologies each trading data requirements against usability and speed in different ways. This section categorizes four typologies identified across the reviewed sources: screening and or minimal-information methods, parametric methods, single-indicator or visualization methods, and decision-support/optimization methods.

2.2.1 Screening And Minimal Information Method

Roberts et al., (2022) presented at the Central Europe towards Sustainable Building conference and published in Acta Polytechnica CTU Proceedings, addressed the question of how LCA can be applied with minimal information to support early-stage material selection. This work is important for this thesis because it treats data minimality not as an unavoidable limitation to be tolerated but as the design constraint the method itself must be built around the same premise underlying the BIM- integrated screening tools (Carbo Life Calculator, Tally, One Click LCA) selected for use in this thesis methodology.

2.2.2 Parametric method

(Röck et al., 2018) developed a parametric approach that visualizes environmental potentials during early design stages within a BIM environment allowing designers to observe the environmental consequence of a design change without re-running a full LCA workflow each time. Ajtayné Károlyfi & Szép, (2023) extended this parametric philosophy specifically to conceptual structural design, proposing a parametric

BIM framework aimed at assessing embodied environmental impact of structural systems at the point where geometry and structural typology are still being explored rather than fixed. (Kim et al., (2025) advanced this further with BIM-IGL, a framework integrating generative design with LCA at the conceptual stage, automating the generation and environmental evaluation of multiple design alternatives rather than assessing a single fixed scheme.

2.2.3 Single-indicator and visualization method

One theme across the parametric literature is the collapsing of multi-indicator LCA output into a single more usable metric or visual signal. As Röck et al., (2018) discussed above, exemplify this by pairing parametric calculation with a visualization layer specifically designed to communicate environmental performance to designers who are not LCA specialists. This single-indicator or visualization-first philosophy recurs in Cavalliere et al., (2019) who developed a method for continuous BIM-based assessment of embodied environmental impacts throughout the design process, allowing impact figures to be revisited and refined as design detail increases rather than calculated once at a fixed point in time.

2.2.4 Decision-support and optimization method

Another typology treats LCA as an input to formal optimization, Kanyilmaz et al., (2023) developed a multi-objective conceptual structural design tool based on the Non-dominated Sorting Genetic Algorithm II (NSGA-II), which generates Pareto-optimal design solutions balancing structural cost against embodied carbon, validated by comparison against three case studies drawn from the literature. Their work demonstrated that rapid exploration of various conceptual design alternatives on a cost-versus-carbon Pareto frontier can reveal more sustainable design options than would be identified through conventional design development. Kamari et al., (2022) took a related but distinct decision-support approach, developing a Sustainability Opportunity Metric (SOM) and associated BIM-based LCA tool built specifically to function under the high input uncertainty characteristic of early design, prioritizing usability and iteration speed over point-estimate precision.

Table 2.1 Typology of simplified LCA methods identified in the reviewed literature

Typology	Core mechanism	Primary trade-off
Screening	Reduced input dataset, coarse material categories are usable	Speed and low data burden vs. resolution
Parametric	Geometry/material variables linked live to impact calculation tool	Requires parametric model and software skills
Single-indicator / visualization	Multi-indicator output collapsed to one score or visual signal	Loses accuracy of individual impact categories
Decision-support / optimization	LCA embedded as an objective function within an optimization or uncertainty-aware tool	Computationally intensive

2.3 EARLY-STAGE LCA LITERATURE ON STRUCTURAL COMPONENTS

Because this thesis is concerned specifically with structural components rather than whole-building assessment, this section reviews the subset of the literature that addresses embodied carbon and LCA at the level of structural systems, frames and individual elements during early design.

2.3.1 The Magnitude Of Early-Decision Impact On Structural Embodied Carbon

Strong evidence as to why early-stage structural decisions matter disproportionately comes from (Dunant et al., (2021). Using a database of real structural designs combined with a generative design model, the abovementioned author shows that for steel structural frames, it is not inefficient member sizing but rather the layout of the structural grid and the choice of decking that have the largest influence on a frame's embodied carbon. Their analysis found that real as-built designs are relatively efficient from a cost perspective but not as such when it comes to the environmental aspect, with their generative model indicating that typical building frames could achieve embodied carbon reductions in the order of 40 to 60 percent, alongside modest cost reductions, through better-informed grid and decking selection alone. This finding is significant for this thesis question: it demonstrates that the design variables with the greatest carbon consequence, grid layout and system, typology are precisely the variables fixed earliest in a project at HOAI Leistungsphase 2 or 3, way before the detailed member level data an LCA would require exists. If a simplified method cannot capture the consequence of grid and system choice at this early stage, it is arguably assessing the wrong variables regardless of its numerical accuracy on member-level quantities.

D'Amico & Pomponi, (2020) provide a complementary, quantitatively rigorous foundation for exactly the kind of typological benchmark estimation this thesis's LP2-stage dataset relies upon. Generating 31,380 parametrically varied structural frame designs across reinforced concrete, steel and engineered timber gravity systems, the authors characterize correlations between structural mass per unit floor area and basic design variables such as bay area, floor load magnitude and structural material, presenting the resulting correlation coefficients in tabular form for direct practical use.

(Kanyilmaz et al., 2023b) reinforce this picture from an optimization perspective, framing sustainable conceptual design decisions as the primary lever for reducing the construction industry's environmental impact precisely because such decisions should be made early, within the given time provided and have the largest cumulative influence on a project's end cost and embodied carbon.

2.3.2 Structural System Comparison And Material Selection At Early Design

Several sources address how structural system choice specifically the early design this thesis's LP2 dataset is built around affects LCA outcomes. Moncaster et al., (2018) caution methodologically that LCA results are sensitive not only to design decisions but to temporal spatial, and physical variations in the assessment method itself, meaning that comparisons of structural system choice can be confounded by inconsistent LCA methodology as much as by genuine design differences, a caution that is relevant to this thesis decision to hold tool and database choice constant wherever possible across its LP2/3/5 comparisons. Morsi et al., (2022) conducted a BIM based LCA comparison of different structural system scenarios for a residential building providing a direct case study structure to this thesis' adopted comparative design, though applied to system-type comparison rather than design stage comparison. Zaker Esteghamati et al., (2022) similarly explored sustainable early design of mid-rise office buildings, the same typology as this thesis's Snowdon Towers derived case study, using comparative LCA results across different structural subsystems, offering a close typological example for this thesis's case study framing.

2.3.3 Optimization Of Individual Structural Elements

At a finer grain, Riez et al., (2025) examines the environmental performance of beams specifically optimizing and comparing different structural typologies at the element level. The element level focus is a useful complement to the frame and system level literature reviewed above, since it demonstrates that embodied carbon optimization opportunities exist at multiple structural scales simultaneously, from overall grid layout down to individual member typology, reinforcing the argument that a simplified early design LCA method needs to be sensitive to structural systems and typology not only to gross material quantity.

2.3.4 Structural LCA In Specialized And Infrastructure Context

A number of sources extend structural LCA into more specialized structural typologies, providing useful methodological cross-validation even when they fall outside this thesis' building-structure scope. (Martínez-Muñoz et al., 2021) conducted a comparative life cycle analysis of concrete and composite bridges under varying steel recycling ratios while a related 2025 study examined carbon emissions from precast versus cast-in-situ concrete railway bridge components using BIM-based LCA. (Li & Bao, 2026) investigated the carbon emissions mechanisms of design-oriented railway tunnel engineering. While bridges and tunnels are outside this thesis scope, these studies collectively reinforce a cross-typology finding relevant to this thesis: that BIM-based LCA integration and early design stage decision-making are recurring, high value research directions across structural engineering sub-disciplines generally, not only in building design, sharing broader credibility to the thesis question.

2.3.5 Tall Buildings And High-Rise Structural LCA

Helal et al., 2023) address a specific challenge; integrating embodied greenhouse gas emissions assessment into structural design of tall buildings, presenting both a conceptual framework and a software tool intended to support design decision-making at this scale. (Omrany et al., 2023), reviewed applications of BIM-LCA integration challenges may intensify with building scale and structural complexity, a consideration for any future extension of this thesis methodology to taller building typologies than the mid-rise case study used here.

2.3.6 Whole-Life And Cradle-To-Grave Structural Assessments

Felicioni et al., (2023) present a comparative cradle to grave LCA approach applied to a residential tower case study in Aalborg, Denmark, addressing how construction design choices propagate through to whole life environmental outcomes. Shen et al., (2025) conducted a novel whole life carbon assessment across thirty buildings in California providing a rare multi-building dataset against which single-case study findings can be contextualized. Mooney et al., 2026), contributed a whole life-carbon-case study specifically for new building affordable housing while (Tu et al., 2026), offered an international comparative perspective, examining whole life carbon reduction practices in early building design across China and the United States industry contexts, a useful reminder that the question of applicability this thesis investigates for Germany is part of a wider, internationally active research conversation rather than a unique concern for Germany.*

2.3.7 Recent Optimization And AI Assisted Approaches (2025-2026)

Recent sources in the literature indicate a shift towards automation and artificial intelligence in early structural design LCA. Abd El Fattah, 2026) proposes an integrative, LCA-driven structural optimization process for sustainable office building design. Kathiravel & Feng, (2024) address structural and embodied carbon performance optimization for low-carbon buildings through BIM-based integrated design. (Z. Chen et al., 2025), propose a modular framework for estimating carbon emissions specifically from building component replacements within an LCA context, extending the temporal scope of structural LCA beyond initial construction. They also introduce an AI-enabled pre-design programming approach for low-carbon buildings framed around the idea of spatial form following carbon flow, while Al-Obaidy et al., (2026) present BCEF, an early design framework oriented towards circular and low-impact buildings. Ferreira et al., (2026) proposed a purpose-driven approach to integrating LCA and BIM, arguing that the specific purpose an LCA is intended to serve is simply compliance reporting versus active design support and this should determine the method and tool selected. Nemati Aghdam & Dixit, (2026) provide a systematic review of methods and frameworks integrating environmental sustainability and resilience in building design and construction, offering a broader disciplinary frame within which this thesis's narrower structural-component focus sits. Hansen et al., (2023) addressed a core practical bottleneck for early-stage LCA: the prediction of material quantities themselves, proposing methods to accelerate quantity prediction specifically to support LCA-based decisions earlier in building design.

Table 2.2 Structural-component-specific early-design LCA sources by structural scope

Structural scope	Sources
Frame/system-level embodied carbon	Dunant et al. (2021); D'Amico & Pomponi (2020); Kanyilmaz et al. (2023)
Structural system comparison	Moncaster et al. (2018); Morsi et al. (2022); Zaker Esteghamati et al. (2022)
Component/Element-level optimization	Riez et al. (2025)
Infrastructure (bridges/tunnels)	Martínez-Muñoz et al. (2021); precast/cast-in-situ bridge study (2025); Li & Bao (2026)
High-rise buildings	Helal et al. (2023); Omrany et al. (2023)
Whole-life/cradle-to-grave	Felicioni et al. (2023); Shen et al. (2025); Mooney et al. (2026); Tu et al. (2026)
AI/automation-assisted (2024-2026)	Abd El Fattah (2026); Kathiravel & Feng (2024); Chen et al. (2025); Che & Zhuang (2026); Al-Obaidy et al. (2026); Ferreira et al. (2026); Hansen et al. (2023)

2.4 BIM-LCA INTEROPERABILITY AS A DRIVER OF SIMPLIFICATION

Simplified LCA methods are identified in sources, dependent on Building Information Modelling as their data source, making BIM-LCA interoperability a precondition for simplification rather than a separate technical concern. (Andreani et al., (2019) frame this dependency explicitly through the concept of 7D BIM for sustainability assessment, applying it to a design-of-alternatives case study under severe climate and heavy-use conditions, and demonstrating that sustainability dimensions (their 'seventh dimension') can be embedded into a BIM workflow alongside the conventional geometric, time, and cost dimensions.

Jia et al., (2026) systematic review of 124 primary studies (introduced in the context of this thesis's earlier chapters) synthesizes the barriers to this integration into what the authors term the BIM-LCA Interoperability Triad: semantic and ontological mismatches between BIM object classification and LCA material/process classification; workflow and temporal misalignment between when BIM models are authored and when LCA data is required; and system architecture and data-exchange limitations between BIM authoring tools and LCA calculation engines. (Obrecht et al., (2020) in an earlier systematic literature review of BIM-LCA workflows presented at the IOP Conference Series, identified more than 50 relevant BIM-LCA case studies in the published literature at that time, indicating that even by 2020 the field had accumulated a substantial applied literature without having resolved the interoperability barriers subsequently catalogued by Jia et al., (2026) evidence that the barriers are structural rather than merely a temporary tooling gap that further tool development alone would resolve.

This interoperability challenge is precisely why this thesis's design tests three separate BIM-integrated screening tools; Carbo Life Calculator, Tally, and One Click LCA against the same underlying structural model, rather than assuming a single tool's BIM-LCA data flow is representative of BIM-LCA integration generally. Cavalliere et al., (2019) discussed that a scholar can offer one concrete technical response to the workflow-misalignment dimension of the Interoperability triad, proposing continuous reassessment as a design progresses, using coarser data where only coarse design information exists and progressively replacing it as BIM model detail increases.

2.5 DATA GRANULARITY, LOD AND SIMPLIFICATION TRADE-OFFS

The accuracy consequences of simplification are more addressed through the Level of Development (LOD) literature. As established in this research, Nilsen & Bohne, (2019) provide the most granular treatment of how LCA accuracy changes across LOD, finding substantial Global Warming Potential (GWP) underestimation at low LOD (LOD 200) relative to high-detail models (LOD 350), narrowing considerably by LOD 300, the threshold this thesis adopts as equivalent to HOAI- Leistungsphase 3.

(Hansen et al., 2023) address the upstream cause of much of this LOD-related error: the difficulty of predicting material quantities accurately before detailed design exists. Their work on accelerating quantity prediction is methodologically significant for this thesis because it treats quantity estimation error as one of the three factors this thesis's sensitivity analysis isolates as a distinct, independently addressable problem. This supports the analytical separation this thesis focuses on between quantity estimation error, structural system assumption error, and emission-factor data error as three independently measurable contributors to overall deviation, rather than treating 'low LOD' as a single undifferentiated source of inaccuracy.

Kumar et al., (2025) , provides a clear and available synthesis of the LOD-to-method mapping this study relies on: LOD 300 to 350 is identified as the point at which more precise, material-based impact assessment becomes possible, while LOD 400 and above is associated with the resolution needed for procurement and certification purposes. This mapping shows this research’s own HOAI-to-LOD and the decision to derive the LP2/LOD 200 dataset from a controlled simplification of the Snowdon Towers baseline model rather than from an independently sourced lower-detail model, since holding the building constant while varying only LOD isolates the accuracy effect (Nilsen & Bohne, 2019) and Kumar et al., 2025) describe from puzzling differences between buildings.

2.6 THE GERMAN DATA AND REGULATORY ECOSYSTEM AS AN APPLICABILITY TEST-BED

To reiterate, Germany's construction sector provides a well-organized setting in which to experiment the applicability question this thesis poses. This combines a mandatory federal environmental dataset (ÖKOBAUDAT), a standardized design-phase structure (HOAI Leistungsphasen), and an active certification landscape (BNB, DGNB, QNG) that already requires LCA reporting at building completion.

(H. Chen et al., (2025)from the Technical University of Munich, identified a specific and practically consequential limitation within this ecosystem: ÖKOBAUDAT and its associated calculation tool eLCA provide only limited reference values for construction-phase modules A4 (transport to site) and A5 (installation), without accounting for variation in transport distance, mode, or load capacity, and eLCA does not currently support detailed assessment of these modules at all. This finding informs this thesis's own system boundary decision to include A4 using default assumptions while excluding A5 from the primary analysis. (Schumacher et al., 2022) complement this technical finding with practitioner-level evidence, surveying 161 German construction professionals and finding that respondents' organizations still perform LCA late in the design process despite Germany's comparatively mature data infrastructure, showing a lack of standardized, tool-interoperable workflows as the primary practical barrier to earlier assessment.

Apellániz et al., n.d., affiliated with Universität der Künste Berlin, provide a comparable applied precedent within the German context, presenting a parametric LCA workflow piloted on an office building complex in Berlin using the same One Click LCA tool ecosystem, with design optimization driven by Global Warming Potential as an objective. Given the similarity in building typology with this thesis,

geographical context, and reliance on One Click LCA, the study represents a valuable methodological reference for investigating early-stage LCA workflows rather than serving only as a general international comparator

2.7 RESEARCH GAP SYNTHESIS

Drawing together the sections above, four specific gaps in the literature can be identified, each of which this thesis is positioned to address.

- A substantial body of literature Dunant et al., (2021), D'Amico & Pomponi, (2020), Kanyilmaz et al., (2023b) establishes that early structural design decisions have disproportionate embodied carbon consequences, and a separate body of literature (Basbagill et al., (2013), Kumar et al., 2025), Roberts et al., (2022) establishes that simplified LCA methods can in principle function under early-design data constraints, no identified source tests the applicability of BIM-integrated screening tools specifically against a standardized, legally defined design-stage framework such as HOAI, despite HOAI being the framework that actually governs when structural data becomes available in German practice.
- While the LOD-accuracy literature (Nilsen & Bohne, 2019), (Kumar et al., 2025) quantifies accuracy loss in general LOD terms, and the German-specific literature (H. Chen et al., 2025); (Schumacher et al., 2022) documents both technical database gaps and practitioner-level workflow barriers, no identified source connects these two strands through a controlled, single-building, multi-tool and multi-stage comparison.
- Although sources like (Röck et al., 2018), (Cavalliere et al., 2019), (Ferreira et al., 2026) argue that the purpose an LCA serves should determine its method, the sources do not operationalize this argument for structural components by comparing multiple BIM-integrated screening tools against a common baseline.
- The German-specific applicability literature remains comparatively thin relative to the broader international literature, as far as this literature goes, Chen, Reitberger and Lang (2025), Schumacher et al. (2022), and Apellániz et al. (2021) address the German context , despite Germany's mature LCA data and regulatory infrastructure.

This thesis addresses these four gaps by combining the HOAI Leistungsphasen framework with a controlled, single-building (Snowdon Towers-derived) comparison across design stages (LP2/LOD 200, LP3/LOD 300) and BIM-integrated screening tools (Carbo Life Calculator, Tally, One Click LCA), implementing the question this literature review has shown to be well-motivated but under-addressed, particularly within the German regulatory and data context.

2.8 Standards, Interoperability formats and data exchange

The interoperability barriers discussed are not merely a matter of tool design choices, they are rooted in the data exchange standards that BIM and LCA software rely upon. Industry Foundation Classes (IFC), the open, vendor-neutral BIM data schema maintained by buildingSMART International, provide the theoretical basis for exchanging geometric and material information between authoring tools (Revit, ArchiCAD, Tekla) and downstream analysis tools, including LCA plugins. However, IFC's object classification hierarchy was developed primarily for geometric coordination and clash detection rather than for environmental impact assessment, meaning that mapping an IFC-classified structural element (for example, IfcColumn or IfcBeam) to the correct ÖKOBAUDAT or EPD material category typically requires a manual or semi-automated mapping step instead of a direct translation. This is precisely the semantic mismatch identified as the first pillar of Jia et al., 2026) BIM-LCA Interoperability Triad. It also

recurs as a practical implementation challenge in this thesis tool-selection methodology where none of the three selected screening tools (Carbo Life Calculator, Tally, One Click LCA is exclusively built based on ÖKOBAUDAT as a native dataset.

ISO 19650, the international standard for information management using BIM, provides a complementary process-level standard governing how and when information is exchanged between project stakeholders across a project's lifecycle. ISO 19650 does specify information requirements (through concepts such as Exchange Information Requirements (EIRs), Information Requirements (IRs), but it does not prescribe what specific LCA data or environmental indicators must be included. Those requirements are intended to be defined by the appointing party or by other standards. Several sources call for this gap to be addressed: (Ferreira et al., (2026) argue that BIM–LCA integration should be purpose-driven. Applied within the ISO 19650 information management framework, this perspective suggests defining project-specific LCA information requirements aligned with key design milestones. In the German context, these information requirements could be structured around HOAI Leistungsphasen, with distinct LCA-related data exchanges supporting decision-making at each phase. This principle correlates with the phase-linked information framework developed in this thesis.

2.9 Level of Development; Definitions and structural element implications

Because Level of Development (LOD) functions as the bridge, in this thesis methodology, between the international BIM-accuracy literature and the German HOAI Leistungsphasen framework, it is useful to set out the BIMForum LOD Specification's element-level definitions. Table 2.3 summarizes these definitions specifically as they apply to structural elements (columns, beams, slabs, and foundations), synthesized from the BIMForum LOD Specification.

Table 2.3 BIMForum Level of Development definitions applied to structural elements, with associated LCA data implications

LOD	Structural element definition	LCA data implication
100	Conceptual massing only; no defined structural system	No meaningful quantity take-off possible; typology-level assumption only
200	Generalized systems with approximate size, shape, location, and orientation	Typological benchmark ratios (e.g., kg reinforcement/m^2 GFA) are the viable quantity source
300	Precise geometry and quantity sufficient for coordination; systems and sizing defined	Element quantities become viable; approximates DIN 276 Kostenberechnung-level detail
350	Interface and connection detail between systems more defined	Reinforcement schedules and connection detail begin to inform mass estimates more precisely
400	Fabrication, assembly, and detailing information sufficient for construction	Near-complete bill of quantities; suitable for a detailed-design accuracy baseline
500	As-built, field-verified representation	Accurate quantities; unavailable prior to construction completion

LOD 300 represents the first level at which structural elements are individually defined with project-specific dimensions and quantities, rather than being represented as generalized system-level assumptions. This aligns with the present study's decision to treat HOAI Leistungsphase 3 (Entwurfsplanung) as the closest German equivalent to this international information threshold, since the associated DIN 276 Kostenberechnung provides a comparable level of quantity definition.

2.10 Comparative International Perspectives on Early design LCA adoption

While this study focus is the German regulatory and data context, the literature makes it clear that the real question is whether simplified LCA methods can reliably support early-stage structural decisions is being investigated across multiple national contexts simultaneously, with each context shaped by different regulatory drivers, data inputs, and professional practices. Situating the German case within this wider comparative picture clarifies what is genuinely context-specific about this thesis's findings and what may generalize more broadly.

(Tu et al., (2026) provide comparative evidence available, examining industry perspectives on whole-life carbon reduction in early building design across China and the United States. Although their study does not include Germany, it establishes an important methodological point; that practitioner-reported barriers to early-stage LCA adoption (workflow standardization, tool interoperability, professional incentive structures) can differ meaningfully between national contexts even where the underlying LCA science and data challenges (LOD, quantity estimation, database granularity) are essentially the similar. This distinction between universal technical barriers and context-specific institutional barriers informs how technical deviation patterns (SQ2, SQ3) are expected to be broadly informative beyond the German context, while applicability conclusions regarding workflow integration (SQ4) are explicitly scoped to German practice.

The European regulatory environment within which Germany's HOAI/ÖKOBAUDAT ecosystem sits, is part of a broader continental shift toward mandatory embodied carbon disclosure. The Energy Performance of Buildings Directive (EPBD), applicable across all EU member states, requires lifecycle greenhouse gas potential disclosure for new buildings above 1,000 square meters from 2028, extending to all new buildings from 2030, with manufacturer EPDs becoming mandatory inputs from 2027. This regulatory trajectory means that Germany's comparatively mature ÖKOBAUDAT/BNB/DGNB infrastructure, functions as an early instance of an obligation the rest of the EU construction sector will shortly be required to meet. This will in turn strengthen the practical relevance of this research’s findings beyond the German context, even though its case study and regulatory framework remain German-specific by design.

A dimension across the internationally comparative literature is the choice between reinforced concrete, structural steel, and engineered timber as the primary structural material, a decision that, as per D'Amico and Pomponi (2020) and Dunant et al. (2021), is typically fixed extremely early in design and carries substantial embodied carbon consequences independent of subsequent optimization. Martínez-Muñoz, Martí and Yepes (2021) examine this material choice in the infrastructure context (concrete versus composite bridges), while other sources reviewed like (Morsi et al., 2022; Zaker Esteghamati et al., 2022) address it for building structures. Table 2.4 synthesizes the general findings reported across this literature regarding relative embodied carbon by structural material, presented as qualitative ranks, since absolute embodied carbon intensity depends heavily on the specific structural system, span, loading, and regional emission-factor database used, a limitation consistent with Moncaster et al.'s (2018) methodological warning that LCA results are sensitive to assessment method as well as to genuine material differences.

Table 2.4 Qualitative synthesis of relative embodied carbon findings by structural material across the reviewed literature

Structural material	General finding across reviewed sources	Key caveat
Reinforced concrete	Typically, highest embodied carbon per unit mass, but high structural efficiency at scale can offset this for some spans	Highly sensitive to cement content and choice of supplementary cementitious materials
Structural steel	Lower material-stage carbon than concrete per unit strength, but sensitive to recycled content assumptions	Grid layout and decking choice can outweigh material-stage differences
Engineered timber	Generally lowest embodied carbon of the three at the material stage, subject to biogenic carbon accounting method	Accounting treatment of biogenic carbon and end-of-life significantly affects comparability across studies

2.11 Implications of method selection

This section makes it clear that the connections between the literature reviewed above and the methodological choices developed in later sections, make it so that the link between literature review and methodology is verifiable.

- The finding that early-stage structural decisions (grid layout, system typology) carry disproportionate embodied carbon consequences (Dunant et al., 2021; D'Amico & Pomponi, 2020) justifies this study's focus on structural components specifically, and justifies treating structural system and typology as a unique, separately-tested sensitivity factor.
- The screening-information typology (Roberts et al., 2022; Basbagill et al., 2013) justifies this thesis's narrowing to BIM-integrated screening tools as the preferred method under test, which require modelling skills and computational infrastructure beyond this thesis's practical scope.
- The BIM-LCA interoperability literature especially the inability of ÖKOBAUDAT as a native connection in any of the three selected tools justifies this study's methodological step of substituting ÖKOBAUDAT emission factors into Carbo Life Calculator as a controlled comparison condition, implementing the semantic-mismatch problem identified by (Jia et al., 2026).
- The LOD-accuracy literature (Nilsen & Bohne, 2019; Kumar et al., 2025) and its element-level definitions justify this study’s decision to derive its LP2/LOD 200 dataset from a controlled simplification of a single detailed baseline model (Snowdon Towers)
- The German-specific findings (Chen, Reitberger & Lang, 2025; Schumacher et al., 2022) justify this system boundary decision (A1-A3, with A5 excluded from the primary analysis) and its interpretive framing, where technical deviation findings (SQ2, SQ3) are treated as internationally informative while workflow conclusions (SQ4) are scoped specifically to German practice.

2.12 Certification Tiers

The three German certification frameworks referenced above operate at different levels of obligation and reward. BNB applies exclusively to federal public-sector buildings and functions as a mandatory

assessment system rather than a voluntary certification, with ÖKOBAUDAT as its binding data source, meaning federal construction projects have no discretion over which environmental database to use for compliance reporting. DGNB, by contrast, is a voluntary, market-driven certification available to private developers, awarded across bronze, silver, gold, and platinum tiers based on a weighted scoring system spanning environmental, economic, sociocultural, technical, and process quality criteria, of which embodied and operational carbon performance form a substantial component. QNG lies between these two in terms of obligation. It is voluntary in principle, but functionally mandatory for developers seeking KfW low-interest or subsidized financing for new-build or retrofit projects, since QNG compliance is a precondition for accessing this financing route. This subsidy linkage is significant for this thesis, because it means that a simplified LCA method demonstrating early, reliable insight into likely QNG or DGNB performance would carry direct financial relevance to a developer's early-stage decision-making, showing how relevant the practical stakes of the accuracy findings are.

