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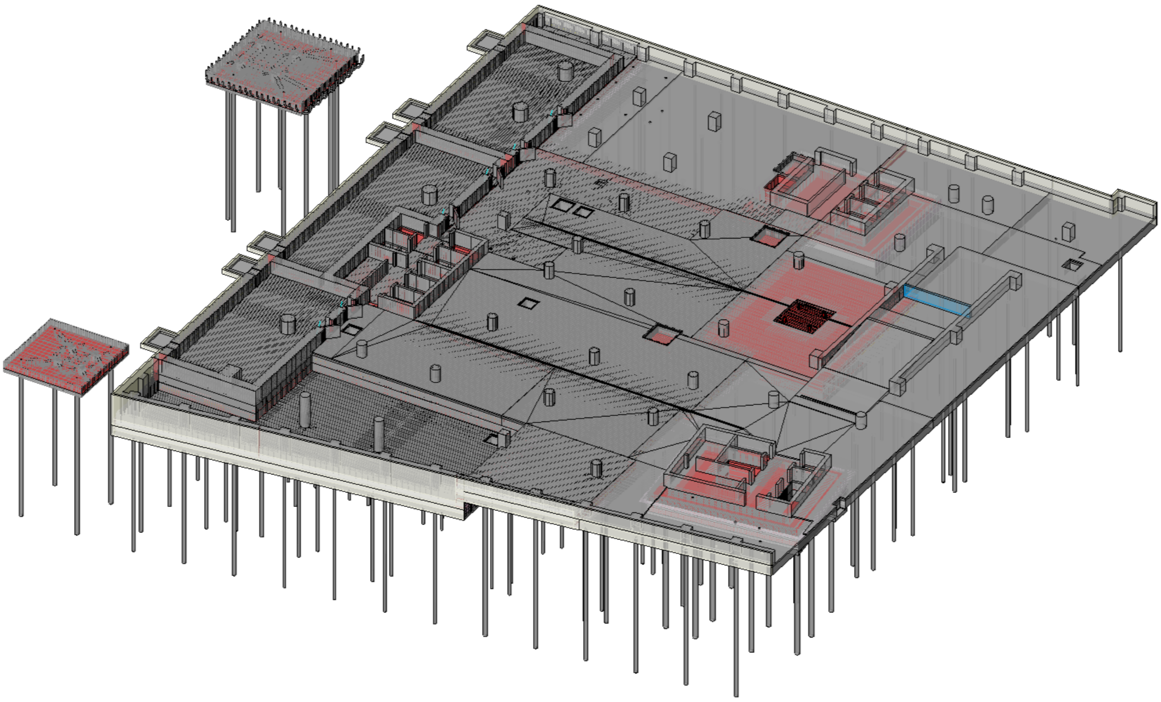

Optimizing Climate Calculations in Construction:

An Empirical Analysis of BIM Integration and Workflow Enhancement

Master's thesis in Design and Construction Project Management

KARL BROLIN
FREDRIK HOFMANN
HENK HOOGENDIJK

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
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Supervisor: Mikael Johansson, Department of Architecture and Civil Engineering
Examiner: Mikael Johansson, Department of Architecture and Civil Engineering

Master's Thesis 2024
Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: BIM model visualising the case project for the study.

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Abstract

In early 2022 a new law was implemented in Sweden which calls for climate calculations to be conducted in conjunction with new construction projects. The purpose of this thesis is to analyze a case project that has adapted a model-based construction approach and investigate whether this approach creates a base for extracting climate calculations in a proficient manner. This will be done by answering the research questions, centered around workflows, strategies for continuous climate calculations, and the necessary model requirements. To be able to answer these questions a literature study was conducted as well as an open interview study with stakeholders involved in the project. In addition to these sources of information a series of experiments was also conducted in order to investigate the possibilities of the software currently used by the consulting firm Sweco.

The thesis results in a workflow that supports the use of iterative climate calculations in the early stages of projects. The workflow reduces the amount of manual data collection and analysis needed to conduct the calculations allowing actors to focus on optimizing design related decisions for better sustainability outcomes. The research also highlights the challenges that comes with these integrated solutions. Overall, this thesis contributes to valuable insight into optimising climate calculations within BIM frameworks. This work highlights the importance of continued development and refinement of integration strategies to address existing challenges and maximize the benefits of technology in advancing sustainable construction practices. This thesis fills a gap in research on the implementation of Total BIM and LCA practices which has been found to be limited.

Keywords: AEC, BIM, Total BIM, LCA, Climate Calculation, Workflow

Sammanfattning

I början av 2022 infördes en ny lag i Sverige som kräver klimatberäkningar vid nybyggnation. Syftet med detta examensarbete är att analysera ett projekt som har använt en modellbaserad byggmetod och undersöka om denna metod kan ligga till grund för effektiva klimatberäkningar. Detta kommer att göras genom att besvara forskningsfrågor som fokuserar på arbetsflöden, strategier för kontinuerliga klimatberäkningar och nödvändiga modellkrav. För att besvara dessa frågor genomfördes en litteraturstudie samt en öppen intervju studie med personer involverade i projektet. Dessutom utfördes experiment för att undersöka möjligheterna med den mjukvara som konsultföretaget Sweco för närvarande använder.

Avhandlingen resulterar i ett arbetsflöde som stödjer användningen av iterativa klimatberäkningar i projektens tidiga skeden. Arbetsflödet minskar den manuella datainsamlingen och analysen som krävs, vilket gör det möjligt för aktörerna att fokusera på att optimera designrelaterade beslut för bättre hållbarhetsresultat. Den aktuella forskningen lyfter även fram de utmaningar som följer med integrerade lösningar. Sammantaget bidrar denna avhandling med värdefulla insikter i optimering av klimatberäkningar inom BIM-ramverk. Arbetet belyser vikten av fortsatt utveckling och optimering av integrationsstrategier för att hantera befintliga utmaningar och maximera teknologins fördelar i syfte att främja hållbara byggmetoder. Denna avhandling fyller en lucka i forskningen om implementering av Total BIM och LCA-metoder, som har visat sig vara begränsad.

Nyckelord: Byggnation, BIM, Total BIM, LCA, Klimatberäkning, Arbetsflöde

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Karl Brolin, Fredrik Hofmann and Henk Hoogendijk, Gothenburg, June 2024

Contents

1

Introduction

The world is facing the challenge of urgent climate change, and the need for sustainable solutions is dire all across the different sectors. The construction industry, being one of the more resource-intensive and infamous large impactors, faces significant challenges. High emission of greenhouse gases, inefficient energy and extensive use of non-renewable material to name a few.

Quantifying and identifying the climate impact of a building is an important first step. With climate calculations a building's impact on the climate is calculated from the raw materials until the construction phase is finished. Often a Life Cycle Assessment (LCA) is conducted where all the steps are included, from material extraction to demolition and reuse. This first step assessment is an important insight to explore alternative materials to each part or element of a building.

This thesis will examine current practice of climate calculations and challenge their effectiveness. While further exploring potential improvements.

1.1 Background

In Sweden, the construction industry stand for roughly 21% of the nations total greenhouse gas emission, where 4.2% of its emissions is new buildings (Boverket, 2023). In January 2022 a new law was introduced which states that all new buildings must have a climate declaration and more laws are set to be introduced in 2027 (Boverket, 2023). Due to the recent interest and lack of research it is key to further analyse and optimise climate calculations in the construction industry.

To conduct a more precise LCA analysis a lot of information has to be provided in the digital representation of the building. Total BIM as a tool in building projects provides the necessary information for a thorough climate calculation during and at the finish line of a building project.

The construction industry has been the subject of transformation for many years, this transformation has been fueled by factors such as technological innovations and a change of demand in the market. One of these technologies is Building Information Modelling (BIM), it offers a comprehensive digital representation of building projects. The industry in general is still heavily reliant on 2D drawings, they have been criticised for a number of faults for example their redundant information and the amount of work needed to have drawings that represent the current state of the building (Disney, Roupe, et al., 2022). In theory many of these issues can be sorted by the use of BIM, however it is common practice that both BIM and traditional 2D drawings are created and maintained throughout the project creating two parallel processes. During recent years the concept of Total BIM has been developed where the use of transitional 2D drawings are scrapped and replaced with the sole use of BIM methodologies (Disney, Roupe, et al., 2022). The case being reviewed in this thesis is a Total BIM project the study will therefore be built on Total BIM rather than a project implementing both BIM and 2D drawings.

The design phase in construction consists of many different tasks with different complexities. With various complexity of tasks comes various levels of need of communication between disciplines in the project, especially between the design members (Hansen et al., 2021). Tasks that are more iterative and complex are delegated to design teams which demands simultaneous communication. Iterative design tasks differs from traditionally production processes that are mainly conducted with sequential work.

The transition towards a more digitised construction industry with BIM based design has evolved the communication methods (Abou-Ibrahim and Hamzeh, 2017). The evolved methods has lead to the usage of BIM where the information flows between group members are available for everyone in the project to take part of. This has lead to quicker responses and enhanced interaction between members in the project.

To utilise BIM at its full potential the management has to provide comprehensive instructions to the design team (Svalestuen et al., 2017). This reduces the unnecessary iterations and streamlines the process. To harness the full potential of BIM, it is crucial for the design groups to utilised the same model.

This thesis has been conducted in collaboration with the consultant company Sweco. After discussions the thesis landed in how to make Swecos workflow more efficient with the use of BIM models to conduct climate calculations.

1.2 Aim and problem statement

The aim of the study is to investigate how the Total BIM methodologies that are being implemented can be used to develop climate calculations by examining a construction project. At the end of this study, the following questions will be answered:

- How does the implementation of Total BIM methodologies influence the workflow of the project's climate calculations?
- What is the optimal strategy for performing continuous climate calculations during a project's design phase?
- What are the requirements on the BIM-model when performing climate calculations and how does the use of generic data affect the quality of climate declarations?

The outcome of this thesis will give Sweco a base for conducting climate calculations while implementing Total BIM methodologies. It will give them knowledge about what requirements need to be fulfilled for BIM models to act as sufficient sources of information for climate calculations.

1.3 Delimitations

For the purpose of this study it should be noted that the focus of this study will be on the life cycle assessment processes included in the climate declaration law rather than a comprehensive examination of LCA practices in general. This delimitation has been done as there are multiple variations of LCA standards and methodologies that are effected by factors such as the specific industry and context of the study.

The scope of this report is limited to a single project therefore the conclusions and findings might be difficult to transfer to projects in a different context. However, this delimitation allows for a detailed and contextually rich analysis of the case being studied. Some of the files and project information are disclosed in order to protect the integrity of the tenants. This might have some impact on the result due to the unavailability to analyse and experiment on all the models used in the case project.

As this thesis is written in cooperation with Sweco the stakeholder perspective will primarily be focused on the perspective of the consultants as they are the actor directly involved in the implementation of Total BIM and climate calculations within the projects. Other stakeholders will be included to a lesser extent as the main focus is to understand internal processes and challenges that appears when integrating Total BIM and climate calculations. There was an active decision made to limit the software being tested to the ones already available and incorporated in Sweco's workflow. This decision was made as there was a desire to come up with a possible solution that avoids any additional costs from new software licences.

Further the Swedish Housing agency's (Boverkets) climate database will be the only general database analysed in line with the earlier mentioned Swedish climate declaration law, this leads the thesis focusing on the Swedish AEC industry.

2

Method

The methodology is structured to achieve the research objectives effectively and systematically. The following study adopts an objective paradigm in the form of an abductive approach, which consists of a literature study to gather and examine relevant information, discussed alongside findings from open interviews and the results of computer experiments.

2.1 Literature study

The literature study aims to gather specific information and knowledge on how Total BIM can add value to climate calculations. This research phase is crucial for understanding the current industry and identifying gaps in existing knowledge. Relevant literature, including articles and reports, was searched using Google Scholar and the Chalmers Library. Additional documents and reports were sourced from various construction associations and organizations dealing with climate calculations and digitization in the form of BIM and Total BIM. Some of the reports and article were also provided by the supervisor of this thesis. Keywords such as "Total BIM," "climate calculation," "LCA (Life Cycle Assessment)," "AEC (Architecture, Engineering, Construction)," and "workflow" were used to identify relevant literature. These keywords helped in locating specific studies that address the integration of BIM with climate calculations.

2.2 Open interviews

The study includes a series of open interviews with stakeholders involved in BIM implementation and climate calculations. Participants include engineers, BIM specialists, and sustainability consultants. The open interviews aim to gather qualitative data on thoughts, experiences, barriers, and opportunities related to the integration of Total BIM with climate calculations. The open interviews were conducted in an open format to allow participants to freely discuss their insights and experiences. This approach enabled the collection of rich, detailed data that is essential for understanding the current workflow within the consultant company and how the implementation of BIM in climate calculations are currently done. These open interviews were important to be able to link real life scenarios with the findings in the literature study.

2.3 Computer experiments

Computer experiments were conducted to gain a better understanding of current methods and to investigate the potential for automating and improve some of the processes involved in climate calculations using BIM. A part of the BIM model was used to extract data into different climate calculation software. It was also use to investigate requirement tools for the model. This process involved testing and investigate the efficiency of various software tools in handling BIM data for climate calculations and how sofwares can ensure quality the BIM models information. The data from these experiments were analyzed to identify optimized methods and workflows for performing climate calculations based on a BIM model. The results provided insights into how new workflows can enhance the accuracy and efficiency of continuous climate calculations.

2.4 Comparative analysis

Given the lack of studies discussing the implementation of Total BIM in combination with climate calculations in Sweden indicates a knowledge gap in this area. To address this, the study draws on literature from different countries with similar AEC backgrounds and compares the approaches taken in these countries with the current state of the construction industry in Sweden. Since the construction industry in Europe is quite similar to that in Sweden, the findings from other countries can be transferred well to the Swedish context.

2.5 Ethical considerations

The research complies with guidelines on data protection, confidentiality, and informed consent. All participants' identities and sensitive information will be protected. Data discussed in the study will be anonymized as agreed upon with the project stakeholders, ensuring that individual participants cannot be identified from the published results.

This structured methodology ensures a comprehensive and systematic approach to exploring the integration of Total BIM with climate calculations, addressing the research objectives effectively.

3

Literature study

This chapter reviews key concepts transforming the AEC industry. It covers BIM and its enhancement through Level of Development (LOD) and Model Maturity Index (MMI) frameworks. Life Cycle Assessment (LCA) is examined for its role in environmental impact assessment, along with the regulatory frameworks guiding it. Additionally, LCA & BIM software, integration workflows, and classification codes are explored, highlighting their synergy in promoting sustainable construction.

3.1 Life Cycle Assessment (LCA)

The principle of life cycle analysis builds on Newton's First Law of Thermodynamics, energy cannot be created or destroyed it can be transformed from one form to another. According to Horne et al. (2009) the most relevant question when performing LCA analyses is, what are the implications for climate change of different energy scenarios and how can we identify the desired services from low levels of impact?

There are many different definitions of LCA. However the core sense is a systematic analysis of environmental impact that has its sources in the creation of a product or service (Horne et al., 2009). There are international standards for conducting life cycle assessments that are published by the International organisation for Standardiaation (ISO). According to the standards ISO 14040 and ISO 14044 (International Organization for Standardization, 2006) there are four phases in an LCA study:

- The goal and scope definition phase.
- The inventory analysis phase.
- The impact assessment phase.
- The interpretation phase.

The first phase that includes the goal and scope covers the system boundary and level of detail (International Organization for Standardization, 2006). It is dependent on the subject and the intended use for the LCA. The second phase, life cycle inventory (LCI) is an inventory of data that connects to the system being studied. This includes collection of data that is needed to meet the requirements of the study. The next stage is the life cycle impact assessment phase (LCIA) the purpose of this phase is to include additional insight that helps evaluating a product system's LCI results. The LCIA therefore aids the user by gaining a deeper knowledge about said product system's environmental significance. The final phase, life cycle interpretation presents the results of an LCI, LCIA, or both. They are summarised and discussed and can then be used as a basis for conclusions, recommendations, and decision-making.

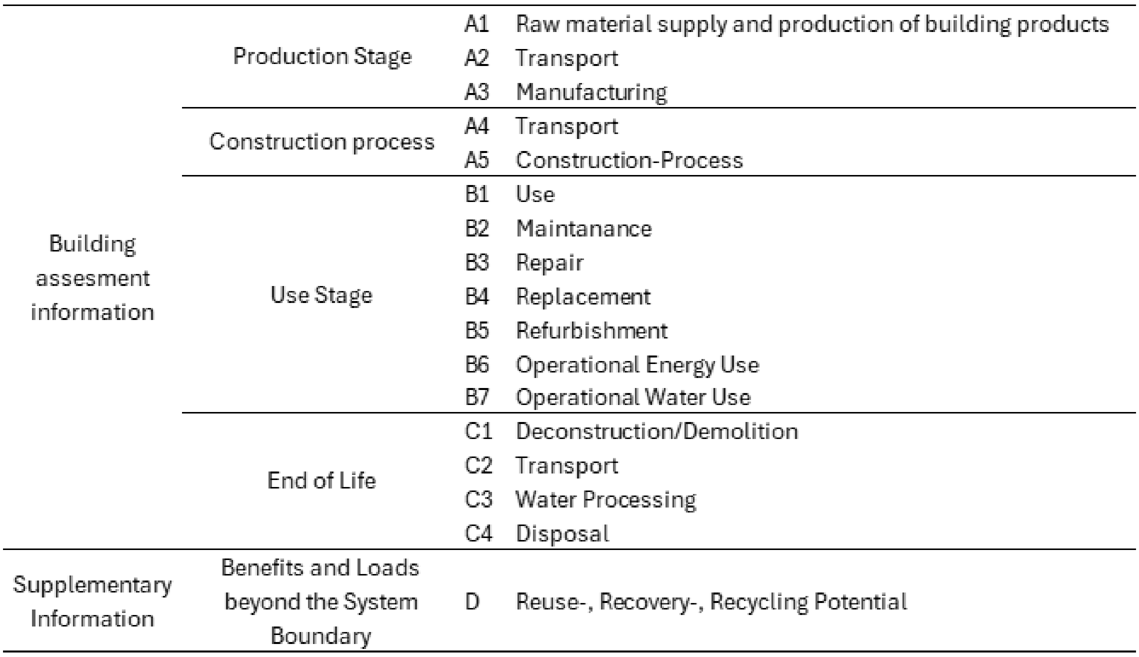
3.1.1 Data selection and impact assessment method for LCA

One key factor for every LCA analysis is the data being used for the LCIA. This data can be collected from numerous sources and can be consisting of data from a generic LCA database or a specific Environmental Product Declaration (EPD) database (Wastiels and Decuypere, 2019). To be able to create a calculation that reflects the performance of the actual building using EPDs is seen as beneficial. As the EPDs are product specific they therefore reflect the impact of the specific product used in the construction better than data from a generic database. EPDs are created by manufacturers and are product specific and follow the rules of the EN 15804 standard, they are reviewed by a third party which can ensure a certain grade of security (Boverket, 2023). The fact that there are multiple sources for data collection can cause some problems and in addition to the differing sources of data, the age and collection method also creates variation in building inventory data (Anand and Amor, 2017). It has been proven that these variation has a significant impact on the decision making based on the LCA results. It also creates a difficulty in comparing LCA reports between buildings. According to Anand and Amor (2017) one reason for the existing variations is the lack of standards that exists when it comes to data collection methods for buildings LCA. In addition to the variation and lack of standardised methods there is also a problem with lack of data. This is especially true for the design phase and it leads to a larger number of assumptions that have to be made, practitioners often find themselves facing the issue of selecting the correct data where data is missing (Anand and Amor, 2017).

Another factor that has impact of the final result of the LCA is the selection of impact assessment method. This method is the approach that is used to evaluate the potential environmental impact that comes from a product, process, or project. There are two mainstream impact assessment methods: Midpoint and Endpoint methods (Huijbregts et al., 2017). Midpoint methods focus on environmental impact categories that can be considered intermediate. They asses environmental factors such as resource depletion, emission to air, or energy consumption. These factors are concerned as intermediate as they are not the final endpoints of environmental damage, they contribute to broader environmental impacts. Endpoint methods on the other hand consider the overall environmental impact of the system being analysed. Here the effects of multiple stressors are summed up into broader categories for example human health impacts or ecosystem quality. These methods give a holistic view but the modelling is more complex therefore these methods often have a larger grade of uncertainty. The choice of assessment method is often decided by the goal and scope of the environmental impact assessment.

During the impact assessment phase one or multiple impact categories are selected, they represent a specific environmental issue or concern that is being evaluated. These categories provide a structure for comparing the environmental performance of products, processes, or services. They can be used as a tool for stakeholders to be able to understand potential consequences that are linked to their choices. In similarity with many other fields energy and emissions are the most used metrics in construction (Anand and Amor, 2017). For example, the midpoint indicator *Climate change* has global warming potential (GWP) as a widely used characterisation factor. GWP quantifies the integrated infrared radioactive forcing increase of a greenhouse gas, expressed in kg CO_2-eq (Huijbregts et al., 2017). Other impact categories such as zone depletion, freshwater eutrophication, resource depletion, and land use, provide additional insight to the different environmental consequences that can be connected to the life-cycle of a product, process, or service. Overall, impact categories play a crucial roles in LCA studies as they give stakeholders the opportunity to analyse and compare performance of their options and make informed choices that eventually leads to a minimised environmental impact.

A buildings life cycle can be divided into four main stages according to the European standard EN 15978 (Boverket, 2023), product stage, construction process stage, use stage, and end of life stage. The stages are also divided in to individual modules that describe the processes within the life cycle. The modules enables a structured display of the results which makes them easier to interpret and identify critical points of the life cycle. The system boundaries according to EN 15978 is displayed in figure 3.1.



Building assesment information	Production Stage	A1	Raw material supply and production of building products
		A2	Transport
		A3	Manufacturing
	Construction process	A4	Transport
		A5	Construction-Process
	Use Stage	B1	Use
		B2	Maintanance
		B3	Repair
		B4	Replacement
		B5	Refurbishment
		B6	Operational Energy Use
		B7	Operational Water Use
	End of Life	C1	Deconstruction/Demolition
		C2	Transport
		C3	Water Processing
		C4	Disposal
Supplementary Information	Benefits and Loads beyond the System Boundary	D	Reuse-, Recovery-, Recycling Potential

Figure 3.1: *System boundaries according to EN 15978.*

3.2 Regulatory framework

As of January 1st 2022 the act on climate declaration came into force, the purpose of this is to reduce the climate impact from the construction stage (Boverket, 2023). This act demands that all buildings that require building permits are to develop a climate declaration, with some exceptions. This decision forces the industry to take on the task of performing climate calculations in all projects. Due to the early stage of this law, it is difficult to compare climate calculations between different buildings in a fair manner. This is partly because the purpose of the building has an impact on how the end-product will effect the climate. There is a desire from the governing bodies to implement an upper limit for climate impact in the climate declarations, according to Boverket this step is hindered by the incapability of comparing climate declarations between buildings (Boverket, 2023).

