DTU Civil Engineering
Department of Civil Engineering

BUILDING A SYSTEM ARCHITECTURE CAPABLE OF REPRESENTING LCA CALCULATIONS

Master Thesis

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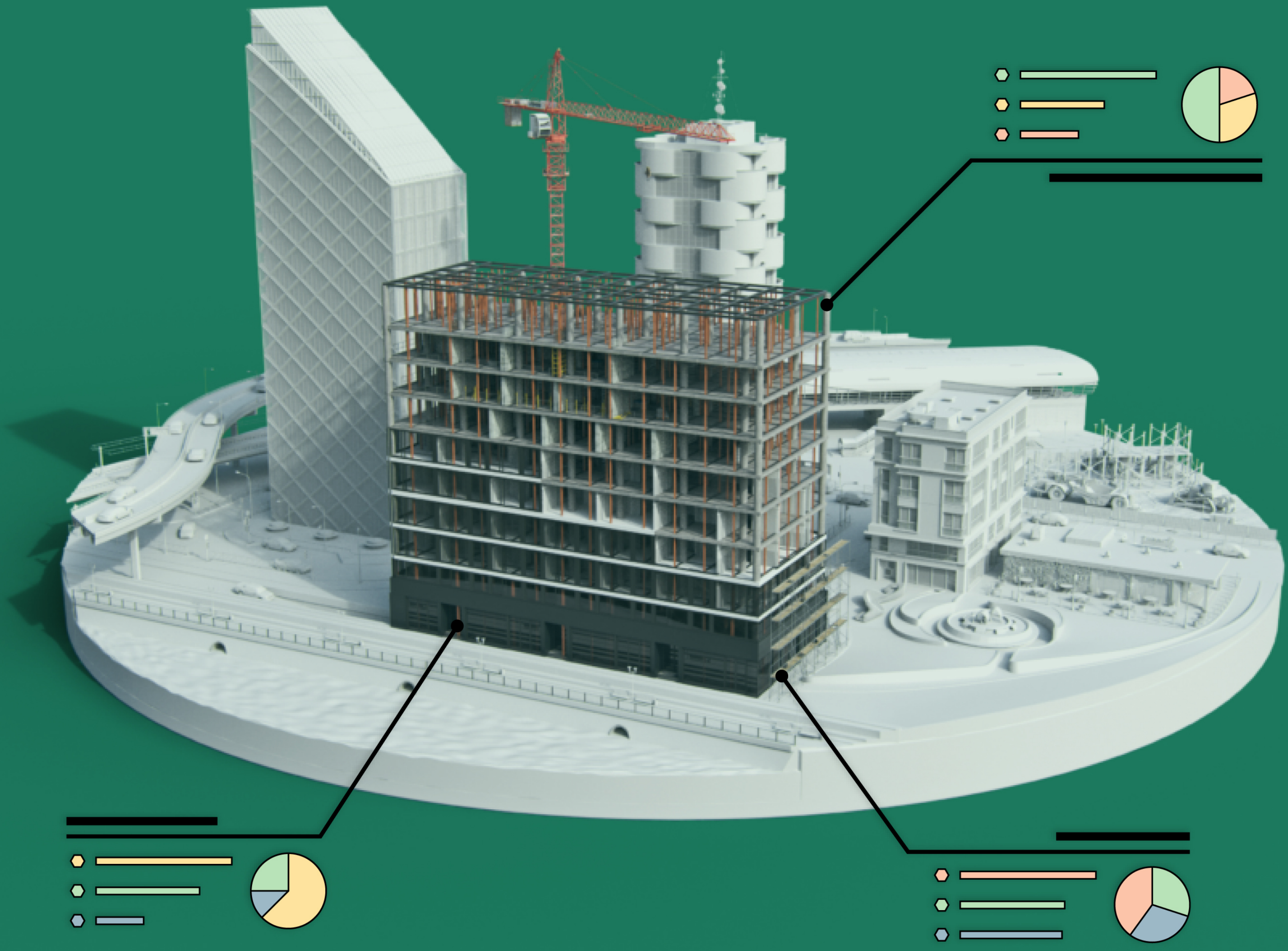

BUILDING A SYSTEM ARCHITECTURE CAPABLE OF REPRESENTING LCA CALCULATIONS

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Abstract

The ongoing phenomenon of climate change continues to cause widespread destruction worldwide. The construction and building industries are one of the primary contributors to greenhouse gas emissions. In response to this, the Danish government has formed regulations requiring the performance of life cycle assessments (LCA) for all new constructions that initiate after 2023, with environmental impact levels below 12 kg CO_2-eq / m^2 for structures larger than 1000 m^2. However, the building industry faces a challenge in performing necessary LCAs due to a shortage of LCA consultants.