The certification landscape's shared reliance on ÖKOBAUDAT as the underlying data source across all three frameworks (BNB, DGNB and QNG) is what allows this study’s single-database, single-tool-ecosystem case study design to remain relevant across all three certification contexts simultaneously.

3

DESIGN-STAGE DATA AVAILABILITY FRAMEWORK

Chapter 2 established that the applicability of simplified Life Cycle Assessment (LCA) methods is fundamentally constrained by the data available at the point an assessment is performed, and that Level of Development (LOD) is the dominant international vocabulary for characterising that constraint. However, LOD is a construct native to Anglo-American BIM practice (originating in the AIA/AGC and BIMForum frameworks) and has no formal counterpart within German construction regulation. Germany's construction sector instead organizes design progression through the Honorarordnung für Architekten und Ingenieure (HOAI), a federal ordinance defining nine standardised service phases (Leistungsphasen). This chapter develops a design-stage data availability framework that translates between these two systems, grounding this thesis's empirical case study in a structure that is both internationally legible, through its correspondence to LOD, and applicable to German professional practice, through its basis in HOAI.

This chapter applies this thesis's first sub-question, SQ1: what data on structural components is realistically available at successive early design stages, and how does this limit the choice of a simplified LCA method that can be applied? This chapter answers it against a specific and independently verifiable national framework, so that the data-availability claims underlying this research in later chapters rest on a documented regulatory basis rather than on the researcher's own assumptions about what a 'typical' early-stage design might contain.

3.1 HOAI 2021 Leistungsphasen AS A FRAMEWORK FOR ASSESSMENT

The Honorarordnung für Architekten und Ingenieure is a federal ordinance governing the remuneration of architectural and engineering services in Germany. It was first introduced in 1976/1977, substantially revised following a 2019 ruling of the European Court of Justice that its binding minimum and maximum fee rates were incompatible with the EU Services Directive; the resulting HOAI 2021, in force since 1 January 2021, removed binding fee enforcement while leaving its underlying service-phase structure unchanged. This distinction is important for the present thesis: HOAI's relevance here is not as a source of pricing information but as the standardized, legally defined structure of nine service phases (Leistungsphasen, LP1 to LP9) into which German building design and delivery is organized. This in turn determines what design information can realistically be expected to exist at any given point in a project's development.

Two annexes are of direct relevance to this thesis. Anlage 10 (Leistungsbild Gebäude und Innenräume) governs architectural object planning, while Anlage 14 (Leistungsbild Tragwerksplanung) governs structural engineering services specifically. Both define the Grundleistungen (basic services) expected within each Leistungsphase, and it is this Grundleistungen definition in German practice, what geometric,

material, and quantity information a structural engineer is expected to have produced at each stage of a project.

Fee-weighting data corroborates the resulting data-availability picture from an independent angle. For Tragwerksplanung under HOAI Anlage 14 (Section 51), Leistungsphasen 2 and 3 together account for 25 percent of total structural engineering fee (10 percent and 15 percent respectively), while Leistungsphase 5 accounts for 40 percent which is the single largest phase. This weighting reflects the substantially greater analytical effort required to produce full detailed design compared to preliminary or design-stage structural concepts, and supports this study's alignment with Leistungsphase 5 as the appropriate detailed-design baseline against which earlier-stage simplified LCA results are compared.

Because this thesis concerns structural components specifically, the Grundleistungen defined for Tragwerksplanung (structural engineering services, Anlage 14.1) deserve more careful consideration than the general Objektplanung Gebäude provisions (Anlage 10.1) discussed above, since it is the structural engineer's contractual deliverables, that determine the quantity and material data available for a structural LCA at each Leistungsphase. At Leistungsphase 2, Anlage 14.1 suggests for the structural engineer to develop a preliminary structural concept in coordination with the architectural Vorplanung, including but not necessarily a first assessment of the load-bearing system and an approximate determination of primary structural dimensions sufficient to confirm technical feasibility, but does not require detailed structural analysis or member-by-member sizing. At Leistungsphase 3, the structural engineer is required to develop the structural system in sufficient detail to support the architectural Entwurfsplanung and the associated DIN 276 Kostenberechnung, including preliminary sizing of primary structural elements including structural calculations sufficient to verify the selected structural concept, though reinforcement detailing and connection design remain outstanding. At Leistungsphase 5, full structural analysis, member design, reinforcement scheduling, and connection detailing are required, generating the complete structural documentation set (Ausführungsplanung) from which contractors price and construct the works.

This structural engineering-specific reading of the Grundleistungen confirms the general Leistungsphase data-availability picture developed below: the Leistungsphase 2-to-3 transition marks the point at which a structural engineer is correspondent to move from system-level feasibility confirmation to element-level preliminary sizing, which is precisely the transition this thesis case study will set its eyes on as its LP2-to-LP3 dataset boundary.

3.2 Mapping Data availability to design stages

Table 3.1 summarises the nine Leistungsphasen, together with an assessment, derived from the Grundleistungen defined in Anlage 10.1 and Anlage 14.1, of the structural data realistically available at each. The three phases embedded to this thesis's design - Leistungsphase 2 (Vorplanung), Leistungsphase 3 (Entwurfsplanung), and Leistungsphase 5 (Ausführungsplanung) - are marked and discussed individually below.

Table 3.1 HOAI Leistungsphasen and associated structural data availability

LP	German designation	English meaning	Structural data typically available
1	Grundlagenermittlung	Conceptual phase	Project brief only; no structural concept
2*	Vorplanung	Preliminary design	Structural system typology chosen; rough geometry; DIN 276 cost framework (Kostenrahmen)
3*	Entwurfsplanung	Design planning	Structural concept elaborated; approximate element quantities; DIN 276 cost calculation (Kostenberechnung)
4	Genehmigungsplanung	Approval planning	Permit-level drawings; quantities largely stable
5*	Ausführungsplanung	Execution planning	Full detailed design; near-final quantities
6	Vorbereitung der Vergabe	Tender preparation	Bill of quantities finalized
7	Mitwirkung bei der Vergabe	Tender confirmation	Contractor quantities confirmed
8	Objektüberwachung	Site supervision	As-built data begins to emerge
9	Objektbetreuung	Post-completion support	As-built data complete

3.2.1 Leistungsphase 2 (Vorplanung)

At Vorplanung, the Grundleistungen defined in Anlage 10.1(Annex) require analysis of the project basis, agreement on design objectives, development of a preliminary design concept, clarification of key constraints and dependencies, integration of other specialist planners' input, preliminary negotiations on approvability, establishment of a cost framework per DIN 276, and production of a schedule. For structural components specifically, this means the structural system typology (for example, reinforced concrete frame versus structural steel) has typically been decided, and an approximate gross floor area and storey configuration exists, but individual structural elements have not yet been sized, and no element-specific quantity take-off is available. This corresponds, in this thesis's data protocol to reliance on typological benchmark ratios the approach validated by D'Amico and Pomponi (2020), whose similar study of structural mass quantities across reinforced concrete, steel, and timber gravity frames provides a basis for such ratios.

3.2.2 Leistungsphase 3 (Entwurfsplanung)

At Entwurfsplanung, the Grundleistungen requires elaboration of the design concept accounting for urban-planning, functional, technical, building-physics, economic, and ecological requirements, integration of other planners' contributions, production of an object description, negotiation of approvability with authorities, and for this thesis a potential cost calculation per DIN 276 (Kostenberechnung), a materially more detailed cost and quantity estimate than Leistungsphase 2's cost framework. For structural components, this generally means individual elements (columns, beams, slabs, foundations) have preliminary sizing, allowing element-specific, if still approximate, quantities to be

singled out. This corresponds, in international LOD terms approximately to LOD 300 which is the threshold Nilsen and Bohne (2019) and Kumar et al. (2025) both identify as a point at there is meaningful improvement in LCA reliability and also confidence in output results.

3.2.3 Leistungsphase 5 (Ausführungsplanung)

At Ausführungsplanung, full detailed structural design exists: final member sizes, reinforcement schedules, and connection details, generating a complete quantity take-off available prior to construction. Reflecting on the 40 percent fee weighting, this phase represents the point of maximal pre-construction design certainty.

3.2.4 Illustrative example: a single structural element across Leistungsphasen

To make the generic data-availability content in Table 3.1 more reliable, it is useful to trace a single structural element, a simple internal column in a reinforced concrete flat-slab frame, through its representation at each of the three examined Leistungsphasen. At Leistungsphase 2, the column exists only as a grid intersection point on a structural layout, associated with a typological assumption (reinforced concrete, flat-slab system) and, in some cases a rule-of-thumb for cross-sectional estimate derived from span and loading benchmarks of the kind tabulated by D'Amico and Pomponi (2020). There is no individual quantity of concrete or reinforcement steel has been calculated for this specific column. At Leistungsphase 3, the column has a defined cross-sectional dimension (for example, 450 millimetres by 450 millimetres) derived from a preliminary structural analysis, from which an approximate concrete volume can be calculated from storey height and cross-section, although its reinforcement content is still typically estimated via a percentage of concrete-volume rule. At Leistungsphase 5, the column has a complete reinforcement schedule specifying bar diameters, spacing, and lap lengths, together with any connection or base-plate detailing, from which both concrete volume and reinforcement mass can be calculated.

This progression from typological assumption, to dimensioned but reinforced estimate, to fully quantified element is what a simplified LCA method must accommodate at each stage, and it explains why the screening/minimal-information typology is the only method typology genuinely compatible with Leistungsphase 2 data, while parametric and single-indicator methods become viable only once Leistungsphase 3's dimensioned geometry exists.

3.2.5 Cross-comparison with international design-stage frameworks

Because much of the simplified LCA literature is from an Anglo-American practice context, it is useful to situate HOAI's Leistungsphasen alongside the two commonly referenced international design-stage frameworks: the RIBA Plan of Work (United Kingdom) and the American Institute of Architects (AIA) phase structure (United States). This cross-comparison serves two purposes for this thesis: it allows international readers to locate this thesis's LP2/LP3/LP5 comparison points within a framework they may already recognise, and it clarifies that the question this thesis investigates, while grounded in the German context, corresponds to an equivalent design-stage transition recognised internationally.

RIBA Stage 2 (Concept Design) and the AIA's Schematic Design (SD) phase both correspond approximately to HOAI Leistungsphase 2 (Vorplanung): massing and structural concept are established, but detailed member sizing is not yet available. RIBA Stage 3 (Spatial Coordination, formerly Developed Design) and AIA Design Development (DD) correspond approximately to HOAI Leistungsphase 3 (Entwurfsplanung): structural system is elaborated with preliminary member sizing, broadly comparable

to this thesis's Leistungsphase 3/LOD 300 correspondence. RIBA Stage 4 (Technical Design) and AIA Construction Documents (CD) correspond approximately to HOAI Leistungsphase 5 (Ausführungsplanung), the detailed-design. Table 3.2 summarizes this cross-comparison.

Table 3.2 Cross-comparison of HOAI Leistungsphasen with RIBA and AIA design-stage frameworks

HOAI (Germany)	RIBA Plan of Work (UK)	AIA phases (USA)	Approximate LOD
LP1-LP2 (Grundlagenermittlung, Vorplanung)	Stage 1-2 (Preparation, Concept Design)	Schematic Design (SD)	LOD 100-200
LP3 (Entwurfsplanung)	Stage 3 (Spatial Coordination)	Design Development (DD)	LOD 300
LP4-LP5 (Genehmigungsplanung, Ausführungsplanung)	Stage 4 (Technical Design)	Construction Documents (CD)	LOD 300-400
LP6-LP7 (Vergabe phases)	Stage 4-5 (Technical Design, Manufacturing and Construction)	Bidding/Negotiation	LOD 400
LP8-LP9 (Objektüberwachung, -betreuung)	Stage 5-7 (Construction, Handover, Use)	Construction Administration (CA)	LOD 500

This cross-comparison should be read with the same caution applied to the HOAI-to-LOD correspondence in Section 3.5: RIBA and AIA phases, like HOAI Leistungsphasen, define contractually and procedurally distinct deliverables shaped by different national construction industry structures (for example, RIBA's explicit separation of a 'Manufacturing and Construction' stage reflects a UK emphasis on offsite fabrication not mirrored identically in HOAI), and the correspondence in the table above is offered as a guidance aid.

3.3 DIN 276-BASED STRUCTURING OF SIMPLIFIED LCA INPUT REQUIREMENTS

DIN 276 (Kosten im Bauwesen) is the German standard for structuring construction cost information into defined cost groups (Kostengruppen), and HOAI ties two of its cost-related deliverables to Leistungsphasen: the Kostenrahmen (cost framework), a rough, typology-based estimate required at Leistungsphase 2, and the Kostenberechnung (cost calculation), a more detailed estimate required at Leistungsphase 3 that is based on approximate but real element quantities.

This Leistungsphase 2-to-3 transition is significant for LCA purposes because DIN 276's cost structure separating substructure, structural frame, and envelope, among other categories, maps reasonably closely onto the element-level categorisation that ÖKOBAUDAT datasets and BIM-integrated screening tools expect as input.

It is on this basis that this thesis considers Leistungsphase 3 as a plausible threshold above which a simplified LCA becomes methodologically comparable to LOD 300 in the international literature, and therefore a candidate point at which simplified LCA may begin to be reliable enough to inform. This DIN 276-to-LOD correspondence is not a formally recognised equivalence but rather, it is an interpretive

bridge this study proposes to connect German regulatory practice to the international LOD-accuracy literature and is presented as such.

A further implication of the DIN 276 cost-structuring logic concerns which of the four simplified LCA method typologies identified are realistically deployable at each Leistungsphase. Because a Kostenrahmen (Leistungsphase 2) provides only typology-level cost and quantity information, the screening/minimal-information typology (Roberts et al., 2022; Basbagill et al., 2013) is the typology executable at this stage without fabricating detail the design does not yet contain. By contrast, a Kostenberechnung (Leistungsphase 3), with its element-specific quantities, is sufficient to support the parametric and single-indicator typologies as well, since these require a defined geometric model. This data-availability-to-method-compatibility relationship is summarized in Table 3.3, and supports this thesis's sub-question SQ1.

Table 3.3 Compatibility of simplified LCA method typologies with HOAI-defined data availability

Leistungsphase	DIN 276 deliverable	Compatible method typology	Executable in this thesis's tools ?
LP2 (Vorplanung)	Kostenrahmen (typology-level)	Screening -information only	Yes, via typological benchmark input
LP3 (Entwurfsplanung)	Kostenberechnung (element-level)	Screening; parametric; single-indicator	Yes, via simplified geometric model

3.4 Standards Compliance

The German-specific instruments discussed above (HOAI, DIN 276, ÖKOBAUDAT) do not operate in isolation; they collaborate, and should remain compliant with the international LCA and BIM standards landscape. This section consolidates that relationship into a single compliance stack, clarifying how each standard limits or supports the layer above and below it.

At the foundation, ISO 14040 and ISO 14044 establish the general LCA methodology - goal and scope definition, inventory analysis, impact assessment, and interpretation - that all downstream, construction-specific standards must satisfy. EN 15804 (as amended by EN 15804+A2) specifies how individual construction products are assessed and reported at the product level, and is the compliance standard that ÖKOBAUDAT datasets, whether generic or manufacturer-specific Environmental Product Declarations, must satisfy. EN 15978 specifies how these product-level datasets are aggregated to the whole-building or whole-component level, and is the standard against which any whole-structure calculation performed by this thesis's selected tools (Carbo Life Calculator, Tally, One Click LCA; Section 4.4) must be interpreted.

DIN 276 sits alongside this international stack as a cost-structuring standard functions in German practice as the de facto quantity-structuring standard that determines what element-level data exists at each HOAI Leistungsphase, and therefore what can be fed into an EN 15978-compliant calculation at

that stage. Industry Foundation Classes (IFC) and ISO 19650, provide the data-exchange layer connecting BIM authoring tools to LCA calculation engines, but as Jia, Zhang and Liu (2026) document through their BIM-LCA Interoperability Triad, this layer remains only partially reliable, suggesting the manual database-mapping step in the thesis methodology

Table 3.4 cements this compliance stack into a single reference, ordered from a general (ISO) to the most German-specific (HOAI) layer, to serve as a navigational reference for the methodology, where each layer is invoked at a specific methodological decision point.

Table 3.4 Standards compliance list governing this thesis methodology

Layer	Standard	Function	Where invoked in this thesis
General LCA methodology	ISO 14040 / ISO 14044	Four-phase LCA structure	Functional unit, system boundary
Product-level environmental data	EN 15804 (+A2)	Product Category Rules; EPD format	ÖKOBAUDAT dataset selection
Building/component-level aggregation	EN 15978	Aggregation of product data to component/building level	Result aggregation
BIM data exchange	IFC; ISO 19650	Geometric/material data exchange between BIM and LCA tools	Tool-database mapping
Cost/quantity structuring	DIN 276	German cost-group structuring, linked to HOAI phases	LP2/LP3 quantity protocol
Design-phase structuring	HOAI 2021 (Anlage 10, Anlage 14)	Nine-phase German design service structure	Case study staging
Certification	BNB; DGNB; QNG; EU EPBD (recast)	Whole-building assessment and disclosure requirements	Applicability discussion

This layered structure clarifies an important scoping point for this thesis: while HOAI and DIN 276 determine when structural data becomes available, and ÖKOBAUDAT/EN 15804 determine what environmental data can be attached to it, it is the tool layer (Section 4.4-4.5) - not any single standard - that determines whether a simplified method can actually connect these two determinations into a usable early-stage LCA output. This is precisely the applicability question this thesis's empirical chapters (5 and 6) are designed to answer.

3.5 Alignment of DIN 276 Cost Groups with Structural Components

DIN 276 organizes construction costs into a hierarchy of Kostengruppen (cost groups), the third level of which (300-series) corresponds to Bauwerk - Baukonstruktionen (building construction works), within which KG 320 (Gründung, foundations) and KG 330 (Außenwände, load-bearing external walls) alongside KG 340s (Innenwände, internal walls) and related structural categories capture the primary structural components this study examines. This cost-group structure is significant beyond its budgeting function

because it is frequently the organizational structure practitioners use to organize BIM model elements and quantity take-offs in German practice. This means that a simplified LCA tool capable of reading or approximating DIN 276 KG 300-series cost-group quantities can draw on data structuring German structural engineers already produce as a matter of course, otherwise would involve a parallel LCA-specific data structure to be built from scratch. This alignment is one of the practical reasons this study tool selection prioritizes BIM-integrated screening tools capable of working from standard structural BIM models.

3.6 Certification-Scheme Submission Timing Relative to Leistungsphasen

BNB, DGNB, and QNG currently assess LCA performance at or close to project completion. It is useful to state this against the HOAI framework developed in this chapter: BNB documentation requires whole-building LCA calculation, which can be performed via eLCA, at Leistungsphase 8 (Objektüberwachung) at the latest, reflecting as-built quantities, although preliminary calculations are often produced earlier at Leistungsphase 5 once detailed design quantities exist. DGNB certification similarly relies on LCA-based criteria that require sufficiently detailed information on material quantities and building components. In practice, the level of information needed for certification aligns more closely with later HOAI Leistungsphasen, where quantities and specifications are developed in greater detail, as earlier phases typically provide only preliminary estimates. QNG, being linked to KfW subsidy approval, generally relies on its sustainability documentation, including LCA-derived embodied carbon figures, before construction financing is finalized, placing its practical submission point at approximately Leistungsphase 5 to 6.

This certification-timing evidence explains from a regulatory and practitioner perspective, the finding reported by Schumacher et al. (2022) that German LCA practice remains concentrated in later design stages. This pattern reflects not only established workflow conventions but also the information requirements embedded within current certification processes, where reliable LCA evaluation depends on a level of material quantity and specification detail typically available only in later Leistungsphasen. Addressing this limitation forms part of the motivation for the applicability question developed in Chapter 1: if simplified LCA methods can demonstrate sufficient reliability at Leistungsphase 2 or 3, they could expand the timeframe in which meaningful LCA-informed decisions can be integrated into German design and certification workflows.

3.7 Mapping Hoai Leistungsphasen To Bim Levels Of Development (Lod)

It was established that Level of Development provides the dominant international framework for characterizing design-stage accuracy, and also how HOAI Leistungsphasen and their associated DIN 276 deliverables support German structural data availability at each stage. This section makes the correspondence between the two systems clear.

The mapping is constructed by comparing the BIMForum LOD Specification's element-level definitions against the Grundleistungen data-availability descriptions. LP1 (Grundlagenermittlung), lacking any defined structural geometry, corresponds to LOD 100. LP2 (Vorplanung), with its typology-level system choice and DIN 276 Kostenrahmen, corresponds to LOD 200, since both describe generalized systems with approximate size, shape, and location. LP3 (Entwurfsplanung), with its element-specific Kostenberechnung quantities, corresponds to LOD 300, the threshold both Nilsen and Bohne (2019) and Kumar et al. (2025) identify as marking a meaningful improvement in material-based impact assessment reliability. LP4 (Genehmigungsplanung) sits at approximately LOD 300 to 350, reflecting permit-level drawings with quantities largely stable but interface detail still developing. LP5 (Ausführungsplanung),

with full reinforcement schedules and connection design, corresponds to LOD 350 to 400, approaching but not necessarily reaching full fabrication-level detail. LP6 and LP7 (tender preparation and assistance) correspond to LOD 400, reflecting a finalized bill of quantities, and LP8 to LP9 (site supervision, post-completion support) correspond to LOD 500, as-built representation.

Table 3.5 Proposed HOAI Leistungsphasen-to-LOD mapping

HOAI LP	**German designation**	**Proposed LOD equivalent**	**Basis for correspondence**
LP1	Grundlagenermittlung	LOD 100	No defined structural geometry; conceptual brief only
LP2	Vorplanung	LOD 200	Generalized system typology; DIN 276 Kostenrahmen
LP3	Entwurfsplanung	LOD 300	Element-specific quantities; DIN 276 Kostenberechnung
LP4	Genehmigungsplanung	LOD 300-350	Permit-level drawings; interface detail developing
LP5	Ausführungsplanung	LOD 350-400	Full reinforcement schedules and connection design
LP6-LP7	Vergabe phases	LOD 400	Finalised, tender-ready bill of quantities
LP8-LP9	Objektüberwachung / -betreuung	LOD 500	As-built, field-verified representation

This correspondence underpins this thesis's own case study design (Chapter 5), in which a Leistungsphase 5-equivalent (LOD 300, Snowdon Towers-derived) baseline model is deliberately simplified downward to produce a Leistungsphase 2-equivalent (LOD 200) dataset, holding the underlying building constant so that observed deviation can be attributed to data-stage effects rather than to differences between independently authored buildings - the same isolation logic Nilsen and Bohne (2019) apply within their own single-building LOD comparison.

One limitation of this mapping is that LOD as an Anglo-American BIM construct, describes model geometric and non-geometric detail , whereas HOAI Leistungsphasen describes defined service deliverables, of which model detail is only one component alongside coordination, approvability negotiation, and cost reporting obligations that have no direct LOD analogue. The mapping in Table 3.5 should therefore be read as a practically useful approximation for the purpose of connecting the German case study for this thesis to the international accuracy literature but clearly not as a claim that HOAI and LOD are formally interchangeable systems.

3.8 Framework limitations

Three limitations of the design-stage data availability framework developed in this chapter are stated below:

- The HOAI-to-LOD mapping proposed is an interpretive construction developed for this thesis, not a recognized equivalence published by BIMForum, buildingSMART, or any German standards body and therefore readers applying this framework beyond this thesis should treat it as a starting hypothesis.
- HOAI Grundleistungen defines expected deliverables, not actual practice; real projects may deviate from the Leistungsphase-linked data availability, particularly on fast-track or design-build projects where phases overlap or are compressed, a limitation that is relevant to interpreting the case study findings of this research.
- The framework addresses structural component data availability specifically and it does not address the parallel data-availability questions for building envelope, MEP systems, or finishes, which may follow different Leistungsphase-to-detail relationships not examined by this thesis.

4

METHODOLOGY

4.1 Research Design Overview

This thesis adopts a comparative, single-case-study design combined with quantitative deviation and sensitivity analysis, restricted to BIM-integrated screening tools as the simplified LCA method typology under investigation. A single building's structural model is used as the basis for constructing two parallel datasets, representing the level of design information realistically available at HOAI Leistungsphase 3, treated as the detailed-design baseline) and at Leistungsphase 2/LOD 200 (Vorplanung-equivalent, treated as the early-stage comparison point), following the HOAI-to-LOD mapping. Each dataset is processed through three BIM-integrated screening tools namely Carbo Life Calculator, Tally, and One Click LCA which are selected to allow tool-level and database-level variation to be examined independently of design-stage variation.

This design deliberately narrows the broader method-typology landscape (screening, parametric, single-indicator, decision-support) to the screening typology, on the grounds set out: screening tools require the least specialist modelling skill, are comparable to one another (all three operate on a BIM-authored structural model rather than a bespoke parametric or optimization environment), and their typology is readily deployable within existing German structural engineering workflows without requiring additional computational infrastructure which is consistent with Schumacher et al.'s (2022) finding that workflow integration, not method sophistication, is the primary challenge reported by German practitioners.

A single-case design was selected in preference to a multi-case design because the objective of this thesis is to characterize the structure and mechanism of stage-to-stage and tool-to-tool deviation in depth, using a real, professionally coordinated structural model and a controlled, single-building comparison.

4.2 Case Study Selection and Description

The case study is built around Snowdon Towers, Autodesk's official Revit sample project, distributed with Revit since the 2024 release. Snowdon Towers is a mixed-use building comprising linked architectural, structural, and MEP models, produced at construction-documents-phase resolution corresponding to HOAI Leistungsphase 5 and approximately LOD 300. It was selected over an independently constructed or hypothetical model for three reasons.

First, it is a genuine, professionally coordinated structural model, meaning its detailed-design dataset reflects realistic member sizing, reinforcement-adjacent detailing, and foundation design.

Second, using a single baseline model from which all comparison datasets are derived removes a factor in any design that draws its early-stage and detailed-design datasets from different buildings: any deviation measured between design stages can be aligned to data-resolution effects.

Third, Snowdon Towers is freely available to any researcher with access to a current Revit license.

The structural system extracted from Snowdon Towers for this case study is a composite reinforced concrete and structural steel frame, and with the office/mixed-use building typology. Primary structural components examined are columns, beams, slabs, structural frames and foundations. Building envelope, MEP, and finishes elements present in the full Snowdon Towers model are excluded from all extracted datasets.

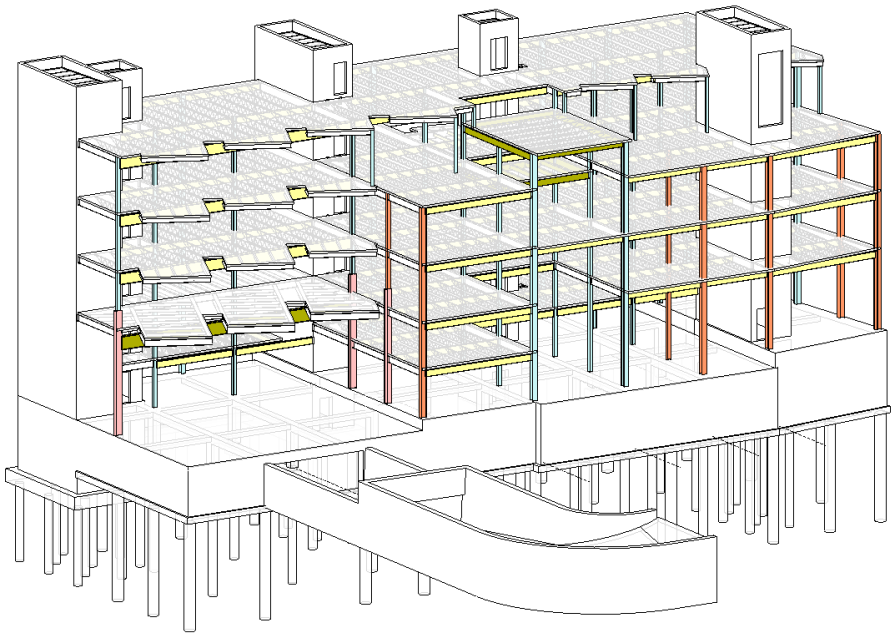


Figure 4.1 Illustration of Snowdon Towers

4.2.1 Justification of case study selection relative to alternatives

Three alternative case study approaches were considered before Snowdon Towers was selected.