3.2.1 Climate declaration requirements

The climate declaration should include data from the Production Stage and the Construction Process modules A1-A5. It differs from the EN 15978 standard as the A5 module Construction-Process is divided into A5 Construction Waste and A5 Energy. Another difference from the standard is that not all construction components are to be included in the climate declaration. Boverket (2023) defines the components that are to be included as the buildings envelope, load-bearing structures, and inner walls. This means that components such as the buildings installations are to be excluded from the declaration.

The data used for the climate declaration can be gathered from product specific EDP's or a generic database that has been created by Boverket (Boverket, 2023). An example of what materials can be found in the database is provided in figure 3.2. The figure displays some of the available materials listed under the category "Concrete". In this case the data in question is climate data containing information about greenhouse gas emissions in kilograms of carbon dioxide equivalents (kgCO_2e) per unit of resource. The generic data that is to be used in the climate declaration is created by Boverket, the data has a conservative nature and their value is set approximately 25% higher than the average values for modules A1-A3 and A5 (Boverket, 2023). Theoretically this leads to a lower calculated impact if EDP's are to be used in calculations to a greater extent. One key difference between the use of EPDs and generic data is that EPDs are product- and manufacturer-specific, whereas generic data is calculated from a wide selection of EPDs and can be considered material-specific instead. For the early stages the generic values are useful as the product that is going to be used in the end product might not be decided yet. Due to the conservative values of the data in Boverket's database, using specific data will lead to a more specific climate declaration (Boverket, 2023). If both generic data and specific data is missing from a product it can not be included in the climate declaration, therefore creating a data gap. When using specific data it is important to list which EPD has been used, especially since they have a period of validity. This period is usually five years long, and all EPDs used in the climate declaration has to be valid at that time. All EPDs has a registration- or declaration number that can identify them that should be included in the declaration.

CLIMATE DATABASE FROM BOVERKET
A service provided by Boverket

Concrete

Version 02.05.000, 2024-01-25

Climate database from Boverket / Concrete

- Ready-mix made concrete, buildings C20/25
- Ready-mix made concrete, buildings C25/30
- Ready-mix made concrete, buildings C28/35
- Ready-mix made concrete, buildings C30/37
- Ready-mix made concrete, buildings C32/40
- Ready-mix made concrete, buildings C35/45
- Ready-mix made concrete, buildings C40/50
- Ready-mix made concrete, buildings C45/55
- Ready-mix made concrete, buildings C50/60
- Ready-mix made concrete, buildings C55/67
- Ready-mix made concrete, buildings C60/75
- Ready-mix made concrete, buildings climate-improved C20/25
- Ready-mix made concrete, buildings climate-improved C25/30
- Ready-mix made concrete, buildings climate-improved C28/35

Figure 3.2: *The figure displays some of the available material choices under the category "Concrete" within Boverket's database.*

Boverket's generic database contains multiple factors that are relevant when performing LCA analyses. The key factors included for every object listed in the database is the data used for calculation. This data is divided in three values, the climate impact *Global Warming Potential - Greenhouse Gas* (GWP-GHG) for A1:A3, A4, and A5 in kilograms of carbon dioxide equivalents per kilogram of material. There is also complementary information such as a conversion value and technical service life. Every component has its own Resource ID (ResursID) that identifies the component as there are differences being made between components that might seem similar at first glance, for example concrete with different classifications. The climate database also contains the factors that have been used to calculate the conservative value set for the components. There is also a typical value for components that has been calculated based on publicly available EPDs and other data sources (Boverket, 2023). This value can be used for making comparisons in the early stages of projects. The database also contains climate data for energy- and fuel consumption, these values are not set in a conservative manner. There are no requirements from Boverket on what software is to be used, it is rather the data that is the focal point. This allows for different options when performing the calculations, for example they can be done in programs dedicated for LCA calculations or plug-ins for BIM programs.

3.2.2 The vision and future of climate declarations

The climate declaration is to be turned in at the end of the production stage. However, the opportunities for lowering the environmental impact of the building primarily exists in the early stages of the project (Boverket, 2023). It is in this phase of the project where different solutions and methods are considered. Here the climate declaration can act as a base for decision making. Therefore it is beneficial to have the climate declaration as a parallel process to be able to find changes that can be made. As the law is still relatively new there is a certain learning curve later on knowledge transfer from previous project will be of great aid. This is especially true for certain processes for example when finding the data that is necessary to gather to perform climate declarations. Boverkets vision is that the climate declaration is a process that spans from the early stages of planning to the end product of a finished building (Boverket, 2023). Therefore the final climate calculation is to be done with the purpose of reflecting the construction as-built. The declaration is then to be approved before the building is put into service.

As previously mentioned there are no requirements for the total emissions for a building within the climate declaration. However, there are plans on implementing further requirements for the climate declarations in order for the environmental factors to play a larger role within projects. Boverket has been tasked by the government to provide legislative proposals for the next steps. In this proposal it is mentioned that maximum allowable values for modules A1:A5 should be introduced, that could happen as early as 2025 (Boverket, 2023). After these limits have been introduced the plan is to lower these limits over time as the industry adapts. Another suggestion is to increase the scope for the climate declaration from modules A1:A5 to include modules: B2 Maintenance, B4 Replacement, B6 Operational energy use, and C1:C4 End of life (Boverket, 2023). These modules are to be included in climate declarations from January 1st 2027. There are also additions to be made on demands for climate declarations for renovations and rules to increase the quality of calculations. The law introduced in 2022 is a first step towards a more comprehensive environmental goals in construction.

3.3 BIM

Today, Building information modeling (BIM), is a widespread technology in the AEC industry. Its benefits are reported in numerous articles to improve efficiency, quality and provides 3D models for a project in early stages (Fox, 2014); (Azhar and Asce, 2011); (Renz et al., 2016). Common practice in Sweden is to create a 3D model in a BIM software and extract 2D drawings from the model and use the 2D drawings as the legally binding documents. However, other than creating 2D drawings, BIM is seldom implemented in the production phase (Disney, Johansson, et al., 2022) which results in outdated BIM-files and bad transfer of knowledge between the project team and production (Disney, Johansson, et al., 2022); (Johansson and Roupé, 2021).

In the late 70's and early 80's, CAD, Computer Aided Design, was discussed as a potential tool to aid and assist workers in the AEC industry (Bijl, 1986). Today, CAD and BIM and several defined technologies, are parts of the AEC industry and some technologies are more than likely involved in every or some stages of a construction project (Megahed and Hassan, 2022). Today, BIM facilitates collaboration amongst different stakeholders involved in the design phase. Working on a shared digital model easier coordinates the stakeholders and allows minimal errors and conflicts between every discipline. In Megahed and Hassan (2022), it is discussed how the post-pandemic world had to accelerate its use of BIM, and its effects on construction projects are significant.

BIM models can be used for more than just extracting 2D drawings, a well detailed BIM model contains information such as material properties of elements, performance specifications, climate data et cetera. Data such as this is easy to include for every element in a digital model in comparison to representing it in 2D drawings. Which leads to the next section, Total BIM.

3.3.1 Total BIM

As mentioned in 3.3, BIM is by now well established in the AEC industry. However, in recent years there have been piloting projects embracing BIM in its totality. Total BIM refers to a total integration and implementation of BIM through the entire projects lifecycle (Disney, Roupe, et al., 2022). Total BIM is more than just implementing the use of 3D modeling it also incorporates dimensions such as time, cost and sustainability (Seyman-Güray and Kismet, 2022). Total BIM means implementing BIM in the projects early planning stage, design phase and construction phase (Disney, Roupé, et al., 2023).

In "Embracing BIM in its totality: a Total BIM case study" by Disney, Roupe, et al. (2022) a successful project, the Celsius project, is studied for the use of BIM in the entire project, hence called Total BIM. This study shows that due to an all-in approach to BIM where all factors are integrated yielded greater success than if implemented individually as traditionally done. The authors also outline 4 main success factors: BIM is the legally binding document, utilisation of production oriented cloud-based BIM software where all model files were live-linked between stakeholder, the deployment of a mobile BIM-viewer software (StreamBIM) for the on site construction team which led to no paper drawings ever being produced, and effective leadership and management implementing Total BIM. The construction management company behind this project were internationally acknowledged for their innovation and digitisation of the construction process, even winning an award.

Total BIM is the concept of embracing BIM in totality, but BIM is not something new. Implementing BIM in the AEC industry has been pushed for many years. But BIM is seldom used during the production phase and this means construction workers, or foremen, have to master the new workflows and methodologies. This is a learning curve and is one of the many challenges for Total BIM. In the Celsius case study it was also reported that the design phase was more expensive, about 11-13% (Disney, Johansson, et al., 2022), although it spared the project of other expenses.

3.3.2 Open BIM

IFC (Industry Foundation Classes) is a standardised file format functioning as a interact able file for BIM software's in the AEC industry (Laakso and Student, 2012). It started developing 1994 and the standardisation process of this format met challenges in a developing industry with fast paced technological advancements. Today, the IFC format is widely used in the AEC industry and standard practice for practitioners to use as a interoperable format between different BIM and BIM viewing softwares.

Information Delivery Specification (IDS) is a file format defining and automatically checks the BIM models requirements and exchange them with BIM workflows (Solibri, 2024). Before IDS was introduces specific rules for BIM tools were required to make which increase possible mistakes and cost. IDS enables fast and automatic model verification. IDS files are standardised to be easily read by tools like Solibri, it checks and verify BIM models depending on the requirements within the file. The benefit of IDS is its ability to confirm that the requested information aligns with the model, ensuring that important data are available for all stakeholders. It creates advanced quality checks, ITOs (Information takeoffs), and classification tasks without encountering missing information.

The BIM Collaboration Format (BCF) facilitates communication about model-based issues between different BIM applications using previously shared IFC models. BCF can be used through file exchanges, uploaded to StreamBIM, or through a dedicated BCF server (buildingSMART, 2024). BCF development began in 2009, initiated by Solibri, Tekla, and the Institute for Applied Building Informatics (iabi) at Munich University of Applied Sciences. It was developed to leverage open communication technology for IFC-based workflows and is now an open standard by buildingSMART International. BCF transfers XML formatted data containing contextual information about an issue, referencing specific views and elements in a BIM model. This information is transferred between applications using IFC GUIDs (globally unique identifier).

3.4 Enhancing the BIM enviroment with LOD and MMI frameworks

The design and engineering processes in construction are usually multidisciplinary and include a range of activities (Abualdenien and Borrmann, 2022). These various activities has defined requirements, conceptualise design trough modeling which forms a cohesive workflow essential for producing a functional asset with quality over the entire life cycle of the process. It is important that the collaboration of this workflow is functioning well. It is therefore crucial for the participants in a project to be on the same level. *What* information should be available at what milestone, *who* is responsible to ensure that this information is delivered and *why* is this information even delivered (BIMforum, 2023). To ensure that these procedures are done Level of Development (LOD) and Model Maturity Index (MMI) can be used.

3.4.1 Level of Development (LOD)

Level of Detail (LoD) originates from computer graphics to communicate the complexity and performance by regulating the details when visualising the virtual world (Abualdenien and Borrmann, 2022). The first implementation of LOD in the AEC industry was conducted by VicoSoftware in 2005, they described these different geometrical levels in five different stages of accuracy (Abualdenien and Borrmann, 2022)(BIMforum, 2023). Years later in 2008 the American Institute of Architects (AIA) used the LoD standards and further developed it and introduced the Level of Development (LOD). This specification has a slightly different name, this specification also comprises of the five stages, as seen in figure 3.3, starting from LOD 100 reaching to LOD 400, this standard are directed more to the AEC industry.

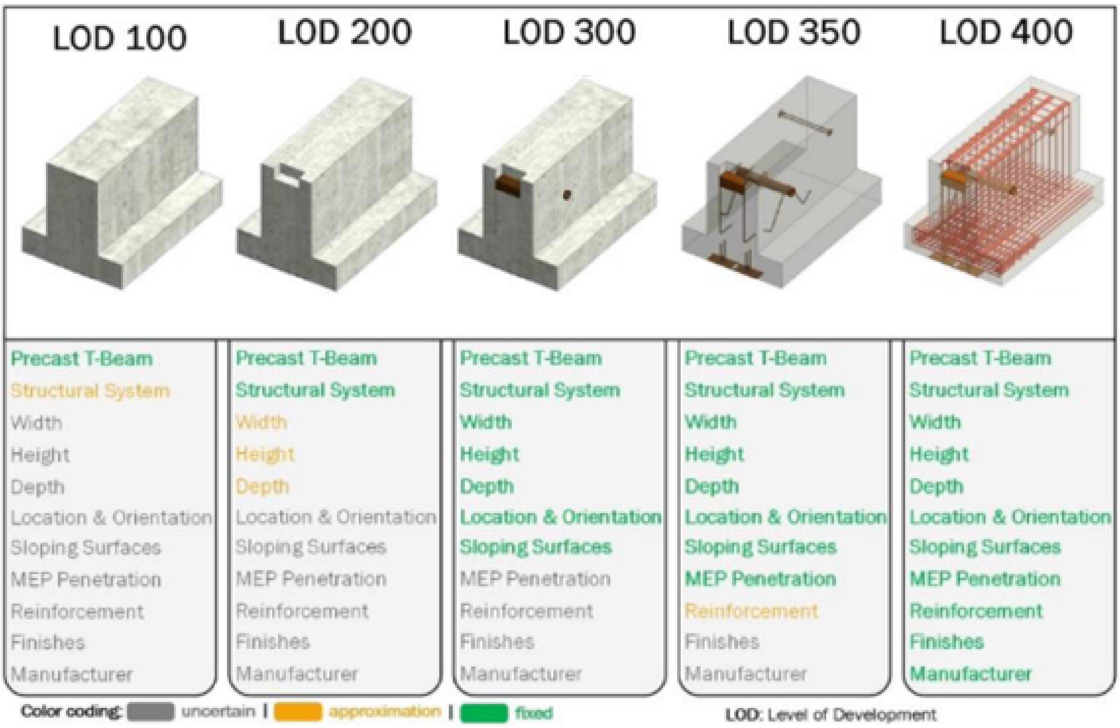


Figure 3.3: *An illustration of the progression of design across LOD 100-400, the example shows a beam in different LODs, figure modified from (Abualdenien and Borrmann, 2022)*

BIMforum (2023) and Schubert et al. (2021) defines the different LOD fundamentals and are summarised in table 3.1 below.

LOD	**Definition**
LOD 100	The element in the model is represented with a symbol or other simple representation. This is the simplest LOD and does therefore not contain building element information such as (e.g cost, BSAB codes, etc.) the shape, size and position are to be considered as an approximation.
LOD 200	Representing the element in the model as a generic system. Integrated information in the object are approximate quantities, size, shape position and orientation. *Information in this stage of LOD are till to be considered approximated.*
LOD 300	The element are considered as a specific system or object in terms of quantity, size, shape, position and orientation. *The information in the element can be measured directly from the model.*
LOD 350	Additionally, to LOD 300 the presentation of the interface to other building elements and systems are included. *Modelling information of parts necessary for coordination between elements regarding the own discipline or other disciplines. The information in the element can be measured directly from the model without reference to non-modelled information.*
LOD 400	The representation of elements in the model are show as a specific system, object or assembly in terms of quantity, size, shape, position and orientation. The level of detail, manufacturing, assembly and installation information is high at this stage. *The modelling of the element contains sufficent information for the production.*
LOD 500	The element in the model is represented as of existing ot as-constructed developed whit a combination of observation, field verification. The level of accuracy should be attached and informed in the element.

Table 3.1: The table describes the different Levels of Detail (LOD) ranging from LOD 100 to LOD 500.

Today in the AEC industry the LOD specifications is a tool used to determine and communicate the level of detail (or development) of a models elements (BIMforum, 2023). Offering comprehensive definitions and visual representations of BIM elements across various building systems, reflecting their different stages of development and utilisation throughout the design and construction phases. This enhances the understanding for all users of the BIM-model during all the stages in a project. The usage of LOD in climate calculations has be shown to be beneficial. Sjödin (2021) investigated a case in Sweden where the implementation of LOD were done to see what parts of the building that had been developed the fastest during the design phase. The parts that were deleoped the fastest had a higher LOD than the slower developed ones. During the climate calculation for the different parts of the building the LOD definitions of the elements in the model helped with visualising the climate effects in the design phase. This benefited the project in an early stage, allowing to allocate where the climate crucial parts of the building where.

3.4.2 Model Maturity Index (MMI)

In 2018, a framework was released by a group funded by the Norwegian Consulting Engineers' Association (Hansen et al., 2021). This framework offers a structured approach for managing and controlling maturity of the BIM-model throughout the design phase. Referred to as the Model Maturity Index (MMI), it contains recommendations for organising design workflows and inform the project with a standard detailing index to better understand and communicate of the models various levels of maturity.

The Model Maturity Index serves as a framework for facilitate communication, planning, and to get an oversight of the BIM model (Hansen et al., 2021) . Unlike the Level of Development, which focuses on the maturity of individual objects, MMI is used for understanding the overall maturity of the entire BIM model. LoD and LOD often point to its orientation around object development rather than looking at the value of understand the whole models development and maturity. Hansen et al. (2021) described MMIs five standard levels and are shown in table 3.2 below.

MMI	Definition
MMI 100	Sketch stage. Conceptual solutions are proposed in the BIM, while objects are sketch suggestions. Solutions in the model and on objects are not set and major changes of the objects can be done.
MMI 200	Established conceptual solutions that are ready for further design. The objects are suggested based on initial ideas. Can't make major changes to these ideas if they affect other parts of the project or disturb other disciplines.
MMI 300	The elements are ready for control towards other disciplines. The elements should be coordinated and placed accordingly within the individual discipline. The objects are considered to have the right geometry and placement at this stage.
MMI 350	The control towards other disciplines are done. Coordination is being updated, and objects are not mature for construction until the collision control is completed.
MMI 400	Ready for construction. The objects have been checked and approved for construction. Any issues or proposed changes must be examined by the relevant disciplines. Once approved, the objects are accepted for construction.
MMI 500	In the As-Built stage, documentation reflecting the final construction is provided. The models has real geometry and placement with additional information required from the contracting partner. The information required often contains the data needed to maintain and manage the facilities.

Table 3.2: This table displays the Model Maturity Index (MMI) ranging from MMI 100 to MMI 500.

To plan how the MMI is to be used in the projects a start-up meeting should be arranged in the beginning of the design process (Styrvold et al., 2019). From the Norwegian creator of MMI it is recommended to use the standard framework while also use complementary index levels specific to a certain project. The reason why sub-levels of the index should be used is because people in the project will have perceptions of MMI from previous projects and therefore need project specific agreements on the MMI-index used in the current project. When forming the supplementary index for the project the design team should very much be involved in the process since they will be the foremost users if the index.

When the MMI is set up for the project controlling the BIM maturity challenge comes next. To keep control of the development the project should be divided into geographical zones (Hansen et al., 2021). The zones can be divided by floor, room, story or even an entire building. The design tasks for each zone can easier be controlled and aligned with the schedule and plan for the BIM maturity development. Another way of dividing, instead of dividing by zones, is to divide by technical systems such as heating, ventilation, air conditioning (HVAC), pluming, electrical and control systems.

For each zone or system, designers should establish delivery lists that specify the design deliveries that must be completed to advance BIM maturity levels (Hansen et al., 2021). It's crucial to avoid giving objects overly detailed descriptions and to understand that not all objects require complete maturity before building. It is advised to schedule using MMI and to regularly compare actual work to the scheduled work. The percent plan completed (PPC) can be used to track the development of BIM maturity over time by identifying delivery flaws. If necessary, design managers need to help designers with rescheduling.

The connection between Levels of Development (LOD) and Model Maturity Index (MMI) in the context of Building Information Modeling (BIM) primarily lies in their shared goal to enhance collaboration, accuracy, and efficiency in the design and construction processes of buildings. Both frameworks serve as guides for specifying and understanding the detail and reliability of information at different stages of a building project. However, they focus on different aspects of the modeling process. In short LOD focuses more on an element level while MMI focuses on the overall model and its maturity.

3.5 LCA & BIM softwares

BIM software enhances design, construction, and project management in the AEC industry. This chapter overviews key BIM tools: Revit for versatile building modeling, Tekla Structures for detailed structural engineering, Solibri for quality assurance and model checking, StreamBIM for real-time collaboration, and One Click LCA for sustainability assessments. These tools collectively improve efficiency, accuracy, and collaboration across the AEC industry.

3.5.1 Software for Design and Construction

BIM software plays a crucial role in the design and construction industry, enhancing efficiency, accuracy, and collaboration. Two prominent BIM software tools used for designing buildings are Revit and Tekla Structures. While both serve to improve project outcomes through digital modeling, they have unique features and applications in different stages and aspects of the construction process.

Revit, developed by Autodesk, is designed to support architects, engineers, and construction professionals in designing buildings by storing information within the virtual building (Yuvita and Budiwirawan, 2022). It serves as a multidisciplinary tool that facilitates the collaborative design and management of a building project from concept to construction. The primary purpose of Revit is to create, visualize, and manage a digital representation of a physical building or place with integrated characteristics (Autodesk, 2024).

Revit allows users to design buildings with components in 3D, generate 2D drawings from the 3D model, and access building information connected to every element within the building model's database (Autodesk, 2024). It is utilized across various stages of the design and construction process to improve efficiency, accuracy, and collaboration among stakeholders. In some cases, the program is used during the facilitation stage, as information about each object is associated with its real-life data.

A significant feature of Revit is parametric modeling, which ensures that changes in the building model are automatically updated throughout the model, keeping designs and documentation coordinated and more reliable (Habte and Guyo, 2021). Revit's collaboration functionality across multiple disciplines is crucial, allowing architects, structural engineers, and other actors to share and work on a single file. Its 3D visualization function enhances communication and understanding of the design, making it easy to review the model regardless of the viewer's role (Autodesk, 2024).

Tekla Structures, developed by Trimble, is a comprehensive BIM software tailored for civil and structural engineering projects (Tekla, 2024). It is recognized for its capabilities in managing complex structures, detailing, fabricating, and constructing metal, concrete, and composite structures. Tekla is predominantly used in the construction of buildings, bridges, and other infrastructure projects. Unlike Revit, Tekla is more focused on structural engineering due to its highly detailed simulations. Revit is more aligned with the needs of architects and engineers during the early and middle design phases.

While both Revit and Tekla Structures aim to enhance project efficiency through digital modeling, they have key distinctions. Revit caters to a wider range of design processes, supporting multidisciplinary collaboration from concept to construction. In contrast, Tekla Structures is specialised in structural engineering and construction, making it ideal for the detailed simulation and management of complex structural projects. Despite these differences, both software tools are integral to the design and construction industry, each serving specific professional disciplines and project stages effectively.