The architecture, engineering, and construction (AEC) industry have been making progress with the use of building information modeling (BIM) and common data environment (CDE) services. One such CDE, the Virtual Commissioning (VC) platform, has been developed by Mikki Seidenschnur and Ali Kücükavci's Ph.D, but is missing an LCA service.

As a result, the thesis aimed to incorporate the advantages of BIM and CDE into an LCA tool that addresses the issues of manual LCA processes, which are time-consuming and result in inaccurate outcomes. To accomplish this, the tool was developed through programming in C# and Python, where a plugin was created in Revit to extract BIM, and embedded LCA data, to LCAbyg. The data is managed through a CDE, allowing relevant stakeholders to access the information and ensuring that the LCA data is always up-to-date. The tool also includes a microserver that allows for the LCA to be run directly from a web application, facilitating iterative LCA.

The efficacy of the tool was demonstrated through a case study following the design science research methodology. The study was conducted in Building 118 at the DTU campus in Lyngby. After a thorough assessment of the building, the tool was applied, and the global warming potential (GWP) of the building elements was compared to reference data from 21 other structures. Although the accuracy of the results was inconsistent, this may have been due to differences in the buildings. The time required for conducting the LCA was also considered, with an estimation of the current LCA time given by Andreas Sørensen. The results indicated that the time could potentially be reduced by up to 70%, or up to 70 hours, through the use of the tool.

Finally, the LCA tool was evaluated through the validation of the accuracy of 22 predefined elements created in the tool. The elements were recreated and compared from a reference report with known results of GWP. Although most of the elements were within the acceptable deviation of 25 %, the average deviation was found to be higher than the acceptable levels, with an average deviation of 57%, which exceeds the acceptable limit.

In conclusion, while the tool demonstrated the potential to reduce the time spent on LCA, its accuracy was not deemed satisfactory.

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Abbreviations

Application Programing Interface	API
Architecture, Engineering and Construction	AEC
Bill of Quantities	BoQ
Building Information Modeling	BIM
Building Regulation 2023	BR23
Common Data Environment	CDE
Environmental Product Declaration	EPD
Global Warming Impact	GWP
Gross Floor Area	GFA
Graphical User Interface	GUI
International Foundation Class	IFC
JavaScript Object Notation	JSON
Level of Detail	LOD
Life Cycle Assessment	LCA
Life Cycle Inventory Assessment	LCIA
Life Cycle Inventory	LCI
Reference Study Period	RSP
Virtual Comissioning	VC
Visual Programming Language	VPL

Contents

1 Introduction

The phenomenon of global warming has led to a number of detrimental effects, including droughts, flooding, hurricanes, and wildfires, according to the Intergovernmental Panel on Climate Change (IPCC) report of 2022. One of the primary sources of greenhouse gas emissions is the building and construction industry, which accounts for approximately 40 % of total emissions. The majority of these emissions stem from heating, cooling, and lighting of buildings, as well as the materials utilized in construction [1].

In an effort to mitigate the negative impact of the building and construction sector on the environment, the Danish government has implemented regulations requiring documentation of a life cycle assessment (LCA) for all new constructions, effective January 1st, 2023 (BR23). Additionally, for constructions larger than 1000 m^2 , the environmental impact must be less than 12 kg CO_2-eq / m^2. The requirements for LCAs will continue to increase in the coming years [2].

However, this new regulation poses a significant challenge for the building industry, as it requires a large number of LCAs to be performed in a short amount of time. This may cause a bottleneck for many companies, as Jesper Ring, CEO of Frame, suggests through a hypothetical calculation. According to Statistics Denmark, there are approximately 37,000 new constructions built each year [3], and two to three LCA are conducted per construction according to the LCA handbook [4], thus requiring 37,000 LCAs to be conducted annually. Given that there are currently only 900 LCA consultants in Denmark, as per Green Building Council Denmark [5], this would mean that each consultant would have to perform over 100 LCAs per year, which is a daunting task given the complexity and time-consuming nature of LCAs.

In parallel to these challenges, the Architectural, Engineering, and Construction (AEC) industry is rapidly advancing with the use of building information modeling (BIM) software and other advanced technologies. BIM allows for more efficient data sharing between different disciplines, and newer technologies, such as common data environment (CDE) services, provide data on demand to users.

A recent open-source and cloud-based CDE, named the Virtual Commissioning (VC) platform, has been developed by Mikki Seidenschnur and Ali Kücükavci, to accommodate the advancing technologies in the industry. The idea behind the platform is to create customized services and tools, within the CDE, and connect with BIM models in Revit. However, the platform is missing a service an LCA service.

Given that most of the time carrying out LCAs consists of the manual process of inputting data from BIM to LCA software, developing a toolchain to utilize the benefits of the VC platform, maybe a solution to solve the time-consuming and inaccurate results of the manual processes of the today's workflows.