- The first alternative was to use a real, currently active German building project, following the findings of Apellániz, Pasanen and Gengnagel's (2021) Berlin office building case study. This was not pursued because accessing a real project's data at multiple design stages, with the cooperation of the design team, was not feasible within this study timeframe and access limitations, and because a live project would not permit the controlled, single-building-derived comparison design, since real early-stage design records for a since-completed building are rarely preserved or made available at the resolution this methodology requires.
- The second alternative was to construct an entirely original structural model from scratch, sized and detailed. This was also set aside because an originally authored model, however carefully detailed, would not carry the same claim to realism as a professionally coordinated, commercially released reference model. Additionally, because constructing both a detailed-design and an early-stage version from first principles would not remove the risk of the researcher's own assumptions shaping the baseline as much as the derived comparison dataset. However, deriving the early-stage dataset from an independently produced detailed baseline at least fixes the baseline's origin outside the researcher's modelling choices.
- The third alternative was to use one of the published external benchmark datasets - for instance, One Click LCA's European embodied carbon benchmark report as the primary baseline. This was set aside as a primary baseline because published benchmark reports provide final results without the matching early-design data needed to test SQ2 and SQ3, since no early-stage drawings are typically published alongside a completed building's final LCA figures. This option is retained instead as a secondary plausibility check, on whether this thesis's LOD 300 baseline result falls within a realistic range for comparable European office buildings.

4.2.2 Model access and software requirements

Snowdon Towers requires Autodesk Revit 2024 or later to access natively, distributed as a bundled sample project within the software installation. All three LCA tools used in this thesis methodology operate as Revit plugins or Revit-integrated services, meaning a single Revit license and installation is sufficient to support the full data collection workflow, without requiring additional standalone software beyond each tool's own plugin installation and, for Tally and One Click LCA, an active account with the respective tool vendor. Academic licensing was confirmed for Revit, Tally, and One Click LCA prior to data collection; Carbo Life Calculator, being open-source, required no licensing step.

4.2.3 Functional Unit and System Boundary

The functional unit adopted is kilograms of CO2-equivalent Global Warming Potential per square metre of gross floor area (kg CO2e/m^2 GFA), linked to the primary structural components. This functional unit is consistent with that used in the majority of the comparative literature (Dunant et al., 2021; D'Amico and Pomponi, 2020; Zaker Esteghamati et al., 2022), supporting external comparison of this thesis results against the wider and global literature.

The system boundary comprises EN 15978 modules A1 to A3 (product stage: raw material supply, transport to manufacturer, and manufacturing) as the primary boundary, with module A4 (transport to site) included only where a given tool's default database provides it, and module A5 (installation) excluded from the primary analysis. This boundary decision follows from the data limitation documented by Chen, Reitberger and Lang (2025) namely, that ÖKOBAUDAT and eLCA provide only limited reference values for A4 and no detailed support for A5. From the practical observation that none of this thesis's three selected tools provides equivalent German-context A4/A5 modelling capability, meaning that including these modules would introduce specific default-assumption variation unrelated to the design-stage and database effects this thesis investigates. This boundary limitation is revisited when interpreting results. Two further boundary conditions apply. First, biogenic carbon accounting is not applicable to this thesis's reinforced concrete and steel frame case study material and is therefore not addressed, although this is flagged as a material-comparison limitation relevant to any future extension of this methodology to timber structures. Second, module D (benefits beyond the system boundary, e.g. end-of-life recycling credits) is excluded throughout, consistent with this study’s design-phase decision-support framing.

4.3 Selection of BIM-Integrated Screening Tools for Testing

Three BIM-integrated screening tools are used throughout this thesis workflow: Carbo Life Calculator, Tally, and One Click LCA. These were selected jointly to satisfy two requirements: that each tool belongs to the screening/minimal-information typology and that the three tools differ meaningfully in their underlying emission-factor database, so that database-level variation can be observed clearly and not just assumed.

4.3.1 Carbo Life Calculator

Carbo Life Calculator is a free, open-source Revit plugin that calculates embodied carbon from modelled BIM elements. It uses a fully user-editable material and emission-factor database, with results exportable to CSV. Its defining methodological feature, for this thesis's purposes, is that its database is fixed by the tool vendor: the researcher may not load any set of emission factors, but its inclusive of various factors including ÖKOBAUDAT, allowing Carbo Life Calculator to function as a controlled instrument in this

thesis's design, isolating calculation-engine and geometry-interpretation differences from database differences.

4.3.2 Tally

Tally is a Revit plugin, originally developed by KT Innovations in partnership with Autodesk and now stewarded by Building Transparency, that calculates whole-building or component-level embodied impact using the GaBi/Sphera life cycle inventory database. Tally's database is fixed and vendor-supplied and is generic and internationally (primarily European/North American) sourced. This makes Tally, the representative instance of a generic international dataset condition, contrasted against One Click LCA's German-context dataset and Carbo Life Calculator's controlled dataset. Tally requires a paid license beyond a short trial period (7 days) and fortunately non-commercial academic licensing was obtained from the tool steward for the purposes of data collection.

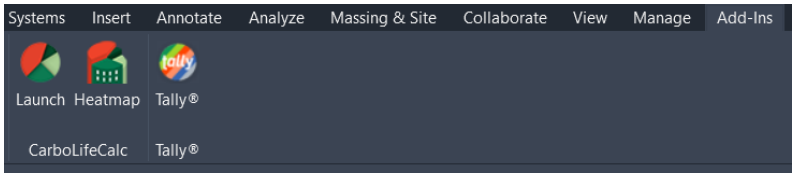


Figure 4.2 CarboLifeCalculator and Tally as Revit Add-Ins

4.3.3 One Click LCA

One Click LCA is a commercial whole-building LCA platform with a dedicated Revit/BIM plugin and a multi-national emission-factor database that includes a specific German dataset linked to ÖKOBAUDAT. This German-context dataset is what allows One Click LCA to serve two roles simultaneously as one of the three tools under comparison, and as the source of the detailed-design baseline, since its ÖKOBAUDAT-linked database keeps the baseline consistent with the German regulatory framework developed.

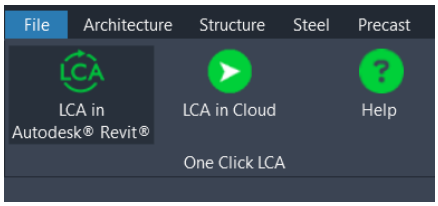


Figure 4.3 One Click LCA as a Revit plugin

4.3.4 Rationale for tool selection and comparative positioning

Table 4.1 summarizes the three tools against the dimensions relevant to the sensitivity analysis namely database source, database editability, and licensing model. This table makes it clear why the three tools, taken together, allow SQ3's 'granularity of underlying emission-factor data' factor to be tested. Tally and One Click LCA represent two independently fixed databases (generic-international versus German-specific), while Carbo Life Calculator, as a user-editable instrument, allows the researcher to hold the database constant across a controlled run and vary only the calculation engine and geometric interpretation.

Table 4.1 Comparative positioning of the three selected BIM-integrated screening tools

Tool	Database source	Database editable?	Licensing	Role in this thesis's design
Carbo Life Calculator	User-defined; open-source, GitHub-hosted	No, dataset selectable	Free, open-source	Controlled instrument; isolates calculation effects
Tally	GaBi/Sphera, generic and international	No, vendor-fixed	Paid (academic license attainable)	Represents generic/international dataset condition
One Click LCA	Multi-national, including German (ÖKOBAUDAT)-linked dataset	Yes, if imported (also dataset selectable)	Commercial	Represents German-specific dataset condition; source of detailed-design baseline

This tool selection deliberately excludes Beacon (Thornton Tomasetti's structural-engineer-focused Revit plugin) and the eLCA/ÖKOBAUDAT combination, notwithstanding their relevance to the German context. Beacon was excluded on practical access grounds, as institutional licensing could not be confirmed within the timeframe. eLCA/ÖKOBAUDAT was considered as a potential fourth, independent baseline source, but was ultimately not used as the calculation baseline.

4.4 Derivation of the LOD 200 Dataset from the Baseline Model

This study derives its LOD 200 (Leistungsphase 2-equivalent) dataset by deliberately simplifying the Snowdon Towers detailed-design structural model, following the element-level definitions set out in the BIMForum LOD Specification. This approach holds the building constant across both design-stage datasets, so that any deviation measured can be attributed to data-resolution effects rather than to differences between independently modelled buildings.

4.4.1 Simplification protocol

The derivation followed a defined, element-by-element protocol, applied uniformly across all structural components in scope; Reinforcement and connection detail removed. LOD 200 structural elements are represented as generalized systems with approximate size, shape, and location only; rebar schedules, connection design, and base-plate detailing present in the LP3 baseline were deleted or completely suppressed in the derived model.

Member sizing rounded to generic/typical dimensions. Precisely engineered column, beam, and slab dimensions in the baseline model were replaced with typical or representative sizes for the structural typology (composite reinforced concrete and steel frame), reflecting LOD 200's approximate size characteristic.

Foundation detail collapsed to generic massing. Baseline foundation elements, with their specific reinforcement and depth detailing, were simplified to generic footing volumes without reinforcement or precise depth specification.

Overall grid, storey heights, and building footprint held unchanged. This aligns with the observation that gridlines and overall massing are typically fixed very early in design and are not what differentiates LOD 200 from LOD 300, the baseline model's grid, storey configuration, and footprint were retained without modification, isolating element-level development as the only varying factor between the two datasets.

Table 4.2 Element-level simplification protocol applied to derive the LOD 200 dataset from the Snowdon Towers baseline

Component	LP3/LOD 300 baseline representation	Derived LP2/LOD 200 representation
Columns	Calculated cross-section	Typical cross-section; no reinforcement detail
Beams	Calculated depth/width; shear and flexural reinforcement	Typical depth & width; reinforcement estimated via mass ratio
Slabs	Calculated thickness	Typical thickness; reinforcement estimated via mass ratio
Foundations	Sized footings; reinforcement and precise depth specified	Generic footing size; no reinforcement or precise depth
Grid / storey geometry	As-designed grid and storey heights	Unchanged from baseline

4.4.2. Quantity derivation approach

Following the two options identified in the design process, the geometry-driven approach was adopted as the primary quantity-derivation method. Each of the three tools automatically calculates material quantities from the simplified LOD 200 geometry. This choice shows the intended functionality of the tools and provides a realistic simulation of how BIM-integrated screening tools would be used in practice during Leistungsphase 2. The alternative benchmark-ratio-driven approach, based on the derived quantity ratios tabulated by D'Amico and Pomponi (2020), was retained as a documented alternative for discussion and not implemented as a second empirical analysis. Doing so would have doubled the data-collection burden while yielding a comparison that is more valuable as a point of discussion than as an additional primary result set.

4.5. Baseline Definition and Database Alignment

Baseline definition and the circularity limitation

This thesis adopts One Click LCA's result on the LP3/LOD 300 baseline dataset as the reference against which all deviation is calculated, rather than an independently generated reference such as ÖKOBAUDAT. All accuracy metrics are therefore calculated as: n being any selected LOD stage

$$\text{Deviation } \% = \frac{(\text{Tool_result_at_LODn} - \text{OneClickLCA_LOD300_baselineresult})}{\text{OneClickLCA_LOD300_baselineresult}} \times 100$$

This is applied to every tool at every design-resolution stage, including One Click LCA's own LOD 200 run compared against its own LOD 300 run.

This decision was made for consistency of database source and calculation environment across all comparison points, and to keep the baseline anchored to the German ÖKOBAUDAT-linked dataset. It carries an important limitation: because One Click LCA serves simultaneously as a tested tool and as the standard the other tools are measured against, this design cannot distinguish genuine calculation error in One Click LCA itself from apparent error in Tally or Carbo Life Calculator. Any systematic bias in One Click LCA's database or calculation logic is inherited by the baseline. Therefore, interpret deviation from baseline as deviation from One Click LCA's detailed-design estimate, not as absolute error against a verified ground truth. This limitation is addressed when interpreting cross-tool comparisons.

Despite this limitation, two comparisons within this design remain unaffected by the baseline's circularity. First, divergence between Tally and One Click LCA at the same design-resolution stage is attributable to database or calculation-methodology differences regardless of which tool is treated as baseline because neither tool's result depends on the other. Second, the LOD 200-to-LOD 300 deviation trend observed within One Click LCA alone is a self-contained comparison requiring no external baseline at all, since it compares One Click LCA to itself at increasing design resolution. As this thesis research question concerns how accuracy changes across design stages, this self-contained comparison is arguably the single arguably direct answer this methodology produces.

Database standardization via Carbo Life Calculator

To isolate the calculation-engine effect from the database effect, Carbo Life Calculator is run twice at each design-resolution stage: once loaded with emission factors matched to One Click LCA's German/ÖKOBAUDAT-linked dataset values (the controlled run), and once left at its own default or researcher-selected values (the uncontrolled run). Because the controlled run uses the same underlying emission factors as the One Click LCA baseline, any remaining deviation between Carbo Life Calculator's controlled result and the One Click LCA result at the same design-resolution stage is linked to differences in geometric interpretation or calculation methodology between the two tools but not to database differences. This yields four data points per design stage: One Click LCA, Tally, Carbo Life Calculator (controlled), and Carbo Life Calculator (uncontrolled).

4.6 Accuracy and Sensitivity Metrics

4.6.1 Deviation calculation

The primary accuracy metric is percentage deviation in total embodied carbon (kg CO2e/m^2 GFA) at the LOD 200-derived dataset relative to the LOD 300/One Click LCA baseline, calculated per tool as (Tool_LOD200_result − OneClickLCA_LOD300_result) / OneClickLCA_LOD300_result × 100, with the sign retained to indicate whether a given tool's early-stage result over or under-estimates the baseline. This produces, across the four data points identified in Section 4.6.2 (One Click LCA, Tally, Carbo Life Calculator controlled, Carbo Life Calculator uncontrolled), four independent deviation percentages at the LOD 200 stage.

4.6.2 One-factor-at-a-time sensitivity design

A one-factor-at-a-time (OFAT) sensitivity analysis isolates the relative contribution of the three deviation-driving factors identified, following the methodological caution raised by Moncaster et al. (2018) that observed deviation may reflect legitimate methodological variation. Each factor is varied independently while the other two are held constant at their baseline (LOD 300) value:

- Structural system assumption. The LOD 200 dataset is calculated twice: once using the correct structural system as confirmed in the LOD 300 baseline (composite reinforced concrete and steel frame system), and once assuming a plausible alternative a designer might reasonably select at Leistungsphase 2 with the same information available (for example, a beam-and-slab system). The resulting difference isolates sensitivity to structural system assumption error.
- Quantity estimation error. The LOD 300 baseline geometry is retained, but material quantities are recalculated using the LOD 200-level simplification protocol applied to that same geometry, isolating the effect of quantity/geometric simplification alone, independent of any change in structural system or database.
- Emission-factor granularity. The LOD 300 baseline quantities are recalculated twice: once using generic ÖKOBAUDAT-equivalent datasets, and once using the equivalent manufacturer-specific EPDs available within One Click LCA's German dataset, isolating the generic versus product-specific database effect as a systematic, conservative bias in early-stage results.

The resulting three results are ranked by magnitude to identify the dominant driver of deviation at the LOD 200 stage, answering SQ3. Table 4.3 summarizes this OFAT design, including which comparisons each factor draws upon.

Table 4.3 One-factor-at-a-time sensitivity analysis design

Factor	Held constant	Varied	Isolates
Structural system assumption	Geometry, database, quantity method	System typology (ideal vs. plausible alternative)	System-choice sensitivity at LOD 200
Quantity estimation error	Geometry (baseline), database	Quantity derivation method (LOD 300 actual vs. LOD 200 simplification applied to same geometry)	Quantity/geometric simplification effect
Emission-factor granularity	Geometry, quantities (baseline)	Database (generic ÖKOBAUDAT-equivalent vs. product-specific EPD)	Generic-vs-EPD conservative markup effect

4.6.3 Applicability threshold definition

To answer this thesis's fourth sub-question (SQ4): under what conditions a simplified LCA method can be considered applicable, an accuracy threshold of ±15 percent is defined in advance of data collection. This value is a researcher-set judgement, not a figure stated in any single cited source, but it is informed by evidence on both sides of the range. On the lower bound, (Atik et al., n.d.), compared two independently applied LCA approaches on the same building envelope and found a minimum difference of approximately 8 percent in Global Warming Potential even under this controlled, indicating that some

deviation is an inherent feature of methodological and tool choice, independent of design-stage data resolution. On the qualitative upper side, Nilsen and Bohne (2019) report that lower BIM Level of Development (such as LOD 200) systematically underestimates environmental impact relative to higher LOD (such as LOD 300), confirming that deviation in this domain can be substantial, without this thesis relying on a specific cited percentage for that upper bound. Positioned above the documented ~8 percent methodological noise floor, and set safely below the 40 - 60 percent range of embodied-carbon reduction Dunant et al. (2021) show is achievable through early-stage structural decisions, ±15 percent represents a threshold small enough to preserve the decision-relevant signal a designer would actually be using a simplified method to detect.

4.7 Operationalization of Sub-Questions SQ1-SQ4

Table 4.4 consolidates the preceding sections into a single, explicit mapping from each of this thesis's four sub-questions (Section 1.3) to the specific methodological procedure that answers it, so that the connection between research question and method is traceable.

Table 4.4 Mapping of sub-questions to methodological procedures

Sub-question	Methodological procedure
SQ1: What data is available at successive stages, and how does this constrain method choice?	HOAI/DIN 276-based data inventory cross-referenced against method-typology compatibility; LOD 200 derivation protocol
SQ2: How large is the deviation between simplified and detailed-design results?	Deviation calculation across four tool/database combinations against the LOD 300/One Click LCA baseline
SQ3: Which factors drive the deviation?	One-factor-at-a-time sensitivity analysis (structural system, quantity error, database granularity)
SQ4: Under what conditions is a simplified method applicable?	Pre-specified ±15% accuracy threshold, cross-tabulated with OFAT factor attribution

4.8 Data Collection Workflow

This section sets out the precise, step-by-step execution sequence followed to generate this thesis dataset, so that the procedure summarized can be replicated independently.

4.8.1 Model preparation

Step 1: Extract the structural model (columns, beams, slabs, foundations) from the Snowdon Towers linked Revit model, isolating it from the architectural and MEP models per the component scope defined

Step 2: Verify and document the extracted model's material assignments (concrete grade, reinforcement specification) and confirm these are internally consistent with the structural system description, establishing the LOD 300 baseline model.

Step 3: Duplicate the baseline model and apply the element-level simplification protocol to produce the LOD 200 derived model, retaining the unmodified grid and storey geometry.

4.8.2 Tool runs

Step 4: Run One Click LCA on the LOD 300 baseline model using its German/ÖKOBAUDAT-linked dataset, generating the reference baseline result.

Step 5: Run One Click LCA, Tally, and Carbo Life Calculator (uncontrolled) on the LOD 200 derived model, each using its own default/native database, generating three of the four LOD 200-stage data points.

Step 6: Load German/ÖKOBAUDAT-linked emission factors in Step 4 into Carbo Life Calculator's database by selecting in the drop-down menu; re-run Carbo Life Calculator on the LOD 200 derived model using this controlled database, generating the fourth LOD 200-stage data point (Carbo Life Calculator, controlled).

Step 7: Run One Click LCA on the LOD 200 derived model a second time (already captured in Step 5) to complete the self-contained LOD 200-to-LOD 300 comparison independent of baseline circularity.

4.8.3 Sensitivity analysis runs

Step 8: Using One Click LCA, re-run the LOD 200 derived model with the alternative structural system assumption substituted for the correct system, holding geometry, database, and quantity method constant, to isolate structural system assumption sensitivity.

Step 9: Using One Click LCA, apply the LOD 200 quantity-simplification protocol to the LOD 300 baseline geometry, holding the baseline's correct structural system and database constant, to isolate quantity estimation error.

Step 10: Using One Click LCA, recalculate the LOD 300 baseline quantities using generic ÖKOBAUDAT-equivalent datasets in place of the manufacturer-specific EPDs used in Step 4, holding geometry and quantities constant, to isolate the generic versus EPD database effect.

This ten-step sequence generates a total of eight primary result values (four tool/database combinations at LOD 200, one LOD 300 baseline, and three OFAT sensitivity variants), from which all deviation percentages and sensitivity rankings are calculated.

4.9 Attribution Logic for Multi-Tool Comparison

Because this thesis design produces deviation from multiple, structurally different comparisons (tool-to-tool, database-to-database), an attribution logic is required to interpret which comparison isolates which underlying cause. Three attribution rules are applied:

- Rule 1 - Database attribution. If Tally and One Click LCA diverge from one another at the same design-resolution stage (both run on identical geometry), that divergence is attributed to differences in underlying emission-factor database, since both tools apply their own fixed, vendor-supplied database to the same input geometry.
- Rule 2 - Calculation-engine attribution. If Carbo Life Calculator's controlled run (using One Click LCA's database values) still diverges from One Click LCA's result on the same geometry, that residual divergence is attributed to differences in calculation methodology or geometric interpretation between the two tools' underlying engines, since the database variable has been held constant by design.
- Rule 3 - Design-stage attribution. If a consistent deviation pattern is observed across multiple or all tools when moving from the LOD 300 baseline to the LOD 200 derived dataset, that pattern

is attributed to genuine quantity/geometric-resolution effects, since it persists independently of which tool's database or calculation engine is used.

These three rules are applied jointly, not in isolation: where Rule 1 and Rule 2 together account for only a small proportion of total observed deviation at the LOD 200 stage, this is read as evidence that Rule 3 (design-stage data-resolution effect) is the dominant mechanism, supporting the central question regarding how accuracy changes with design-stage progression, independent of which specific screening tool a practitioner might choose to use.

4.9.1 Reproducibility and Data Management

All model files, exported quantity take-offs, tool-generated result reports, and the emission-factor mapping table used to align Carbo Life Calculator's controlled run with One Click LCA's German dataset are retained and documented in the appendices to this thesis, to support independent verification of the deviation and sensitivity results. Where a tool's output format does not support kg CO2e/m^2 GFA as a reported unit, the conversion applied (using the gross floor area is documented alongside the raw tool output, so that any recalculation error introduced during unit conversion is distinguishable from genuine tool-level deviation. Version numbers and database release dates for all three tools (Carbo Life Calculator, Tally, One Click LCA) are recorded at the time of each run, since emission-factor databases are periodically updated and a later replication attempt using updated database versions should not be assumed to reproduce this thesis's specific numeric results even when the same methodology is followed.

4.9.2 Worked Illustration of the Deviation Calculation

To make the accuracy reliable before it is applied to this thesis results, this section works through a hypothetical numeric illustration using placeholder values, calibrated to be broadly consistent with the magnitude of deviations reported in the literature reviewed. These illustrative figures are not this thesis's actual findings; they exist solely to demonstrate how the calculation works in practice.

Suppose the One Click LCA baseline run on the LOD 300 dataset returns a result of 420 kg CO2e/m^2 GFA. Suppose the same tool, run on the LOD 200 derived dataset, returns 510 kg CO2e/ m^2 GFA. Applying the formula: (510 − 420) / 420 × 100 = +21.4 percent. This positive deviation would indicate that the LOD 200 result overestimates the baseline by approximately 21 percent, a magnitude that would fall outside this study’s specified ±15 percent applicability threshold, and would accordingly trigger the OFAT sensitivity analysis to determine whether this overestimation is applicable primarily to conservative generic emission factors, to the quantity-simplification protocol, or to a structural system misassumption, before a final judgement (applicable, applicable with limits, or not applicable) is reached for that specific tool at that design-resolution stage. This same calculation is repeated independently for Tally, Carbo Life Calculator (controlled), and Carbo Life Calculator (uncontrolled), yielding four deviation percentages. Table 4.5 illustrates, using the same hypothetical values extended across all four tool/database combinations, how these four results would be tabulated and read together before the logic is applied.

Table 4.5 Illustrative (hypothetical, non-empirical) deviation summary across the four tool/database combinations at the LOD 200 stage

Tool / database condition	Illustrative LOD 200 result (kg CO2e/m^2 GFA)	Illustrative deviation from LOD 300 baseline (420)	Provisional applicability (±15% threshold)

One Click LCA (German/ÖKOBAUDAT-linked)	510	+21.4%	Outside threshold - requires OFAT attribution
Tally (GaBi/Sphera, generic)	545	+29.8%	Outside threshold - requires OFAT attribution
Carbo Life Calculator, controlled	465	+10.7%	Within threshold - applicable
Carbo Life Calculator, uncontrolled (default database)	500	+19.0%	Outside threshold - requires OFAT attribution

Reading this illustrative table against the attribution logic, the controlled Carbo Life Calculator run (using the same database as the One Click LCA baseline) falls within the applicability threshold while the uncontrolled run and Tally do not, Rule 1 (database attribution) would be implicated as a meaningful contributor to the overall deviation pattern, motivating closer examination of the generic versus EPD OFAT result specifically before a final applicability judgement is reached. This is precisely the kind of reasoning chain applied to this study.

4.9.3 Communicating Result Uncertainty

Following the normative principle that early-stage LCA output should communicate uncertainty, this thesis results are reported with their associated range across the four tool/database combinations at the LOD 200 stage. Where the four combinations converge to within a narrow range, this convergence is reported as evidence of a robust, tool-independent finding; where they diverge substantially, the full range is reported alongside the attribution analysis explaining which factor is responsible for the spread, rather than collapsing the divergence into a single misleadingly precise mean value. This reporting convention is applied consistently and is revisited when discussing the practical implications of the findings for German structural design practice.

This methodology does not involve any people as participants, personal data, or survey instrumentation, and accordingly did not require formal research-ethics review beyond standard institutional data-management practice. Two practical compliance matters were nonetheless addressed before to data collection. First, all three tools used in this study were accessed under terms consistent with their respective academic or open-source licensing provisions, Tally's non-commercial academic license was confirmed in writing with Building Transparency prior to any data collection, and no tool output is reproduced in this thesis beyond the extent permitted for academic research and citation purposes. Second, the Snowdon Towers sample model is distributed by Autodesk as a sample project for demonstration and research purposes; its uses in this thesis are limited to structural quantity extraction and simplification for academic analysis, consistent with that intended purpose, and no proprietary or client-confidential project data is involved at any stage of this methodology.

4.9.4 Limitations of the Methodology

Single-case design. The reliance on a single building (Snowdon Towers) limits statistical generalizability to other structural systems or building typologies; findings should be read as indicative of the

mechanisms and approximate magnitude of stage-to-stage and tool-to-tool deviation rather than as universally applicable percentage figures across German construction practice as a whole.

Baseline circularity. Using One Click LCA's detailed-design result as the accuracy baseline means this methodology cannot distinguish genuine calculation error in One Click LCA from apparent error in the other tools; deviation from baseline should be read as deviation from One Click LCA's estimate, not as absolute error against independently verified truth.

Derived, not independently authored, early-stage dataset. The LOD 200 dataset is produced by simplifying the LOD 300 baseline, which removes the between-building variable but introduces a different risk: the simplification protocol, however closely it follows the BIMForum LOD Specification, reflects the researcher's own interpretation of what a Leistungsphase 2 model would plausibly contain independently produced early-design fact.