3.5.2 BIM viewers

Building Information Modeling (BIM) viewers play a crucial role in enhancing the quality and coordination of construction projects. They enable stakeholders to visualize, analyze, and manage BIM data effectively. Two notable BIM viewers are Solibri and StreamBIM, each offering unique functionalities aimed at improving project outcomes.

Solibri is a specialised software within the BIM ecosystem, focusing on quality assurance, quality control, model checking, and coordination (Solibri, 2024). It is designed to improve the quality and performance of BIM models across various stages of the construction process, serving architects, engineers, constructors, and BIM managers. Solibri provides tools to analyze and validate the correctness and coordination of BIM models.

The primary purpose of Solibri is to ensure that BIM models are accurate, consistent, and free of errors (Wangara, 2018). It identifies inconsistencies, clashes, and potential issues within the models, communicating these errors to different disciplines, which reduces problems during the construction phase (Solibri, 2024). Additionally, Solibri offers add-ons for carbon calculation, integrating information from various databases chosen by the user. It visualizes carbon calculations for a more interactive process, saving time, reducing costs, and improving project quality (Wangara, 2018). The 3D visualization makes it easy to explain errors and problems to project stakeholders who may not be directly involved in the modeling, such as project managers.

Solibri's Information Takeoff (ITO) feature enables users to examine component details within a model, offering visual analysis in the 3D view and a spreadsheet representation in the ITO view (Solibri, 2015). Data can be exported to a personalized Excel worksheet for further utilization. The information from ITO includes identification, classification, location, quantities, and more, which can be grouped in various ways.

Solibri is designed to integrate with other BIM platform and softwares with the industry standard file format (IFC), ensuring compatibility with a wide range of softwares used in the AEC industry (Solibri, 2024). Softwares like Revit, Tekla structures and ArchiCAD and more are softwares that integrate well Solibri. The integration facilitates a smooth workflow between different stages of design, analysis and carbon calculations.

StreamBIM is a BIM software that focuses on streamlining construction projects through effective collaboration, real-time information sharing, and access to BIM data on-site (StreamBIM, 2024). It is designed to enable for easy communication between all stakeholders involved in a construction project this includes architects, engineers, contractors, and facility managers. It is designed to be ease to use and aims to take advantage of BIM to professionals across various stages of the construction process.

Key features of StreamBIM ensure quality and consistency in a construction project (StreamBIM, 2024). It allows users to access and navigate 3D BIM models in real-time from a mobile device or web browser, ensuring that all project participants can view and understand the project wherever they are located. This mobile format also allows for the BIM model to be further used in production as a replacement to traditional drawings. The software's layout facilitates easy communication between team members, enabling the sharing of information, models, documents, tasks, and the creation of issues, assignments, and updates. Its documentation management features include version control and document history, keeping everyone updated with the latest information. These functions enhance team coordination and support effective project management.

StreamBIM supports a range of data formats commonly used in the AEC industry, including IFC for BIM models, as well as other file types like PDF for documents and drawings (StreamBIM, 2024). The compatibility with these standard formats makes it effective and easy to function within the broader BIM ecosystem, enabling users to share and collaborate on projects regardless of the original software used to create the models.

In summary, Solibri and StreamBIM are essential BIM viewers that significantly enhance construction project quality and collaboration. Solibri excels in quality assurance, model checking, and coordination, while StreamBIM focuses on real-time collaboration and information sharing. Both tools support a wide range of data formats and integrate well with other BIM software, making them invaluable in the AEC industry.

3.5.3 LCA tools

Life Cycle Assessment tools are essential in the construction industry for evaluating and optimizing the environmental impacts of building projects. These tools analyze various sustainability indicators such as carbon emissions, energy use, and resource consumption over the entire life-cycle of a building. LCA tools help professionals in achieving compliance with green building certifications and regulations, enhancing the sustainability of construction projects. One prominent LCA tool in the industry is One Click LCA.

One Click LCA is an LCA software that enable users to efficiently measure and optimise the environmental impacts of their projects, including carbon emissions, energy use, and other sustainability indicators (One Click LCA, 2024). It supports compliance with various green building certifications and regulations, such as LEED, BREEAM, and EN 15804 standards (One Click LCA, 2024). This makes it a valuable tool for construction projects reaching their sustainability goals and certifications.

The software offers detailed life cycle assessment capabilities, analysing the environmental impact of building materials and processes over their entire life-cycle (One Click LCA, 2024). The software works with different databases that the user themselves choose. For example the user can use different templates adapted to certain requirements for certifications etc. The many different databases offers a lot of different information regarding building materials environmental impact data, making it easier for the users to select suitable options for their designs.

When working with One Click LCA the user can choose to work with it as a plug-in for various CAD software or import excel spreadsheets into the web browsers version of One Click LCA (One Click LCA, 2024). One Click LCA automates several aspects of the life cycle assessment process. By directly importing data from BIM models or from the bill of quantities, it can automatically calculate the environmental impact of materials based on the project's specific configurations. This automation not only saves time but also ensures consistency and accuracy in sustainability evaluations.

In summary, One Click LCA is a critical tool for the construction industry's growing focus on sustainability. Its ability to integrate with BIM platforms, combined with comprehensive LCA calculations, carbon footprint analysis, and support for green building certifications, makes it a good software for any project that aims to reduce the environmental impacts and achieve sustainability objectives in their construction projects.

3.6 Workflows for the integration of LCA and BIM

As the construction sector is going through a process of digitisation tools such as BIM can be a contributor to actors' success on the market (Wastiels and Decuypere, 2019). The adoption of BIM allows for an efficient exchange of information between actors within a project, this creates a platform for efficiently carrying out analyses. The need for manual data entry decreases as the model itself carries the data needed for discipline specific simulation tools. According to Wastiels and Decuypere (2019) the integration of LCA in the design process is not standard practice yet, even tough both BIM and LCA practices are in full development there are still some uncertainties of how the two should be integrated. The integration between BIM and LCA has been suggested by researchers and practitioners in the design phase to be able to create a platform for informed decision making early on with the aim of reducing the environmental impact (Azizoglu and Seyis, 2020).

The unification of these two technologies has a potential of reducing the total time spent on performing calculations, improving the application of methodologies while also minimising the negative impact on the environment (Azizoglu and Seyis, 2020). BIM and LCA has the potential of eliminating some of the difficulties for each other by using their features to cover areas where one of them is lacking. In the article *"Analyzing the benefits and challenges of building information modelling and life cycle assessment integration"* the authors lists a number of benefits that follow from the integration between BIM and LCA (Azizoglu and Seyis, 2020). These benefits include improved environmental impact assessments with higher accuracy, a sleek form of workflow, and as mentioned above a better base for making decisions. However, the integration also has its challenges. In the article, diverse data sources, the need for training and specialised software, and resistance to change within the industry are listed as some of the problems that must be overcome (Azizoglu and Seyis, 2020).

3.6.1 The fundamentals of integrating BIM and LCA practices

There is a large variety of tools that has been developed for both BIM and LCA, each of the supporting different steps in the individual design processes. This creates multiple paths to reach the end goal of integrating BIM and LCA. Wastiels and Decuypere (2019) has established a list containing six fundamental steps for designing a building in BIM and using the information for performing an LCA study.

1. The BIM model is developed, the geometry of the building is constructed using BIM elements containing supplementary information.

2. Based on the model a bill of quantities (BOQ) is established, a list of materials/elements with their respective quantities.

3. The environmental impact associated with each material or element is identified and attached to an LCA profile, which can be based on EPDs or generic data, and can relate to either a material level or a level of building component.

4. The quantities from the BOQ are linked to their LCA profile, expressed in environmental impacts per unit.

5. From the BOQ, attributed LCA data and LCA methodology specified in the selected tool calculations can be performed.

6. The results can then be visualised and analysed.

Based on these steps there are two main strategies of workflows that can be identified (Wastiels and Decuypere, 2019). The first one being information getting extracted from the BIM model and developed in to a BOQ. This information is then used in LCA calculations in a separate LCA tool. The second strategy is based on LCA data being added in the BIM model and assigned to the different BIM elements. The calculations can then be performed within the BIM software using a plugin. There are also some methods that fit in between these strategies as they can be seen as extremes in this context. In the article *"Identification and comparison of LCA-BIM integration strategies"* written by Wastiels and Decuypere (2019) five workflows are listed, they have been identified through evaluations and focus group discussion. The following workflows are identified:

1. BOQ Export
   BOQ or *Bill of Quantities* is a strategy which begins with extracting the quantities from a BIM model, usually as a spreadsheet. Afterwards the extracted data of materials and quatities is imported to a LCA software. Common practicing is then to manually link the different components to existing LCA profiles and create new profiles when neccessary. This is the most common method of integration between BIM and LCA and one of the challenges is maintaining and updating the link between model-BOQ-LCA.

2. IFC Import of Surfaces
   This method involves a direct import of the BIM model to the dedicated LCA software via the Industry Foundation Classes (IFC) format. This method require more data connected to the different BIM elements, Global Unique Indentifier (GUID). This methods upper hand is the automatic import of data and maintenance of links between the BIM data and LCA profiles. Which involves/requires more frequently updated BIM models.

3. BIM Viewer for linking LCA Profiles
   In this strategy, the model is imported to a BIM viewer where the components are linked to a LCA profile. After exporting the BIM model to a BIM viewing program a modeler or LCA analyst assigns LCA profiles to each unique component. These profiles are later used in combination with the geometry data to calculate its environmental impact.

4. LCA Plugin for BIM Software
   In certain BIM software's there are LCA-plugins which enables assigning LCA profiles to building elements directly in the BIM software. All the steps are directly processed in the BIM software, including calculations, data visualisation and analysis. This method provides an in-depth analysis directly while working in the BIM model which allows an iterative optimisation process.

5. LCA-Enriched BIM Objects
   This is the most integrated strategy where every BIM object in the BIM model is embedded with LCA information. This method ensures that the BIM objects and geometrical data are directly connected to the LCA profiles. This centralises data within the BIM objects and allows design optimisation processes with real-time environmental impact information.

3.6.2 The challenges of implementing BIM and LCA practices

One point of concern is incorporating EPDs in to the BIM model. This is especially true for the verification of EPD data within the model as the EPDs are product specific. This means that they are specific for one product and the data is no longer valid if the object for example a window is scaled to a different size. It is also likely that EPD data will not be available for all objects or materials within the model (Wastiels and Decuypere, 2019). This means that the product specific data most likely will have to be complemented with generic data to be able to produce a correct LCA evaluation. Criticism has been directed towards the robustness of EPDs this is discussed in *The Fallacies of Carbon Modelling in Construction* by Jirout (2024). Where it is questioned how of EPDs are created.

Due to the complex nature of BIM and the great number of stakeholders involved in the model, communication is one of the challenges that has to be overcome. One instance where this issue often has to be faced is when handling the exchange of what information is to be included in the model between stakeholders. Traditionally the requirements of information is shared through media that is not interpretable by computers such as excel sheets or PDF documents (Van Berlo et al., 2024). This makes it difficult for the right person to get access to the right information that is relevant for their situation. For those who want to use data from the BIM model the case is often that they know what data is required for their tasks but have a hard time specifying it. Information gaps in the model also affects various processes such as automated cost estimation as it heavily relies on specific data sets.

3.6.3 Ensuring model quality using Information Delivery Specification (IDS)

To aid the issues that surround the definition of information requirements a new standard is being developed by buildingSMART. buildingSMART is an organisation that aims to improve the exchange of information between different softwares in the construction industry. This standard is called *The Information Delivery Specification (IDS)* (Van Berlo et al., 2024). The goal of this standard is to provide information requirements that are defined in a way that makes them easily readable for both humans and computers. Through the use of IDS requirements on the BIM model can be set on multiple levels for example on the use of properties, materials, classifications and more. An IDS can be used on a certain part of a model, for example the buildings envelope to make sure all objects are assigned with a value for a particular parameter. By implementing IDS in this manner it can be used to check the IFC files for missing or incorrect data before they are shared with other stakeholders therefore minimising the chances of problems later on. It brings validation of the IFC for both stakeholders and software that perform automated analyses.

IDS however, is not designed to establish design requirements or what often are referred to as 'rules' (Van Berlo et al., 2024). For instance, specifying that all windows in a building must have opaque kind of glass isn't feasible within IDS. However, IDS is suitable for defining a requirement that requires each window to have a property specifying the type of glass used. It is then important to still use a rule checker to check if the windows of this example actually are opaque or not.

3.7 Classification codes

Effective object classification is a key factor for conducting successful BIM projects as it has a major impact on the information flow, communication, and data exchange within the project. Building Information Properties (BIP) is a standardised approach to classification that describes the 3D objects properties before an IFC export. Rather than being a single parameter BIP is a comprehensive system that encompasses multiple factors. BIP acts as a framework for making identification on a small scale easier and creates a system that can be transferred between projects. It has been developed collaboratively by actors in the industry and aims to create a standard of sorts between different software being used in the construction sector. Other than acting as a platform for ensuring consistent identification of objects on a type level creating a security that is carried between projects. By implementing the BIP system, the contents of the models used in projects can also be reviewed and verified in a consistent manner.

BIP consists of multiple type codes that are assigned to individual objects, these type codes are linked to specific classification systems such as BSABwr for installation objects and BSABe for construction elements. The BSABe codes are structured in a way that allows for them to be applied in an early stage. For example a column with unknown material would have the BSABe code "27.D". To specify the material, add "27.D/11" for concrete or "27.D/34" for steel. In table 3.3 the structure of the code system is illustrated. First number is referencing nature of the building element, second number is where and ".D" is what type of building element. Adding "/xx" specifies the material.

BSAB	Definition
2	Supporting structure
27	Supporting structure in house frame
27.D	Column
27.D/11	Column made of concrete
27.D/34	Column made of steel

Table 3.3: This table shows an example of the BSAB Code system, in this case it is the BSAB code for an Column developing as the description becomes more accurate.

The BSAB system is a structure for information in the Swedish construction sector, and is based on the principle of the SS-ISO 12006-2:2015 standard. The system consists of codes connected to titles that describe construction elements. The system is implemented in AMA which is reference structure that describes requirements for materials, execution, and finished results for standard processes in Swedish construction. The requirements can be seen as standard practice as they are presumed to insure a result with accepted quality produced by proven technology and professional execution. The texts are also used as references when constructing technical descriptions.

4

Results

To be able to answer the research questions of this thesis an analysis of Sweco's practices regarding carbon calculations has been made. By mapping their current workflow it is easier to identify processes that can be seen as bottlenecks as they slow down the rest of the chain. In addition to this analysis several experiments has also been conducted, the motivation for these experiments is to get a better understanding of how the different software's are intertwined and what possibilities lie within them. This approach allows for a comprehensive understanding of the current practices at Sweco and the future opportunities for optimisation.

4.1 Open interview study

The project used in this case study is a construction project of a office building in central of Gothenburg with high ambitions of digitalisation as the foremost tool for design, construction, communication and project management. The BIM strategist has explained the will to come as close as possible to the concept of Total BIM. It has been request from the client Vasakronan. Their goal is to use new digitalisation methods to make their operation within the organisation more effective. They also want to make their property management more sustainable while also be part of the development of digital tools which will simplify the work for all stakeholders of their projects. These requirements align with Swecos goal of finding more effective and sustainable ways of working in a more digitised manner.

In this project, the idea is to use as much recycled material as possible. The focus is on structural completion but also on the addition of building components and smart installations that significantly reduce the construction's environmental impact. The previous building on the site contributes with a lot of material that will be repurposed in the project.

The project is procured in different stages with different contractors and subcontractors for the various stages. Swecos role is to manage the project trough all of these different stages and have a leading role in collaboration with the different contractors. Sweco also contributes with consult work throughout the whole project, from the design phase to the facility management phase. The first stage involve demolishing of the existing building on the estate. After the demolishing the ground work started where they started the piling and then proceeded to build the concrete foundation. The stage following includes the rest of the house structure and facade.

4.1.1 Current workflow

During the initial part of the study we conducted several meetings with the BIM-strategist, the BIM-coordinator and the environmental consultant in the project from Sweco. The purpose of these initial meetings was to gain an understanding of Sweco's current processes within the project. The consultants explained how their workflow is currently structured and discussed what challenges they have to overcome.

Sweco works with different contractors for different parts of the project during the design face. The designs are updated regularly and are uploaded to a cloud environment where they are stored, updated and exported to the file format IFC. These files are then quality controlled and all the different disciplines files are combined in StreamBIM where the project is managed. Documentation, 3D-model, issue and task management and communication are all done in StreamBIM to streamline the workflow and communication between all the different stakeholders in the project.

Figure 4.1 shows how Swecos current workflow is planned. The designers work in the software best designed for their discipline it could be Tekla or Revit, when the work is done their models are then exported to IFC files which are then collision controlled in Solibri by the BIM-coordinator, in this stage BCF-reports are produced. The models that are checked are uploaded into StreamBIM with the BCF-report showing issued found during the different quality control stages. In StreamBIM all the stakeholders can follow the work and makes it easy for the designers to revolve their issues since the BCF-report shows where the issue is located with a describing text. This process happens frequently throughout the project, the models information enriches for each design cycle. This can be connected to objects or models change of MMI and other information.

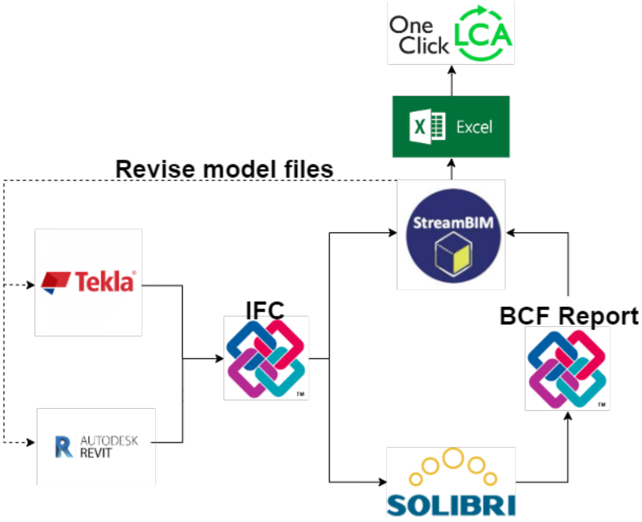
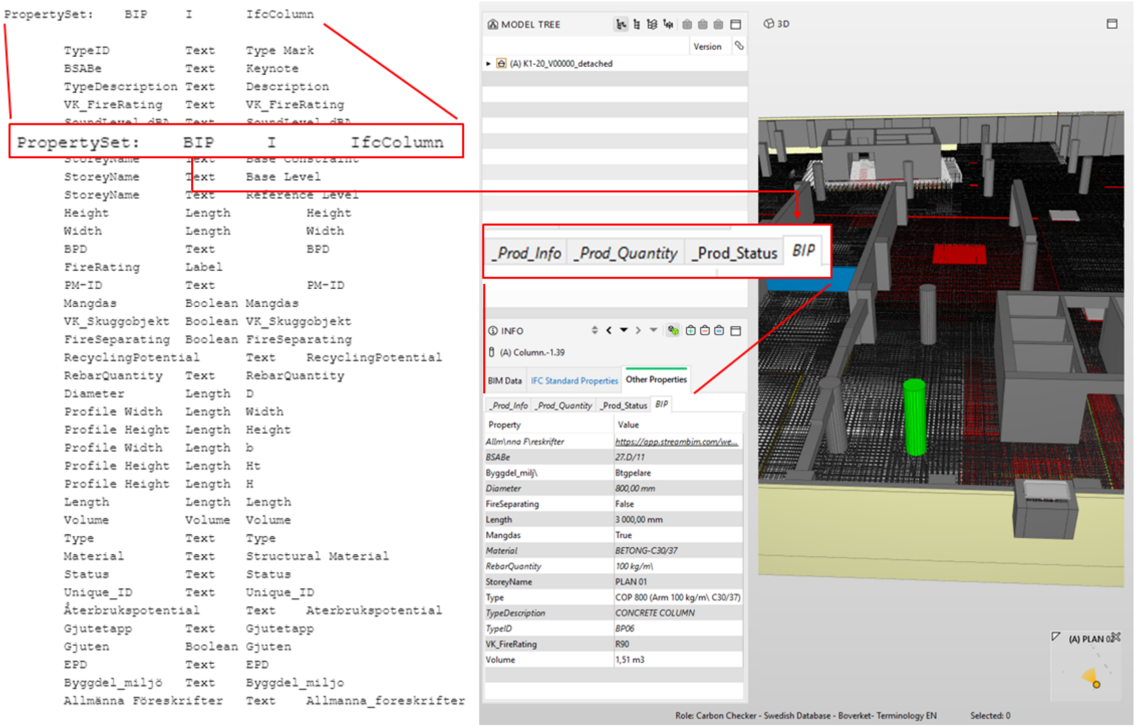


Figure 4.1: *The figure shows the current workflow, from the design phase to collision control and carbon calculation.*

In the end part of the workflow in figure 4.1 the BIM-coordinator extracts a bill of quantities from the updated models, these quantities are divided in elements to then be grouped by material to make it easier when conducting the LCA. The environmental consultant then uses the BOQ in One Click LCA to create an LCA. During this stage some materials are not classified. The BIM-coordinator and environmental consultant therefore discusses and matches the material with the most fitting material from the database, this takes a lot of time and they both explain that this is a bottleneck where a lot of their time get spent. This is also a problem since none of them actually know if this will relate to the reality, there is a lot of uncertainty. They lift up that the problem often occurs when the model and elements does not contain all of the required information. The solution to this is often to copy data from earlier projects. The environmental consultant gave an example on a wall which does not contain the right information for them to be certain of what type of wall it is. They often then look at projects of the same sort to gain an understanding of what wall to choose in the current project. The consultant also explained that if the model and all its elements contained "ResursID" from Boverkets database, the work would be a lot easier and would decrease time spent on guessing what material to use when conducting the LCA. The BIM-strategist explained that the idea in the beginning was to conduct climate calculations on a continuous basis but since the process has been too time consuming the managers decided to not produce climate calculations every quarter but instead wait until a climate calculation is needed. This has resulted in less control of how the projects carbon emissions differs depending on choices made throughout the project.