2 Background

This chapter will focus on background research on the Life cycle assessment (LCA) framework, LCA methodology in the built environment, life cycle inventory (LCI) databases, and criteria of the building regulations 2023 (BR23) regarding LCA. Next, BIM maturity levels and levels of detail will be addressed together with the common data environment. Finally, a literature review will be conducted on state-of-the-art BIM-LCA tools and approaches.

2.1 Life cycle assessment

Life cycle assessment (LCA) is an international methodology for assessing a product's environmental aspects over its life cycle. LCA is widely used and an accepted methodology for assessing the environmental performance of buildings [6]. The methodology has recently gained broad attention and has been adopted in many industries as climate change has become a global priority.

2.1.1 Framework of LCA

LCA is a standardized methodology that aims to quantify the environmental impacts of products within the entire life cycle [7]. The method can be used to break down environmental processes and assist in minimizing the environmental impact of products. The framework of LCA is categorized into four main stages, according to the ISO Standard ”ISO 14040” on LCA studies and life cycle inventory (LCI) studies [8].

1. goal and scope
2. life cycle inventory (LCI)
3. life cycle impact assessment (LCIA)
4. interpretation

The goal and scope define the system boundary of the study. The boundary has to be set correctly for the goal of the LCA to be matched sufficiently. The scope may require modification during the study as LCA is an iterative process, and information during the study may change the original scope. The LCI describes the input and output of the production system regarding material and energy flows, including data collection and calculation procedures. Next, the life cycle impact assessment (LCIA) evaluates the significance of impact categories from the LCI results. They are, hereby, matching inventory results with impact categories to achieve a complete result for the interpretation stage. The final stage is the interpretation stage, which considers the inventory analysis and impact assessment and finally provides consistent results that reach conclusions, explain limitations, and provide recommendations [9], as well as visualized in the four main stages shown in fig. 2.1. The two directional arrows in fig. 2.1 between the stages signify that the process is iterative, meaning that the stages can be revisited after an iteration.

2.1.2 LCA in the built environment

According to the European Standard EN 15978, a framework for assessing the environmental performance of buildings is presented in fig. 2.2.

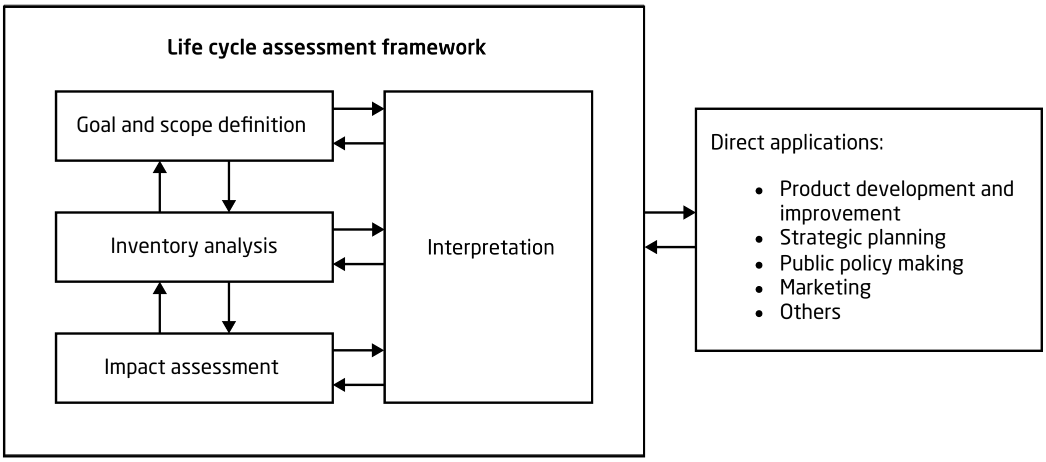

Figure 2.1: General LCA framework

From fig. 2.2, step number two shows the specification of the object of assessment; one of the specifications is the functional equivalent which is the technical characteristics and functionalities of the building. These are important to specify as the final comparison will be based on their functional equivalent. For instance, information on building type, the pattern of use, and required service life. Other factors include reference study period (RSP), system boundary, and building model. The RSP is essential since it creates the basis for how many years the building ought to last. The RSP is usually based on the purpose of the LCA, and the type of building [10].

The system boundary includes the processes taken into account for a given LCA. These processes can be broken down into five stages (A - D): product stage, construction process, use stage, end-of-life stage, and benefits and loads beyond the system boundary, whereas the last stage is supplementary. Each stage is then divided into sub-stages (e.g., A1, A2, A3), illustrated in fig. 2.3.