Tool and licensing constraints. Beacon was excluded from this thesis's tool selection on practical licensing-access grounds despite its direct relation and relevance to structural engineering practice; its inclusion in future work could strengthen the generalizability of this thesis's tool-comparison findings.

Pre-specified applicability threshold as a bounded, researcher-set judgement. The ±15 percent threshold used to classify applicability is set by the researcher and is not stated in any single cited work; it is positioned above an empirically documented minimum inter-method deviation of approximately 8 percent (Atik, Domenech Aparisi and Raslan, 2021) and is qualitatively consistent with Nilsen and Bohne's (2019) finding that lower LOD systematically underestimates impact relative to higher LOD, without this thesis attributing a specific numeric ceiling to that paper. Alternative thresholds could reasonably be argued for, and accordingly the sensitivity of this thesis's applicability conclusions to this threshold choice.

German-specific scope. This methodology is built around German regulatory and data infrastructure (HOAI, DIN 276, ÖKOBAUDAT-linked datasets). The technical deviation mechanisms identified through the OFAT analysis are expected to be informative beyond the German context, but the conclusions reached through the pre-specified threshold are scoped specifically to this study and should not be assumed to transfer to other national regulatory contexts without independent verification.

5

CASE STUDY AND COMPARATIVE DATASETS

5.1 Building and structural system description

The case study building is Snowdon Towers, Autodesk's official Revit sample project. As per Autodesk's own project documentation, the building is a mixed-use development located in Brownsville, Pennsylvania, USA, developed on a downtown infill site previously occupied by a cluster of disused structures demolished in November 2020; the sample project reimagines the site using a point cloud of the original façades as its design basis. Table 5.1 summarizes the building's program, drawn from Autodesk's project documentation.

Table 5.1 Snowdon Towers program summary (source: Autodesk project documentation)

Use	**Area / scale**
Retail	4,921 SF across three tenant spaces (street level)
Office	6,984 SF across three tenant spaces (upper levels)
Restaurant	2,600 SF, street level, with upper-level mezzanine dining
Residential	18,235 SF, 21 units (studio and one/two-storey loft units, Level 2 and above)
Outdoor public space	8,571 SF, including a street-level pocket park and a green roof with bandstand/bleacher seating
Parking garage	10,281 SF, 20 spaces, lower level

For this thesis's LCA calculations, two distinct floor-area figures apply, corresponding to the two area conventions used by the three tools selected for analysis: a Gross Floor Area (GFA) of 6,829 m^2, used as the normalization basis by One Click LCA and Tally and adopted as this thesis's functional unit and a Gross Internal Area (GIA) of 5,350 m^2, used natively by Carbo Life Calculator and reconciled to the GFA basis via the conversion procedure.

5.1.1 Structural system

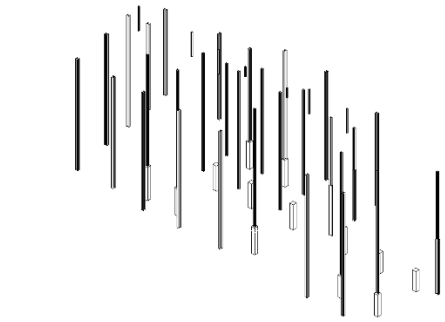
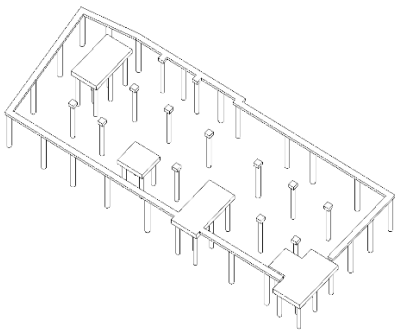
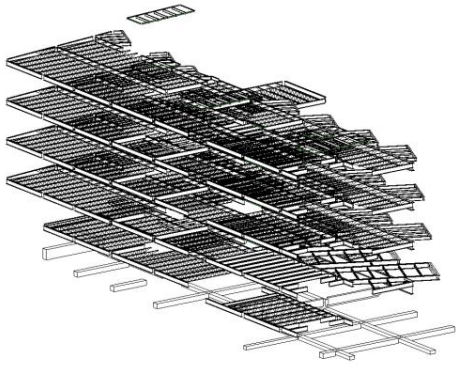
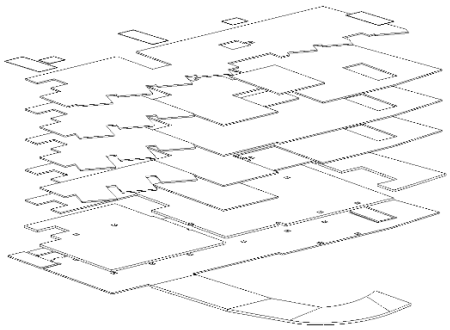
The structural system examined in this thesis is a composite reinforced concrete and structural steel system. Autodesk's project documentation states that the structural model 'showcases both steel and

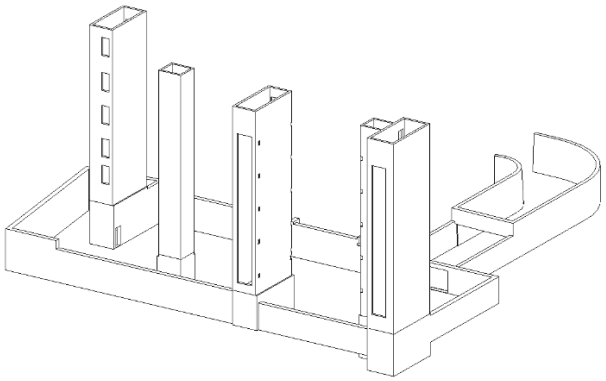
concrete systems.' In practice, this manifests as cast-in-situ concrete forming the building's primary vertical structure (columns), floor slabs, and foundations, combined with a structural steel floor-framing system comprising wide-flange (W-shape) beams and open-web steel joists of varying depth, consistent with common composite construction practice for a US commercial/mixed-use building of this scale.

Because the Snowdon Towers sample project does not specify a finalized concrete compressive strength for all cast-in-place elements, a value of 4,000 psi (28 MPa) was adopted uniformly across both the baseline and derived datasets, representing a typical specification for mid-rise composite construction of this type and ensuring this assumption does not introduce a discrepancy between the two design-stages compared in this study.

Structural steel framing follows a mixed-depth system organized by span and load: short-span members are represented predominantly by W8X10 sections, mid-span members by W12X26 and W14X30 sections, and long-span members by open-web steel joists of the K-series (for example, 16K2 and 20K6), consistent with a floor system combining primary framing, secondary framing, and joist infill of varying capacity across the building's structural bays. This mixed-depth framing system is described in more structural and derivation-specific detail later in this chapter, since it is the component of the structural system that required a substantial simplification when deriving this thesis's LOD 200 dataset.

Table 5.2 Table showing the structural system of Snowdon Towers

 T	
Structural columns	Structural foundations
	
Structural framing	Structural slabs



Structural walls

5.1.2 Level structure

The Snowdon Towers structural model is organized across a level structure comprising Levels 1 through 5, a roof level (R2), a parapet level, a dedicated parking level, and a top-of-footing reference level, reflecting the building's mixed-use structure: lower levels accommodate retail, restaurant, and parking uses, with residential loft units occupying Level 2 and above, consistent with Autodesk's project documentation. Autodesk's documentation additionally notes that Level 1 occurs along a sloped street with a six-foot total drop from east to west, requiring multiple view ranges and plan regions to represent correctly in Revit; this geometric complexity is confined to Level 1 and does not affect the structural framing levels (L2 through R2).

This level structure is preserved unchanged between the LOD 300 baseline and the LOD 200 derived dataset, consistent with the decision to hold grid, storey heights, and building footprint constant across both design-resolution stages, so that only element-level development varies between the two datasets.

Autodesk's documentation further notes that the building incorporates three stair cases and two elevators, with stair and railing functionality modelled to align with typical industry practice for repeating vertical-circulation elements. These vertical-circulation cores interact with the structural framing system at each level (providing localized support and load transfer points) but are themselves architectural, and are accordingly excluded from the structural quantities reported in this thesis. Their presence is noted here only because the structural bays immediately adjacent to the cores exhibit denser framing than typical bays elsewhere in the floor plate, a detail visible in the structural framing schedules (Table 5.1a) and relevant context for interpreting any localized concentration of steel-framing simplification effort.

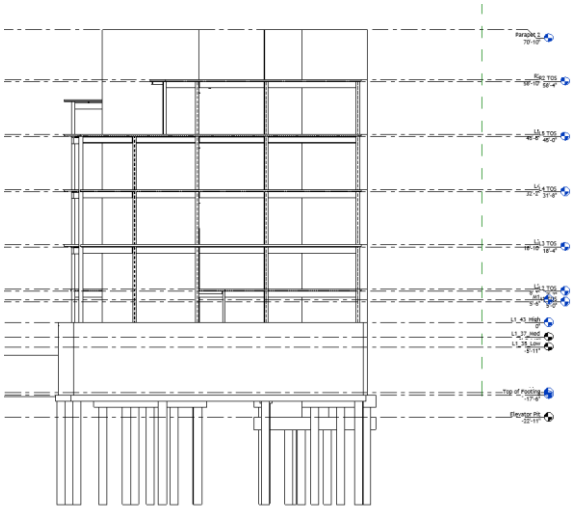


Figure 5.1 Illustration of the level structure

5.1.3 Documented schedule inventory

To support traceability of the quantities underlying both datasets, a consistent set of Revit schedules was generated and retained at both design-resolution stages. Table 5.2 lists this schedule inventory; the LOD 300 baseline additionally retains an Area Schedule and Level Schedule not regenerated at LOD 200, since floor area and level structure are held constant between the two stages and were not considered to require re-verification at the derived resolution. Schedules for LOD 300 and 200 to be attached to the appendix

Table 5.3 Structural schedule inventory retained for the LOD 300 baseline and LOD 200 derived datasets

Schedule	LOD 300 baseline	LOD 200 derived
Area Schedule	Retained	Area held constant
Level Schedule	Retained	Levels held constant because they are defined at LOD 200
Structural beam system	Retained	Significant changes made to generate generic elements
Structural columns	Retained	Minimal changes made due to structural inconsistency they may cause
Structural foundations	Retained	Minimal changes
Structural walls	Retained	Minimal changes
Structural framing	Retained	Changes made to derive generic elements

5.2 Baseline Dataset (LOD 300 / Leistungsphase 3)

The baseline dataset represents the Snowdon Towers structural model at its native resolution, as corresponding to HOAI Leistungsphase 3 (Entwurfsplanung) and approximately LOD 300. At this resolution, structural elements carry approximate but individually defined sizing, and connections are represented generically (for example, beam-to-beam, beam-to-column, and drilled-pier-at-continuous-footing conditions are all modelled) without fabrication-level detailing; reinforcement is represented schematically but not calculated bar schedules.

The baseline LCA calculation was performed using One Click LCA, configured with its 'LCA for DGNB 2023' calculation template and its German, ÖKOBAUDAT-linked emission-factor dataset, consistent with the German regulatory framing and the tool-selection rationale. Consistent with the system boundary, the reported baseline figure is restricted to modules A1-A3 (product stage).

The resulting baseline value is 197.39 kg CO2e/m^2 GFA (A1-A3), calculated on a Gross Floor Area of 6,829 m^2. This figure is adopted as the reference baseline against which all Leistungsphase 2/LOD 200 stage results and all OFAT sensitivity variants are compared, per the baseline definition and its associated circularity limitation that was laid out. As discussed further in this chapter, this baseline figure was derived from One Click LCA's own aggregated project-level calculation output and not from a manually summed resource-line export, avoiding the duplication risk identified during the earlier data-verification process.

5.3 Derived Dataset (LOD 200 / Leistungsphase 2)

The LOD 200 dataset was derived from the LOD 300 baseline model by applying the six-step Revit downgrade procedure and element-level simplification protocol. This section documents how that procedure was applied specifically to Snowdon Towers' structural elements, including the element-family removals, the beam and joist size-mapping decisions, and the resulting characteristics of the derived model.

5.3.1 Category and family removal

Following Step 2 of the downgrade procedure (strip detail by category and filters), the following families and categories were removed from the derived model in their entirety, either because they fall outside this structural component scope or because they represent fabrication-level detail inconsistent with LOD 200:

- All rebar
- Embedded connection detail families (base plates, gussets, and similar fabrication-level connection components)
- Non-structural categories outside the component scope: cable trays, ceilings (basic and compound), curtain panels and mullions, detail items (bolts, nuts), doors and door openings, windows and window openings, and generic non-structural models (for example, Enscape camera objects and generic opening-wall families)

This removal implements the reinforcement and connection detail removed and foundation detail collapsed to generic massing rules from the methodology, and reflects Step 6 of the downgrade procedure (documenting the resulting model as one in which primary geometry and approximate sizes are reliable, while detailed connections, reinforcement, and fabrication information have been removed or simplified).

5.3.2 Beam and joist size mapping

As noted earlier, the structural steel floor-framing system required a substantial simplification of any component category, since the LOD 300 baseline's mixed-depth beam and joist system (short-span W8X10 sections, mid-span W12X26/W14X30 sections, and long-span K-series joists such as 16K2 and 20K6) does not correspond to a single generic LOD 200 representation in the way a uniform concrete flat-slab system might. Rather than collapsing every member to one generic size which would misrepresent the load-path logic of the framing system, members were grouped and mapped by approximate depth and span, on the explicit assumption, stated in this thesis's working documentation, that existing W-shape and joist series have been grouped by approximate depth and span. Table 5.4 summarizes the resulting mapping logic by structural tier.

Table 5.4 Beam and joist size-mapping applied to derive the LOD 200 structural framing dataset

Framing tier	**LOD 300 baseline representation**	**LOD 200 treatment**
Top-tier / highest-load members	16K2 and comparable heavy joist sections	Retained at existing size; not downgraded, since these members were judged already close to a generic LOD 200 representation
Medium-tier members and joists	Mixed W-shape and mid-depth joist sizes	Reduced to a smallest set of generic representative sizes
High-to-medium tier long-span members	20K6 and comparable deep joist sections	Reduced to more generic, coarser equivalent sizes
General structural framing (all tiers)	Member-specific sizing per baseline structural analysis	Adjusted to a representative size for every tertiary use of the element, with remaining sizes collapsed to generic equivalents; framing sizes overall severely reduced to generic size relative to baseline

5.3.3 Treatment of columns, foundations, and floors

Unlike the beam and joist framing system, structural columns, foundations, and floors required comparatively little adjustment when moving from the LOD 300 baseline to the LOD 200 derived dataset. Column sizes were adjusted only slightly, since the baseline's column sizing was judged already close to a generic LOD 200 representation. Foundations were left almost as modelled in the baseline, for the same reason. Structural floors (slabs) were adjusted only slightly especially with their thickness, again reflecting that floor thickness and outline in the baseline were already close to LOD 200 resolution, consistent with the general observation that gridlines, storey configuration, and several element categories are typically fixed very early in design and do not differentiate strongly between LOD 200 and LOD 300.

This differential pattern and simplification for structural framing, minimal simplification for columns, foundations, and floors means that the overall LOD 200-versus-LOD 300 deviation should not be read as uniformly distributed across component types; the framing system is expected to be the dominant contributor to any observed deviation, a hypothesis returned to a component-level discussion.

5.3.4 Visual and schedule level detained

Detail Level was set to Coarse in plan and 3D views for LOD 200, so that Revit's graphic simplification reinforces the underlying geometric simplification rather than only affecting element data. Structural schedules were regenerated at the derived resolution, covering the structural beam system, structural framing (across four continuation schedules reflecting the building's floor levels and framing tiers), structural columns, structural foundations, and structural walls, mirroring the equivalent schedule set retained for the LOD 300 baseline. The full before/after image set (baseline views, LOD 200 coarse views, structural connection details, and both schedule sets) is retained in this thesis supporting documentation (Appendix)

5.3.5 Quantity derivation method applied

The geometry-driven approach was applied throughout each of the three tools calculated material quantities from the simplified LOD 200 geometry described above, rather than from typological benchmark ratios. This means the LOD 200 dataset's quantities reflect the combined effect of (a) genuine geometric simplification and (b) each tool's quantity take-off and emission-factor logic.

5.4 Tool outputs at the LOD 200 Stage

Following the ten-step data collection workflow, the LOD 200 derived dataset was processed through all three tools, yielding four data points: One Click LCA and Tally, each using their own default/native database, and Carbo Life Calculator, run twice using its Materials template (controlled condition) and Simplified template (uncontrolled condition). All Carbo Life Calculator figures reported below have already been converted from their native Gross Internal Area basis (5,350 m^2) to the Gross Floor Area basis (6,829 m^2).

Table 5.5 reports these four results in absolute terms (kg CO2e/m^2 GFA, A1-A3) alongside their percentage deviation from the LOD 300 baseline established in (197.39 kg CO2e/m^2 GFA. Deviations are reported here as calculated values only, their attribution to specific underlying causes (database, calculation engine, or design-stage effects) is addressed later using the attribution logic.

Table 5.5 LOD 200-stage results across all four tool/database conditions, with deviation from the LOD 300 baseline

Tool / condition	LOD 200 result (kg CO2e/m² GFA, A1-A3)	Deviation from LOD 300 baseline (197.39)
One Click LCA (ÖKOBAUDAT/German dataset)	211.89	+7.35%
Tally (GaBi/Sphera, generic international)	244.36	+23.80%
Carbo Life Calculator, Materials template (controlled)	213.88	+8.35%
Carbo Life Calculator, Simplified template (uncontrolled)	282.52	+43.13%

Two descriptive observations on this dataset are recorded here, with fuller interpretation deferred to a later chapter. First, all four results overestimate the LOD 300 baseline (all deviations are positive), meaning no tool/condition combination underestimated embodied carbon at the LOD 200 stage for this case study, a directionally consistent pattern across independently calculated results. Second, the four results span a wide absolute range, from +7.35 percent (One Click LCA) to +43.13 percent (Carbo Life Calculator, Simplified template), indicating that tool and database choice materially affects the magnitude of apparent deviation even though geometry was held identical across all four runs, consistent with (Moncaster et al., 2018) methodological-variation caution.

5.5 Sensitivity Analysis results of OFAT

Following the one-factor-at-a-time (OFAT) sensitivity design set out, three additional runs were performed using One Click LCA to isolate the contribution of structural system assumption, quantity estimation error, and emission-factor granularity respectively, corresponding to Steps 8-10 of the data collection workflow. Table 5.5 reports the raw results of these three runs, again alongside their deviation from the 197.39 kg CO2e/m² GFA baseline.

Table 5.6 OFAT sensitivity analysis raw results (One Click LCA)

OFAT run	Description	Result (kg CO2e/m² GFA)	Deviation from baseline
Step 8	LOD 200 dataset recalculated using a plausible alternative structural system assumption in place of the confirmed composite system	186.00	-5.77%
Step 9	LOD 300 baseline geometry recalculated using the LOD 200 quantity-simplification protocol isolating quantity estimation error alone	212.00	+7.40%
Step 10	LOD 300 baseline quantities recalculated using the alternative (EPD-labelled) emission-factor dataset, isolating emission-factor granularity	241.57	+22.38%

Point to note are recorded descriptively here is Step 8 (structural system assumption) is the only OFAT run producing a negative deviation of the three, meaning that substituting a plausible alternative structural system at the LOD 200 stage moved the result closer to, and then past, the baseline in the opposite direction from every other result in this chapter, a finding revisited in ranking of deviation-driving factors.

5.6 Cross verification and Data Quality Notes

This section documents the verification steps applied to the datasets presented in this chapter, and records the data-quality issues identified during their collection, consistent with the reproducibility and uncertainty-communication principles set out.

5.6.1 Baseline verification and the resolved duplication concern

An earlier, superseded LOD 300 baseline export file (a manually compiled One Click LCA resource table) was found during the data-verification process to contain apparent duplicate line items across several material categories, which would have inflated a manually summed A1-A3 total to approximately 329.75 kg CO2e/m² GFA had it been used. This figure was not adopted. The 197.39 kg CO2e/m² GFA baseline reported in Section 5.2 was instead taken from One Click LCA's own aggregated project-level calculation output, avoiding the row-duplication risk present in the manually compiled export. This resolution is recorded here so that the discrepancy between the two figures, if encountered elsewhere in this study supporting materials, is understood as a resolved data-quality issue but not an unexplained inconsistency.

5.6.2 Carbo Life Calculator cross-verification

The Carbo Life Calculator Materials-template (controlled) result was independently cross-checked against the tool's own Overview summary screen. The Overview screen reports an A1-A3 total of 1,144.26 tCO2e against a Total GIA of 5,350 m^2, which recalculates to 213.88 kg CO2e/m^2 GIA (1,144,260 kg CO2e ÷ 5,350 m^2) - an exact match to the figure reported in Table 5.5.

A further, independent cross-check was performed by summing per-element embodied carbon values from the raw Carbo Life Calculator project files (.clcx format) for both the controlled and uncontrolled runs. This raw-file recomputation produced totals approximately 6 percent higher than the tool-reported figures in both cases (300.58 versus 282.52 kg CO2e/m^2 GIA for the uncontrolled run; 227.42 versus 213.88 kg CO2e/m^2 GIA for the controlled run), pointing to runtime adjustments (waste factors, uncertainty factors, or module-inclusion toggles) applied by the tool's calculation engine that are not fully captured by summing stored per-element values alone. Also to note, the ratio between the uncontrolled and controlled results is nearly identical between the two calculation approaches (1.322 from the raw-file recalculation versus 1.321 from the tool-reported figures), indicating that the relative relationship between the two Carbo Life Calculator conditions, therefore the database-granularity sensitivity finding this comparison is designed to support is sufficient, even though the raw project files could not be used to independently reproduce the tool's exact absolute output.

5.6.3 Default uncertainty factor

Carbo Life Calculator's Overview screen states explicitly that its reported values are based on a calculated uncertainty factor of 10.00 percent, applied by default within the tool. This uncertainty margin is embedded within both the 213.88 and 282.52 kg CO2e/m^2 GFA figures reported, meaning Carbo Life Calculator's results are reported on a systematically more conservative basis than One Click LCA and Tally.

6

ACCURACY OF SIMPLIFIED METHODS ACROSS DESIGN STAGES

This chapter reports and interprets the embodied carbon results generated for the Snowdon Towers case study, a mixed-use building combining reinforced concrete and structural steel construction in Brownsville, Pennsylvania. Two design-resolution datasets were assembled from a single structural model: a reference dataset reflecting design detail comparable to a Leistungsphase 3 (Entwurfsplanung) stage, and a simplified dataset reflecting design detail comparable to an earlier Leistungsphase 2 (Vorplanung) stage, It was derived by removing reinforcement, connection, and fabrication information from the reference model while holding grid, storey heights, and building footprint unchanged. Four tool-and-database conditions were applied to the simplified dataset - One Click LCA, Tally, and Carbo Life Calculator run twice using its Materials and Simplified emission-factor templates, and then three additional single-factor sensitivity runs isolated structural system assumption, quantity estimation method, and emission-factor granularity as distinct sources of potential deviation. All results reported below cover product-stage impacts (A1-A3) only, normalized to a Gross Floor Area of 6,829 m2, with Carbo Life Calculator's native Gross Internal Area (5,350 m2) figures converted onto this same basis for comparability.

6.1. Embodied Carbon Results by Stage

The reference dataset, calculated using One Click LCA configured with its German, database-linked emission-factor set, returned a product-stage embodied carbon intensity of 197.39 kg CO2e per square metre of Gross Floor Area. This figure anchors every comparison in this chapter and was independently cross-checked against the calculating tool's own aggregated project summary, reducing the risk that double-counted line items could have inflated the figure.

The simplified dataset was processed through four tool-and-database combinations. Table 6.1 reports the resulting embodied carbon intensities in absolute terms.

Table 6.1 Embodied carbon intensity (A1-A3, kg CO2e/m² GFA) across the reference dataset and four simplified-stage tool/database conditions

Dataset / condition	**Embodied carbon intensity (kg CO2e/m² GFA)**
Reference dataset (One Click LCA, German dataset)	197.39
Simplified dataset - One Click LCA	211.89
Simplified dataset - Tally	244.36
Simplified dataset - Carbo Life Calculator (Materials template- controlled)	213.88
Simplified dataset - Carbo Life Calculator (Simplified template-uncontrolled)	282.52

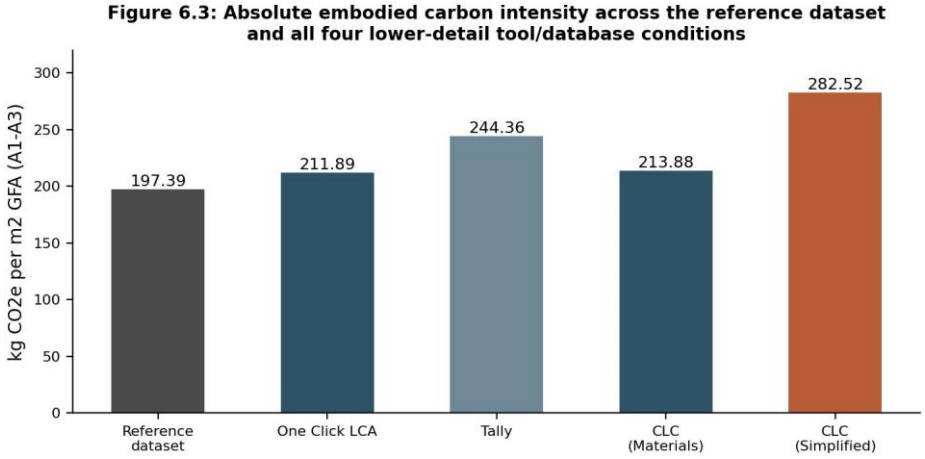


Figure 6.1 Absolute embodied carbon intensity across the reference dataset and all four simplified-stage tool/database conditions.

For clarity, the materials template is what is previously described as the controlled run and the simplified template is the uncontrolled run. These are referred to as templates because they appear as such in the drop down in Carbo Life Calculator. Every simplified-stage result rest above the reference figure. None of the four tool-and-database combinations produced an underestimate, a pattern that holds regardless of which database or calculation engine was used. The narrowest gap belongs to One Click LCA, whose own simplified-stage run (211.89) sits only 14.50 kg CO2e/ m2 above its reference-stage run, a self-contained comparison unaffected by any difference between tools, since both figures come from the same calculation engine and the same emission-factor source. The widest gap belongs to Carbo Life Calculator's Simplified template, whose result (282.52) exceeds the reference figure by more than 85 kg CO2e/ m2, nearly one and a half times the reference value itself.

A further cross-check was carried out on the two Carbo Life Calculator results by summing embodied carbon from the tool's own project files. This raw recalculation produced totals roughly six percent higher than the reported figures in both the Materials-template and Simplified-template conditions, plausibly reflecting a waste factor, uncertainty adjustment, or module-inclusion setting applied internally by the tool at the point of final reporting. What matters for the comparison in this chapter is that the relationship between the two conditions survived this cross-check almost exactly: the ratio between the Simplified-template and Materials-template totals came out at 1.322 from the raw recalculation against 1.321 from the tool's own reported figures. The absolute numbers used throughout this chapter are therefore the tool-reported values in Table 6.1, with the relative comparison between the two Carbo Life Calculator conditions treated as independently corroborated.