When an IFC export from Revit is done it can be ran through a user-created configuration file. Here users can create their own Property Sets and fill them with parameters from Revit. The results is user defined groups of parameters that are easy accessible in BIM viewer software such as Solibri or StreamBIM. For instance, in this project Sweco has created these configuration files for different disciplines so that all elements connected to the structural model has the same information structure. In these files the first line describes the Property Set, its name, if it is associated with Instances or Types and a list of IFC elements for which the property set is created. The following lines then describe all the properties of the set, names, types, and their associated Revit parameter. An example of how the user-created configuration files work is shown in figure 4.2. In that case it displays a property set called "BIP" for all columns.



```
PropertySet:	BIP	I	IfcColumn

	TypeID		Text	Type Mark
	BSABe		Text	Keynote
	TypeDescription Text	Description
	VK_FireRating	Text	VK_FireRating
	StoreyName	Text	Base Level
	Height		Length		Height
	Width		Length		Width
	BPD		Text		BPD
	FireRating	Label
	PM-ID		Text		PM-ID
	Mangdas		Boolean Mangdas
	VK_Skuggobjekt	Boolean VK_Skuggobjekt
	FireSeparating	Boolean FireSeparating
	RecyclingPotential	Text	RecyclingPotential
	RebarQuantity	Text	RebarQuantity
	Diameter	Length	D
	Profile Width	Length	Width
	Profile Height	Length	Height
	Profile Width	Length	b
	Profile Height	Length	Ht
	Profile Height	Length	H
	Length		Length	Length
	Volume		Volume	Volume
	Type		Text	Type
	Material	Text	Structural Material
	Status		Text	Status
	Unique_ID	Text	Unique_ID
	Återbrukspotential	Text	Aterbrukspotential
	Gjutetapp	Text	Gjutetapp
	Gjuten		Boolean Gjuten
	EPD		Text	EPD
	Byggdel_miljö	Text	Byggdel_miljo
	Allmänna Föreskrifter	Text	Allmanna_foreskrifter
```

Property	Value
Allm\nna F\reskrifter	https://app.streambim.com/we...
BSABe	27.D/11
Byggdel_milj\	Btgpelare
Diameter	800,00 mm
FireSeparating	False
Length	3 000,00 mm
Mangdas	True
Material	BETONG-C30/37
RebarQuantity	100 kg/m\
StoreyName	PLAN 01
Type	COP 800 (Arm 100 kg/m\ C30/37)
TypeDescription	CONCRETE COLUMN
TypeID	BP06
VK_FireRating	R90
Volume	1,51 m3

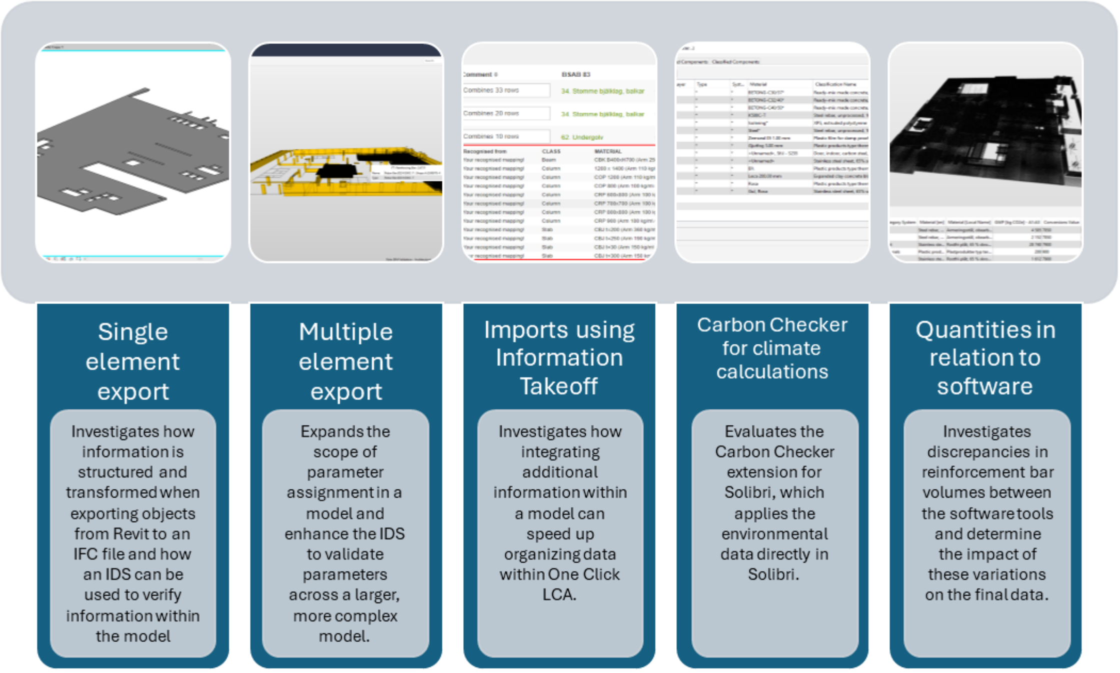
Figure 4.2: *The figure shows the user-created configuration file to the left. In this case it displays the property set "BIP" for columns. To the right is the same property set displayed in Solibri when a single column is selected.*

As the project progressed, Sweco decided to implement MMI (Model Maturity Index) to better manage the model and understand how developed each part of it was. While this method has been successful, it also brought some challenges between different project phases. The BIM-strategist pointed out that since the first stage has a higher MMI compared to the second stage, it's hard for designers to collaborate effectively. They are dealing with different levels of maturity in the model, making it tough to synchronise their efforts in a smooth way. The BIM-strategist pointed out an example from the model where some holes in the model had been designed in the first stage but the information about these holes had not been communicated to the designers in the beginning of designing stage two. This is just an example of how hard it is to manage a project in stages when the designing of the different stages has different happen at different times and therefore have different MMI.

4.2 Experiments

This section presents a series of experiments that has been conducted in order to explore and analyse the methods and tools that are used within Sweco's workflow for conducting carbon calculations based on BIM. The primary aim of the experiments is to get an better understanding of the integration of carbon calculation methodologies within BIM. This is done by identifying areas of improvement, and asses the efficiency of software tools that are used by Sweco and tools that could potentially be used as a replacement in the future.

The experiments in this chapter has been divided as they look closer at different aspects of the process. They range from data import and export, utilisation of software, and use of new technology. Each experiment has been designed to address specific questions therefore contributing to a comprehensive understanding of carbon calculations within the context of BIM. A summary of the experiments is displayed in figure 4.3 where a short description of the experiments and their purpose is listed. Due to the integrity of the projects the experiments has only been conducted on the structural model. As a result of only using the structural model for the experiments some of the codes etc. that has been produced may need some adjustments in order for them to be functional with an architectural model.



Single element export

Investigates how information is structured and transformed when exporting objects from Revit to an IFC file and how an IDS can be used to verify information within the model

Multiple element export

Expands the scope of parameter assignment in a model and enhance the IDS to validate parameters across a larger, more complex model.

Imports using Information Takeoff

Investigates how integrating additional information within a model can speed up organizing data within One Click LCA.

Carbon Checker for climate calculations

Evaluates the Carbon Checker extension for Solibri, which applies the environmental data directly in Solibri.

Quantities in relation to software

Investigates discrepancies in reinforcement bar volumes between the software tools and determine the impact of these variations on the final data.

Figure 4.3: *The figure shows a summary of the five experiments each of them provided with a short description of the individual experiment.*

4.2.1 Single element export

The purpose of this experiment was to get a better understanding of how information is structured and transformed within objects when they are exported from Revit in to an IFC file. In order for the object structure to be easily interpretable a single element was chosen for export, in this case a slab as seen in figure 4.4. The slab was isolated in Revit and then the correct export settings were chosen, the export was made through a user-created configuration file created by Sweco for the structural model. After the export was made the slab was reviewed in Solibri to make sure that the structured followed the user-created configuration, which it did.

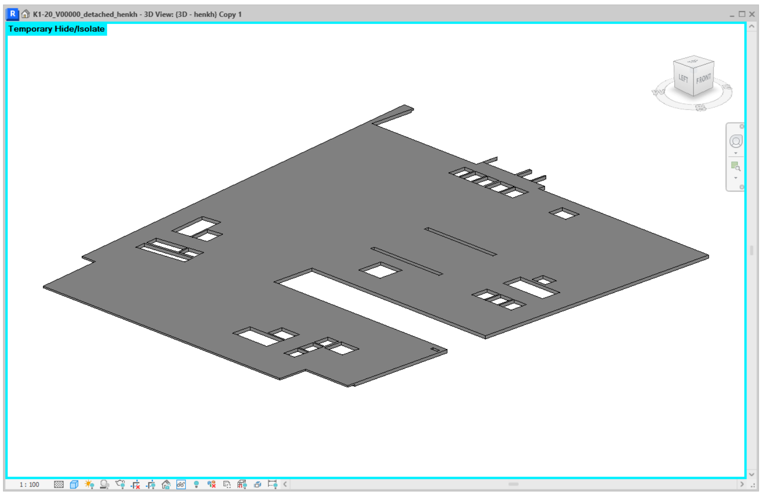
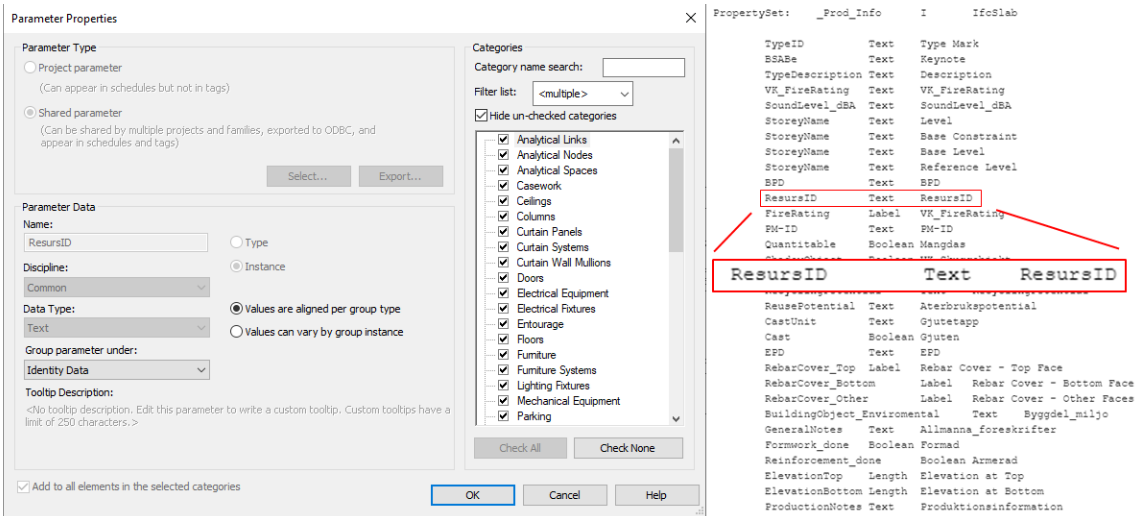


Figure 4.4: *The slab used in the first test rendered in Revit.*

The next step was to add a parameter from Boverket's database in order to understand the difficulty of assigning new parameters in hindsight. In this case the chosen parameter was the Resource ID, the correct ID was found in the database in this case it was *6000000032* for the slab in this export. Then a new project parameter was created in Revit in this case called "ResursID" it was created as a Text label grouped under identity data in Revit, the categories that were to be assigned with the parameter was also selected as seen in figure 4.5. The slab was then selected and assigned with the value *6000000032* for the "ResursID" parameter. Then an addition was made to the user-created configuration file as seen in figure 4.5, a new line was added in the "_prod_info" property set for slabs as seen in Appendix A. The slab was then exported through the updated configuration file and reviewed in Solibri once more with the new parameter attached as intended.



○ Project parameter
(Can appear in schedules but not in tags)
● Shared parameter
(Can be shared by multiple projects and families, exported to ODBC, and appear in schedules and tags)

Name: ResursID
○ Type
● Instance
Discipline: Common
Data Type: Text
● Values are aligned per group type
○ Values can vary by group instance
Group parameter under: Identity Data
Tooltip Description:
<No tooltip description. Edit this parameter to write a custom tooltip. Custom tooltips have a limit of 250 characters.>
☑ Add to all elements in the selected categories

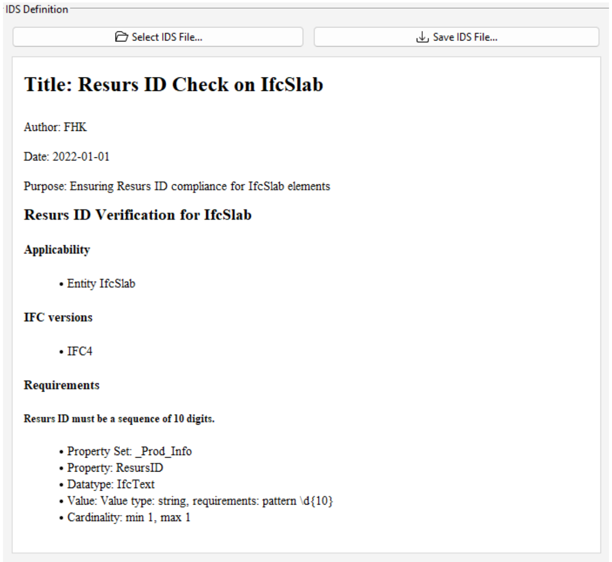
Category name search:
Filter list: <multiple>
☑ Hide un-checked categories
☑ Analytical Links
☑ Analytical Nodes
☑ Analytical Spaces
☑ Casework
☑ Ceilings
☑ Columns
☑ Curtain Panels
☑ Curtain Systems
☑ Curtain Wall Mullions
☑ Doors
☑ Electrical Equipment
☑ Electrical Fixtures
☑ Entourage
☑ Floors
☑ Furniture
☑ Furniture Systems
☑ Lighting Fixtures
☑ Mechanical Equipment
☑ Parking

```
PropertySet:    _Prod_Info      I       IfcSlab

        TypeID          Text    Type Mark
        BSABe           Text    Keynote
        TypeDescription Text    Description
        VK_FireRating   Text    VK_FireRating
        SoundLevel_dBA  Text    SoundLevel_dBA
        StoreyName      Text    Level
        StoreyName      Text    Base Constraint
        StoreyName      Text    Base Level
        StoreyName      Text    Reference Level
        BPD             Text    BPD
        ResursID        Text    ResursID
        FireRating      Label   VK_FireRating
        PM-ID           Text    PM-ID
        Quantitable     Boolean Mangdas
        ReusePotential  Text    Aterbrukspotential
        CastUnit        Text    Gjutetapp
        Cast            Boolean Gjuten
        EPD             Text    EPD
        RebarCover_Top  Label   Rebar Cover - Top Face
        RebarCover_Bottom       Label   Rebar Cover - Bottom Face
        RebarCover_Other        Label   Rebar Cover - Other Faces
        BuildingObject_Enviromental     Text    Byggdel_miljo
        GeneralNotes    Text    Allmanna_foreskrifter
        Formwork_done   Boolean Formad
        Reinforcement_done      Boolean Armerad
        ElevationTop    Length  Elevation at Top
        ElevationBottom Length  Elevation at Bottom
        ProductionNotes Text    Produktionsinformation
```

Figure 4.5: *The left side shows the project parameter that was added in Revit. The right side of the figures shows the user-created configuration file for the property set _Prod_Info for instances IFCSlab with the new addition marked in red.*

A simple IDS file was then to be coded to check the validity of the new parameter. This task was approached by searching buildingSMART's website for an example file that could be used as a template. Using one of these provided example files of code, firstly it was put into ChatGPT and the language model was tasked to provide a new file based on the input file. The aim of this new IDS was to check the model for a correctly formatted "ResursID" label. The complete IDS file can be found in Appendix A. This IDS checks all slab elements for a ten digit value for a parameter called "ResursID" in the property set "_prod_info". In figure 4.6 below the IDS is shown through Solibri's IDS reader that formats the IDS in a readable way.



Title: Resurs ID Check on IfcSlab

Author: FHK

Date: 2022-01-01

Purpose: Ensuring Resurs ID compliance for IfcSlab elements

Resurs ID Verification for IfcSlab

Applicability

- Entity IfcSlab

IFC versions

- IFC4

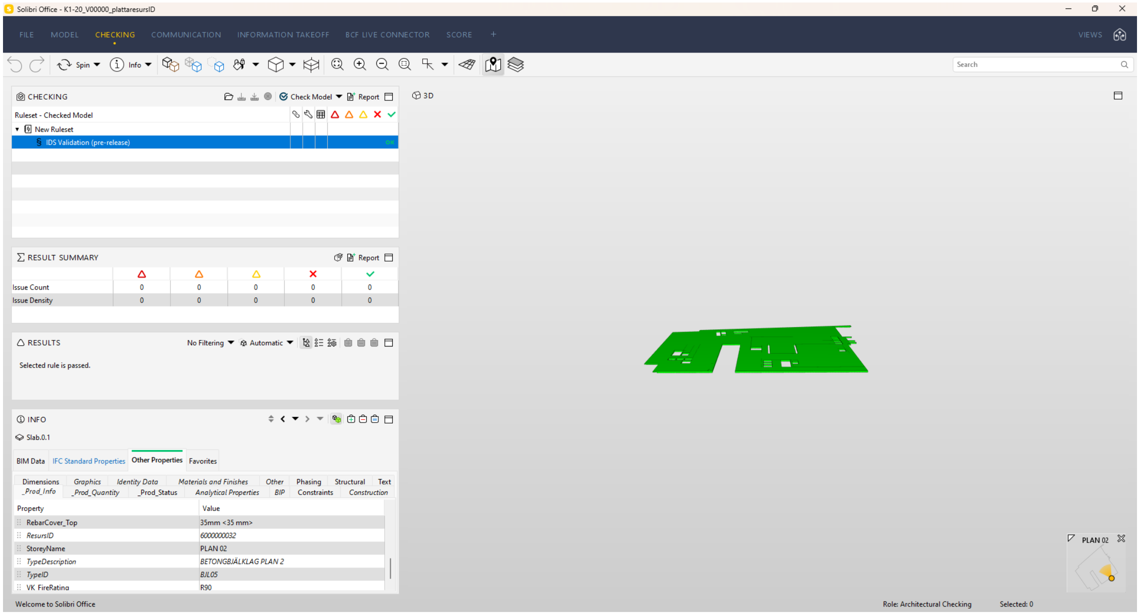
Requirements

Resurs ID must be a sequence of 10 digits.

- Property Set: _Prod_Info
- Property: ResursID
- Datatype: IfcText
- Value: Value type: string, requirements: pattern \d{10}
- Cardinality: min 1, max 1

Figure 4.6: *The figure shows the IDS through Solibri's IDS reader, listing its applicability and requirements.*

Once the IDS was structured successfully it was tested on three files: the slab with the correct "ResursID", one slab was assigned with an empty "ResursID", and one slab with a "ResursID" formatted incorrectly with eight digits instead of ten. The tests were ran in Solibri by using a rule called "IDS Validation" where a model is checked to ensure that it includes all the information the user has specified in the IDS that is loaded into Solibri. The first slab passed the demands of the IDS successfully as seen in figure 4.7. However, neither of the other two slabs passed and ended up with two different messages indicating their individual issue. For the slab missing an ID the description displayed the message: "No property matching ResursID in a property set matching _Prod_info". The IDS can not find the parameter at all, the reason behind this is that parameters that are left without a value before the IFC export are excluded from the IFC hence the error message. The second slab with an incorrectly formatted "ResursID" displayed the message "Non-matching value for property ResursID in property set _Prod_info: Value (...) does not match the pattern". This indicates that the format of the parameter does not match the format required by the IDS.



Solibri Office - K1-20_V00000_plattaresursID

Ruleset - Checked Model
New Ruleset
IDS Validation (pre-release) OK

	△	△	△	✕	✓
Issue Count	0	0	0	0	0
Issue Density	0	0	0	0	0

Selected rule is passed.

Slab.0.1

Property	Value
RebarCover_Top	35mm <35 mm>
ResursID	6000000032
StoreyName	PLAN 02
TypeDescription	BETONGBJÄLKLAG PLAN 2
TypeID	BJL05
VK_FireRating	R90

Welcome to Solibri Office

Role: Architectural Checking

Selected: 0

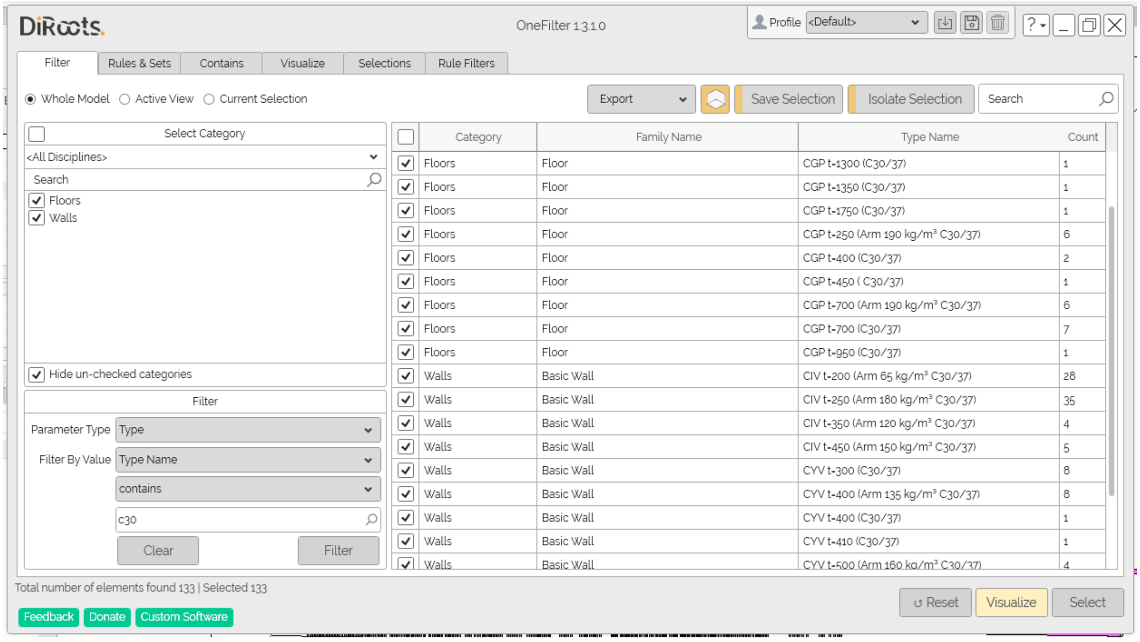
Figure 4.7: *The figure shows a successful check on one slab with a ten digit ResursID.*

4.2.2 Multiple element export

The purpose of this experiment was to widen the scope for the parameter assigning of the model, and re-coding the IDS to be more comprehensive and therefore able to check the validity of the present parameters on a larger model with multiple elements. For this experiment a substantial portion of the model was selected to test the IDS and assign information using a selection plug-in in Revit. A selection was made, making sure to include a larger variety of elements leading to a more complete assessment and validation process.

Once the selected part of the model had been isolated, the "ResursID" parameter was assigned to some elements. A number of elements were also left without an assigned ID with the purpose of checking how the IDS would react on finding these. One column was also assigned with an incorrect value with the Resource ID exceeding the ten digit requirement. The "ResursID" Revit parameter itself remained unchanged from the previous test and can be seen in figure 4.5. To be able to assign the parameter to multiple elements at once instead of going through them individually the plug-in DiRootsOne was used, specifically the tool called "OneFilter". The tool allows for easier selections that can be based on multiple factors. Figure 4.8 displays a selection for all floor and wall elements that has a parameter called "Type Name" that contains "C30". A list of those elements is generated within the plugin and can then be selected and isolated in Revit. After this selection is made the correct value for the "ResursID" parameter can be assigned as all the elements in this selection are constructed with the same type of concrete, ready-mix made concrete C30/37. Since they are made out of the same material they all share the same Resource ID, speeding up the process of assigning this parameter. This process was repeated for several other elements in the model.

Before the model could be exported into an IFC some changes had to be made to the user-created configuration file. In the previous test the "ResursID" parameter was added to the property set BIP for all IFCSlab elements, this time it was added for all elements in the same way.



● Whole Model ○ Active View ○ Current Selection

<All Disciplines>

☑ Floors
☑ Walls

☑ Hide un-checked categories

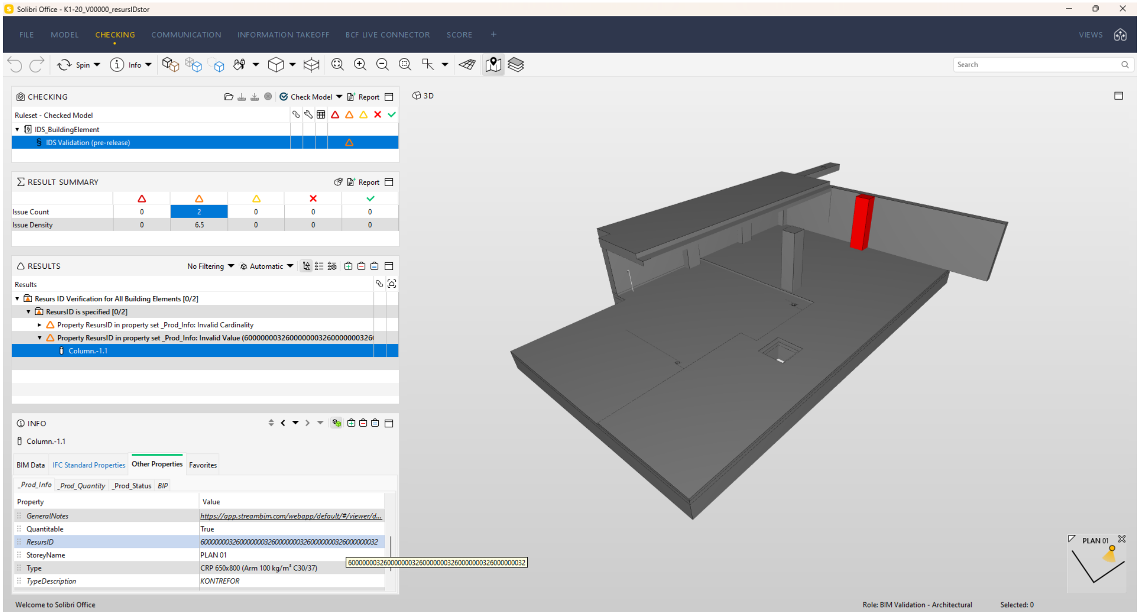
Parameter Type: Type
Filter By Value: Type Name
contains
c30

☐	Category	Family Name	Type Name	Count
☑	Floors	Floor	CGP t-1300 (C30/37)	1
☑	Floors	Floor	CGP t-1350 (C30/37)	1
☑	Floors	Floor	CGP t-1750 (C30/37)	1
☑	Floors	Floor	CGP t-250 (Arm 190 kg/m^3 C30/37)	6
☑	Floors	Floor	CGP t-400 (C30/37)	2
☑	Floors	Floor	CGP t-450 (C30/37)	1
☑	Floors	Floor	CGP t-700 (Arm 190 kg/m^3 C30/37)	6
☑	Floors	Floor	CGP t-700 (C30/37)	7
☑	Floors	Floor	CGP t-950 (C30/37)	1
☑	Walls	Basic Wall	CIV t-200 (Arm 65 kg/m^3 C30/37)	28
☑	Walls	Basic Wall	CIV t-250 (Arm 180 kg/m^3 C30/37)	35
☑	Walls	Basic Wall	CIV t-350 (Arm 120 kg/m^3 C30/37)	4
☑	Walls	Basic Wall	CIV t-450 (Arm 150 kg/m^3 C30/37)	5
☑	Walls	Basic Wall	CYV t-300 (C30/37)	8
☑	Walls	Basic Wall	CYV t-400 (Arm 135 kg/m^3 C30/37)	8
☑	Walls	Basic Wall	CYV t-400 (C30/37)	1
☑	Walls	Basic Wall	CYV t-410 (C30/37)	1
☑	Walls	Basic Wall	CYV t-500 (Arm 160 kg/m^3 C30/37)	4

Total number of elements found 133 | Selected 133

Figure 4.8: *The figure shows how Floors and Walls was filtered containing the text "c30" in the family name.*

After the model had been enriched with information the IDS had to be reconstructed in order for it to work on a larger scale. The IDS from the previous test was coded to only check IFC elements grouped under IFCSlab i.e the slab elements. This had to be changed, after some trial and error a list was created for the applicability of the IDS were the IFC elements that are to be included in the check can be listed. The requirement itself remained unchanged from the previous test, elements must contain a ten digit value for a parameter called "ResursID" in the property set "_prod_info". The IDS in its entirety can be found in Appendix B. After the IDS had been reconstructed, the new model was checked in Solibri using the "IDS Validation" rule. The IDS once again worked as intended as the elements with a correct "ResursID" passed through the IDS and those that were incorrect or missing were caught in the validation process. Figures 4.9 and 4.10 below displays the IDS checking results in the "Result Summary" tab, showing an issue count of two. These issues include missing ID codes and incorrectly formatted ID codes. The column marked in red in figure 4.10 was marked by the IDS as it had an incorrectly formatted "ResursID", it can be seen in the info box in the left side if the figure. The elements completely missing a "ResursID" can be seen in figure 4.9 mostly consisting of reinforcing bars, a beam and a column.



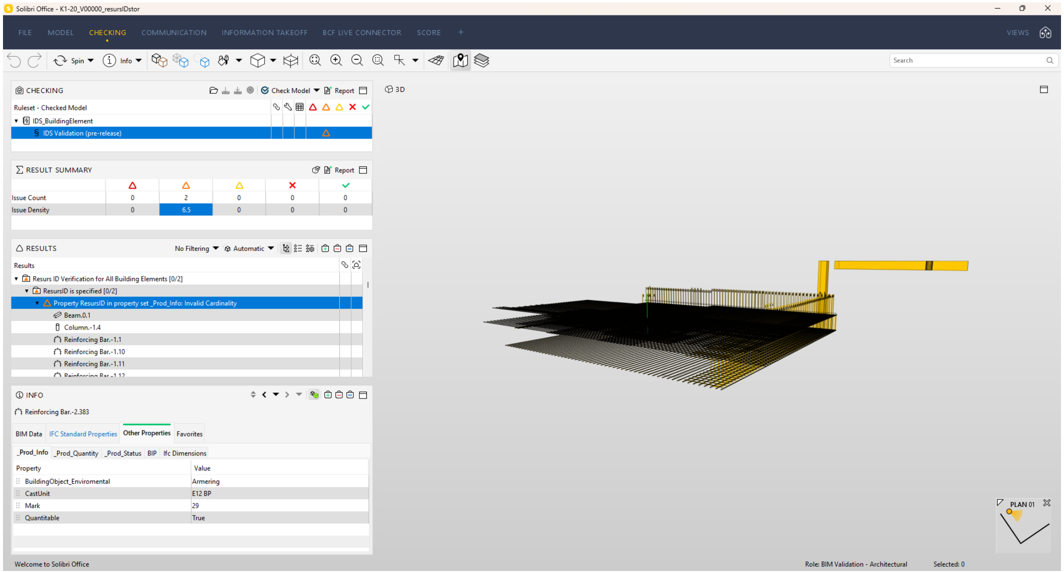
	△	△	△	✕	✓
Issue Count	0	2	0	0	0
Issue Density	0	6.5	0	0	0

Resurs ID Verification for All Building Elements [0/2]
- ResursID is specified [0/2]
  - Property ResursID in property set _Prod_Info: Invalid Cardinality
  - Property ResursID in property set _Prod_Info: Invalid Value (600000000326000000003260000000326
    - Column.-1.1

Property	Value
GeneralNotes	https://app.streambim.com/webapp/default/#/viewer/d...
Quantitable	True
ResursID	6000000003260000000032600000000326000000003260000000032
StoreyName	PLAN 01
Type	CRP 650x800 (Arm 100 kg/m³ C30/37)
TypeDescription	KONTREFOR

6000000003260000000032600000000326000000003260000000032

Figure 4.9: *The figure shows the results of the test conducted on a larger part of the structural model. The column with an incorrectly formatted "ResursID" is highlighted in red.*



Ruleset - Checked Model
- IDS_BuildingElement
  - IDS Validation (pre-release)

	△	△	△	✕	✓
Issue Count	0	2	0	0	0
Issue Density	0	6.5	0	0	0

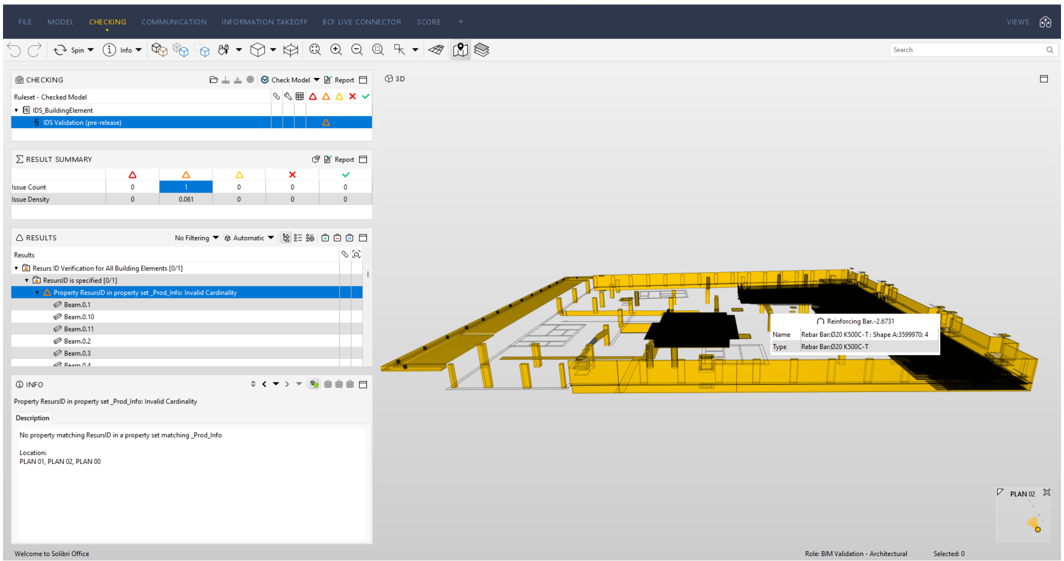
Results
- Resurs ID Verification for All Building Elements [0/2]
  - ResursID is specified [0/2]
    - Property ResursID in property set _Prod_Info: Invalid Cardinality
      - Beam.0.1
      - Column.-1.4
      - Reinforcing Bar.-1.1
      - Reinforcing Bar.-1.10
      - Reinforcing Bar.-1.11
      - Reinforcing Bar.-1.12

Reinforcing Bar.-2.383

Property	Value
BuildingObject_Enviromental	Armering
CastUnit	E12 BP
Mark	29
Quantitable	True

Figure 4.10: *The figure shows the results of the test conducted on a larger part of the structural model. All objects in this view did not pass the IDS validation due to missing a value for the "ResursID" parameter.*

To further validate the IDS and its effectiveness in ensuring the presence of the correct parameters a comprehensive test was then conducted on the entire model. Thus scaling up the test model even more this time using the entire provided structural model. DiRootsOne was used yet again to provide additional elements with a Resource ID. The IDS validation progress was the initialised within Solibri, figure 4.11 shows the results from this process. This time there was an issue count of one with the only type of issue being objects missing an ID.



Ruleset - Checked Model
- IDS_BuildingElement
  - IDS Validation (pre-release)

	△	△	△	✕	✓
Issue Count	0	1	0	0	0
Issue Density	0	0.061	0	0	0

Results
- Resurs ID Verification for All Building Elements [0/1]
  - ResursID is specified [0/1]
    - Property ResursID in property set _Prod_Info: Invalid Cardinality
      - Beam.0.1
      - Beam.0.10
      - Beam.0.11
      - Beam.0.2
      - Beam.0.3
      - Beam.0.4

Property ResursID in property set _Prod_Info: Invalid Cardinality

No property matching ResursID in a property set matching _Prod_Info

Location:
PLAN 01, PLAN 02, PLAN 00

Reinforcing Bar.-2.6731

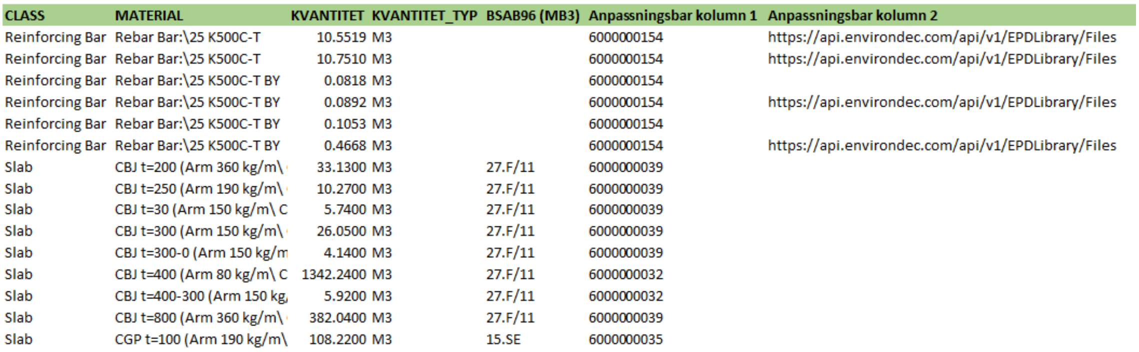
Name	Rebar Bar:Ø20 K500C-T : Shape A:3599970: 4
Type	Rebar Bar:Ø20 K500C-T

Figure 4.11: *The figure shows the results from the IDS validation of the complete model. The elements in this view did not pass the validation as they are missing a value for the parameter "ResursID".*

4.2.3 Imports using Information Takeoff

The purpose of this experiment was to take a closer look into how the use of additional information within the model could speed up the process of organising data within One Click LCA. In order to bring the quantities from Solibri to One Click LCA an Information Takeoff (ITO) had to be created. The ITO can then be exported from Solibri as an Excel file and imported in One Click LCA. This ITO is essentially a bill of quantities, it lists all the materials and their quantities as well as additional information that might be needed for the climate calculations. One Click LCA provides a template for imports from Excel with columns needed for the calculations listed, this template can be seen in figure 4.12.

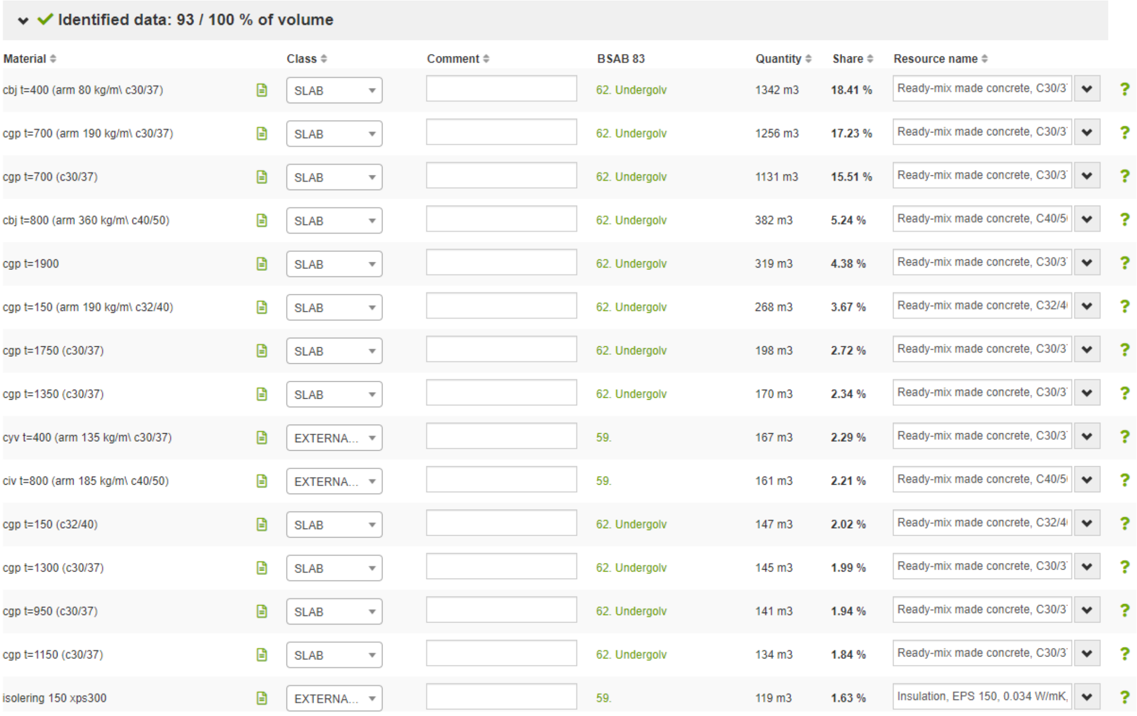
In the case of this test the relevant columns were: Class, Material, Quantity, and Quantity type. An ITO was then constructed in Solibri with the corresponding columns, one issue was the column quantity type which displays the unit for the quantities. This is due to the fact that the unit for quantities varies for the materials, for example all concrete is handled in cubic meters whereas doors are counted per instance. Therefore columns for square meter, count, volume, diameter, etc. had to be provided for all elements in the ITO so that the correct quantity could be calculated in excel and placed in the Quantity column before the import to One Click LCA. This meant that there had to be a certain degree of manual work after exporting the ITO to excel.



CLASS	MATERIAL	KVANTITET	KVANTITET_TYP	BSAB96 (MB3)	Anpassningsbar kolumn 1	Anpassningsbar kolumn 2
Reinforcing Bar	Rebar Bar:\25 K500C-T	10.5519	M3		6000000154	https://api.environdec.com/api/v1/EPDLibrary/Files
Reinforcing Bar	Rebar Bar:\25 K500C-T	10.7510	M3		6000000154	https://api.environdec.com/api/v1/EPDLibrary/Files
Reinforcing Bar	Rebar Bar:\25 K500C-T BY	0.0818	M3		6000000154	
Reinforcing Bar	Rebar Bar:\25 K500C-T BY	0.0892	M3		6000000154	https://api.environdec.com/api/v1/EPDLibrary/Files
Reinforcing Bar	Rebar Bar:\25 K500C-T BY	0.1053	M3		6000000154	
Reinforcing Bar	Rebar Bar:\25 K500C-T BY	0.4668	M3		6000000154	https://api.environdec.com/api/v1/EPDLibrary/Files
Slab	CBJ t=200 (Arm 360 kg/m\	33.1300	M3	27.F/11	6000000039	
Slab	CBJ t=250 (Arm 190 kg/m\	10.2700	M3	27.F/11	6000000039	
Slab	CBJ t=30 (Arm 150 kg/m\ C	5.7400	M3	27.F/11	6000000039	
Slab	CBJ t=300 (Arm 150 kg/m\	26.0500	M3	27.F/11	6000000039	
Slab	CBJ t=300-0 (Arm 150 kg/m	4.1400	M3	27.F/11	6000000039	
Slab	CBJ t=400 (Arm 80 kg/m\ C	1342.2400	M3	27.F/11	6000000032	
Slab	CBJ t=400-300 (Arm 150 kg,	5.9200	M3	27.F/11	6000000032	
Slab	CBJ t=800 (Arm 360 kg/m\	382.0400	M3	27.F/11	6000000039	
Slab	CGP t=100 (Arm 190 kg/m\	108.2200	M3	15.SE	6000000035	

Figure 4.12: *The figure displays the template provided by One Click LCA, the elements in this figure is a small sample of the total model. The template contains information about class, material, quantity, quantity type, BSAB code, Resource ID, and EPD links.*

Once the BOQ had been constructed correctly it was imported to One Click LCA. Then each material had to be connected to Boverket's database so that the materials could be provided with the correct environmental data. This process was also of the manual nature as the elements had to be connected to the database, grouped after their type names. This resulted in a large list of elements that had to be assigned. As figure 4.13 shows the elements are structured in a list within One Click LCA. As seen in the figure there are 93 rows of data that has to be connected to the database.

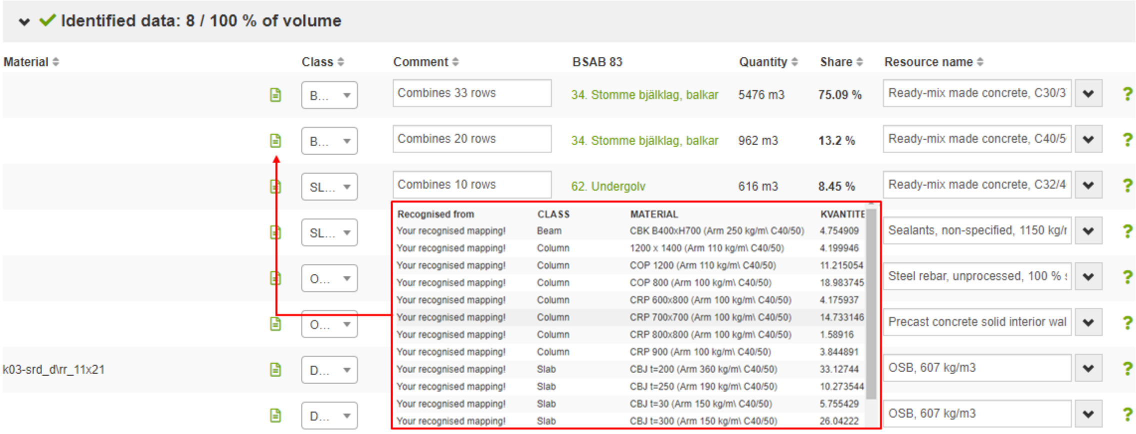


Identified data: 93 / 100 % of volume

Material	Class	Comment	BSAB 83	Quantity	Share	Resource name
cbj t=400 (arm 80 kg/m\ c30/37)	SLAB		62. Undergolv	1342 m3	18.41 %	Ready-mix made concrete, C30/3
cgp t=700 (arm 190 kg/m\ c30/37)	SLAB		62. Undergolv	1256 m3	17.23 %	Ready-mix made concrete, C30/3
cgp t=700 (c30/37)	SLAB		62. Undergolv	1131 m3	15.51 %	Ready-mix made concrete, C30/3
cbj t=800 (arm 360 kg/m\ c40/50)	SLAB		62. Undergolv	382 m3	5.24 %	Ready-mix made concrete, C40/5
cgp t=1900	SLAB		62. Undergolv	319 m3	4.38 %	Ready-mix made concrete, C30/3
cgp t=150 (arm 190 kg/m\ c32/40)	SLAB		62. Undergolv	268 m3	3.67 %	Ready-mix made concrete, C32/4
cgp t=1750 (c30/37)	SLAB		62. Undergolv	198 m3	2.72 %	Ready-mix made concrete, C30/3
cgp t=1350 (c30/37)	SLAB		62. Undergolv	170 m3	2.34 %	Ready-mix made concrete, C30/3
cyv t=400 (arm 135 kg/m\ c30/37)	EXTERNA...		59.	167 m3	2.29 %	Ready-mix made concrete, C30/3
civ t=800 (arm 185 kg/m\ c40/50)	EXTERNA...		59.	161 m3	2.21 %	Ready-mix made concrete, C40/5
cgp t=150 (c32/40)	SLAB		62. Undergolv	147 m3	2.02 %	Ready-mix made concrete, C32/4
cgp t=1300 (c30/37)	SLAB		62. Undergolv	145 m3	1.99 %	Ready-mix made concrete, C30/3
cgp t=950 (c30/37)	SLAB		62. Undergolv	141 m3	1.94 %	Ready-mix made concrete, C30/3
cgp t=1150 (c30/37)	SLAB		62. Undergolv	134 m3	1.84 %	Ready-mix made concrete, C30/3
isolering 150 xps300	EXTERNA...		59.	119 m3	1.63 %	Insulation, EPS 150, 0.034 W/mK,

Figure 4.13: *The figure shows a section of the BOQ imported in One Click LCA, at the top the amount of rows is displayed as 93. To the far right in the column "Resource name" the corresponding material in Boverket's database is selected.*

To be able to try and find a way to go around assigning the list of elements to their corresponding value in Boverket's database some changes were made to the ITO. The template from One Click LCA were provided with some columns that were listed as "customisable columns". Using one of the models from the previous tests the "ResursID" and links to certain EPDs could be provided in two of these columns and was therefore included in the new ITO. After this new ITO had been exported and the quantities selected in order for them to fit into the template provided by One Click LCA it could be imported to the LCA tool. A small example of the template filled with information can be seen in figure 4.12. The list of elements could then be grouped by their Resource ID in One Click LCA, this meant that the connection only had to be done once for every individual Resource ID thus speeding up the process of assigning the materials. This new import of the BOQ enriched with "ResursID" parameter is shown in figure 4.14. The amount of rows has decreased to 8 instead of the previous 93.