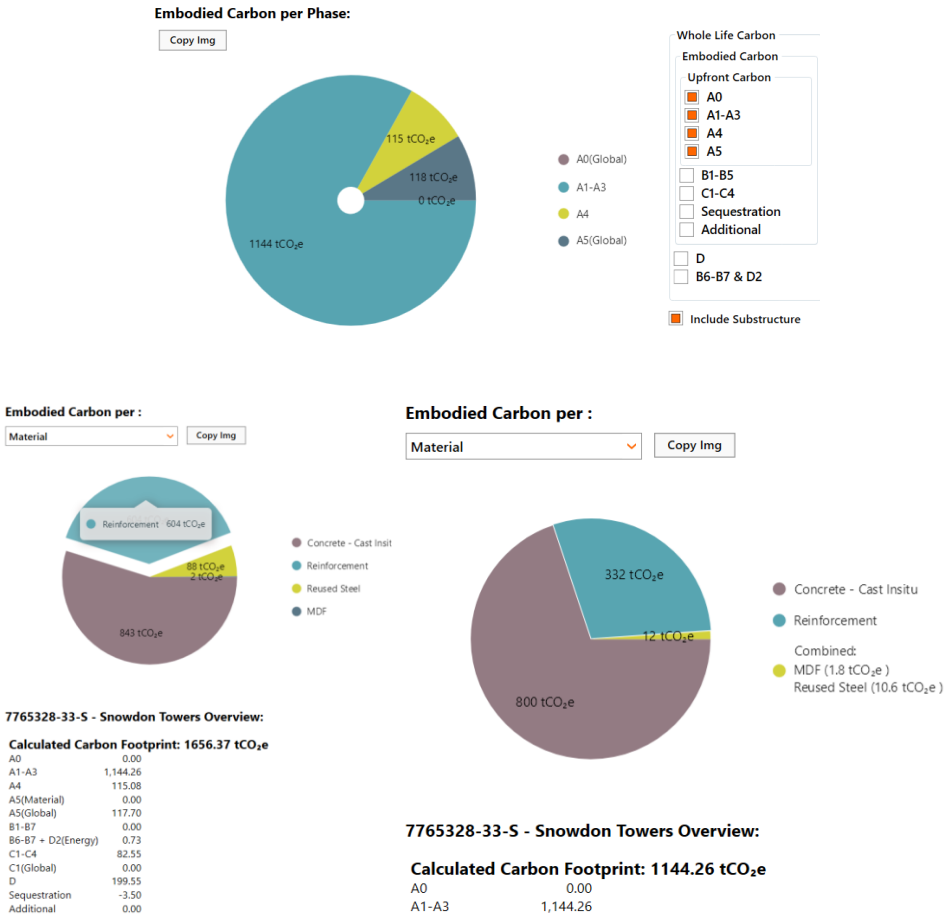


Figure 6.2 Screenshot of the Carbo Life Calculator Overview screen showing the 1,144.26 tCO2e / 213.88 kg CO2e per m² breakdown

Material composition offers a further way to read the reference figure before turning to how each condition deviates from it. Carbo Life Calculator's own material-level breakdown of the reference dataset attributes roughly 69.8 percent of total embodied carbon to cast-in-situ concrete, around 29 percent to steel reinforcement, and the remainder to structural steel framing and a small allowance for other materials including reused steel and engineered wood products. Concrete therefore carries the largest single share, consistent with its role forming the building's columns, slabs, and foundations, but reinforcement and structural steel together account for close to two-fifths of the total - a large enough share that any simplification affecting how steel quantities are estimated could plausibly move the overall result by a meaningful margin, a possibility examined later in this chapter.

6.1.1.A brief account of each condition

One Click LCA's own simplified-stage run produced the smallest movement away from its reference figure of any condition tested, which is notable because it is the only comparison in this chapter unaffected by any difference in calculation engine or emission-factor source. Both runs came from the same tool, the same database, and the same underlying calculation logic, with only the level of geometric detail changed between them. Tally's simplified-stage run, calculated using its own generic, internationally sourced database, produced a considerably larger movement, consistent with the tool

applying material-average emission factors not specifically calibrated to the geographic or regulatory context this case study otherwise draws on. Independent evidence from Tally's reporting structure supports the underlying premise of this caveat, even where it cannot resolve it . Tally reports embodied carbon by material division, and its breakdown for the simplified-stage dataset shows structural steel framing reported entirely separately from concrete and its embedded reinforcement. This contributes 20 percent of total Global Warming Potential, with concrete and its integral rebar accounting for the remaining 80 percent. This confirms that structural steel framing is a substantial, non-trivial contributor to this building's embodied carbon. It does not establish what Carbo Life Calculator's undifferentiated reinforcement figure actually contains, but it does corroborate the assumption motivating that caveat; a steel framing system of this building's scale is large enough that how a tool classifies and reports it materially affects the interpretability of any material-level breakdown. Drawn from that tool Carbo Life Calculator's Materials-template run (controlled), using more product-oriented factors, produced a result close to One Click LCA's despite coming from an entirely different calculation engine. This suggested the two tools converge when both are given comparably specific underlying data. Carbo Life Calculator's Simplified-template run, its most generic configuration, produced by far the largest movement of any condition.

6.2. Deviation from the Reference Dataset

Percentage deviation was calculated for each of the four tool/database conditions relative to the 197.39 kg CO2e/ m2 GFA reference figure. Table 6.2 presents these deviations alongside a provisional applicability classification, applying a pre-specified threshold of ±15 percent: a condition falling inside this band is classified as applicable, and a condition falling outside it is classified as applicable with limits or not applicable, depending on whether the excess deviation can be traced to a correctable input choice.

Table 6.2 Deviation from the reference dataset and provisional applicability classification

Condition	Deviation	Provisional classification
One Click LCA	+7.35%	Applicable
Tally	+23.80%	Outside threshold
Carbo Life Calculator (Materials template)	+8.35%	Applicable
Carbo Life Calculator (Simplified template)	+43.13%	Outside threshold

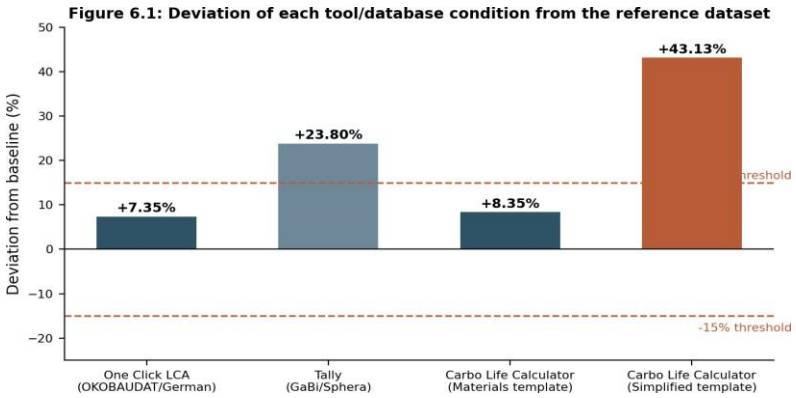


Figure 6.3 Deviation of each tool/database condition from the reference dataset, plotted against the pre-specified ±15 percent applicability band.

Two of the four conditions land comfortably inside the applicability band, and two land well outside it. What stands out is the pairing: One Click LCA and Carbo Life Calculator's Materials template - the two conditions drawing on, product-oriented data, both cluster near the eight-percent mark, while Tally and Carbo Life Calculator's Simplified template - the two conditions drawing on a more coarse, generic data, both land well beyond the threshold, with the Simplified-template result nearly three times the size of the band itself. A designer choosing between these four tools purely on the strength of their default settings would reach a materially different conclusion about whether early-stage simplified assessment can be trusted, depending entirely on which tool and which internal database configuration they happened to select.

Whether Tally and Carbo Life Calculator's Simplified template should be read as simply 'not correct,' however, depends on a factor this chapter can only partially resolve: how each tool communicates its own confidence in the number it reports. Carbo Life Calculator states that its output is calculated with a built-in uncertainty allowance of ten percent (which can be freely adjusted), meaning both of its reported figures in Table 6.2 already carry this margin embedded within them before any comparison is made. One Click LCA, by contrast, is capable of displaying an estimated uncertainty percentage driven by factors such as design completeness, dataset quality, and missing information but this feature was not visible under the academic license used for this case study, so no equivalent figure could be recorded for the One Click LCA results reported here. Tally does not expose an uncertainty percentage anywhere in its output, and its internal margin, whatever it may be, cannot be adjusted by the user. The practical consequence is that Table 6.2's deviations are being measured against a single fixed threshold while the four results carry different, partially undisclosed levels of built-in risk factor. This is an asymmetry that should temper how confidently any single tool is singled out as more or less accurate purely on the basis of where its headline figure lands relative to fifteen percent.

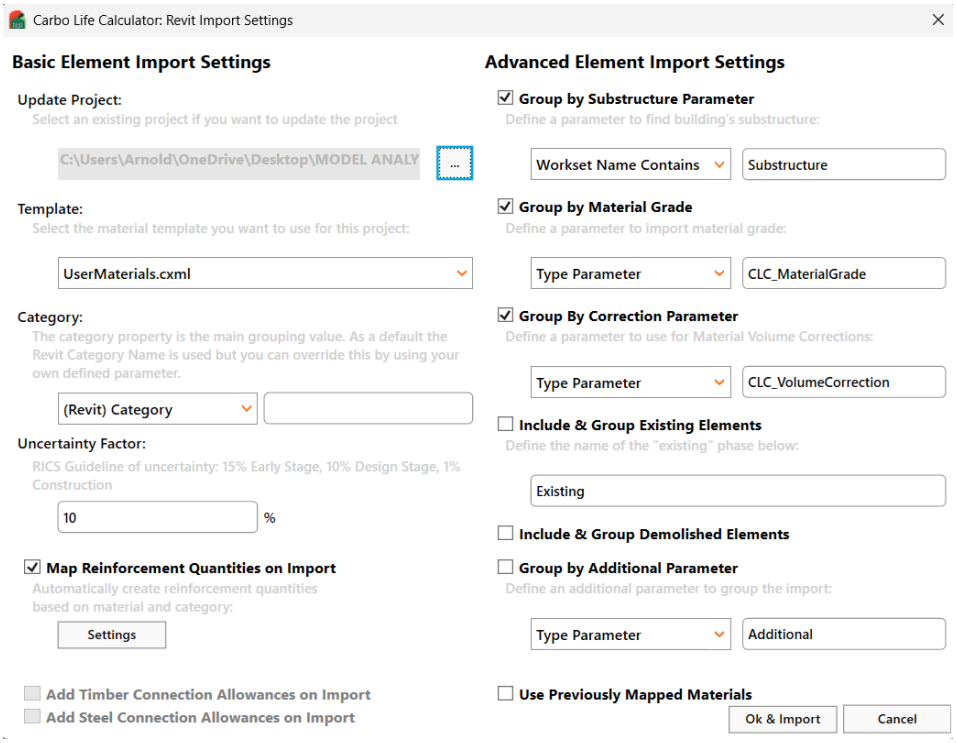


Figure 6.4 Screenshot showing Carbo Life Calculator's stated 10% uncertainty factor on its screen

6.2.1 Direction and consistency of the observed pattern

A finding worth isolating on its own is the uniform direction of every result in Table 6.2. Overestimation rather than underestimation dominates across every tool and every database configuration tested, with no exceptions. This matters for how a simplified assessment method might reasonably be used in early design. A designer relying on any of these four tools at the simplified-design stage would, for this case study, always be working with a number that overstates the eventual embodied carbon intensity, never one that understates it. From a risk-management standpoint this is the safer direction for an error to run in, since a designer working from an inflated figure is more likely to over-invest in carbon reduction than to under-invest, but it also means none of the four conditions offers a genuinely balanced, unbiased early estimate. Every one of them is systematically pessimistic relative to the reference dataset, just by differing amounts.

6.2.2 Whether the two outlying conditions could be brought within range

Landing outside a pre-specified threshold does not mean a tool is unusable at an early design stage; it may instead mean its default configuration needs adjustment before its output can be trusted at that stage. Whether that reclassification is plausible depends on how much of each outlying result can be traced to a factor a designer could reasonably change. Carbo Life Calculator's Simplified-template result, at over forty percent deviation, is large enough that no single and easily correctable input choice is likely to close the gap entirely; bringing it within a fifteen-percent band would probably require abandoning the Simplified template altogether in favor of the Materials template, which is less a correction than a different tool configuration. Tally's result, at just under twenty-four percent deviation, sits closer to the threshold and is a more plausible candidate for a genuine caveat-based reclassification, particularly given that Tally's default database is generic and internationally sourced rather than calibrated to the German or regional context this case study draws on elsewhere. if a German or region-specific dataset

substitution within Tally is possible and available, it could narrow this gap by an amount comparable to the granularity effect measured later in this chapter.

A further practical dimension worth noting is the interaction between an overstated embodied carbon figure and the parallel cost decisions a structural designer typically makes alongside it. Research on early-stage structural optimization has shown that cost and embodied carbon frequently move together, with lower-carbon structural configurations often also proving less expensive once material efficiency is accounted for (Kanyilmaz, Dang and Kondratenko, 2023). An inflated carbon figure of the kind produced by three of the four conditions tested here would not necessarily mislead a designer about which structural option is better, since the direction of comparison between two design alternatives calculated with the same tool would likely still hold even if the absolute figures are both too high. What an inflated figure would probably distort is the perceived scale of the problem itself. A designer working from a forty-percent-inflated figure may judge more aggressive and more costly mitigation measures to be necessary than the building's actual reference-stage performance would justify.

6.3. Sensitivity Analysis

Three additional runs, each varying a single factor while holding the remaining conditions fixed, were carried out using One Click LCA to establish which of three candidate mechanisms; structural system assumption, quantity estimation method, and emission-factor granularity, contributes most to the distribution of results already reported. Table 6.3 lists the three outcomes.

Table 6.3 Isolated sensitivity factors and their deviation from the reference dataset

Factor isolated	Result (kg CO2e/m² GFA)	Deviation
Structural system assumption (plausible alternative system substituted)	186.00	-5.77%
Quantity estimation method (simplified take-off applied to LOD 300)	212.00	+7.40%
Emission-factor granularity (manufacturer-specific data substituted for generic data)	241.57	+22.38%

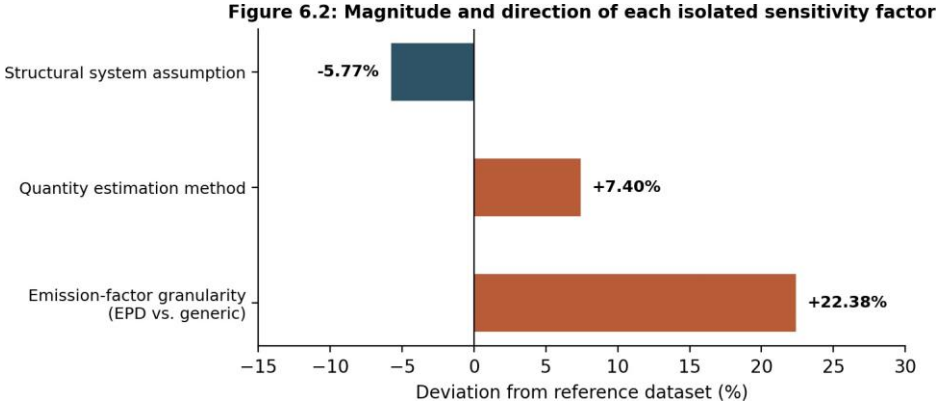


Figure 6.5 Magnitude and direction of each isolated sensitivity factor, ranked from smallest to largest absolute effect.

Ranked by absolute magnitude, emission-factor granularity dominates the other two factors combined, producing a swing more than three times larger than the quantity-estimation effect and roughly four times larger than the structural-system effect. This ordering has a direct effect on how the wide spread reported earlier should be read: if quantity simplification alone accounted for only 7.40 percent of deviation when tested in isolation, then a substantial share of the 43.13 percent deviation recorded for Carbo Life Calculator's generic template, or the 23.80 percent recorded for Tally, is unlikely to be explained by geometric simplification alone. Dataset choice appears to be causing more of the changes.

6.3.1 Generic member sizing assumption

Substituting a plausible alternative structural system for the composite system actually present in the case study building produced the only negative result among the three factors tested, and the smallest in absolute terms. A designer guessing at structural system during early design, at least for a building of this general type and scale, does not appear to introduce large error, a modestly reassuring finding, since structural system is precisely the kind of decision most likely to remain genuinely undecided at the earliest design stage. The negative sign is itself informative. It indicates that the alternative system tested here would, if it had been the actual choice, have produced a lower embodied carbon intensity than the composite system the building actually uses.

The alternative tested, replaced the building's mixed steel-and-concrete floor framing, wide-flange beams and open-web joists spanning between concrete columns, with different elements in their generic form but of comparable span, width, height, thickness and loading capacity, a substitution a designer might plausibly consider at the earliest stage of a mixed-use commercial project before a structural engineer has fixed the framing strategy. That this substitution produced a smaller and oppositely signed effect than either of the other two factors, suggests that a structural system, while clearly consequential for a building's overall carbon performance, is not where this case study's early-stage assessment risk concentrates. A designer choosing between a concrete and a composite steel framing strategy at the concept stage is, on this evidence, working with a decision whose carbon consequences a simplified tool can represent reasonably well, even before the choice is finalized.

6.3.2 Quantity estimation method

Applying the simplified take-off method to the same LOD 300 model shows only the effect of the calculation method, not reduced design detail. The 7.40 percent deviation is similar to the approximately 8 percent variation reported between different LCA calculation approaches using the same building data (Atik, Domenech Aparisi and Raslan, 2021). Therefore, the difference is likely not a specific error in this case study, but represents the normal variation that can occur between different assessment methods.

6.3.4 Emission-factor granularity

The largest isolated effect by a clear margin came from substituting manufacturer-specific emission factors for the generic dataset used in the reference calculation, holding geometry and quantities fixed throughout. This produces a result worth stating plainly than softening: the manufacturer-specific substitution returned a higher figure than the generic dataset, not a lower one. Generic construction material databases of the kind used here are typically built with a deliberate conservative margin, so that a designer relying on generic figures in the absence of a specified product is not inadvertently encouraged to under-report impact, which would ordinarily predict the opposite pattern. With generic data sitting above manufacturer-specific data and not below it. The reversed direction observed here does not point to an error in either figure. It likely reflects that the specific manufacturer products

substituted into this particular building's material list happen to carry a higher declared carbon intensity than the regional generic average for the same material category which is a genuinely possible outcome for any individual product, irrespective of how conservatively the generic dataset as a whole is calibrated.

This reversal creates a direct tension with the pattern observed among the four main tool/database conditions, where the two conditions drawing on more product-specific data both showed lower deviation than the two drawing on generic data. The two comparisons are not measuring quite the same thing. The isolated single-factor test holds geometry and calculation engine fixed and varies only the dataset, so any difference it produces can be attributed to the dataset alone. The four-tool comparison, by contrast, varies calculation engine, geometry interpretation, and dataset all at once between tools, so its database effect is entangled with interpretation differences that the isolated test cannot show. Dataset granularity clearly matters in both readings of the evidence, but its direction cannot be assumed to run one way consistently.

6.3.5 Reading the three factors together

Placed side by side, the three isolated factors describe three quite different kinds of risk a designer takes on when using a simplified early-stage tool. Getting the structural system reconfigured carries the smallest and generously forgiving consequence measured here, and pushes the result in the opposite direction from every other error source identified in this chapter. A designer who guesses incorrectly at this stage is not, based on this evidence, punished heavily for it. Getting the level of geometric detail wrong carries a moderate consequence, one that tracks closely with what independent research already treats as an expected baseline of disagreement between any two calculation approaches and suggesting it is closer to a simplified feature of early-stage assessment than a mistake to be eliminated. Getting the emission-factor dataset wrong or simply not knowing in advance which direction a dataset substitution will move the result carries by far the largest consequence of the three, and is the one factor in this chapter where the direction of the effect could not be predicted from first principles. A designer seeking to improve the reliability of an early-stage estimate would, on this evidence, gain far more from analyzing which emission-factor dataset a tool defaults to than from refining structural assumptions or waiting for more detailed geometry.

6.4 Generic Versus Product-Specific Data Effects

Because dataset granularity emerged as the strongest single factor in the sensitivity testing, and because the direction of its effect differed between the isolated test and the wider tool comparison, this final results section brings both readings together in a single view.

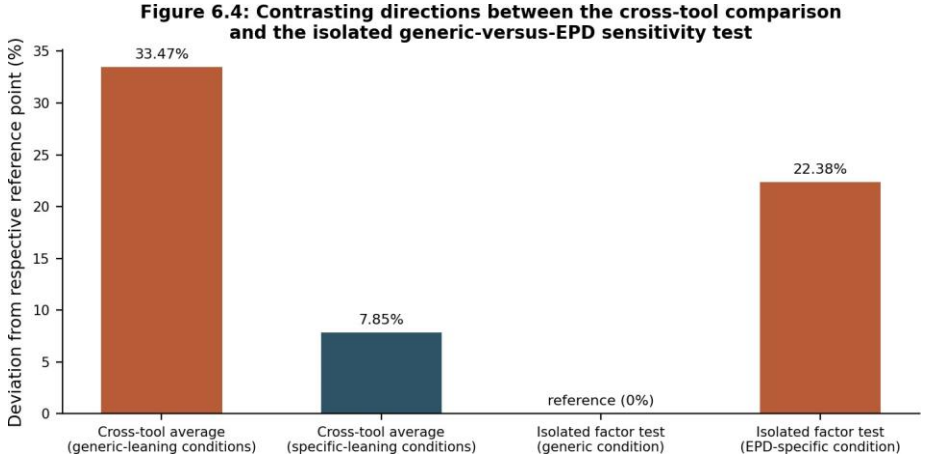


Figure 6.6 Contrasting directions between the cross-tool comparison and the isolated generic-versus-EPD sensitivity test.

Averaged across the two conditions drawing on coarser data (Tally and Carbo Life Calculator's Simplified template), the cross-tool comparison shows deviation of roughly 33 percent. Averaged across the two conditions drawing on more granular data (One Click LCA and Carbo Life Calculator's Materials template), the same comparison shows deviation of roughly eight percent, a gap of some 25 percentage points, and one that would ordinarily be read as clear evidence that generic datasets inflate results relative to product-specific ones. The isolated test tells a different story: holding a single building's geometry, quantities, and calculation engine completely fixed and swapping only the underlying dataset moved the result from a generic-condition baseline to a manufacturer-specific figure more than 22 percent higher.

Both readings cannot simultaneously be treated as the general rule, and this chapter does not attempt to force them into agreement. What can be said with reasonable confidence is narrower but still useful. First, dataset choice is a real and substantial driver of deviation under either reading, however the disagreement is about direction. Second, the cross-tool comparison is the less trustworthy of the two for isolating a database effect, since three variables move together across the four tools tested (calculation engine, geometry interpretation, and dataset), whereas the single-factor test moves only one. Third, the counter-intuitive direction found in the isolated test-specific data reading higher than generic, should be treated as the more mechanistically clean of the two results, even though it runs against the conventional expectation that generic databases are calibrated conservatively upward. A single case study cannot settle which pattern would hold generally across other buildings, other material specifications, or other manufacturer selections; what it does establish is that the conventional assumption should not be applied automatically without case-specific verification.

6.4.1 Implication for early-stage practice

A practical reading of the finding is that a designer cannot safely assume because a simplified early-stage tool is running on generic instead of manufacturer-specific data, that the resulting figure is biased in a known, predictable direction. The cross-tool evidence in this chapter would support treating generic-dataset results as conservative overestimates, the isolated single-factor evidence would support the opposite assumption for at least some material categories. Given this, the safer practical guidance emerging from this case study is not to rely on a directional assumption at all, but to treat dataset granularity as a source of uncertainty whose sign should be checked against the specific materials involved, as opposed to being inferred from general design philosophy of the database.

This finding carries particular weight for construction practice in regulatory environments that lean on a centralized, government-maintained environmental database as their primary compliance data source, of the kind found in Germany. Such databases are typically built with a deliberate margin above best-estimate values so that a project relying on generic entries in the absence of a specified manufacturer is not inadvertently rewarded for under-reporting impact. The findings of this chapter suggest that, for at least some material categories, the manufacturer-specific values adopted once a supplier is selected may exceed the generic values used during the conceptual design stage. Consequently, as a project progresses from concept to procurement, the expected direction of adjustment is not necessarily downward. A quality-assurance process built on the assumption that switching from generic to product-specific data will always improve an already-conservative figure may, for some materials, be assuming a safety margin that does not exist.

Taken together, the four result sections in this chapter point toward a single, consistent conclusion about where deviation actually originates in this case study. Structural system assumption contributes only a small, single-digit effect. Quantity estimation method contributes an effect close to what literature already says is as an unavoidable baseline of inter-method noise. Emission-factor granularity contributes an effect several times larger than either of the other two factors, and does so in a direction that resists easy generalization. The wide spread recorded across the four tool/database conditions earlier in this chapter is therefore best explained not as a story about design-stage data resolution in general, but as a story substantially driven by which environmental dataset a given tool happens to draw on by default, a distinction with direct consequences for how the applicability of any simplified LCA tool should be evaluated.

6.5 Consolidated Picture Across the Four Analyses

Table 6.4 draws the chapter's separate threads into a single reference point: the applicability classification of each tool/database condition, alongside the sensitivity factor judged more responsible for that condition's particular result.

Table 6.4 Consolidated applicability classification and primary attributed cause

Condition	Deviation	Classification	Primary attributed cause
One Click LCA	+7.35%	Applicable	Combination of quantity-method and dataset granularity, both modest
Carbo Life Calculator (Materials template)	+8.35%	Applicable	Similar combination; product-oriented dataset keeps granularity effect small
Tally	+23.80%	Outside threshold, plausibly correctable	Generic, non-regional default dataset; not a geometry or engine
Carbo Life Calculator (Simplified template)	+43.13%	Outside threshold, not easily correctable by a single input change	Coarse default dataset combined with the tool's own built-in uncertainty allowance

This chapter's four sections converge on a finding that is more specific, and more actionable, than a blanket statement about whether simplified early-stage LCA is or is not accurate enough to trust. The geometry-driven side of early-stage simplification with the removal of reinforcement, connection, and fabrication detail from a design model, produces deviation on the order of what independent research already treats as an expected minimum. The dataset-driven side of early-stage simplification produces deviation several times larger, in a direction that this case study shows cannot be assumed in advance. For a designer or researcher deciding whether a given simplified tool is fit for purpose at an early design stage, the evidence gathered here points toward analyzing dataset configuration before evaluating anything else.

It is worth restating why this ordering of priorities matters practically. A designer with limited time at the concept stage of a project cannot verify every input a simplified tool relies on; some form of prioritization is unavoidable. The evidence gathered across this chapter suggests that ranking effort is better spent confirming which emission-factor dataset a chosen tool defaults to, and whether that default is appropriate to the project's material specification and geographic context, than on refining the structural model itself or waiting for additional geometric detail to become available. This is a counter-intuitive allocation of effort relative to how early-stage design review is often structured, where attention typically concentrates on geometry and structural strategy in place of the administrative question of which background dataset a piece of software happens to be pointed at.

6.6 Interpretive Caveats

Three qualifications should accompany every figure and classification reported in this chapter.

- First, every result traces back to a single building, examined through a multi-structural material configuration; the eight-percent cluster, the twenty-three-percent Tally result, the forty-three-percent Simplified-template result, describe this case study and should not be read as universal constants transferable to other buildings, other structural systems, or other geographic contexts without independent testing.
- Second, the reference dataset against which every deviation was measured came from one of the four tools under comparison rather than from a source entirely external to the comparison. Any systematic bias present in that tool's calculation logic would be inherited by the baseline, meaning the deviations reported here are best read as differences from that particular tool's detailed-stage estimate.
- Third, the uncertainty margins carried by each tool are not comparable: one tool's figures already embed a stated ten-percent allowance, another tool's allowance is calculated but was not observable under the license used for this case study, and the third tool's allowance is neither disclosed nor adjustable. A reader placing weight on the precise ranking between conditions should treat that ranking as informative about relative pattern.