✓ Identified data: 8 / 100 % of volume

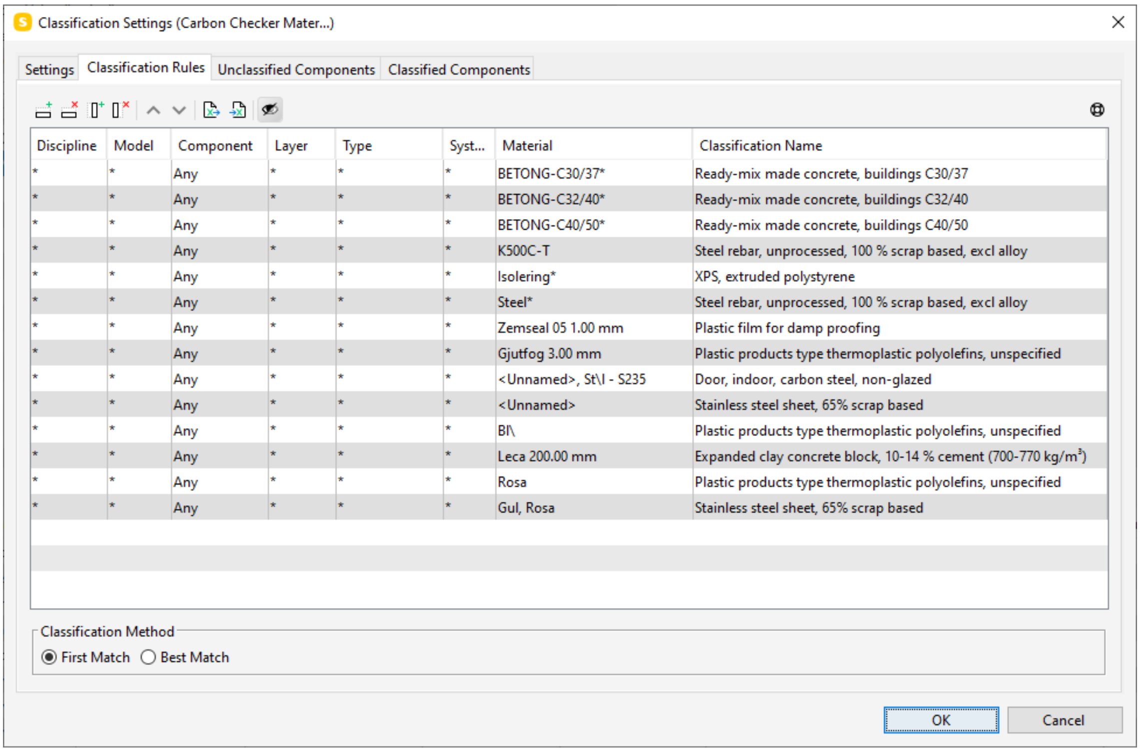
Material	Class	Comment	BSAB 83	Quantity	Share	Resource name
	B...	Combines 33 rows	34. Stomme bjälklag, balkar	5476 m3	75.09 %	Ready-mix made concrete, C30/3
	B...	Combines 20 rows	34. Stomme bjälklag, balkar	962 m3	13.2 %	Ready-mix made concrete, C40/5
	SL...	Combines 10 rows	62. Undergolv	616 m3	8.45 %	Ready-mix made concrete, C32/4
	SL...					Sealants, non-specified, 1150 kg/r
	O...					Steel rebar, unprocessed, 100 % :
	O...					Precast concrete solid interior wal
k03-srd_d\rr_11x21	D...					OSB, 607 kg/m3
	D...					OSB, 607 kg/m3

Recognised from	CLASS	MATERIAL	KVANTITE
Your recognised mapping!	Beam	CBK B400xH700 (Arm 250 kg/m\ C40/50)	4.754909
Your recognised mapping!	Column	1200 x 1400 (Arm 110 kg/m\ C40/50)	4.199946
Your recognised mapping!	Column	COP 1200 (Arm 110 kg/m\ C40/50)	11.215054
Your recognised mapping!	Column	COP 800 (Arm 100 kg/m\ C40/50)	18.983745
Your recognised mapping!	Column	CRP 600x800 (Arm 100 kg/m\ C40/50)	4.175937
Your recognised mapping!	Column	CRP 700x700 (Arm 100 kg/m\ C40/50)	14.733146
Your recognised mapping!	Column	CRP 800x800 (Arm 100 kg/m\ C40/50)	1.58916
Your recognised mapping!	Column	CRP 900 (Arm 100 kg/m\ C40/50)	3.844891
Your recognised mapping!	Slab	CBJ t=200 (Arm 360 kg/m\ C40/50)	33.12744
Your recognised mapping!	Slab	CBJ t=250 (Arm 190 kg/m\ C40/50)	10.273544
Your recognised mapping!	Slab	CBJ t=30 (Arm 150 kg/m\ C40/50)	5.755429
Your recognised mapping!	Slab	CBJ t=300 (Arm 150 kg/m\ C40/50)	26.04222

Figure 4.14: *The figure shows a section of the BOQ grouped by "ResursID". By hovering over the green icon, a box appears where the objects included in the group can be seen.*

4.2.4 Carbon Checker for climate calculations

In the fourth experiment the Carbon Checker extension for Solibri was tested. This extension utilises the data from Boverket's database and applies all the data to the elements directly in Solibri, the calculations can then be done in Solibri therefore removing the need for an additional software such as One Click LCA. For this test a new model was uploaded to Solibri without any additional parameters such as "ResursID". For Solibri to be able to perform the calculations the elements has to be linked to Boverket's database in a similar fashion to One Click LCA's system. In Solibri a connection is made between the parameter "Material" and the materials name in Boverket's database. Figure 4.15 shows the connections that were made in this model. By only listing the beginning of the material description for some materials they could be grouped and the amount of manual work minimised. For example Concrete C30/37 elements could be grouped by only entering "BETONG-C30/37" and then an asterisk, this allows Solibri to select all the elements that has an material label that starts with "BETONG-C30/37" no matter if the rest of the description is varying with different thicknesses etc. After the desired materials are grouped the correspondent material from the database can be selected from a drop-down menu.

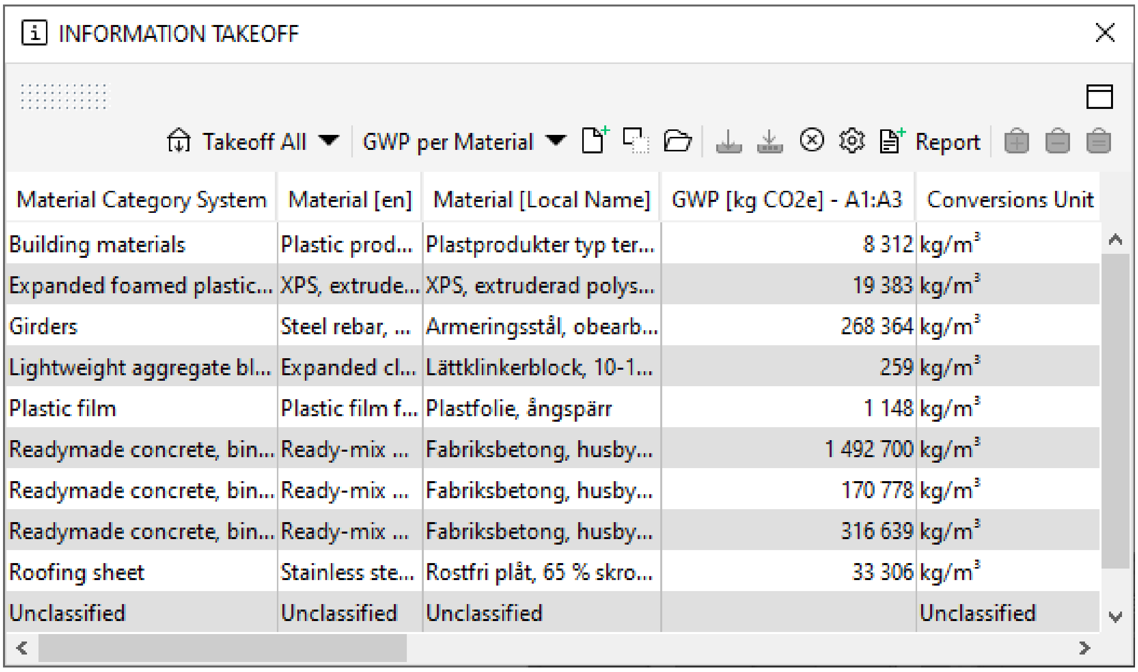


Discipline	Model	Component	Layer	Type	Syst...	Material	Classification Name
*	*	Any	*	*	*	BETONG-C30/37*	Ready-mix made concrete, buildings C30/37
*	*	Any	*	*	*	BETONG-C32/40*	Ready-mix made concrete, buildings C32/40
*	*	Any	*	*	*	BETONG-C40/50*	Ready-mix made concrete, buildings C40/50
*	*	Any	*	*	*	K500C-T	Steel rebar, unprocessed, 100 % scrap based, excl alloy
*	*	Any	*	*	*	Isolering*	XPS, extruded polystyrene
*	*	Any	*	*	*	Steel*	Steel rebar, unprocessed, 100 % scrap based, excl alloy
*	*	Any	*	*	*	Zemseal 05 1.00 mm	Plastic film for damp proofing
*	*	Any	*	*	*	Gjutfog 3.00 mm	Plastic products type thermoplastic polyolefins, unspecified
*	*	Any	*	*	*	<Unnamed>, St\I - S235	Door, indoor, carbon steel, non-glazed
*	*	Any	*	*	*	<Unnamed>	Stainless steel sheet, 65% scrap based
*	*	Any	*	*	*	Bl\	Plastic products type thermoplastic polyolefins, unspecified
*	*	Any	*	*	*	Leca 200.00 mm	Expanded clay concrete block, 10-14 % cement (700-770 kg/m^3)
*	*	Any	*	*	*	Rosa	Plastic products type thermoplastic polyolefins, unspecified
*	*	Any	*	*	*	Gul, Rosa	Stainless steel sheet, 65% scrap based

Classification Method
● First Match ○ Best Match

Figure 4.15: *The figure shows the classification settings for the Carbon Checker extension. The materials are mapped by connecting the material parameter to the corresponding classification name in Boverket's database.*

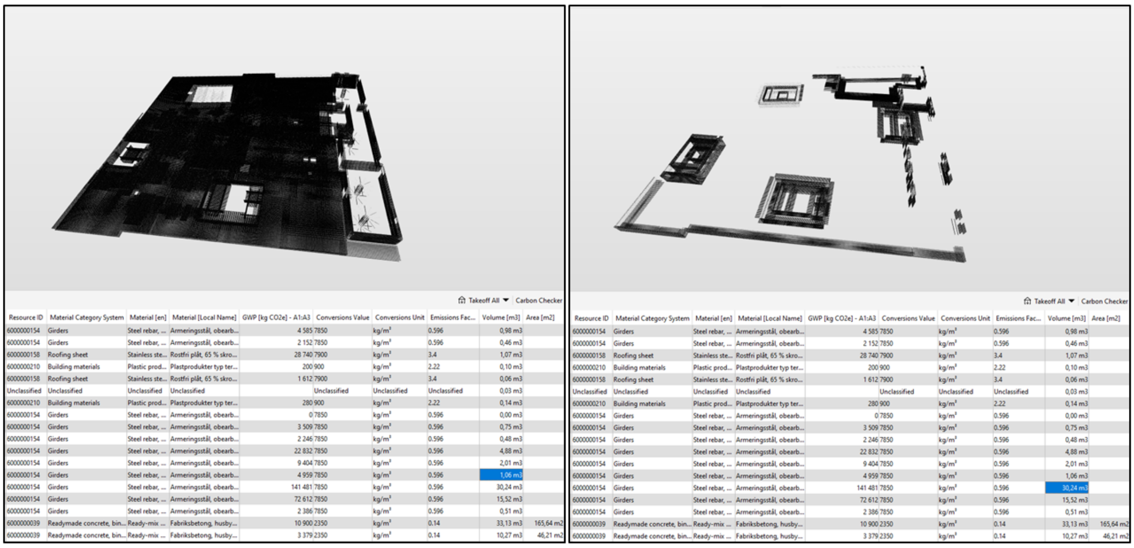
Once a material is assigned to the database all the IFC elements are assigned with a new property set called "Classification" this set contains information from Boverket's database with parameters such as: Resource ID, Emission factor, and Conversion value. With these new parameters Solibri is able to perform the calculations needed to find the environmental impact from the elements listed in figure 4.15. This is done through an ITO, the results can be seen in figure 4.16. As of now the extension only computes the GWP for modules A1:A3, the extension does not include modules A4 and A5. By using a custom Java script for the column GWP the extension makes sure that the correct unit for quantities is being used as mentioned in the previous test. After the ITO had been completed it could be exported to Excel were some additional changes could be made. Worth noting is that the results from the ITO were not quantified using the conservative values. This is due to the fact that Carbon Checker does not use the conservative values, this means that they will have to be increased with 25% for them to be following the climate declaration standards. To be able to use the results for comparison there was a desire to add modules A4 and A5 that represent the emissions from transports and construction waste. As the elements in the ITO were provided with the corresponding material in the database the process of finding the correct factors for A4 and A5 were rather simple. After the 25% increase and the addition of A4 and A5 had been made the test of the extension was complete.



Material Category System	Material [en]	Material [Local Name]	GWP [kg CO2e] - A1:A3	Conversions Unit
Building materials	Plastic prod...	Plastprodukter typ ter...	8 312	kg/m^3
Expanded foamed plastic...	XPS, extrude...	XPS, extruderad polys...	19 383	kg/m^3
Girders	Steel rebar, ...	Armeringsstål, obearb...	268 364	kg/m^3
Lightweight aggregate bl...	Expanded cl...	Lättklinkerblock, 10-1...	259	kg/m^3
Plastic film	Plastic film f...	Plastfolie, ångspärr	1 148	kg/m^3
Readymade concrete, bin...	Ready-mix ...	Fabriksbetong, husby...	1 492 700	kg/m^3
Readymade concrete, bin...	Ready-mix ...	Fabriksbetong, husby...	170 778	kg/m^3
Readymade concrete, bin...	Ready-mix ...	Fabriksbetong, husby...	316 639	kg/m^3
Roofing sheet	Stainless ste...	Rostfri plåt, 65 % skro...	33 306	kg/m^3
Unclassified	Unclassified	Unclassified		Unclassified

Figure 4.16: *The figure shows the window for Information Takeoff from Solibri, it displays GWP per material for modules A1:A3.*

Some issues were also found when analysing the results. For instance the fasteners were not included in the calculations, these elements did not have a value for the parameter "Material" therefore they did not show up when assigning the elements to the database. This is a problem that can be resolved easily in Revit. As the missing elements had a rather small impact on the end product a decision was made to continue with the results. However a more significant issue was also found when examining the reinforcement within the model. When sorting the reinforcement by their respective groups the differences in volumes were substantial. Despite the apparent visual similarity in volume when observing the model, closer analysis revealed large variations. Figure 4.17 shows two different groups of reinforcement bars, the group to the left has a volume of 1,06 m^3 whereas the group on the right-hand side has a total volume of 30,24 m^3. This in turn translates to a variation of GWP between different groups of reinforcement. This discovery motivated a closer examination of the relationship between concrete, rebar, and quantities in general.



Resource ID	Material Category System	Material [en]	Material [Local Name]	GWP [kg CO2e] - A1:A3	Conversions Value	Conversions Unit	Emissions Fac...	Volume [m3]	Area [m2]
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	4 585	7850	kg/m³	0.596	0,98 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	2 152	7850	kg/m³	0.596	0,46 m3	
6000000158	Roofing sheet	Stainless ste...	Rostfri plåt, 65 % skro...	28 740	7900	kg/m³	3.4	1,07 m3	
6000000210	Building materials	Plastic prod...	Plastprodukter typ ter...	200	900	kg/m³	2.22	0,10 m3	
6000000158	Roofing sheet	Stainless ste...	Rostfri plåt, 65 % skro...	1 612	7900	kg/m³	3.4	0,06 m3	
Unclassified	Unclassified	Unclassified	Unclassified		Unclassified	Unclassified	Unclassified	0,03 m3	
6000000210	Building materials	Plastic prod...	Plastprodukter typ ter...	280	900	kg/m³	2.22	0,14 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	0	7850	kg/m³	0.596	0,00 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	3 509	7850	kg/m³	0.596	0,75 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	2 246	7850	kg/m³	0.596	0,48 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	22 832	7850	kg/m³	0.596	4,88 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	9 404	7850	kg/m³	0.596	2,01 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	4 959	7850	kg/m³	0.596	1,06 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	141 481	7850	kg/m³	0.596	30,24 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	72 612	7850	kg/m³	0.596	15,52 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	2 386	7850	kg/m³	0.596	0,51 m3	
6000000039	Readymade concrete, bin...	Ready-mix ...	Fabriksbetong, husby...	10 900	2350	kg/m³	0.14	33,13 m3	165,64 m2
6000000039	Readymade concrete, bin...	Ready-mix ...	Fabriksbetong, husby...	3 379	2350	kg/m³	0.14	10,27 m3	46,21 m2

Resource ID	Material Category System	Material [en]	Material [Local Name]	GWP [kg CO2e] - A1:A3	Conversions Value	Conversions Unit	Emissions Fac...	Volume [m3]	Area [m2]
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	4 585	7850	kg/m³	0.596	0,98 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	2 152	7850	kg/m³	0.596	0,46 m3	
6000000158	Roofing sheet	Stainless ste...	Rostfri plåt, 65 % skro...	28 740	7900	kg/m³	3.4	1,07 m3	
6000000210	Building materials	Plastic prod...	Plastprodukter typ ter...	200	900	kg/m³	2.22	0,10 m3	
6000000158	Roofing sheet	Stainless ste...	Rostfri plåt, 65 % skro...	1 612	7900	kg/m³	3.4	0,06 m3	
Unclassified	Unclassified	Unclassified	Unclassified		Unclassified	Unclassified	Unclassified	0,03 m3	
6000000210	Building materials	Plastic prod...	Plastprodukter typ ter...	280	900	kg/m³	2.22	0,14 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	0	7850	kg/m³	0.596	0,00 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	3 509	7850	kg/m³	0.596	0,75 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	2 246	7850	kg/m³	0.596	0,48 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	22 832	7850	kg/m³	0.596	4,88 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	9 404	7850	kg/m³	0.596	2,01 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	4 959	7850	kg/m³	0.596	1,06 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	141 481	7850	kg/m³	0.596	30,24 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	72 612	7850	kg/m³	0.596	15,52 m3	
6000000154	Girders	Steel rebar, ...	Armeringsstål, obearb...	2 386	7850	kg/m³	0.596	0,51 m3	
6000000039	Readymade concrete, bin...	Ready-mix ...	Fabriksbetong, husby...	10 900	2350	kg/m³	0.14	33,13 m3	165,64 m2
6000000039	Readymade concrete, bin...	Ready-mix ...	Fabriksbetong, husby...	3 379	2350	kg/m³	0.14	10,27 m3	46,21 m2

Figure 4.17: *The figure shows two groups of reinforcement bars within the slab. The left group has a total volume of 1,06* m^3 *and the group to the right has a total volume of 30,24* m^3.

4.2.5 Quantities in relation to software

This experiment was structured when a discovery of incorrect volumes were made during the previous experiment. The purpose is to take a closer look at how the different softwares handle quantities, the effect it has on the end product, and what causes the variation in volumes. The main problem was the volumes missing for some of the groups of reinforcement bars. The volumes being used for the calculations in Carbon Checker are calculated by Solibri. By analysing the results from the ITO in Solibri a total volume for the reinforcement bars in the whole model, the results can be seen in table 4.1. To be able to get a better understanding of the reinforcement volume in the model two other values were produced. One by exporting the total lengths and diameters from Solibri and calculating the volumes manually. This was done by using the the very same ITO that had some incorrect volumes for the rebar and exporting it to excel. This ITO contains values for both length and diameter therefore allowing for a simple calculation to get a total volume from the reinforcement bars, the result can be seen in table 4.1 and is refereed to as calculated. The other method used for calculating the reinforcement volume was by creating a schedule or BOQ in Revit. A schedule was created in Revit, the schedule is essentially a BOQ allowing for a total value from the reinforcement bars within Revit. The schedule was constructed by listing all the reinforcement bars by type and adding the parameter called "Reinforcment Volume" then by exporting the BOQ to excel and adding up the volumes for all groups a total volume could be derived. The result from this method can be seen in table 4.1.

Method	**Volume** [m^3]
Solibri	57,36
Calculated	74,05
Revit	3430.75

Table 4.1: This table displays the results of three different methods of deriving the total volume for the reinforcement bars in the model.