7

DISCUSSION: APPLICABILITY AND LIMITATIONS OF SIMPLIFIED METHODS

The previous chapter reported what happened. This chapter asks what it means.

Four tool-and-database conditions were tested at an early design stage. Two landed inside a pre-agreed accuracy group. Two landed well outside it. Three separate factors were isolated to find out why. One factor, dataset granularity, turned out to matter far more than the other two combined. This chapter works through what that pattern actually tells a designer, a German practitioner, and a researcher building on this thesis later.

7.1 When Is Simplification Defensible?

This thesis asked one question. Under what conditions can a simplified LCA method be trusted at an early design stage to assist in making a structural decision? The results give a clear, if slightly uncomfortable, answer.

Simplification is defensible when the emission-factor dataset is chosen carefully. It is not automatically defensible just because a tool is fast, free, or easy to use. Look at the four conditions tested. One Click LCA and Carbo Life Calculator's Materials template both landed close to the accuracy threshold. Both draw on more specific, product-oriented data. Tally and Carbo Life Calculator's Simplified template both landed well outside the threshold. Both draw on more generic data. The pattern is not subtle. Dataset choice, not toolset, is showing more of the recognition. This matters because it changes where a designer should focus their attention. A common instinct is to worry about geometry. Is the model detailed enough yet? Should we wait for more design certainty before running an assessment? The sensitivity testing in this thesis suggests that instinct is only partly right.

Getting member sizing wrong, while keeping the correct materials and system, caused only a small error. Getting the calculation method wrong, in a way that mimics an early-stage take-off, caused a moderate error, and one that closely matches what independent research already treats as unavoidable background noise. Getting the dataset wrong caused the largest error by a wide margin, and the direction of that error could not be predicted in advance. So, the honest answer to this thesis's central question is a conditional one.

Simplified LCA is defensible at an early design stage, but only if the practitioner checks which dataset a tool is actually using before trusting its output. Geometry can be coarse. Sizing can be approximate. The dataset cannot be an afterthought.

7.1.1 A three-part test

From the evidence gathered here, three practical questions can help decide whether a simplified result is trustworthy enough to act on.

Is the dataset regional or product appropriate? A generic, internationally sourced dataset applied to a specific regional project is a large risk factor identified in this thesis.

Has the result been checked against a second tool or dataset? Where two independent conditions agree closely, as One Click LCA and Carbo Life Calculator's Materials template did here, that agreement is evidence of reliability.

Is the deviation, if any, explainable? A large deviation that can be traced to a specific, correctable setting is a different situation from a large deviation with no clear cause.

None of these three questions requires a fully detailed model. All three can be answered at the earliest stages of design, often within minutes. That is the practical, usable version of this thesis's applicability finding.

7.1.2 What the four tested conditions actually tell us, side by side

It helps to see the four results lined up against this three-part test. Table 7.1 does that.

Table 7.1 The four tested conditions, read against the three-part applicability test

Condition	Right dataset for context?	Confirmed by a second condition?	Deviation explainable?
One Click LCA	Yes - German dataset	Yes - close to Materials template	Small, expected
Carbo Life Calculator (Materials)	Yes - product-oriented	Yes - close to One Click LCA	Small, expected
Tally	No - generic default	No - an outlier among the four	Yes - fixable by dataset change
Carbo Life Calculator (Simplified)	No - generic dataset	No - largest deviation of the four	Partly - dataset plus built-in uncertainty margin

The pattern stops looking like four unrelated numbers and starts looking like two clear groups. One group passes all three checks. The other group fails the first two and only partially passes the third. That grouping is a real, usable finding buried inside this chapter's opening question.

7.2 Implications for German Practice

This thesis is grounded in Germany's design-stage framework and its national environmental database. It is worth asking what a German structural engineer or architect should actually take from these findings.

7.2.1 The Leistungsphase 2-to-3 transition matters, but not for the reason usually assumed

German practice organizes design progression into phases. Leistungsphase 2 is early and rough. Leistungsphase 3 is more developed. It is tempting to assume that the accuracy gap between these two phases comes from geometry alone. A rougher model at Leistungsphase 2, as the thinking goes, must contain less certain data. The findings here complicate that assumption. Geometry did contribute to deviation, but only a modest amount. Plenty of the gap traced back to which emission-factor dataset was in use, not to how detailed the model was. A German practitioner working at Leistungsphase 2 should not conclude that accuracy is unattainable simply because the design is unfinished. They should instead check whether the tool they are using is pulling from a German or regional dataset, or from something more generic.

7.2.2 ÖKOBAUDAT-linked data performed best in this case study

One Click LCA, configured with its German dataset, produced the smallest deviation of any condition tested. This is a useful, practical finding for anyone working within the German regulatory system. It suggests that tools already built around ÖKOBAUDAT, or capable of connecting to it, carry a real accuracy advantage over tools relying on generic international data.

This does not mean every ÖKOBAUDAT-linked result will always be accurate. It means that, choosing a tool with a genuine link to German data is a sound default, not merely a matter of regulatory compliance.

7.2.3 The certification timing problem is not solved by this thesis, but it is better understood

German certification schemes such as BNB and DGNB generally expect LCA evidence once a design is well developed, often close to Leistungsphase 5. Part of the motivation for this thesis was to test whether that timing is necessary, or whether earlier assessment could be made reliable enough to matter.

The answer is qualified. Earlier assessment can be reliable, but only under the right dataset conditions. On this point, BNB guidance is already stricter than this thesis's findings might suggest is necessary: ÖKOBAUDAT is not merely preferred but mandatory, with specific dataset versions locked to specific benchmark releases. The real gap is not dataset guidance but tool and timing guidance. It remains unclear whether a screening tool outside the official ÖKOBAUDAT pathway would be accepted as evidence at all, or whether an early Leistungsphase 2 or 3 submission would be permitted alongside BNB's existing simplified-proof provisions for select building types. That is the distinction current guidance leaves unresolved, and this thesis suggests it is worth clarifying

7.2.4 A note on generalizing from one case study

This case study used a mixed-use commercial building with a composite concrete and steel structure. German construction includes a great deal of residential and lightweight timber-frame work that looks nothing like this building. The dataset-sensitivity finding is likely to generalize reasonably well, because

it reflects how environmental databases are built, not the specific shape of this one building. The exact size of the effect, however, may not transfer to other material palettes or building types.

7.2.5 A note on subsidy-linked certification

QNG certification is tied to KfW financing. That link gives this thesis's findings a financial, not just environmental, edge. A developer relying on an early-stage estimate that turns out to be forty percent too high may budget for carbon-reduction measures that were never actually necessary, or may delay a financing application while chasing a target that a more careful dataset check would have shown was already met.

This is a small but real point. Accuracy at the early design stage is not only a technical question. For a QNG-linked project, it is also a cost and scheduling question, and the tool and dataset choice examined throughout this thesis has a direct line to both.

7.3 Comparison with Existing Literature

No case study stands alone. This section checks these findings against what other researchers have already reported, and points out where the results here agree, disagree, or add something new.

7.3.1 Where the findings agree with prior work

(Dunant et al., 2021) found that early design decisions can cut embodied carbon by forty to sixty percent, mostly through better grid layout and decking choice. That finding motivated much of this thesis. It implied that early design is worth assessing carefully, even when imperfect but because the decisions made there matter enormously. Member-sizing errors, the closest analogue to a rough early design guess, turned out to be small. A designer who assumes generic sizing at concept stage is not punished heavily for it. This is good news for the argument that early assessment is worth doing at all, even when full detail is not yet available.

(Nilsen & Bohne, 2019) reported that lower levels of design detail tend to underestimate environmental impact compared to higher levels of detail. The pattern found here runs in the same direction, though for a different reason. Every simplified-stage condition in this thesis overestimated the reference dataset, not underestimated it. The direction differs, but the message is the same: design resolution changes the answer, and not by a small margin.

(Atik et al., n.d.), found a minimum difference of roughly eight percent between two independently applied LCA methods on the same building, even under controlled conditions. The quantity-estimation result in this thesis, at 7.4 percent, sits almost exactly on that figure. This is a reassuring cross-check. It suggests the noise floor identified in earlier research is a real, repeatable feature of LCA tool comparison, not a one-off finding specific to a different building or a different pair of tools.

(Moncaster et al., 2018) warned that differences in LCA method, not just design, can change the answer a designer receives. This thesis provides a direct and concrete demonstration of that warning. Four tools, given identical geometry, produced four different answers. Method mattered as much as data resolution, sometimes a bit more.

7.3.2 Where the findings complicate prior work

Generic environmental databases are usually built with a deliberate conservative margin. The idea is straightforward that if a designer has not yet chosen a specific product, the database should assume the worst, not the best, so nobody is rewarded for guessing optimistically. A quantified example is Norway's TEK17 building regulations, as implemented through One Click LCA's compliance tooling, mandate a 25% markup on generic environmental data, while EPD (product-specific) data gets no markup at all. The documentation states this explicitly: "Generic data has a top-up factor of 25% added to the GWP value. EPDs do not get a top-up factor." Usefully, this same documentation names the German ÖKOBAUDAT database as one of the generic databases this framework applies to, alongside Swedish and Finnish equivalents.

This case study does not fully support that assumption. When manufacturer-specific data was substituted for generic data, holding everything else constant, the result went up, not down. The specific product data used here happened to carry a higher declared carbon intensity than the generic average for the same material category.

This is not evidence that the conservative-markup design is wrong in general. Database designers cannot guarantee every individual product will sit below the generic average, only that the average itself is calibrated conservatively. But it is evidence that a designer should not treat the conservative-markup assumption as a safe, automatic rule for every material. At least for some products, the assumption does not hold.

7.3.3 Where this thesis adds something new

Much of the existing literature on early-stage LCA accuracy is framed around Level of Development, an international, largely UK and US-based concept. Very little of it connects that framework to Germany's own design-stage structure, or to ÖKOBAUDAT specifically.

This thesis builds that connection .It shows that the international LOD-accuracy findings and the German Leistungsphase framework describe the same phenomenon, and that German practitioners can use existing international research to inform decisions made within their own labelled system. That translation was not clearly documented in recent literature or at least not tested against a real case study.

7.3.4 A note on why German practice still runs late

Earlier survey research on German practitioners found that a lot of LCA work still happens late in design, and that the main reason given was workflow difficulty, not a lack of underlying data. This thesis was not designed to test that workflow claim, but the results are consistent with it.

None of the four tools tested here required detailed design information to run. Every one of them produced an answer from a coarse, early-stage model in a matter of minutes. If usable early answers are this readily available, then workflow habit, not technical necessity, looks like the more plausible explanation for why German practice still waits. That is a modest but useful piece of corroborating evidence for a claim that was previously supported mainly by self-reported survey data.

7.4 Practical Recommendations for Practitioners

This section turns the results into concrete recommendations, written for the people who would actually use them: structural engineers, architects, and sustainability consultants working at early design stages.

7.4.1 For a designer choosing a tool

Check the default dataset before running the first calculation. Ask whether it is generic and international, or specific to the project's country or region. This single check explained more of the deviation in this thesis than every other factor combined.

Prefer a tool with a genuine connection to a national or regional database over a tool that only offers a generic, one-size-fits-all dataset. In this case study, the tool connected to German data produced the most reliable result of the four tested.

Do not assume geometric detail is the limiting factor. A coarse early model, correctly identified with the right materials and system, is unlikely to cause large error.

7.4.2 For a designer interpreting a result

Treat a single number from a single tool with some caution, especially early in design. Where possible, run a second tool or a second dataset configuration and compare.

If two independent conditions agree closely, trust the result more. If they disagree by a wide margin, investigate the dataset each one is using before assuming either number is wrong.

Do not assume that switching from generic to product-specific data will always produce a lower, more favorable figure. It can go the other way. Check the specific product before assuming the direction of the change.

7.4.3 For a German project specifically

Where possible, use a tool with a direct ÖKOBAUDAT connection, particularly for projects that will eventually need BNB, DGNB, or QNG documentation. The dataset link matters more than which specific software brand is used.

If a tool defaults to a generic, non-German dataset, check whether a German or European template exists before accepting the default output. In this thesis, that single template change was the clearest, available fix for the least reliable result tested.

Do not wait until Leistungsphase 5 purely because early data feels too uncertain. A Leistungsphase 2 or 3 assessment, built on the right dataset, can already provide a usable signal for structural decision-making.

7.4.4 For anyone building on this research

Test more than one building. A single case study, however carefully documented, cannot confirm how far these specific percentages travel to other structures.

Test more than one structural material combination. This case study used a composite concrete and steel system. A pure timber or pure concrete building might behave differently, especially around the generic-versus-specific dataset question.

Where a tool's uncertainty margin is hidden or cannot be adjusted, as was the case for two of the three tools used here, treat that as a real limitation of the tool. Future comparative studies should push tool vendors for transparency on this point.

7.4.5 A one-page version of this section

Table 7.2 condenses every recommendation above into a single quick-reference list, organized by the moment in a project where each one applies.

Table 7.2 Quick-reference recommendations by project stage

Project moment	Recommendation
Before choosing a tool	Check the default dataset. Prefer regional or national data over generic international data.
First simplified result	Do not treat geometry as the main risk. A coarse but correctly-typed model is usually fine.
Reading any single result	Cross-check with a second tool or dataset where possible; treat agreement as a good sign.
Switching to specific product data	Do not assume the number will fall. Check the actual product before expecting a lower figure.
Working on a German project	Favour ÖKOBAUDAT-linked tools; check for a regional template before accepting a generic default.
Planning further research	Repeat this comparison on a different building and a different structural material before generalizing.

7.5 Limitations

Every finding in this thesis comes with conditions attached. Some have already been mentioned. It is worth gathering them together here so a reader knows exactly how far to trust each conclusion.

7.5.1 One building, one material combination

Every number in this thesis comes from a single building. That building combines reinforced concrete and structural steel. Many buildings do not. A timber structure, a pure concrete structure, or a steel-only structure could behave quite differently, especially around the generic-versus-specific dataset finding, which depends heavily on which specific products happen to be available for comparison.

7.5.2 The reference dataset is not independent benchmark

The baseline used throughout this thesis came from one of the four tools under comparison, not from a source entirely outside the study. Any consistent bias in that tool's calculation logic would be inherited

by the baseline, not exposed by it. Every deviation reported here should be read as a difference from that particular tool's own detailed-stage estimate.

7.5.3 Uncertainty margins are not comparable across tools

One tool discloses a fixed ten percent uncertainty allowance. Another tool calculates an uncertainty figure, but that figure was not visible under the license used for this thesis. The third tool does not disclose an uncertainty figure at all, and does not allow one to be set manually. This means the deviations compared throughout this thesis sit on slightly different foundations, even though they are presented side by side. A reader should treat the ranking between tools as informative.

7.5.4 The applicability threshold was set by the researcher

The plus-or-minus fifteen percent threshold used to judge whether a result counts as applicable was chosen by the author. It sits between two cited figures from the literature, but no single source states this exact number. A different, reasonable researcher might have chosen a tighter or looser threshold, and reached a slightly different applicability verdict as a result.

7.5.5 Three factors, not every possible factor

Only three sources of deviation were tested: member sizing, quantity estimation method, and dataset granularity. Other plausible factors exist. Transport assumptions, construction-stage impacts, and end-of-life assumptions were all excluded from this thesis's system boundary from the onset. Their contribution to overall deviation remains unknown.

7.5.6 The steel classification question was not fully resolved

One material breakdown used in this thesis could not clearly show whether structural steel framing was reported as its own category or folded into a broader reinforcement figure. A second tool's output suggests structural steel is a substantial, separately identifiable share of total impact, which supports treating the ambiguity as a real limitation.It remains an open question.

7.5.7 What these limitations do, and do not, validate

None of these limitations overturn the central finding of this thesis. Dataset choice mattered more than geometric detail in every comparison run. That pattern showed up consistently, across multiple tools, multiple sensitivity tests, and multiple ways of checking the numbers. What the limitations do is set the boundary around how far that finding should be trusted to go. It is a strong finding for this building, this material combination, and this set of four tools. It is a plausible, worth-testing hypothesis for anything beyond that.

8

CONCLUSION

This thesis set out to answer one question. Can simplified Life Cycle Assessment methods be applicable to support early-stage structural design decisions? After a full case study, four tools, three sensitivity tests, and one detailed reference dataset, the answer is only clearer.

8.1 Summary of Findings

8.1.1 Geometry is not the main risk

A rough, early-stage model, correctly assigned the right materials and system, produced only a small error compared to a fully detailed one. This was the smallest deviation measured anywhere in this thesis, and the only one that pointed in a considerable direction. A designer working with limited geometric certainty is not, on this evidence, taking on much risk by doing so.

8.1.2 The calculation method adds a small, expected amount of error

Applying a coarser, early-stage take-off method to the same design produced a moderate deviation. That figure landed almost exactly on a noise floor (the smallest difference you see between two LCA calculations even when everything is done carefully and correctly) already documented elsewhere in the literature for comparing two independent LCA approaches on the same building. This is not a flaw specific to this thesis's case study. It looks like a general, unavoidable feature of comparing one calculation method against another.

8.1.3 The dataset is the real risk

Every other factor tested in this thesis was smaller than this one, usually by a wide margin. Which environmental dataset a tool defaults to, generic or product-specific, national or international, explained more of the spread between the four tools compared. Two tools landed close to the reference figure. Two landed far from it. The difference tracked the dataset each one used.

8.1.4 The direction of that risk is not predictable in advance

A widely held assumption in construction LCA is that generic data is conservative, and specific data brings the number down once it becomes available. This case study found the opposite in one test: switching from a generic dataset to a manufacturer-specific one increased the result, not decreased it. This does not mean the conservative-markup design behind generic databases is wrong in general. It means a designer cannot assume, model by model, which way the number will move.

8.1.5 Putting the four findings together

Line these four findings up and a clear hierarchy appears. Dataset choice matters most. Calculation method matters a moderate, expected amount. Geometric detail matters least of all. That ordering runs against a common instinct in early design practice, where attention usually goes to the model first and the data source second, if it is considered at all. The evidence gathered here suggests that instinct should be reversed.

8.2 Contribution to Knowledge

This thesis contributes something in four specific places. None of them are large on their own. Together, they close a real gap in how early-stage LCA accuracy has been studied.

8.2.1 A direct, controlled comparison across four tools on one building

Most published comparisons of LCA tools change more than one variable at once. This thesis held the building, the geometry, and the design stage fixed, and changed only the tool and its dataset. That design makes it possible to say, with some confidence, that dataset choice rather than tool identity drove the differences observed. Few existing studies isolate the variable this cleanly.

8.2.2 A working translation between German design stages and international design-detail language

The Level of Development framework is well established internationally but has no official German equivalent. This thesis built a working correspondence between Germany's Leistungsphasen and international LOD levels, then tested it against a real case study rather than leaving it as a theoretical mapping. German practitioners now have a tested, way to connect their own design-stage language to the wider accuracy literature.

8.2.3 Evidence that the conservative-markup assumption does not always hold

Generic environmental databases are usually designed to be conservative. This thesis found a case where switching to more specific data made the result worse, not better. That single result will not overturn how these databases are designed, but it does show, with a real example, that the assumption should not be treated as automatic. This is a small but genuine addition to the literature on database design and dataset selection in early-stage LCA.

8.2.4 A reusable method for isolating design-stage accuracy from tool accuracy

The attribution logic developed in this thesis, separating database effects, calculation-engine effects, and design-resolution effects from one another, is not specific to the three tools tested here. It could be applied to any comparison of early-stage LCA tools, in any country, using any dataset. That reusability is itself a contribution, independent of the specific numbers this thesis produced.

None of these four contributions is, on its own, a dramatic finding. Read together, they shift the framing of a question that earlier research had largely left open. The question was not really whether early-stage

LCA can be accurate. It was what accuracy actually depends on. This thesis answers that second, more useful question with a specific, testable, and reasonably well-evidenced result.

8.3 Answer to the Research Question

This thesis asked how applicable simplified LCA methods are for supporting early-stage structural design decisions, and how their accuracy changes across successive design stages. It is worth answering that question , in plain terms, rather than leaving it scattered across earlier chapters.

Simplified LCA is applicable at an early design stage. It is not universally applicable, and it is not applicable by default. It is applicable when the practitioner checks one thing carefully: which environmental dataset the tool is actually using.

Where that dataset is appropriate to the project's material and regional context, the results in this thesis came close to a fully detailed reference figure, even when the underlying model was coarse and the design stage was early. Where the dataset was generic and poorly matched to the project's context, the results drifted far enough from the reference figure to be genuinely misleading.

Design-stage progression, on its own, mattered less than expected. Moving from a rough model to a detailed one changed the answer by a modest, predictable amount. Moving from one dataset to another changed the answer by a much larger, less predictable amount. If this thesis has one central finding to offer, it is that early-stage LCA accuracy is a data-sourcing problem more than it is a modelling-detail problem.

This finding has a specific, practical consequence for German practice, since Germany's certification landscape already provides the tool, this finding calls for. ÖKOBAUDAT-linked data outperformed generic international data in every comparison run in this thesis. The infrastructure needed to make early-stage LCA more trustworthy in Germany already exists. What has been missing is a habit of checking, before a number is trusted, whether that infrastructure is actually being used.

That is the answer this thesis set out to find. Simplified methods can support early-stage structural decisions. They can do so reliably, but only if the dataset behind them is treated as seriously as the geometry in front of them.

8.4 Final Concluding Statement

Simplified Life Cycle Assessment methods are applicable to early-stage structural design decisions, but their applicability is conditional, not automatic. It depends far less on how detailed the design is and far more on which environmental dataset sits behind the number a tool produces. A designer who checks that one thing before trusting a result gains a genuinely useful early signal, one accurate enough to inform real structural choices well before a project reaches detailed design. A designer who does not check it risks acting on a figure that looks precise but is, in fact, shaped more by database selection than by the building itself. That is the central takeaway of this thesis: early-stage structural carbon assessment is ready to be trusted, but only by practitioners willing to ask where its numbers actually come from

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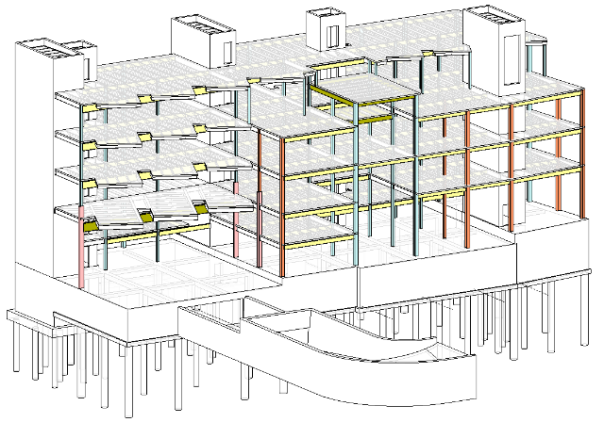
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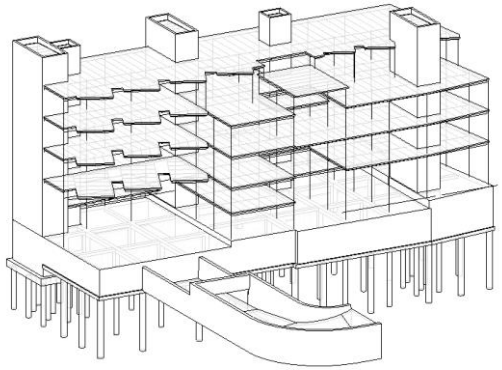
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B. APPENDIX

a) Visual representation of the baseline model (LOD 300) and derived model (LOD 200) respectively

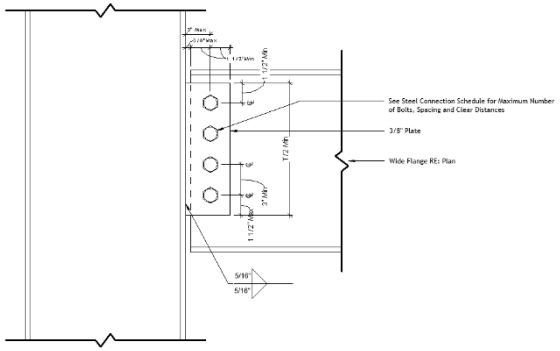


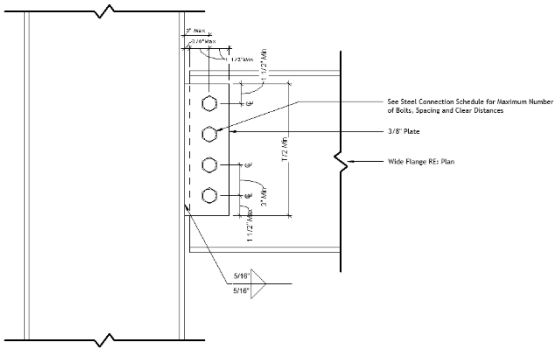
Appendix Fig. a-2 LOD 300



Appendix Fig. a-1LOD 200

b) Visual representation of the connections between different structural components

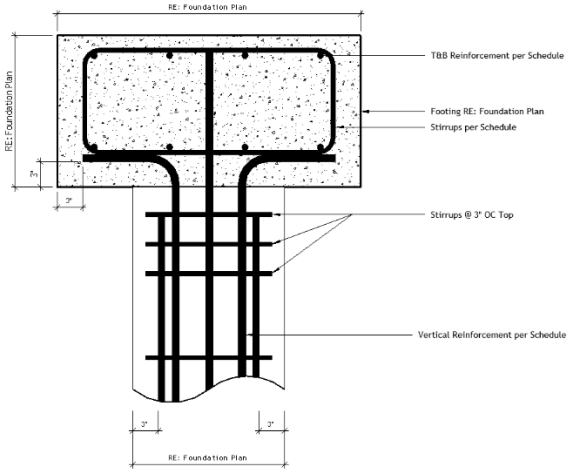




Appendix Fig. b-1Beam to beam connection

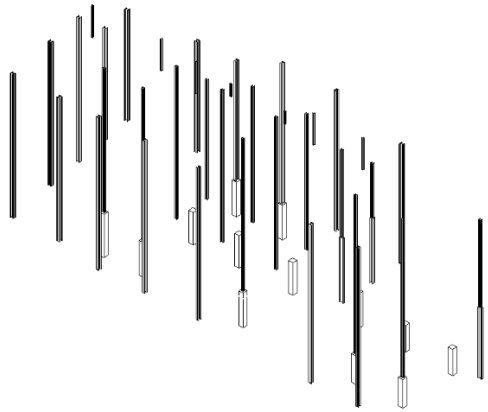
Appendix Fig. b-2 Beam to column connection

ii

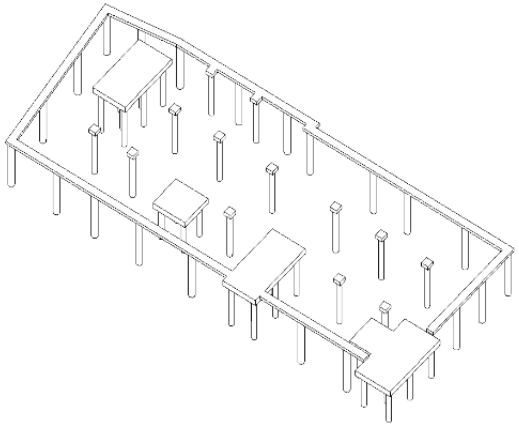


Appendix Fig. b-3 Drilled pier to continuous footing

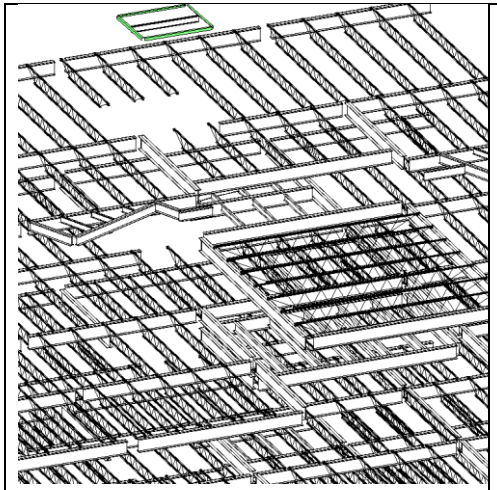
c) Model coordination



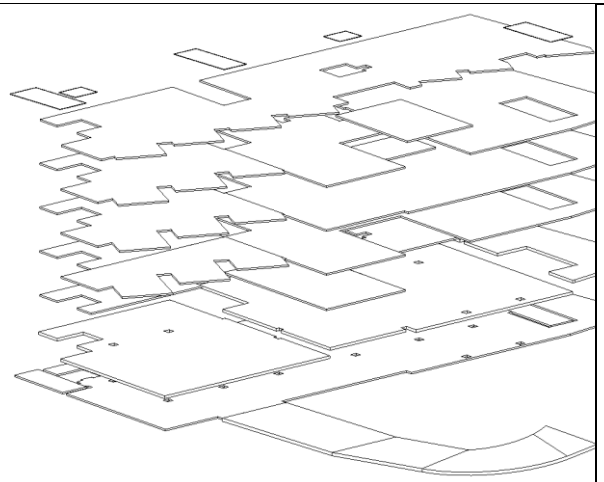
Appendix Fig. c-1Structural columns



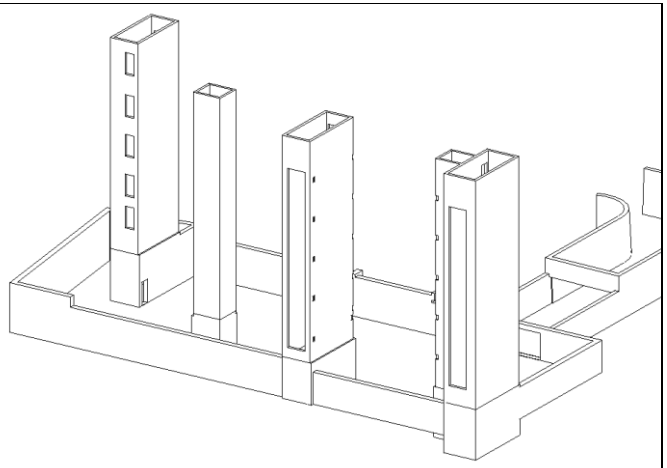
Appendix Fig. c-2 Structural foundations



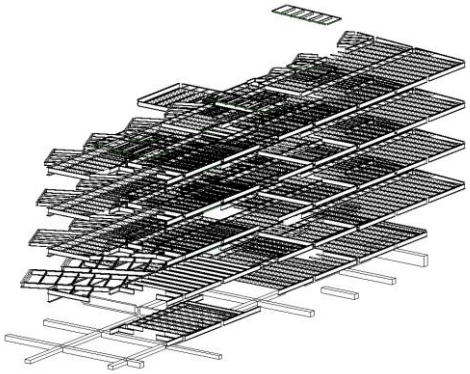
Appendix Fig. c-3 Structural framing



Appendix Fig. c-4 Structural slabs



Appendix Fig. c-5 Structural walls



Appendix Fig. c-6 Structural framing 2

iv

d) Schedules before (LOD 300 baseline) and after (LOD 200 derivation) respectively

BEFORE

Area schedule

<Area Schedule (Gross Building)>

A	B
Name	Area
Parking	13,032 SF
L1	13,032 SF
L2	6,315 SF
L3	10,777 SF
L4	11,388 SF
L5	10,872 SF
Roof	8,098 SF
	73,514 SF

Structural beam system

<Structural Beam System Schedule>

A	B	C	D	E	F	G
Beam Type (No Family	Layout Rule	Centerline Spacing	Reference Level Elevati	Elevation from Level	Comments	Count
16K2	Fixed Distance	4'-0"	58'-4"	0"	@ Max 4'-0"	1
16K2	Maximum Spacing	<varies>	58'-4"	0"	@ Max 4'-0"	3
16K6	Fixed Distance	4'-0"	<varies>	0"	@ Max 4'-0"	15
16K6	Maximum Spacing	<varies>	<varies>	0"	@ Max 4'-0"	23
18LH04	Maximum Spacing	3'-7 185/256"	5'-0"	0"	@ Max 4'-0"	1
20K6	Maximum Spacing	<varies>	<varies>	<varies>	@ Max 4'-0"	7
W8x10	Maximum Spacing	<varies>	<varies>	<varies>	@ Max 4'-0"	24
W14X30	Maximum Spacing	3'-11 171/256"	45'-0"	-2'-4"	@ Max 4'-0"	1
W16X26	Maximum Spacing	3'-9 105/256"	18'-4"	0"	@ Max 4'-0"	1

Structural column

<Structural Column Schedule>

A	B	C	D	E	F	G	H	I	J
Type	Base Level	Base Offset	Top Level	Top Offset	Length	Description	Type Comments	Type Mark	Count
CC24x24	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
CC24x24	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
CC24x24	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
CC24x24	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
CC24x24	Top of Footing	0"	L1_43_High	0"	17'-6"				1
W18x119	L1_35_Low	0"	L3	4'-0"	28'-9"				1
W10x49	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W10x49	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W14x109	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W14x109	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W14x109	L1_37_Med	0"	L3	4'-0"	26'-3 1/2"				1
W18x119	L1_37_Med	0"	L3	4'-0"	26'-3 1/2"				1
W10x49	L1_37_Med	0"	L5 TOS	0"	48'-5 1/2"				1
W14x109	L1_37_Med	0"	L5 TOS	0"	48'-5 1/2"				1
W14x109	L1_37_Med	0"	L5 TOS	0"	48'-5 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	-6'-8 5/8"	55'-0 7/8"				1
W10x49	L1_37_Med	0"	R2 TOS	-6'-8 1/8"	55'-1 3/8"				1
W14x109	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W14x109	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W14x109	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W14x109	L1_37_Med	0"	R2 TOS	-4'-11 1/2"	56'-10"				1
W14x109	L1_37_Med	0"	R2 TOS	-4'-11 1/2"	56'-10"				1
HSS6x6x5/8	L1_43_High	0"	L2 TOS	0"	7'-7"				1
W14x109	L1_43_High	0"	L5 TOS	0"	45'-0"				1
W14x109	L1_43_High	0"	L5 TOS	0"	45'-0"				1
W14x109	L1_43_High	0"	L5 TOS	0"	45'-0"				1
W10x49	L1_43_High	0"	R2 TOS	0"	58'-4"				1
W14x109	L1_43_High	0"	R2 TOS	0"	58'-4"				1
W14x109	L1_43_High	0"	R2 TOS	0"	58'-4"				1
W14x109	L1_43_High	0"	R2 TOS	0"	58'-4"				1
W14x109	L1_43_High	0"	R2 TOS	0"	58'-4"				1
W10x49	L3	4'-0"	L5 TOS	0"	22'-2"				1
W10x49	L3	4'-0"	R2 TOS	0"	35'-6"				1
W10x49	L3	4'-0"	R2 TOS	0"	35'-6"				1
W8x31	L5	0"	R2 TOS	0"	12'-10"				1
W8x31	L5	0"	R2 TOS	0"	12'-10"				1
W8x31	L5	0"	R2 TOS	0"	12'-10"				1
W8x31	L5	0"	R2 TOS	0"	12'-10"				1
W8x31	L5	0"	R2 TOS	0"	12'-10"				1
W8x31	R2 TOS	-5'-2"	R2 TOS	0"	5'-2"				1
W8x31	R2 TOS	-5'-2"	R2 TOS	0"	5'-2"				1

Structural foundation

<Structural Foundation Schedule>

A	B	C	D	E	F	G
Family and Type	Level	Description	Type Mark	Width	Foundation Thickness	Count
Wall Foundation: Bearing Footing - 36"x18"		SF		3'-0"	1'-6"	9
Foundation Slab: FNDN-36	Elevator Pit			14'-8"	3'-0"	1
Foundation Slab: FNDN-36	Elevator Pit			25'-8 1/2"	3'-0"	1
SFD_Round: 24x24x20'	Elevator Pit		DP24"-10'	2'-0"	20'-0"	14
Foundation Slab: FNDN-36	Top of Footing			27'-6"	3'-0"	1
Foundation Slab: FNDN-36	Top of Footing			29'-6 1/2"	3'-0"	1
SFD_Round: 24x24x25'	Top of Footing		DP24"-12'	2'-0"	25'-0"	16
SFD_Round: 30x30x25'	Top of Footing		DP30"-10'	2'-6"	25'-0"	21
SFD_Pile_Cap_Rectangle: 36x36x24 Pile_24	Parking	Cap		3'-0"	2'-0"	12
SFD_Pile_Cap_Rectangle: 36x36x24 Pile_30	Parking	Cap		3'-0"	2'-0"	1
SFD_Round: 24x24x25'	Parking		DP24"-12'	2'-0"	25'-0"	12
SFD_Round: 30x30x25'	Parking		DP30"-10'	2'-6"	25'-0"	1

Structural wall

<Structural Wall Schedule>

A	B	C	D	E	F	G	H	I	J	K
Type	Base Constraint	Base Offset	Bottom Width	Top Constraint	Top Offset	Top Width	Width	Structural Usage	Structural Material	Count
Concrete 10"	Elevator Pit	0"		Up to level: L1_35_Low	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Elevator Pit	0"		Up to level: L1_35_Low	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_35_Low	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Elevator Pit	0"		Up to level: L1_35_Low	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_35_Low	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	Elevator Pit	0"		Up to level: L1_35_Low	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Elevator Pit	0"		Up to level: L1_35_Low	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_37_Med	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	Elevator Pit	0"		Up to level: L1_37_Med	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	Elevator Pit	0"		Up to level: L1_37_Med	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_37_Med	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Elevator Pit	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Elevator Pit	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_35_Low	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_35_Low	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_35_Low	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_37_Med	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_37_Med	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_37_Med	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_37_Med	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Top of Footing	0"		Up to level: L1_37_Med	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	-3'-5 1/2"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Top of Footing	0"		Up to level: L1_43_High	-3'-5 1/2"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_43_High	-3'-5 1/2"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_43_High	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_43_High	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_43_High	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_35_Low	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_35_Low	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_35_Low	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_35_Low	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_35_Low	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_37_Med	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-0 37/128"	Up to level: L1_43_High	-7'-11"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-0 37/128"	Up to level: L1_43_High	-7'-11"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	L1_43_High	-6'-11"		Up to level: L1_43_High	-2'-10"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-5'-11"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-5'-11"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-3'-5 1/2"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-3'-5 1/2"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-3'-5 1/2"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1

Structural framing

<Structural Framing Schedule>

A	B	C	D	E
Reference Level	Type	Structural Usage	Elevation at Top	Count
L1_35_Low	CB18x24	Primary	-5'-11"	1
L1_35_Low	CB24x24	Primary	-5'-11"	6
L1_35_Low	CB24x30	Primary	-5'-11"	5
				12
L1_37_Med	CB24x24	Primary	-3'-5 1/2"	8
L1_37_Med	CB24x30	Primary	-3'-5 1/2"	9
L1_37_Med	CB24x39	Primary	-3'-5 1/2"	2
				19
L1_43_High	CB24 x51	Primary	0"	2
L1_43_High	CB24x24	Primary	0"	2
				4
M1 TOS	18LH04	Secondary	5'-0"	8
M1 TOS	W18x55	Primary	4'-7"	5
M1 TOS	W18x55	Primary	5'-0"	6
				19
L2 TOS	16K6	Secondary	7'-7"	55
L2 TOS	16K6	Secondary	7'-9 1/2"	1
L2 TOS	_Size	Tertiary	7'-4 1/2"	1
L2 TOS	W8x10	Primary	7'-7"	2
L2 TOS	W8x10	Secondary	7'-7"	2
L2 TOS	W18x55	Primary	7'-4 1/2"	14
L2 TOS	W18x55	Primary	7'-7"	8
L2 TOS	W18x86	Primary	7'-7"	1
				84

L3 TOS	16K6	Secondary	18'-4"	89
L3 TOS	_Size	Tertiary	18'-1 1/2"	1
L3 TOS	C8X11.5	Secondary	18'-4"	3
L3 TOS	W8x10	Primary	18'-4"	2
L3 TOS	W8x10	Secondary	18'-1 1/2"	4
L3 TOS	W8x10	Secondary	18'-4"	23
L3 TOS	W16X26	Secondary	18'-4"	10
L3 TOS	W18x55	Primary	18'-1 1/2"	22
L3 TOS	W18x55	Primary	18'-4"	23
L3 TOS	W18x55	Secondary	18'-4"	2
L3 TOS	W18x86	Primary	18'-4"	13
L3 TOS	W36x232	Primary	16'-9 7/8"	1
				193
L4 TOS	16K6	Secondary	31'-8"	105
L4 TOS	20K6	Secondary	31'-8"	25
L4 TOS	_Size	Tertiary	31'-5 1/2"	1
L4 TOS	W8x10	Secondary	31'-5 1/2"	1
L4 TOS	W8x10	Secondary	31'-8"	9
L4 TOS	W12X26	Primary	31'-8"	9
L4 TOS	W18x55	Primary	31'-5 1/2"	27
L4 TOS	W18x55	Primary	31'-8"	19
L4 TOS	W18x55	Secondary	31'-5 1/2"	2
L4 TOS	W18x86	Primary	31'-5 1/2"	3
L4 TOS	W18x86	Primary	31'-8"	1
L4 TOS	W30x235	Primary	31'-5 1/2"	1
				203

x

L5 TOS	16K6	Secondary	45'-0"	89
L5 TOS	20K6	Secondary	45'-0"	25
L5 TOS	_Size	Tertiary	44'-9 1/2"	1
L5 TOS	C8X11.5	Secondary	45'-0"	3
L5 TOS	W8x10	Secondary	44'-9 1/2"	4
L5 TOS	W8x10	Secondary	45'-0"	12
L5 TOS	W12X26	Primary	45'-0"	9
L5 TOS	W14X30	Secondary	42'-8"	5
L5 TOS	W18x55	Primary	42'-8"	4
L5 TOS	W18x55	Primary	44'-9 1/2"	25
L5 TOS	W18x55	Primary	45'-0"	20
L5 TOS	W18x55	Secondary	44'-9 1/2"	2
L5 TOS	W18x86	Primary	44'-9 1/2"	3
L5 TOS	W18x86	Primary	45'-0"	1
L5 TOS	W30x235	Primary	44'-9 1/2"	1
				204
R2 TOS	16K2	Secondary	58'-4"	53
R2 TOS	20K6	Secondary	53'-4 1/2"	7
R2 TOS	20K6	Secondary	58'-4"	25
R2 TOS	_Size	Tertiary	58'-1 1/2"	1
R2 TOS	W8x10	Secondary	58'-4"	21
R2 TOS	W12X26	Primary	58'-4"	23
R2 TOS	W18x55	Other	58'-1 1/2"	2
R2 TOS	W18x55	Primary	53'-2"	2
R2 TOS	W18x55	Primary	53'-4 1/2"	2
R2 TOS	W18x55	Primary	58'-1 1/2"	18
R2 TOS	W18x55	Primary	58'-4"	9
R2 TOS	W18x86	Primary	58'-1 1/2"	3
R2 TOS	W30x235	Primary	58'-1 1/2"	1
				167

Parapet 2	_Size	Tertiary	<varies>	10
Parapet 2	_Size	Tertiary	68'-4 7/8"	2
Parapet 2	_Size	Tertiary	68'-5 1/2"	1
Parapet 2	_Size	Tertiary	68'-11 3/8"	2
Parapet 2	_Size	Tertiary	69'-2 3/8"	5
Parapet 2	W8x10	Secondary	68'-6 3/8"	2
Parapet 2	W8x10	Secondary	68'-7"	1
Parapet 2	W8x10	Secondary	68'-8"	2
Parapet 2	W8x10	Secondary	68'-8 1/2"	1
Parapet 2	W8x10	Secondary	68'-9 5/8"	2
Parapet 2	W8x10	Secondary	68'-10"	1
Parapet 2	W8x10	Secondary	68'-11 1/4"	2
Parapet 2	W8x10	Secondary	68'-11 3/8"	1
Parapet 2	W8x10	Secondary	69'-0 3/4"	2
Parapet 2	W8x10	Secondary	69'-0 7/8"	3
				37

AFTER

Structural beam system

<Structural Beam System Schedule>							
A	B	C	D	E	F	G	H
Beam Type (No Family	Layout Rule	Centerline Spacing	Reference Level Elevati	Elevation from Level	Comments	Count	Beam Type
16K2	Maximum Spacing	<varies>	<varies>	<varies>	@ Max 4'-0"	50	K-Series Bar Joist-Angle
W8x10	Maximum Spacing	<varies>	<varies>	<varies>	@ Max 4'-0"	26	W Shapes : W8x10

Structural wall

<Structural Wall Schedule>

A	B	C	D	E	F	G	H	I	J	K
Type	Base Constraint	Base Offset	Bottom Width	Top Constraint	Top Offset	Top Width	Width	Structural Usage	Structural Material	Count
Concrete 10"	Elevator Pit	0"		Up to level: L1_35_Low	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Elevator Pit	0"		Up to level: L1_35_Low	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_35_Low	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Elevator Pit	0"		Up to level: L1_35_Low	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_35_Low	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	Elevator Pit	0"		Up to level: L1_35_Low	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Elevator Pit	0"		Up to level: L1_35_Low	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_37_Med	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	Elevator Pit	0"		Up to level: L1_37_Med	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	Elevator Pit	0"		Up to level: L1_37_Med	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Elevator Pit	0"		Up to level: L1_37_Med	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Elevator Pit	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Elevator Pit	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_35_Low	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_35_Low	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_35_Low	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_37_Med	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_37_Med	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 24"	Top of Footing	0"		Up to level: L1_37_Med	0"		2'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_37_Med	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Top of Footing	0"		Up to level: L1_37_Med	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	-3'-5 1/2"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Top of Footing	0"		Up to level: L1_43_High	-3'-5 1/2"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_43_High	-3'-5 1/2"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 19"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-7"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	Top of Footing	0"		Up to level: L1_43_High	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1

Concrete 10"	L1_35_Low	0"	Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_35_Low	0"	Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_35_Low	0"	Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_35_Low	0"	Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_35_Low	0"	Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"	Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"	Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"	Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_37_Med	0"	Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_37_Med	0"	Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-0 37/128"	Up to level: L1_43_High	-7'-11"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-0 37/128"	Up to level: L1_43_High	-7'-11"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 18"	L1_43_High	-17'-11"	2'-3 31/64"	Up to level: L1_43_High	-2'-10"	1'-6"	1'-6"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_43_High	-8'-11"		Up to level: L1_43_High	-2'-10"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_43_High	-5'-11"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_43_High	-5'-11"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-3'-5 1/2"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-3'-5 1/2"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	-3'-5 1/2"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_43_High	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 10"	L1_43_High	0"		Up to level: Parapet 2	0"		10"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1
Concrete 12"	L1_43_High	0"		Up to level: Parapet 2	0"		1'-0"	Bearing	Concrete, Cast-in-Place	1

Structural Column

<Structural Column Schedule>

A	B	C	D	E	F	G	H	I	J
Type	Base Level	Base Offset	Top Level	Top Offset	Length	Description	Type Comments	Type Mark	Count
12x18	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
12x18	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
12x18	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
12x18	Top of Footing	0"	L1_35_Low	0"	11'-7"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_37_Med	0"	14'-0 1/2"				1
12x18	Top of Footing	0"	L1_43_High	0"	17'-6"				1
W18x119	L1_35_Low	0"	L3	4'-0"	28'-9"				1
W6x31	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W6x31	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W10x49	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W10x49	L1_35_Low	0"	R2 TOS	0"	64'-3"				1
W10x49	L1_37_Med	0"	L3	4'-0"	26'-3 1/2"				1
W10x49	L1_37_Med	0"	L3	4'-0"	26'-3 1/2"				1
W10x49	L1_37_Med	0"	L5 TOS	0"	48'-5 1/2"				1
W10x49	L1_37_Med	0"	L5 TOS	0"	48'-5 1/2"				1
W10x49	L1_37_Med	0"	L5 TOS	0"	48'-5 1/2"				1
W6x31	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W6x31	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W6x31	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W6x31	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W6x31	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W6x31	L1_37_Med	0"	R2 TOS	-6'-8 3/8"	55'-1 1/8"				1
W6x31	L1_37_Med	0"	R2 TOS	-6'-7 7/8"	55'-1 5/8"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	0"	61'-9 1/2"				1
W10x49	L1_37_Med	0"	R2 TOS	-4'-11 1/2"	56'-10"				1
W10x49	L1_37_Med	0"	R2 TOS	-4'-11 1/2"	56'-10"				1

W10x49	L3	4'-0"	L5 TOS	0"	22'-2"			1
W10x49	L3	4'-0"	R2 TOS	0"	35'-6"			1
W10x49	L3	4'-0"	R2 TOS	0"	35'-6"			1
W8x31	L5	0"	R2 TOS	0"	12'-10"			1
W8x31	L5	0"	R2 TOS	0"	12'-10"			1
W8x31	L5	0"	R2 TOS	0"	12'-10"			1
W8x31	L5	0"	R2 TOS	0"	12'-10"			1
W8x31	L5	0"	R2 TOS	0"	12'-10"			1
W8x31	R2 TOS	-5'-2"	R2 TOS	0"	5'-2"			1
W8x31	R2 TOS	-5'-2"	R2 TOS	0"	5'-2"			1

Structural foundation

<Structural Foundation Schedule>

A	B	C	D	E	F	G
Family and Type	Level	Description	Type Mark	Width	Foundation Thickness	Count
Wall Foundation: Bearing Footing - 36"x18"		SF		3'-0"	1'-6"	9
Foundation Slab: FNDN-36	Elevator Pit			14'-8"	3'-0"	1
Foundation Slab: FNDN-36	Elevator Pit			25'-8 1/2"	3'-0"	1
SFD_Round: 24x24x20'	Elevator Pit		DP24"-10'	2'-0"	20'-0"	14
Foundation Slab: FNDN-36	Top of Footing			27'-6"	3'-0"	1
Foundation Slab: FNDN-36	Top of Footing			29'-6 1/2"	3'-0"	1
SFD_Round: 24x24x25'	Top of Footing		DP24"-12'	2'-0"	25'-0"	37
SFD_Pile_Cap_Rectangle: 36x36x24 Pile_24	Parking	Cap		3'-0"	2'-0"	13
SFD_Round: 24x24x25'	Parking		DP24"-12'	2'-0"	25'-0"	13

Structural framing

<Structural Framing Schedule>

A	B	C	D	E
Reference Level	Type	Structural Usage	Elevation at Top	Count
L1_35_Low	CB18x24	Primary	-5'-11"	1
L1_35_Low	CB24x24	Primary	-5'-11"	11
				12
L1_37_Med	CB24x24	Primary	-3'-5 1/2"	17
L1_37_Med	CB24x30	Primary	-3'-5 1/2"	2
				19
L1_43_High	CB24 x51	Primary	0"	2
L1_43_High	CB24x24	Primary	0"	2
				4
M1 TOS	16K2	Secondary	5'-0"	8
M1 TOS	W18X40	Primary	4'-7"	5
M1 TOS	W18X40	Primary	5'-0"	6
				19
L2 TOS	16K2	Secondary	7'-7"	54
L2 TOS	16K2	Secondary	7'-9 1/2"	1
L2 TOS	_Size	Tertiary	7'-4 1/2"	1
L2 TOS	W8x10	Primary	7'-7"	2
L2 TOS	W8x10	Secondary	7'-7"	2
L2 TOS	W18X40	Primary	7'-4 1/2"	14
L2 TOS	W18X40	Primary	7'-7"	9
				83
L3 TOS	16K2	Secondary	18'-4"	88
L3 TOS	_Size	Tertiary	18'-1 1/2"	1
L3 TOS	C8X11.5	Secondary	18'-4"	3
L3 TOS	W8x10	Primary	18'-4"	2
L3 TOS	W8x10	Secondary	18'-1 1/2"	4
L3 TOS	W8x10	Secondary	18'-4"	33
L3 TOS	W18X40	Primary	18'-1 1/2"	22
L3 TOS	W18X40	Primary	18'-4"	23
L3 TOS	W18X40	Secondary	18'-4"	2
L3 TOS	W18x55	Primary	18'-4"	13
L3 TOS	W36x232	Primary	16'-9 7/8"	1
				192