As the results show there is a significant difference between the volume derived from Revit and the two other methods. To further analyse the differences between the volumes derived from Solibri and Revit a new IFC export of the model was made. This time the Revit model was exported with the addition of the "Reinforcement Volume" parameter from Revit as it will allow for an easy comparison between the values. This allows the creation of an ITO where the volumes of individual reinforcement bars can be examined. As seen in figure 4.17 the volumes derived from Solibri had an issue that left the volume of some bars at zero. However, the volumes provided by the new Revit parameter were unreasonably high. Some samples were taken and a single bar was isolated and a manual calculation for its volume was performed. These comparisons resulted in a lower value for the manually calculated volumes in all instances. These inflated numbers from the Revit parameter in combination with missing values for some of the groups in Solibri leads to a significant difference. Due to the gaps in the rebar data from Solibri and the inflated numbers from Revit, the volumes manually calculated using the diameters and lengths had to be deemed the most reliable. To analyse this further a comparison was made between Revit and Solibri for all materials, the results can be seen in table 4.2.

Material	**Volume Solibri** [m^3]	**Volume Revit** [m^3]	**Reinforcement Volume** [m^3]
Door, indoor, carbon steel, non-glazed	2.30		
Plastic products type thermoplastic polyolefins, unspecified	0.23	0.23	
Ready-mix made concrete, buildings C30/37	5475.80	5476.29	
Ready-mix made concrete, buildings C32/40	615.86	667.59	
Ready-mix made concrete, buildings C40/50	962.45	962.74	
Stainless steel sheet, 65% scrap based	1.24	1.13	
Steel rebar, unprocessed, 100% scrap based, excl alloy	57.36	1.92	3430.75
Unclassified	6.59	1.94	
XPS, extruded polystyrene	173.68	173.64	

Table 4.2: This table shows the results of the ITO from the comparison between the volumes derived from Solibri and Revit. The "Reinforcement Volume" parameter is also derived from Revit.

As table 4.2 shows the majority of the materials has a similar volume in both cases. There is some variance for example the unclassified elements, this can be explained by the fact that some elements do not have an assigned Revit volume, the majority of them being smaller objects such as fasteners. This isolates the issue of quantities to lie within the volumes of the reinforcement bars and not any other materials. In the column "Volume Revit" in table 4.2 the volume for the rebar calculated by Revits standard volume parameter is listed. As the table shows once again this volume deviates from the other volumes in table 4.1.

After further investigation regarding the inflated "Reinforcement Volume" parameter it was found that the parameter had the same value for individual rebars within the same rebar group despite the bars actually differentiating in length. This is what caused the inflation of the numbers as the parameter should be applied to the rebar in their totality instead of applying it to individual rebars. Instead, the correct way to calculate the reinforcement volume for individual rebars within Revit would be to create a parameter that calculates the volume based on the diameter and length parameters.

The point of departure for this experiment was to to track the source of the groups of reinforcement bars that has an incorrect volume. However, the results in table 4.1 and 4.2 shows that there can be a significant difference for quantities of the same elements between software. These quantities lay the base for the climate calculations, therefore the results of this experiment shows that the set-up for the quantities has to be conducted with great caution. In this case this is particularly true for the reinforcement value. The mistake of applying the "Reinforcement Volume" parameter to individual reinforcement bars instead of applying it to the sum of all rebar within the project resulted in a volume almost 50 times higher than the correct volume.

5

Discussion

In this chapter, the findings from the literature, interviews, and experiments are interpreted and discussed. The discussion is divided into three sections to discuss the results in relation to the research questions.

5.1 Key factors for optimal strategy in performing climate calculations

This chapter discusses the significance of quantities, the utilisation of MMI alongside Resource ID, and the potential benefits of integrating Resource ID and EPDs into design templates. It also discusses what the future plans and regulations for climate declarations in construction will look like.

5.1.1 The importance of quantities in relation to carbon calculations

One shared factor between all carbon calculations is the significance of the BOQ as mentioned in chapter 3.6. The projects quantities are also directly linked to the cost calculations of the project. As the quantities lay the base for these calculations errors in the bill of quantities can lead to faulty results. This, in turn can affect project budgets, timelines, and sustainability goals. Decisions that are made on inaccurate quantity data can easily shift the focus from where it should be. For instance as the experiment in chapter 4.2.5 shows, the shifts in the reinforcement volumes can be substantial depending on how the quantities are derived. From all the tests conducted in the report the quantities has been identified as the major source of errors when it comes to questionable results from climate calculations. Incorrect quantities in those circumstances can misguide efforts to minimise the carbon footprint or other environmental impacts.

In the context of integration between BIM and LCA accurate quantities ensures a smooth cooperation between softwares. When exchanging data between modeling software such as Revit and analysis tools such as Solibri differences in quantities can interfere with the workflow and more importantly compromise the integrity of the analysis. Stakeholders rely on correct data to understand factors such as progress, cost, and environmental impact. Therefore, these types of issues can disrupt the credibility and undermine trust within the project.

To handle the issue of questionable quantities one possible solution is to hold someone accountable for the quantities. However, this is a responsibility that requires clear communication and collaboration between parties. This means that it is difficult to hold a single group or individual accountable for this responsibility as it requires a collective effort throughout the projects life-cycle. There are some measures that can be taken to minimise the risks regarding quantities. Establishing clear roles and responsibilities for each stakeholder involved in the project and defining who is responsible for inputting and verifying quantity data at each stage of the project is a step in the right direction. Another important point is to work towards having collaborative workflows within the projects. In this case this means that the groups involved in the project quantities should have close collaboration and clear communication channels. For instance individuals responsible for climate calculations should be in close collaboration with those extracting the BOQ as they have knowledge about what quantities are relevant for carbon calculations and what units are preferred etc. This would decrease the amount of manual labour that has to be done later on as quantities adapted for climate calculations would be available straight from the source rather than having to categorise and filter a general BOQ. As the quantities are such a central factor for all calculations the collaboration could be even more extensive. The BOQ needed for cost calculation is in many ways similar to the data needed for climate calculations, this should also be seen as a opportunity for collaboration as it would be beneficial for the greater good of the project.

In conclusion, it is essential to handle the project quantities with care as they serve as a base for several calculations. With solid quantities the integrity, reliability, and effectiveness of several processes such as cost estimation, scheduling, and environmental impact assessment can be ensured. The quantities form the foundation for informed decision-making and successful project outcomes, this is especially true for Total BIM projects. By establishing effective collaboration, clear communication, and quality control processes the risks that come with faulty quantities can be minimised and lead to data that can be trusted for informed decision making in early stages of the project.

5.1.2 MMI in relation to Resource ID

When designing a building, all the different materials and solutions are not set in stone and the designers are likely to make many changes to the design throughout the project. A climate calculation is a living report and is often required at all stages of the project, so it is important to be able to produce such a report even when there are uncertainties in the designed model. The study has shown that it is better to be able to get some kind of result from the climate calculations than not to be able to get any result. The project will benefit from knowing at an early stage which parts contribute most to carbon emissions, which can then be used as a basis for deciding which materials to choose. For example, it's better to have a Resource ID attached to a beam that defines its properties, to be able to run the climate calculations and perhaps change the beam to a different material on the basis of the result. In this case, an element may be associated with a Resource ID but have a low MMI, meaning that it is uncertain what material it will actually be. In a later case, when the decision has been made as to what material the beam should be, the Resource ID should be changed to the correct beam type and a higher MMI should also be set on the beam. This example is visualised in figure 5.1 below, it starts at MMI 100 where the decision between steel and wood has not been made. Later on in the project the decision makers have made a choice to choose steel but not a specific type, at this stages the element is at MMI 300. In the end of the project the steel type chosen was "steel, type 1" which was the beam that actually got build and therefore it ends up with MMI 500.

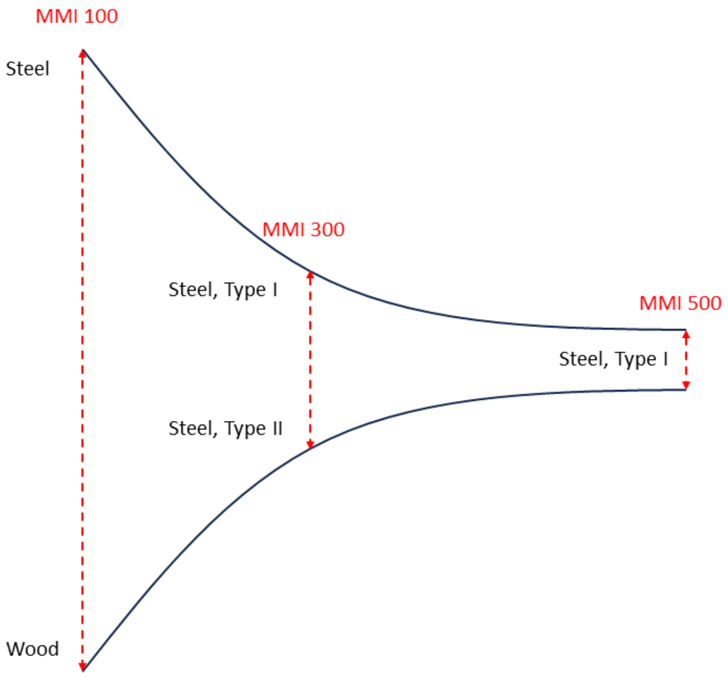


Figure 5.1: *The figure illustrates a timeline for an object that starts at MMI 100 and ends at MMI 500.*

When working with MMI in a project it is important to keep the MMI for objects up to date. Otherwise MMI will lose its purpose and the project will not benefit from implementing it. Decision making in projects will differ, and it is then hard to precise when different decisions regarding material choices are made. MMI should be demanded during all the stages of the project. It will be a key information on where in the model more work has to be done and will lead decision makers to know where they should focus their work to ensure the model evolves.

5.1.3 Potential of assigning Resource ID and EPDs to design templates

The Resource ID is mentioned several times in the report and is one way of making the carbon calculations easier and more streamlined. The Resource ID for elements may change during the project as mentioned above, but it's still useful even if it's not the final Resource ID for the specific element. Integrating Resource ID into the families used by the designers will make the implementation of Resource ID easier. Again, even if this is not the final element chosen, it still provides a good estimate of what it might be at the end of the project. All of this is useful for getting an estimate of the carbon footprint of the project. A disadvantage is when the designers are from different consultancy firms. They are likely to have different families in their software and therefore may not have integrated the required information into the families. A solution to this could be for the project to develop one family for the specific project, which is then given to all the different consultant designers, regardless of which company they work for. This will ensure that the model contains the correct information required, which in turn will make the work of the climate consultant much easier. The best way to incorporate this would be by including it in the requirements during the procurement.

EPDs are one way to define what material and what footprint an element has. The EPDs contains information that could be considered to contain more accurate information about a specific product. This is also the problem with EPDs, they are linked to a specific product making it difficult to use in an early stage of design. It will also be difficult to integrate EPDs into the project-specific families mentioned earlier. On the other hand, if the project agrees, for example, to use the same windows throughout the building, EPDs could be the answer for those elements. It all depends on how specific the project is planned at the start, even before the design phase. Some also argue that EPDs cannot be trusted, how can EPDs be validated as to whether the results are true or not? When using EPDs, there will be more manual work as each element has to be validated, on the other hand it can be argued that the calculation will be more accurate with EPDs.

5.1.4 Future laws and regulations

In the future, the requirements of the climate declarations will increase gradually with time. As mentioned in 3.2, Boverket suggests several steps in the gradual increase of requirements. Two of which are: the expansion of LCA modules and demands set on maximum emissions for modules A1:A5. The expansion of modules would expand the scope of the climate declaration further as it would lead to a larger part of the buildings life-cycle to be included in the calculations. The other step suggests that a maximum value for modules A1:A5 is to be introduced that would limit the total impact of those model in a strict manner. These maximum values could be introduced as early as 2025 due to the desire of swiftly minimising the carbon footprint left by newly constructed buildings. The expanded scope of the climate declaration is planned to be introduced in a later stage, around 2027. There are also plans on higher demands on the calculation process therefore ensuring a higher quality and reliability of the climate declaration's results.

These future plans suggest that the climate declarations that were introduced in 2022 is only a first step. As of now the only requirement is that the calculations has to be performed and turned in and that the correct environmental data is to be used. This first step has introduced the climate declarations to the industry and the fact that it is required by law is in a way forcing the industry towards a future where the environmental factors play a central role in the design stage of all construction. This will be even more true when these new requirements are introduced, the fact that the industry already has been introduced to the climate declarations will hopefully be beneficial as they would have a chance to learn and develop their skills in regards to climate calculations.

These efforts of lowering the environmental impact in construction will greatly influence the importance of the design phase as there is a great possibility of optimising the building from an environmental point of view. This will most likely lead to higher costs during the design phase, it does not however necessarily mean that the construction costs will be higher assuming that both the design of the building and the material use will be optimised. The cost of material might be higher as materials with high environmental performance usually comes with a higher price. In addition to producing the materials there is also an added cost for producing EPDs, those who are directly impacted would be the developers and entrepreneurs. The material manufacturers would be impacted indirectly for example by the cost of developing EPDs.

One possible consequence of these new regulations could be that developers receive fewer participants in tendering processes and that the access to subcontractors is lowered. This in turn would lead to higher prices in general, one reason for the decreased access to subcontractors could be that entrepreneurs turn to smaller projects conducted by private individuals rather than large projects regulated by these guidelines. This change in focus also creates room for actors such as these entrepreneurs to create an edge and gaining an advantage in the industry by sharpening their skills in projects focused on leaving a small carbon footprint. One thing that should be considered is to provide the industry with opportunities to learn this could be done through courses or other educational opportunities provided by the public sector.

Overall, Boverket's plan for the future of climate declaration is to further enhance its comprehensiveness. Which implies for actors to not only do what is required today, but to learn and develop their skills and expertise in calculating the climate declarations.

5.2 The influence of climate calculations on a Total BIM workflow

This chapter discusses how a project workflow is influenced by the use of Total BIM and the desire to create iterative climate calculations. Some points that are brought up in this chapter is the ongoing shift from traditional 2D construction to model-based construction, the combined use of Total BIM and LCA, iterative climate calculations, and how IDS can be used within a projects workflow. These subsections will contribute to a better understanding of the factors that can contribute to an effective project workflow.

5.2.1 Shifting from 2D drawings to model based construction

As mentioned in chapter 3.3, BIM is now considered to be a widespread technology in the construction industry. In Sweden it is common practice to create a 3D model and then extract 2D drawings from said model. Issues have been identified connected to this way of conducting projects for instance, BIM models are seldom used in the construction process. This usually results in differences between the model and the 2D drawings therefore resulting in a lack of trust in the information provided by the model leaving it outdated and forgotten. There are also requirements for having 2D drawings as the legally binding documents in a project therefore creating a need for up to date 2D drawings, shifting the focus away from the BIM model. To be able to shift the focus back to model based construction there have been pilot projects in recent years where a different use of BIM has been implemented. As mentioned in chapter chapter 3.3.1, Total BIM which refers to an embrace of BIM in its totality has been implemented in these pilot projects. In practice this means that the parallel process of having fresh 2D drawings is removed and replaced by a more complete model.

There are several things that were found in the literature review concerning what key-factors are necessary to be able to conduct a successful Total BIM project. Among those things were: having the model as the legally binding document, utilisation of cloud-based software were all models are live-linked, the use of mobile BIM-viewers in construction, and effective leadership and management implementing Total BIM. In the case that has been studied in this project the ambition has been to come as close as possible to a Total BIM approach. This has been done by request from the client and Sweco has been responsible for the operation. There are however some differences from the factors that were considered to be essential by the literature, for instance the 2D drawings are still legally binding in this case. However they are still derived directly from the model in order to get as close to Total BIM as possible. The other key-factors play a crucial role in the case project, by removing the 2D drawings there is less room left for doubting the information provided by the model as it is the central piece for the entire project.

5.2.2 The implementation of Total BIM and LCA practices

Regarding workflow within Total BIM and the implementation of climate calculations in BIM there is a large potential of creating continues calculations throughout the projects life-cycle. This is especially true when moving from the traditional use of BIM (as a parallel process with 2D drawings) towards Total BIM as the model is enriched with more information and detail. In the literature study it was found that the implementation of Total BIM and LCA methodologies offers a number of benefits such as: improved environmental impact assessments with higher accuracy, a streamlined workflow, and a better base for decision making in early stages. There are some obstacles that have to be addressed in order for this implementation to be seamless. One challenge is the diverse data sources that are involved in both BIM and LCA practices. One example can be observed in chapter 4.2.5 there can be difference when looking at quantities within different software. When it comes to data sources in LCA practices there have not been any significant issue found in this report due to the fact that Boverket's database has been the main source of environmental data. In reality however the use of EPDs will be more noticeable in the calculations. To be able to navigate through the data in relation to both the BIM model and the environmental databases there needs to be coordination and management to withhold a certain degree of consistency and accuracy.

The article “Identification and comparison of LCA-BIM integration strategies” written by Wastiels and Decuypere (2019) that is brought up in chapter 3.6 lists six steps that are fundamental for designing a building in BIM and using the information in the model for performing an LCA study. The steps are: develop a BIM model, extract a BOQ, find the environmental data connected to each object, assign the data to the objects, based on the BOQ and environmental data perform calculations, and finally analyse the results. From the findings Sweco currently include all of these steps in their workflow. Figure 4.1 shows the current workflow, a BOQ is extracted from the BIM-viewer were all models are live-linked and the quantities are then imported in to One Click LCA where the last four steps are followed.

The article also identifies five different workflows that have been identified in the industry after analysing how Sweco operates within this project their workflow has been placed under the category "Bill of quantities (BOQ) export". As the title suggests this workflow builds on a BOQ that is extracted from a BIM software, in Sweco's case a BIM-viewer and then imported into a dedicated LCA software. The remaining workflow then takes place within the LCA software were the building components are manually linked to predefined LCA profiles. This model accurately describes Sweco's current workflow regarding the implementation of BIM and LCA practices. Wastiels and Decuypere (2019) describes that one of the main issues that is usually associated with this workflow is the fact that iterative design might not be supported by this workflow. This is due to the fact that importing an updated BOQ into an existing LCA calculation set while preserving the building components already linked to an LCA profile might not be possible. This very issue was also recognised in the open interviews, as mentioned before the plan for the project was to have climate calculations done throughout the project. This idea had to be aborted due to the time and cost-consuming nature of the task.

5.2.3 Iterative climate calculations

Climate calculations in early stages of the project is something that should be desired as it is easier to make changes in the project early on. One dilemma that was raised multiple times during the open interviews was the insecurity regarding materials early on, as it is difficult to create climate calculations when material choices have not been made. Without any precise decision made about materials there is a need for assumptions when performing the climate calculations leading to some what inaccurate results. The standard procedure seems to be to ask designers what material and properties a building element has. However, competent or experienced workers would be able to assume and suggest alternatives to different building elements. This could lead to climate consultants having a say in the design phase and significantly influencing the outcome of the climate declaration.

In the early stages, it is important to remember the purpose of the climate calculation. The total result should not be the focal point, as it will vary throughout the project's life-cycle Instead, the calculations should be aimed at finding the major contributors and investigating if there are any changes that could be made to improve the carbon footprint of the end product in later stages. To do this multiple calculations with different assumptions etc. have to be conducted, this calls for a calculation method that is fast and easy to modify.

Total BIM requires a plan for continuous updating of the model, including binding information such as material for elements, dimensions and positioning in accordance with constructability. If climate calculations were more integrated into the decision making of a project, there is more potential to make effective decisions for the climate calculations. The results of this thesis show that the climate declaration is rarely part of a project other than to present the end results, which is a requirement for new buildings from 2022. This also has a negative impact on the workflow of the climate calculations, where the central project group mostly transfers information via the BIM model to an Excel export which is then forwarded to the climate calculation group.

In this report two tools for climate calculations have been investigated, One Click LCA and Carbon Checker. Several of the experiments conducted in this report explores the possibility to streamline the process of performing climate calculations. The experiments described in chapters 4.2.1, 4.2.2, and 4.2.3 all investigate the potential of using One Click LCA in a way that allows for calculations with less manual labour needed. Less manual labour would lead to more climate calculations being produced in the early stages and therefore enabling comparisons between different solutions or materials backed by environmental data. However these experiments depend on more information being added to the model in order to lower the amount of connections between the model and Boverket's database that has to be done.

In chapter 4.2.4 the Solibri extension Carbon Checker is introduced as a replacement for One Click LCA. As described in the experiment Carbon Checker has a different approach towards the calculations as there is no need for the same amount of connections between the model and the database. All materials could be assigned with 10 connections as seen in figure 4.16, without the need for any previously added information. The connections displayed in figure 4.16 can be exported and used for different versions of the model, this allows for an easy and fast way of conducting multiple climate calculations with the option to make changes regarding material choices. Another benefit of using Carbon Checker is the fact that the model is visualised within Solibri, meaning that tracking the results from different groups to the elements in the model is simple. Figure 4.17 shows an example where the volumes of two different groups of reinforcement bars are visualised in the model, this can also be done by sorting the elements by material.

However, One Click LCA should be considered as a more comprehensive tool as it includes modules A4 and A5 which is not taken into consideration by Carbon Checker. Another important point is that One Click LCA has access to EPDs which is a key factor when conducting the climate declaration. When it comes to results One Click LCA should also be considered a powerful tool as it generates graphs and tables that can be adjusted to show the environmental for different categories which is desired especially when performing the climate declaration since the environmental impact caused by different components. As mentioned above Carbon Checker only includes modules A1:A3 whereas One Click LCA covers modules A4 and A5 as well.

One alternative that should be considered is to use Carbon Checker as a compliment to One Click LCA, this is especially beneficial in early stages of the project. Both tools provide valuable functions for conducting climate calculations. One Click LCA provides a more complete calculation whereas Carbon Checker allows for calculations that require less time spent on the set-up. However, one thing that both tools share is the importance of accurate data and careful consideration of quantity inputs to ensure reliable results that in turn can lead to an informed decision-making process.

5.2.4 The use of Information Delivery Specification (IDS)

One of the areas covered in the report is the newly developed file format Information Delivery Specification or IDS. As described in chapter 3.3.2 and 3.6 the purpose of this standard that is being developed is to create a way of specifying standards in a way that can easily be read by humans and interpreted by computers. Then using software such as Solibri IFC files can be checked using the IDS to make sure that the demands listen in the IDS is met. Using IDS files to check the validoty of object parameters within IFC files were tested in chapter 4.2.1 and 4.2.2. In those cases the IDS was designed to check the objects within the model for a Resource ID parameter. The test in chapter 4.2.1 is based on a simple scenario were a single slab is exported and checked to make sure it has a parameter for Resource ID and that the parameter is formatted correctly using ten digits. The second test in chapter 4.2.2 had an added complexity as the model was exported in completely with an Resource ID assigned to a selected number of objects. Both of the tests were successfully and the IDS was able to pick up on those objects missing an ID or where the IDs were formatted incorrectly. The fact that these IDS's could be constructed in a fairly simple way indicates the potential of the tool that is the IDS.

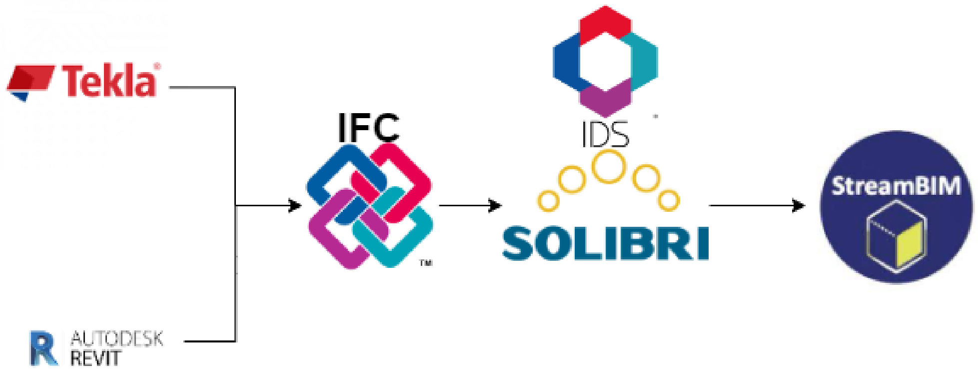


Figure 5.2: *The figure shows the workflow where IDS is included.*

When it comes to setting requirements on the model in the case of the project that has been studied for this project, most of the documentation including the requirements set on the model are kept separately from the model. Sweco provides the other stakeholders involved in the BIM model with documentation on what information, parameters, and documents that have to be included in the model. From the tests performed within this study there have also been cases were there have been information gaps found in the model. Even if these gaps are small and uncommon they could still lead to issues in later stages. One example is smaller elements such as fasteners which in the test conducted in chapter 4.2.4 could not be included in the carbon calculation as they did not have a value for the Material parameter.

One possible modification of Sweco's current workflow could be the additional use of an IDS in order to avoid issues like the one described above. As the use of IDS's has been proven as effective in the test's that has been conducted in this report it could be possible to use an IDS to either replace or complement the additional documentation of the model requirements. As the model is constantly updated the IDS could be used as a filter to make sure that the IFC's are provided with the correct information before being transferred to StreamBIM. By incorporating an IDS in their workflow Sweco could streamline the validation process of model parameters and ensure that they comply with project parameters. Instead of relying on external documentation the IDS allows for an enforcement of the product requirements directly in the model. This will lead to enhanced data integrity and a reduced amount of data gaps. This addition can shift the workflow towards a more automated and standardised approach which would push the process as a whole towards greater efficiency in the BIM processes.

5.3 Requirements on the BIM-model and associated LCA data

This chapter examines key aspects of BIM-based carbon calculations. It covers the requirements for different model types, general standards for accurate carbon calculations, and the impact of data selection on results. These sections provide essential guidelines for optimizing carbon assessments in BIM workflows.

5.3.1 Requirements on different types of models

Due to the integrity of the tenants in this case study the structural model is the only model that has been reviewed. In the structural model you will find elements such as slabs, load-bearing walls, reinforcement, columns, pillars et cetera. In reality the architectural model would also have a central role in the aspect of climate calculations. This would lead to calculations that are more complex with even more objects and materials included. However, the methods and workflows would remain unchanged and there is no need for any additional steps when deriving the climate declaration. There are however some obstacles that could occur when reviewing the architectural model, for instance objects constructed out of a variety of materials. One example would be inner walls that are composed out of multiple materials in an heterogeneous manner. HVAC systems that are retrofitted into walls and slabs of the architectural and structural models would also have to be taken in to consideration. The main takeaway is that the process has to be slightly modified depending on what type of model is being analysed.

5.3.2 General requirements for BIM based carbon calculations

In order to use a BIM model for climate calculations, the models must contain the necessary information. The type of information required can vary, but the main ones are material, volume, area and unit, depending on what element it is. All of these parameters are used to calculate a building's emissions and which elements have the largest carbon footprint. For this project several other parameters have been added. BSAB codes is one of the parameters that has been added to specify what type and material different elements have in the model. The problem with this is that it has created a lot of extra work for the sustainability consultants in the project. At the request of one of the project's sustainability consultants, the study tried to integrate the Resource ID into the model and then group the elements with the same Resource ID. This reduced the amount of manual work, as all the elements were grouped into larger groups, resulting in fewer groups in the climate calculation.

Had this been requested of the designers earlier in the project, the climate consultants would have spent less time guessing about the type of elements in the model, resulting in much less manual work. Studies also show that requirements for models need to be specified early on to make work smoother at later stages. Communication between BIM-strategist and designers needs to be clear for this to work on a large project. When it comes to climate calculations there is no information other than the most necessary parameters, material, volume, area, and unit that is needed. However, the process of assigning objects to LCA profiles becomes easier if there is some sort of identification system that is consistent in throughout all the elements in the model. This could be a system such as the BSAB codes. A system such as the Resource ID makes the process even simpler as those codes are developed with purpose of creating climate calculations.

5.3.3 The impact of data selection in carbon calculations

As mentioned in chapter 3.6 there have been opinions voiced about the validity of carbon calculations on the environmental data connected to them. In the article written by Jirout (2024), *The Fallacies of Carbon Modelling in Construction*, the robustness of EPDs, generic databases, and carbon calculations are questioned. In the article four major errors are identified:

1. Gaps in the data, incorrect data and logical common errors of carbon calculations in the construction industry

2. BIM Models quantities are full of fault's

3. The validity of EPDs

4. Climate databases contains expired data and faulty information

Going to the third error, the validity of EPDs, a scenario of the different stakeholders involved in creating an EPD is described. In this scenario an example is built around a factory worker who has no prior experiences working with environmental issues being tasked with collecting data for the manufacturers product. This data then proceeds down to line of EPD production without any real chance of being validated or checked for blatant errors. However, the article underlines that most likely the workers doing this daily are professional, good and honest workers, but the data is corrupted unknowingly and unintentionally which leads to questions about the robustness of EPD's produced by the manufacturer themselves.

In the case project standard practice is to use EPD's and Boverkets generic database for the climate declaration. This is, according to the 2022 law, valid as base for the declaration. As mentioned in chapter 3.1 and 3.2, Boverkets applies a conservative emission factor most of their materials, and in theory EPD's should often have a lower emission factor but that is not always the case. However both factors being valid choices for the climate declaration, this can lead to huge differences in results depending on several clicks in drop down menus. Further the database do not describe if the different emission factors are means, medians, maximum or minimums. The information given is solemnly its "just generic numbers".

In the article written by Jirout (2024) there is a lot of scepticism about generic databases, one of which is Boverket's. The fact that Boverket presents the conservative emission factors as the first constants in their database, not the typical factors. This cripples the Swedish construction industry, which has to work with emission factors that are 25% higher than they need to be. Since there is one conservative factor for different materials, what are the chances that the standard deviation of the manufacturer's climate performance is always the same for each different type of material? If the conservative factors are to remain as the first choice for Boverket, there is no way to really know if the designers are accomplishing what they set out to do. Maybe the emissions are even worse with the work they have done. In today's carbon calculations there are no strict regulations on what data that should be used more than that it should be either Boverket's generic data or an EPD. In some cases the generic value can be lower than the actual emission values of an EPD, due to the rules of today there is nothing that stops the lower value from being selected. This creates a scenario were values to some extent can be deselected and presented with a generic value instead.

In the future markets even more focus will be put towards environmental product. As of today manufacturers already see how their products will be overlooked if they do not have an EPD. Because without it, the clients wont be able to know if it meets the environmental standards that the client need. Although mentioned in chapter 3.6, EPD's today do not have a standard or quality data control, which can corrupt the EPD's data even though the intentions of those who create the EPD are good. But for a manufacturer to have a chance of competing with others, it is in their interest to learn along the way while EPD's are evolving. Which leads to manufacturers evolving with the process.

6

Final Remarks

This deep dive in optimizing the climate calculations for the climate declaration in the construction industry provides insight on the application and integrated software tools' accuracy and efficiency in the climate declaration. Through several experiments in BIM software's and climate calculation tools, this thesis has unpacked the interactions between calculating applications and the projects workflow. Both shedding light on the potential and the challenges in adopting these technologies.

6.1 Conclusion

It is important to recognise the fundamental role that climate declarations play in the Swedish construction industry. Environmental regulations are set to increase in the near future, and the industry is now in a race to produce more accurate climate declarations and to streamline the process. The ability to assess a building's carbon footprint is therefore invaluable. This thesis presents an option for climate consultants to efficiently influence the design process with already existing tools implemented in their workflow. By integrating these tools this study shows that traditionally labour-intensive processes of collecting and analysing environmental data can be notably automated with an emphasis on being aware of errors.

The experiments that was conducted as part of this research primarily focused on evaluating different sets of configurations and implementation of BIM and climate calculating tools. And how it affect the output of reliable climate data. The results suggest that, with proper integration, these tools not only facilitate easier collection and analysis of data, but also improves the detail and accuracy of the resulting climate declaration. This improvement is critical for making important decisions early on in the design stage, when the potential to influence a project's environmental impact is greatest.

However, while the benefits of integrating BIM with advanced climate calculation tools are clear, several challenges need to be addressed. The first of these challenges is the variability in data quality and availability. The research highlighted instances where the lack of standardised data formats and inconsistencies in data sets can lead to complications in the integration process, ultimately affecting the reliability of the climate calculations. To overcome this, there is a need for industry-wide standards and better data governance practices that ensure the consistency and accuracy of environmental data used across tools and platforms.

Another key challenge identified is the need for stakeholder education and commitment. Successful implementation of integrated tools depends not only on the technology itself, but also on its acceptance and effective use by all project stakeholders. This includes not only designers and engineers, but also project managers and field workers who need to understand and adopt the new workflows. Training and change management are therefore critical components that must be addressed to realise the full potential of these integration's. Featured in figure 6.1 is a proposed workflow. Here IDS and Carbon Checker is added, the IDS is added as a filter to ensure that all information that is to be included in the model is correct. The addition of Carbon Checker is primarily for early stages of the projects life-cycle as it allows for the use of iterative carbon calculations in the design process. As the calculations are factored in at an earlier stage they will have a greater impact on the projects result through the work done by climate consultants.

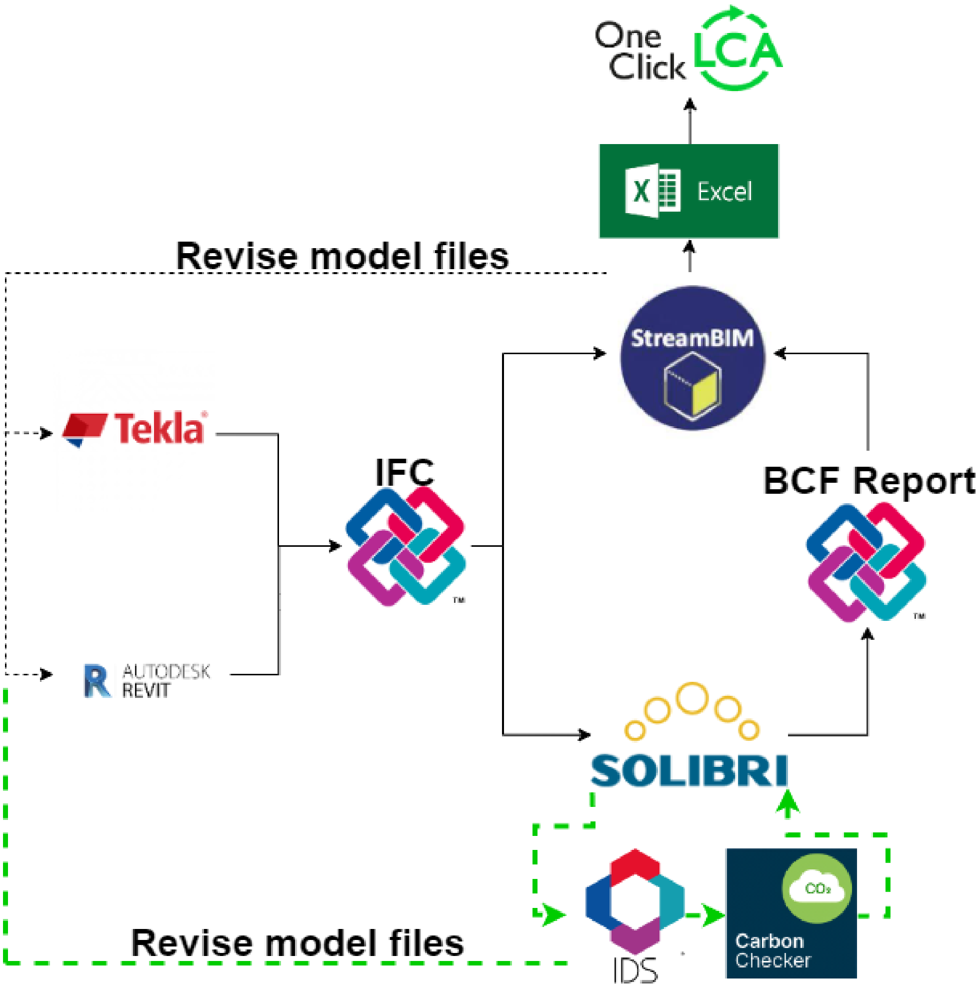
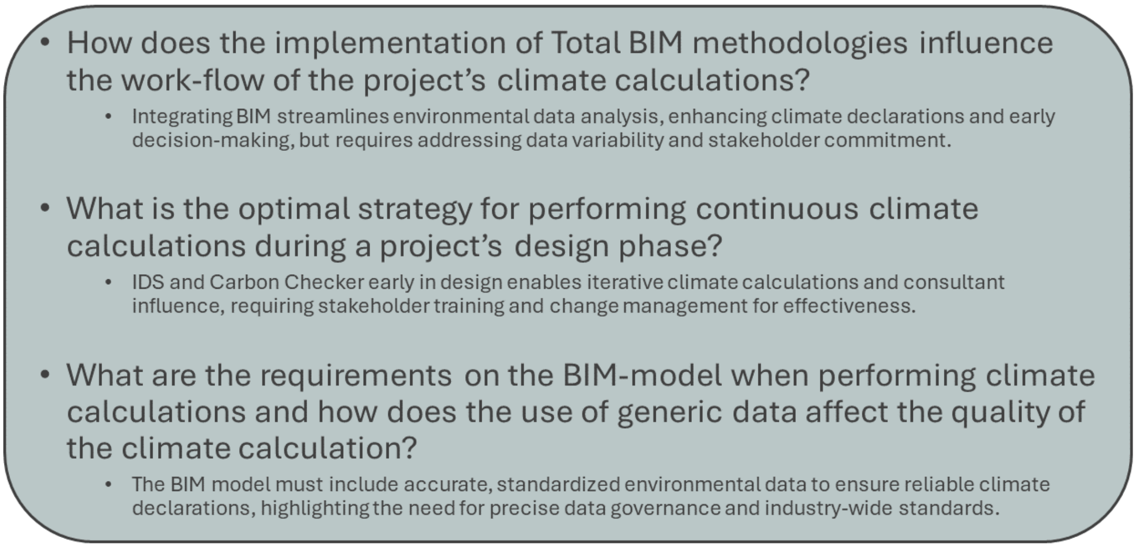


Figure 6.1: *The figure shows the proposed workflow, early in the design phase, BIM-coordinators run the IFC through a specific IDS to check for missing information. And environmental consultants check for potential climate improvements with carbon checker with less attention to minor errors.*

In conclusion, this thesis has shown that while the integration of BIM with climate calculation tools such as One Click LCA and Carbon Checker is a promising way to improve sustainability practices in construction, it is not without its challenges. For the potential benefits to be fully realised, issues such as data standardisation, stakeholder engagement and tool flexibility need to be adequately addressed. Figure 6.2 shows a short summary of the answers to the research questions that were designed for this thesis.



- How does the implementation of Total BIM methodologies influence the work-flow of the project's climate calculations?
  - Integrating BIM streamlines environmental data analysis, enhancing climate declarations and early decision-making, but requires addressing data variability and stakeholder commitment.
- What is the optimal strategy for performing continuous climate calculations during a project's design phase?
  - IDS and Carbon Checker early in design enables iterative climate calculations and consultant influence, requiring stakeholder training and change management for effectiveness.
- What are the requirements on the BIM-model when performing climate calculations and how does the use of generic data affect the quality of the climate calculation?
  - The BIM model must include accurate, standardized environmental data to ensure reliable climate declarations, highlighting the need for precise data governance and industry-wide standards.

Figure 6.2: *The figure summarizes concise answers to the research questions.*

6.2 Suggestions for further research

- Explore the development of more robust integration frameworks to handle the complex dynamics of modern construction projects.

- Study the competitive landscape among consultant firms and construction companies striving to excel in climate declarations.

- Conduct in-depth research on generic databases to enhance understanding and utilization in construction projects.

- Investigate how climate calculations can support early decision-making in construction projects, optimizing sustainability from the initial stages.

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A

Appendix 1

The edited property set from the user-created configuration that was used in the singlel element export test. The linen in red below is the content that was added to the original configuration file provided by Sweco.

```
PropertySet:    _Prod_Info      I       IfcSlab

        TypeID          Text    Type Mark
        BSABe           Text    Keynote
        TypeDescription Text    Description
        VK_FireRating   Text    VK_FireRating
        SoundLevel_dBA  Text    SoundLevel_dBA
        StoreyName      Text    Level
        StoreyName      Text    Base Constraint
        StoreyName      Text    Base Level
        StoreyName      Text    Reference Level
        BPD             Text    BPD
        ResursID        Text    ResursID
        FireRating      Label   VK_FireRating
        PM-ID           Text    PM-ID
        Quantitable     Boolean Mangdas
        ShadowObject    Boolean VK_Skuggobjekt
        FireSeparating  Boolean FireSeparating
        RecyclingPotential      Text
           RecyclingPotential
        ReusePotential  Text    Aterbrukspotential
        CastUnit        Text    Gjutetapp
        Cast            Boolean Gjuten
        EPD             Text    EPD
        RebarCover_Top  Label   Rebar Cover - Top Face
        RebarCover_Bottom       Label   Rebar Cover -
           Bottom Face
        RebarCover_Other        Label   Rebar Cover -
           Other Faces
        BuildingObject_Enviromental     Text
           Byggdel_miljo
```

```
        GeneralNotes    Text    Allmanna_foreskrifter
        Formwork_done   Boolean Formad
        Reinforcement_done      Boolean Armerad
        ElevationTop    Length  Elevation at Top
        ElevationBottom Length  Elevation at Bottom
        ProductionNotes Text    Produktionsinformation
```

The IDS that was used in the single element export test. This IDS checks all slab elements for a ten digit value for a parameter called "ResursID" in the property set "_prod_info".

```
<?xml version=’1.0’ encoding=’utf-8’?>
<ids xmlns="http://standards.buildingsmart.org/IDS" xmlns
   :xs="http://www.w3.org/2001/XMLSchema" xmlns:xsi="http
   ://www.w3.org/2001/XMLSchema-instance" xsi:
   schemaLocation="http://standards.buildingsmart.org/IDS
    ids.xsd">
    <info>
        <title>Resurs ID Check on IfcSlab</title>
        <author>FHK</author>
        <date>2022-01-01</date>
        <purpose>Ensuring Resurs ID compliance for
           IfcSlab elements</purpose>
    </info>
    <specifications>
        <specification name="Resurs ID Verification for
           IfcSlab" ifcVersion="IFC4" description="
           IfcSlab elements must have a Resurs ID within
           the _Prod_Info property set for identification
            and management." instructions="Resurs ID must
            be a sequence of 10 digits and included in
           the _Prod_Info property set." minOccurs="0"
           maxOccurs="unbounded">
            <applicability>
                <entity>
                    <name>
                        <simpleValue>IfcSlab</simpleValue
                           >
                    </name>
                </entity>
            </applicability>
            <requirements>
                <property datatype="IfcText" instructions
                   ="Resurs ID must be a sequence of 10
                   digits." minOccurs="1" maxOccurs="1">
```

```
                    <propertySet>
                        <simpleValue>_Prod_Info</
                           simpleValue>
                    </propertySet>
                    <name>
                        <simpleValue>ResursID</
                           simpleValue>
                    </name>
                    <value>
                        <xs:restriction base="xs:string">
                            <xs:pattern value="\d{10}" />
                        </xs:restriction>
                    </value>
                </property>
            </requirements>
        </specification>
    </specifications>
</ids>
```

B

Appendix 2

The IDS that was used in the multiple element export test. This IDS checks all door, window, wall, column, beam, reinforcingbar, and slab elements for a ten digit value for a parameter called "ResursID" in the property set "_prod_info".

```
<?xml version=’1.0’ encoding=’utf-8’?>
<ids xmlns="http://standards.buildingsmart.org/IDS" xmlns
   :xs="http://www.w3.org/2001/XMLSchema" xmlns:xsi="http
   ://www.w3.org/2001/XMLSchema-instance" xsi:
   schemaLocation="http://standards.buildingsmart.org/IDS
    ids.xsd">
    <info>
        <title>Resurs ID Check on All IFC Building
           Elements (IFC2x3)</title>
        <author>FHK</author>
        <date>2022-04-04</date>
        <purpose>Ensuring Resurs ID compliance across all
            applicable IFC building elements for IFC
           version 2x3</purpose>
    </info>
    <specifications>
        <specification name="Resurs ID Verification for
           All Building Elements" ifcVersion="IFC2X3"
           description="All IFC building elements must
           have a Resurs ID" instructions="The architect
           is responsible." minOccurs="0" maxOccurs="
           unbounded">
            <applicability>
              <entity>
              <name>
                <xs:restriction base="xs:string">
                  <xs:enumeration value="IFCDOOR" />
                  <xs:enumeration value="IFCWINDOW" />
                  <xs:enumeration value="
                     IFCWALLSTANDARDCASE" />
                  <xs:enumeration value="IFCWALL" />
                  <xs:enumeration value="IFCSLAB" />
```

```
                  <xs:enumeration value="IFCCOLUMN" />
                  <xs:enumeration value="IFCBEAM" />
                  <xs:enumeration value="
                     IFCREINFORCINGBAR" />
                </xs:restriction>
              </name>
              </entity>
            </applicability>
            <requirements>
                <property datatype="IFCTEXT" instructions
                   ="ResursID is specified" minOccurs="1"
                    maxOccurs="1">
                    <propertySet>
                        <simpleValue>_Prod_Info</
                           simpleValue>
                    </propertySet>
                    <name>
                        <simpleValue>ResursID</
                           simpleValue>
                    </name>
                    <value>
                        <xs:restriction base="xs:string">
                            <xs:pattern value="\d{10}" />
                        </xs:restriction>
                    </value>
                </property>
            </requirements>
        </specification>
    </specifications>
</ids>
```

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