L4 TOS	16K2	Secondary	31'-8"	128
L4 TOS	_Size	Tertiary	31'-5 1/2"	1
L4 TOS	W8x10	Primary	31'-8"	9
L4 TOS	W8x10	Secondary	31'-5 1/2"	1
L4 TOS	W8x10	Secondary	31'-8"	9
L4 TOS	W18X40	Primary	31'-5 1/2"	27
L4 TOS	W18X40	Primary	31'-8"	19
L4 TOS	W18X40	Secondary	31'-5 1/2"	2
L4 TOS	W18x55	Primary	31'-5 1/2"	3
L4 TOS	W18x55	Primary	31'-8"	1
L4 TOS	W30x235	Primary	31'-5 1/2"	1
				201
L5 TOS	16K2	Secondary	45'-0"	113
L5 TOS	_Size	Tertiary	44'-9 1/2"	1
L5 TOS	C8X11.5	Secondary	45'-0"	3
L5 TOS	W8x10	Primary	45'-0"	9
L5 TOS	W8x10	Secondary	42'-8"	5
L5 TOS	W8x10	Secondary	44'-9 1/2"	4
L5 TOS	W8x10	Secondary	45'-0"	12
L5 TOS	W18X40	Primary	42'-8"	4
L5 TOS	W18X40	Primary	44'-9 1/2"	25
L5 TOS	W18X40	Primary	45'-0"	20
L5 TOS	W18X40	Secondary	44'-9 1/2"	2
L5 TOS	W18x55	Primary	44'-9 1/2"	3
L5 TOS	W18x55	Primary	45'-0"	1
L5 TOS	W30x235	Primary	44'-9 1/2"	1
				203
R2 TOS	16K2	Secondary	53'-4 1/2"	7
R2 TOS	16K2	Secondary	58'-4"	78
R2 TOS	_Size	Tertiary	58'-1 1/2"	1
R2 TOS	W8x10	Primary	58'-4"	23
R2 TOS	W8x10	Secondary	58'-4"	21
R2 TOS	W18X40	Other	58'-1 1/2"	2
R2 TOS	W18X40	Primary	53'-2"	2
R2 TOS	W18X40	Primary	53'-4 1/2"	2
R2 TOS	W18X40	Primary	58'-1 1/2"	18
R2 TOS	W18X40	Primary	58'-4"	9
R2 TOS	W18x55	Primary	58'-1 1/2"	3
R2 TOS	W30x235	Primary	58'-1 1/2"	1
				167
Parapet 2	_Size	Tertiary	<varies>	10
Parapet 2	_Size	Tertiary	68'-4 7/8"	2
Parapet 2	_Size	Tertiary	68'-5 1/2"	1
Parapet 2	_Size	Tertiary	68'-11 3/8"	2
Parapet 2	_Size	Tertiary	69'-2 3/8"	5
Parapet 2	W8x10	Secondary	68'-6 3/8"	2
Parapet 2	W8x10	Secondary	68'-7"	1
Parapet 2	W8x10	Secondary	68'-8"	2
Parapet 2	W8x10	Secondary	68'-8 1/2"	1
Parapet 2	W8x10	Secondary	68'-9 5/8"	2
Parapet 2	W8x10	Secondary	68'-10"	1
Parapet 2	W8x10	Secondary	68'-11 1/4"	2
Parapet 2	W8x10	Secondary	68'-11 3/8"	1
Parapet 2	W8x10	Secondary	69'-0 3/4"	2
Parapet 2	W8x10	Secondary	69'-0 7/8"	3
				37

e) LCA analysis results

Deviation results

1	Project users	Project users	Project users	Project users	Project users									
2	ARNOLD MUYENG	ARNOLD MUYENG	LOD 300 BASELINE	0	LCA for DGNB (DE 2023)									
3	**Section**	**Resource**	**User input**	**Unit**	**Global warming, kg CO2e/m2/a**	**Total use of non re**	**Global warm**	**Total use of**	**Acidificatior**	**Eutrophicati**	**Formation o**	**Mass of raw**	**Question**	**Comment**
4	A1-A3	Ready-mix concret	361.62	m3	116803.26	205576.95	0.342	0.602	185.15	43.03		867888	Foundation, sub-surface, b	
5	A1-A3	Ready-mix concret	19.48	m3	7998.68	0	0.0234	0	20.77	4.15		46752	Columns and	
6	A1-A3	Steel section, 2.5	8.44	m3	65885.87	202264.12	0.193	0.592	0	0		66254	Columns and	
7	A1-A3	Ready-mix concret	478.01	m2	15539.73	17484.82	0.0455	0.0512	17.82	3.49		163133.64	External wal	
8	A1-A3	Ready-mix concret	2474.55	m2	377244.68	0	1.1	0	979.74	195.83		2204980.4	External wal	
9	A1-A3	Ready-mix concret	59.09	m3	24262.95	0	0.0711	0	63.01	12.59		141816	Floor slabs, c	
10	A1-A3	Steel section, 2.5	22.93	m3	179000.34	549516.14	0.524	1.61	0	0		180000.5	Floor slabs, c	
11	A1-A3	Ready-mix concret	6446.23	m2	454944.67	0	1.33	0	1181.53	236.16		2659133.7	Floor slabs, c	
12	A1-A3	Galvanized profilec	4011.2	m2	106296.8	344792.72	0.311	1.01	268.35	23.39		37665.17	Floor slabs, c	
13	**Subtotal for A1-A3:**				**1347976.98**	**1319634.75**	**3.95**	**3.86**	**2716.38**	**518.64**		**6367623.4**		
14	A1-C4	Steel section, 2.5	8.44	m3	0	0	0	0	0	0			Columns and	
15	A1-C4	Steel section, 2.5	22.93	m3	0	0	0	0	0	0			Floor slabs, c	
16	**Subtotal for A1-C4:**				**0**	**0**	**0**	**0**	**0**	**0**				
17	C3	Ready-mix concret	361.62	m3	2368.64	12657.17	0.00694	0.0371	18.57	3.85			Foundation, sub-surface, b	
18	C3	Ready-mix concret	19.48	m3	557.91	0	0.00163	0	2.63	0.593			Columns and	
19	C3	Steel section, 2.5	8.44	m3	0	0	0	0	0	0			Columns and	
20	C3	Ready-mix concret	478.01	m2	1078.91	4976.46	0.00316	0.0146	6.98	1.19			External wal	
21	C3	Ready-mix concret	2474.55	m2	26313.08	0	0.0771	0	124.13	27.96			External wal	
22	C3	Ready-mix concret	59.09	m3	1692.36	0	0.00496	0	7.98	1.8			Floor slabs, c	
23	C3	Steel section, 2.5	22.93	m3	0	0	0	0	0	0			Floor slabs, c	
24	C3	Ready-mix concret	6446.23	m2	31732.71	0	0.0929	0	149.69	33.72			Floor slabs, c	
25	C3	Galvanized profilec	4011.2	m2	374.65	2306.44	0.0011	0.00675	1.11	0.106			Floor slabs, c	
26	**Subtotal for C3:**				**64118.28**	**19940.06**	**0.188**	**0.0584**	**311.09**	**69.21**				

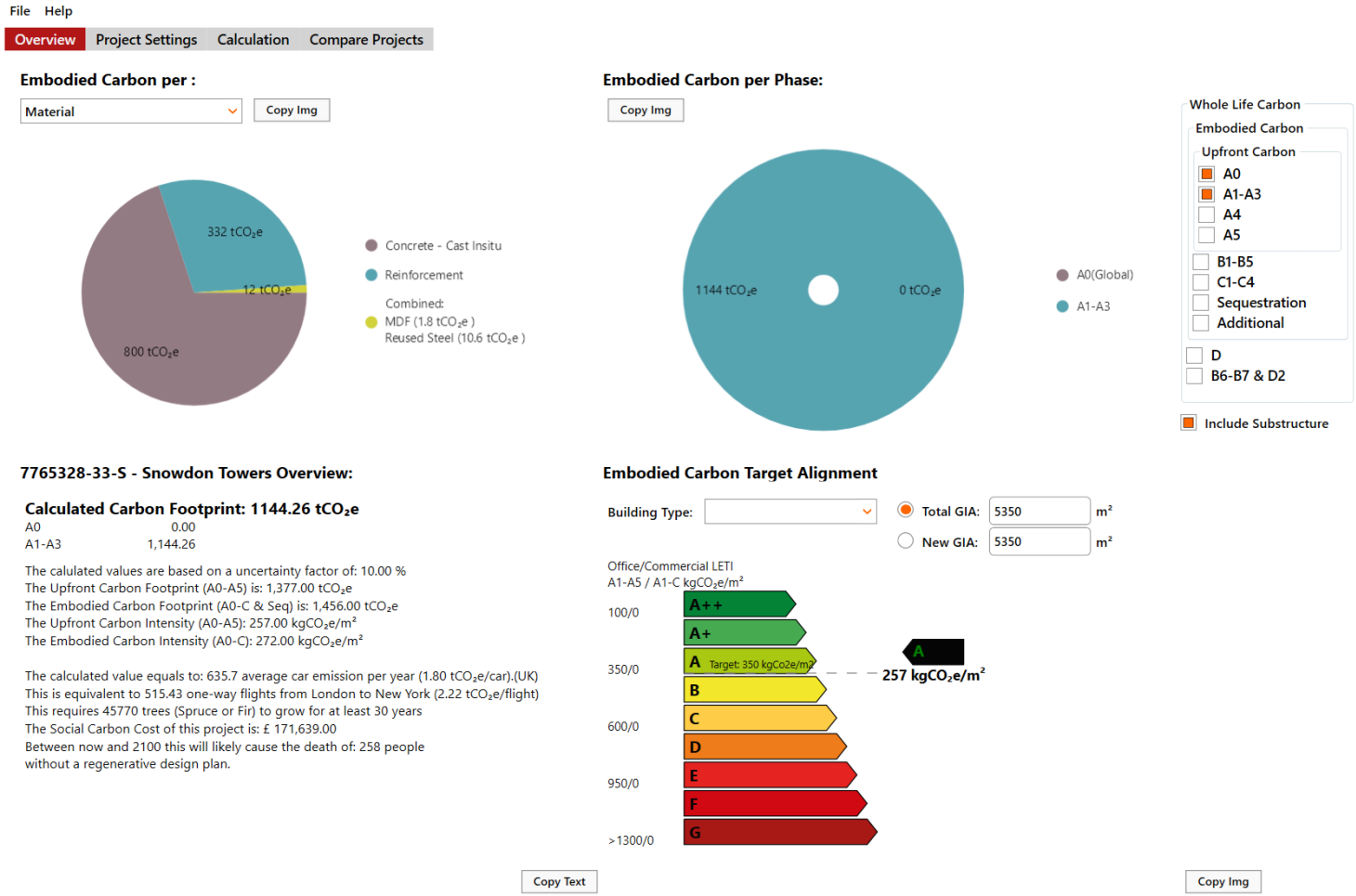
Appendix Fig. e-1 LOD 300 OCL Baseline results

	Project users	Project name	Design name	Date	Tool name								
2	ARNOLD MUYENG	0	LOD 200 FINAL	0	0								
3	**Section**	**Resource**	**User input**	**Unit**	**Global warming, kg CO2e/m²**	**Total use of**	**Global warm**	**Total use of**	**Acidification**	**Eutrophicati**	**Formation o**	**Mass of raw**	**Question**	**Comment**
4	A1-A3	Ready-mix concret	334.2	m3	137225.9	0	137225.9	0	356.39	71.23		802080	Foundation,	
5	A1-A3	Ready-mix concret	7.38	m3	3030.3	0	3030.3	0	7.87	1.57		17712	Columns and	
6	A1-A3	Steel section, 2.5	4.58	m3	35753.23	109759.44	35753.23	109759.44	0	0		35953	Columns and	
7	A1-A3	Ready-mix concret	486.11	m2	16385.65	18436.62	16385.65	18436.62	18.79	3.67		172014.01	External wal	
8	A1-A3	Ready-mix concret	2670.82	m2	365238.79	0	365238.79	0	948.56	189.6		2134806.4	External wal	
9	A1-A3	Ready-mix concret	62.96	m3	25852.01	0	25852.01	0	67.14	13.42		151104	Floor slabs, c	
10	A1-A3	Steel section, 2.5	18.06	m3	140983.26	432806.87	140983.26	432806.87	0	0		141771	Floor slabs, c	
11	A1-A3	Ready-mix concret	6468.82	m2	403997.7	0	403997.7	0	1049.22	209.72		2361350.7	Floor slabs, c	
12	A1-A3	Ready-mix concret	666.78	m3	188741.62	173930.03	188741.62	173930.03	197.74	38.32		1600272	Floor slabs, c	Baustellenbe
13	A1-A3	Reinforcement ste	30125.8	kg	20586.62	73633.43	20586.62	73633.43	38.64	5.25		30125.8	Floor slabs, c	Verstärkung.
14	A1-A3	Steel sheet (0.3-30	44987.86	kg	109212.85	276264.25	109212.85	276264.25	235.36	22.47		44987.86	Floor slabs, c	Stahlbelag. S
15	**Subtotal for A1-A3:**				**1447007.94**	**1084830.6**	**1447007.9**	**1084830.6**	**2919.71**	**555.25**		**7492176.8**		
16	A1-C4	Steel section, 2.5	4.58	m3	0	0	0	0	0	0			Columns and	
17	A1-C4	Steel section, 2.5	18.06	m3	0	0	0	0	0	0			Floor slabs, c	
18	**Subtotal for A1-C4:**				**0**	**0**	**0**	**0**	**0**	**0**				
19	B4	Ready-mix concret	334.2	m3	0	0	0	0	0	0			Foundation,	
20	B4	Ready-mix concret	7.38	m3	0	0	0	0	0	0			Columns and	
21	B4	Steel section, 2.5	4.58	m3	0	0	0	0	0	0			Columns and	
22	B4	Ready-mix concret	486.11	m2	0	0	0	0	0	0			External wal	
23	B4	Ready-mix concret	2670.82	m2	0	0	0	0	0	0			External wal	
24	B4	Ready-mix concret	62.96	m3	0	0	0	0	0	0			Floor slabs, c	
25	B4	Steel section, 2.5	18.06	m3	0	0	0	0	0	0			Floor slabs, c	
26	B4	Ready-mix concret	6468.82	m2	0	0	0	0	0	0			Floor slabs, c	
27	B4	Ready-mix concret	666.78	m3	0	0	0	0	0	0			Floor slabs, c	Baustellenbe
28	B4	Reinforcement ste	30125.8	kg	0	0	0	0	0	0			Floor slabs, c	Verstärkung.
29	B4	Steel sheet (0.3-30	44987.86	kg	0	0	0	0	0	0			Floor slabs, c	Stahlbelag. S
30	**Subtotal for B4:**				**0**	**0**	**0**	**0**	**0**	**0**				

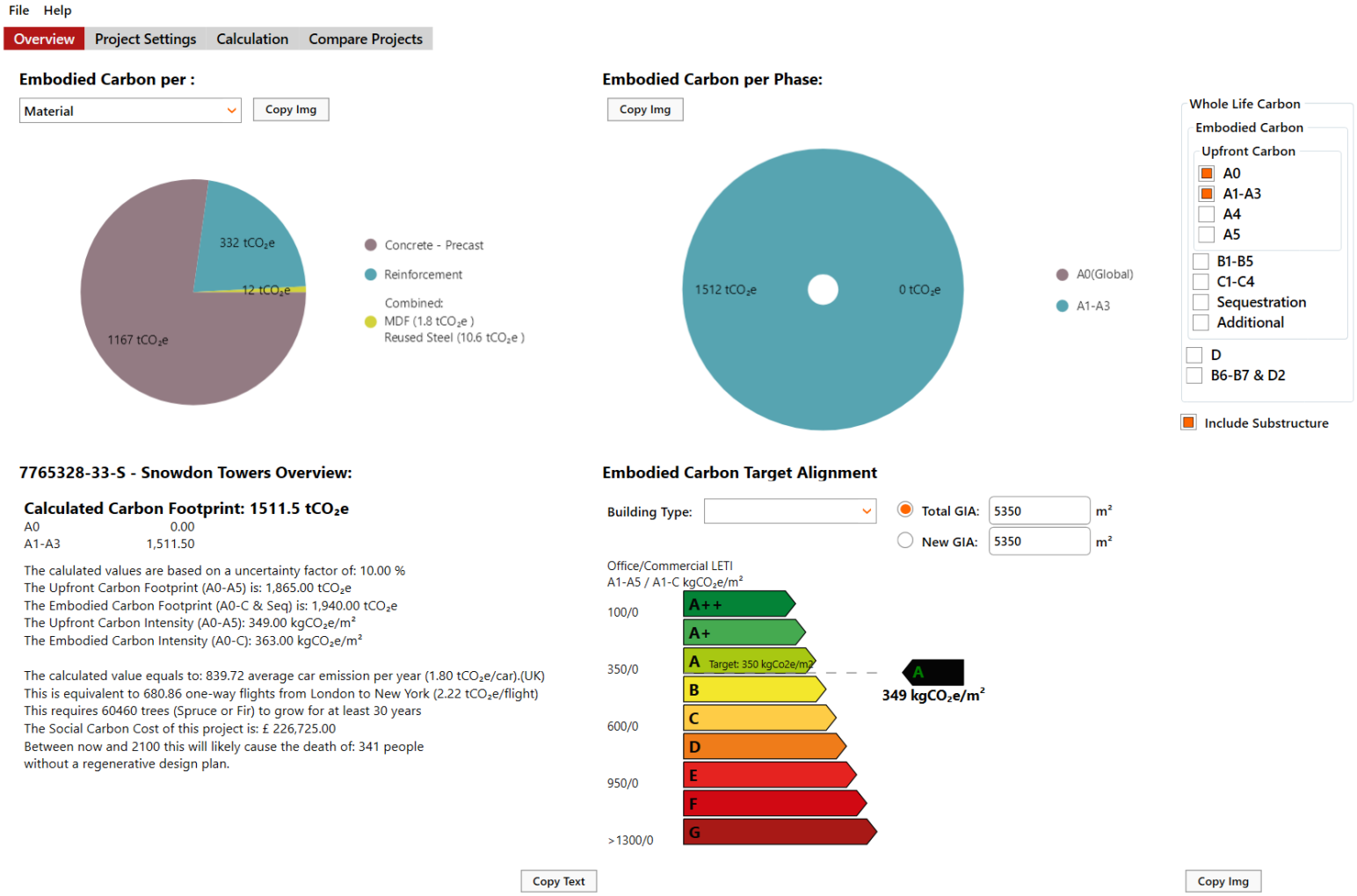
Appendix Fig. e-2 LOD 200 OCL (Okobaudat database)

1	Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
2	[A1-A3] Product	5,528.67	316.10	1,668,702.34	1.03E-02	102,767.17	17,226,578.83	16,155,094.31	1,076,724.80	6,040,395.13
3	[A4] Transportation	84.37	6.87	18,108.33	6.24E-10	2,787.95	264,788.42	258,452.17	6,402.94	
4	[B2-B5] Maintenance and Replacement	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
5	[C2-C4] End of Life	535.46	27.15	230,422.16	2.13E-08	10,649.30	1,983,828.96	1,854,951.03	131,071.43	
6	[D] Module D	176.31	7.72	75,111.94	-5.02E-04	3,489.62	657,770.56	721,620.16	-64,260.89	
7	**Grand Total**	**6,324.81**	**357.84**	**1,992,344.76**	**9.83E-03**	**119,694.04**	**20,132,966.77**	**18,990,117.68**	**1,149,938.28**	**6,040,395.13**

Appendix Fig. e-3 LOD 200 Tally database (generic)



Appendix Fig. e-4 LOD 200 CLC (controlled)



Appendix Fig. e-5 LOD 200 CLC (uncontrolled)

Sensitivity Analysis Results

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**Project users**	**Project name**	**Design name**	**Date**	**Tool name**											
2	ARNOLD MUYENG	ARNOLD MUYENG	SNOWDON TOWEI	7/24/26	LCA for DGNB (DE 2023)											
3	**Section**	**Resource**	**User input**	**Unit**	**Global warm**	**Total use of**	**Global warm**	**Total use of**	**Acidification**	**Eutrophicati**	**Formation o**	**Mass of raw**	**Question**	**Comment**	**Thickness**	**Service life**
4	A1-A3	Ready-mix concret	59.09	m3	19086.07	33592.01	19086.07	33592.01	30.25	7.03		141816	Foundation, sub-surface, basement a			As building
5	A1-A3	Ready-mix concret	19.48	m3	6292.04	11074.16	6292.04	11074.16	9.97	2.32		46752	Foundation, sub-surface, basement a			As building
6	A1-A3	Ready-mix concret	979.14	m3	316262.22	556630.21	316262.22	556630.21	501.32	116.52		2349936	Foundation, sub-surface, basement a			As building
7	A1-A3	Ready-mix concret	361.62	m3	116803.26	205576.95	116803.26	205576.95	185.15	43.03		867888	Foundation, sub-surface, basement a			As building
8	A1-A3	Ready-mix concret	1109	m3	358207	630454.18	358207	630454.18	567.81	131.97		2661600	Foundation, sub-surface, basement a			As building
9	A1-A3	Steel section, 2.5	8.44	m3	65885.87	202264.12	65885.87	202264.12	0	0		66254	Columns and			As building
10	A1-A3	Ready-mix concret	485.86	m2	16359.95	18407.71	16359.95	18407.71	18.76	3.67		171744.27	External wal		147.28545	As building
11	A1-A3	Steel section, 2.5	33.97	m3	265182.8	814089.11	265182.8	814089.11	0	0		266664.5	Floor slabs, c			As building
12	A1-A3	Galvanized profilec	4015.65	m2	106414.72	345175.24	106414.72	345175.24	268.65	23.41		37706.95	Floor slabs, c		0.9	As building
13	**Subtotal for A1-A3:**				**1270493.9**	**2817263.7**	**1270493.9**	**2817263.7**	**1581.92**	**327.95**		**6610361.7**				
14	A1-C4	Steel section, 2.5	8.44	m3	0	0	0	0	0	0			Columns and			As building
15	A1-C4	Steel section, 2.5	33.97	m3	0	0	0	0	0	0			Floor slabs, c			As building
16	**Subtotal for A1-C4:**				**0**	**0**	**0**	**0**	**0**	**0**						
17	B4	Ready-mix concret	59.09	m3	0	0	0	0	0	0			Foundation, sub-surface, basement a			As building
18	B4	Ready-mix concret	19.48	m3	0	0	0	0	0	0			Foundation, sub-surface, basement a			As building
19	B4	Ready-mix concret	979.14	m3	0	0	0	0	0	0			Foundation, sub-surface, basement a			As building
20	B4	Ready-mix concret	361.62	m3	0	0	0	0	0	0			Foundation, sub-surface, basement a			As building
21	B4	Ready-mix concret	1109	m3	0	0	0	0	0	0			Foundation, sub-surface, basement a			As building
22	B4	Steel section, 2.5	8.44	m3	0	0	0	0	0	0			Columns and			As building
23	B4	Ready-mix concret	485.86	m2	0	0	0	0	0	0			External wal		147.28545	As building
24	B4	Steel section, 2.5	33.97	m3	0	0	0	0	0	0			Floor slabs, c			As building
25	B4	Galvanized profilec	4015.65	m2	0	0	0	0	0	0			Floor slabs, c		0.9	As building
26	**Subtotal for B4:**				**0**	**0**	**0**	**0**	**0**	**0**						

Appendix Fig. e-6 LOD 300 to 200 System Change

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Project users**	**Project name**	**Design name**	**Date**	**Tool name**									
2	ARNOLD MUYENG	ARNOLD MUYENG	SNOWDON TOWEI	0	0									
3	**Section**	**Resource**	**User input**	**Unit**	**Global warn**	**Total use of**	**Global warn**	**Total use of**	**Acidificatior**	**Eutrophicati**	**Formation o**	**Mass of raw**	**Question**	**Comment**
4	A1-A3	Precast concrete s	361.62	m3	213529.38	474023.55	213529.38	474023.55	296.67	70.71		875120.4	Foundation,	
5	A1-A3	Precast concrete s	19.48	m3	11502.55	25535.03	11502.55	25535.03	15.98	3.81		47141.6	Columns and	
6	A1-A3	Structural steel sec	8.44	m3	21665.06	65885.92	21665.06	65885.92	62.01	4.54		66254	Columns and	
7	A1-A3	Precast concrete s	478.01	m2	40136.31	89100.42	40136.31	89100.42	55.76	13.29		164493.09	External wal	
8	A1-A3	Precast concrete s	2474.55	m2	542498.67	1204317.4	542498.67	1204317.4	753.72	179.65		2223355.2	External wal	
9	A1-A3	Precast concrete s	59.09	m3	34891.46	77457.14	34891.46	77457.14	48.48	11.55		142997.8	Floor slabs, c	
10	A1-A3	Structural steel sec	22.93	m3	58860.16	179000.5	58860.16	179000.5	168.48	12.33		180000.5	Floor slabs, c	
11	A1-A3	Wood-aluminium f	0.011	m3	13.93	77.07	13.93	77.07	0.108	0.00922		7.59	Floor slabs, c	
12	A1-A3	Structural steel sec	0.04	m3	175.21	633.23	175.21	633.23	0.502	0.0421		314	Other structı	
13	A1-A3	Precast concrete s	6446.23	m2	654235.54	1452367.1	654235.54	1452367.1	908.96	216.65		2681293.2	Floor slabs, c	
14	A1-A3	Galvanized or orga	4011.2	m2	72201.6	202788.44	72201.6	202788.44	136.78	13.28		24708.99	Floor slabs, c	
15	**Subtotal for A1-A3:**				**1649709.9**	**3771185.9**	**1649709.9**	**3771185.9**	**2447.45**	**525.86**		**6405686.4**		
16	B4	Precast concrete s	361.62	m3	0	0	0	0	0	0			Foundation,	
17	B4	Precast concrete s	19.48	m3	0	0	0	0	0	0			Columns and	
18	B4	Structural steel sec	8.44	m3	0	0	0	0	0	0			Columns and	
19	B4	Precast concrete s	478.01	m2	0	0	0	0	0	0			External wal	
20	B4	Precast concrete s	2474.55	m2	0	0	0	0	0	0			External wal	
21	B4	Precast concrete s	59.09	m3	0	0	0	0	0	0			Floor slabs, c	
22	B4	Structural steel sec	22.93	m3	0	0	0	0	0	0			Floor slabs, c	
23	B4	Wood-aluminium f	0.011	m3	0	0	0	0	0	0			Floor slabs, c	
24	B4	Structural steel sec	0.04	m3	0	0	0	0	0	0			Other structı	
25	B4	Precast concrete s	6446.23	m2	0	0	0	0	0	0			Floor slabs, c	
26	B4	Galvanized or orga	4011.2	m2	0	0	0	0	0	0			Floor slabs, c	
27	**Subtotal for B4:**				**0**	**0**	**0**	**0**	**0**	**0**				

Appendix Fig. e-7 EPD database run for LOD 300

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Project users**	**Project name**	**Design name**	**Date**	**Tool name**										
2	ARNOLD MUYENG	ARNOLD MUYENG	LOD 200 FINAL	7/24/26	LCA for DGNB (DE 2023)										
3	**Section**	**Resource**	**User input**	**Unit**	**Global warm**	**Total use of**	**Global warm**	**Total use of**	**Acidification**	**Eutrophicati**	**Formation o**	**Mass of raw**	**Question**	**Comment**	**Thickness**
4	A1-A3	Ready-mix concret	334.2	m3	137225.9	0	137225.9	0	356.39	71.23		802080	Foundation,		382.83368
5	A1-A3	Ready-mix concret	7.38	m3	3030.3	0	3030.3	0	7.87	1.57		17712	Columns and		
6	A1-A3	Steel section, 2.5	4.58	m3	35753.23	109759.44	35753.23	109759.44	0	0		35953	Columns and		
7	A1-A3	Ready-mix concret	486.11	m2	16385.65	18436.62	16385.65	18436.62	18.79	3.67		172014.01	External wal		147.44091
8	A1-A3	Ready-mix concret	2670.82	m2	365238.79	0	365238.79	0	948.56	189.6		2134806.4	External wal		333.04478
9	A1-A3	Ready-mix concret	62.96	m3	25852.01	0	25852.01	0	67.14	13.42		151104	Floor slabs, c		
10	A1-A3	Steel section, 2.5	18.06	m3	140983.26	432806.87	140983.26	432806.87	0	0		141771	Floor slabs, c		
11	A1-A3	Ready-mix concret	6468.82	m2	403997.7	0	403997.7	0	1049.22	209.72		2361350.7	Floor slabs, c		152.09823
12	A1-A3	Ready-mix concret	666.78	m3	188741.62	173930.03	188741.62	173930.03	197.74	38.32		1600272	Floor slabs, c	Baustellenbe	200
13	A1-A3	Reinforcement ste	30125.8	kg	20586.62	73633.43	20586.62	73633.43	38.64	5.25		30125.8	Floor slabs, c	Verstärkung.	Reinforcer
14	A1-A3	Steel sheet (0.3-30	44987.86	kg	109212.85	276264.25	109212.85	276264.25	235.36	22.47		44987.86	Floor slabs, c	Stahlbelag. S	
15	**Subtotal for A1-A3:**				**1447007.9**	**1084830.6**	**1447007.9**	**1084830.6**	**2919.71**	**555.25**		**7492176.8**			
16	A1-C4	Steel section, 2.5	4.58	m3	0	0	0	0	0	0			Columns and		
17	A1-C4	Steel section, 2.5	18.06	m3	0	0	0	0	0	0			Floor slabs, c		
18	**Subtotal for A1-C4:**				**0**	**0**	**0**	**0**	**0**	**0**					
19	B4	Ready-mix concret	334.2	m3	0	0	0	0	0	0			Foundation,		382.83368
20	B4	Ready-mix concret	7.38	m3	0	0	0	0	0	0			Columns and		
21	B4	Steel section, 2.5	4.58	m3	0	0	0	0	0	0			Columns and		
22	B4	Ready-mix concret	486.11	m2	0	0	0	0	0	0			External wal		147.44091
23	B4	Ready-mix concret	2670.82	m2	0	0	0	0	0	0			External wal		333.04478
24	B4	Ready-mix concret	62.96	m3	0	0	0	0	0	0			Floor slabs, c		
25	B4	Steel section, 2.5	18.06	m3	0	0	0	0	0	0			Floor slabs, c		
26	B4	Ready-mix concret	6468.82	m2	0	0	0	0	0	0			Floor slabs, c		152.09823
27	B4	Ready-mix concret	666.78	m3	0	0	0	0	0	0			Floor slabs, c	Baustellenbe	200
28	B4	Reinforcement ste	30125.8	kg	0	0	0	0	0	0			Floor slabs, c	Verstärkung.	Reinforcer
29	B4	Steel sheet (0.3-30	44987.86	kg	0	0	0	0	0	0			Floor slabs, c	Stahlbelag. S	
30	**Subtotal for B4:**				**0**	**0**	**0**	**0**	**0**	**0**					

Appendix Fig. e-8 Geometry Resizing for LOD 300