When carrying out LCA in the built environment, rarely all the processes are taken into account due to the lack of data or that national guidelines, as many countries have their method specifications, including Denmark [6]. The EeBGuide Handbook also recognized that the building sector could not be developed with the same level of detail as in other sectors [11]; however, this creates an unfair foundation for comparing buildings, as one may have less information available than another. Hence this should be taken into account in the interpretation stage. In fig. 2.3, the highlighted processes (A1-A3, B4, B6, C3-C4, D1-D3) are mandatory to include in the LCA according to the BR23. The environmental impact indicators are aggregated from the processes described in fig. 2.3 for all the products described in the system boundary. The environmental impact indicators are matched with the corresponding gross quantities of the products. These values are multiplied and summed up to create the basis of the environmental impact [12]. According to a paper from Muralikrishna and Manickam, analysis of the life cycle stages to the total environmental load is an important aspect and, therefore, crucial to which stages are included in the final assessment.

2.1.3 LCI databases

LCI databases stores datasets of material emissions that create the basis of the calculation of the LCA and is therefore essential that the emission values used in the database

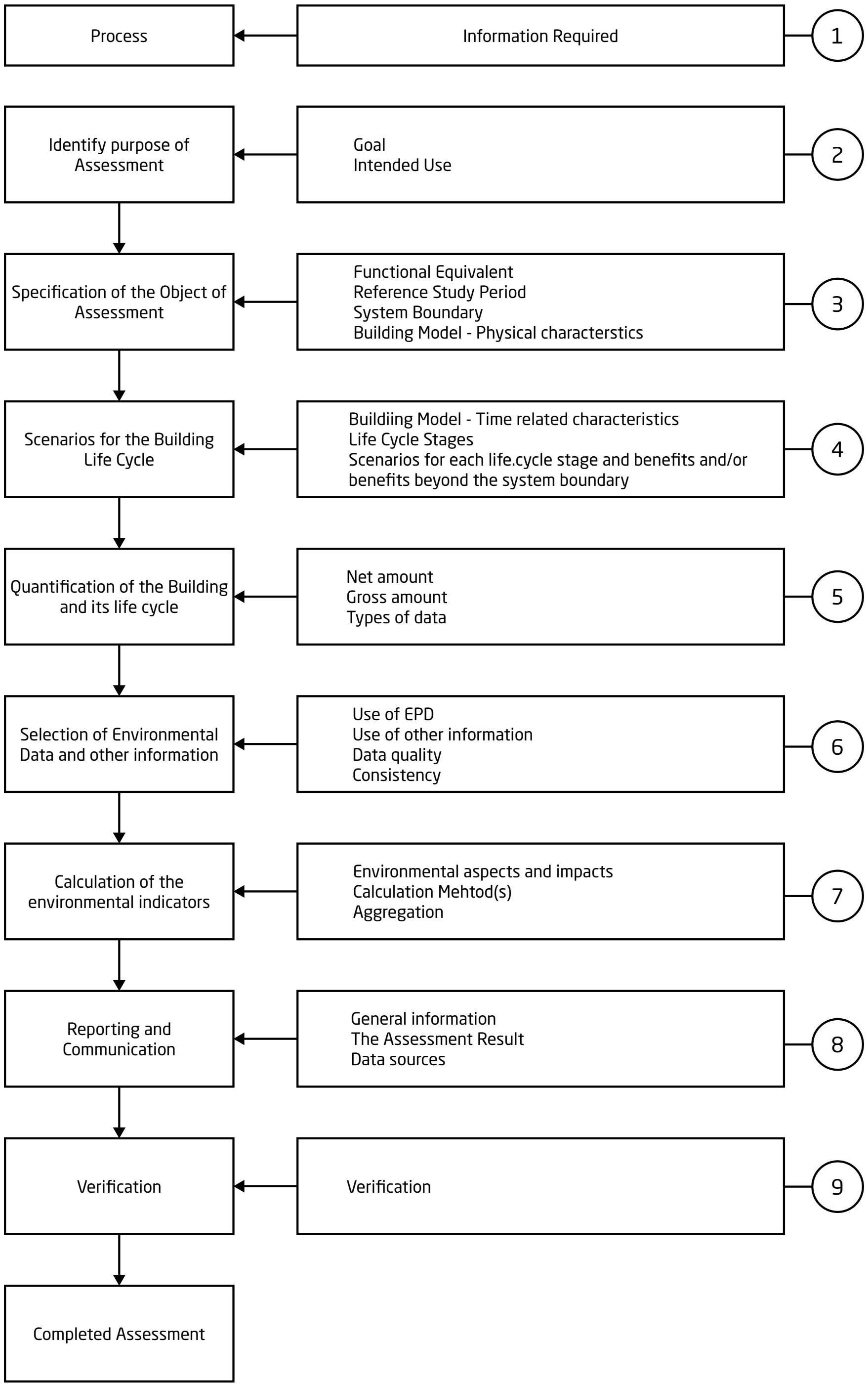

Figure 2.2: Flowchart of the process for the assessment of the environmental performance

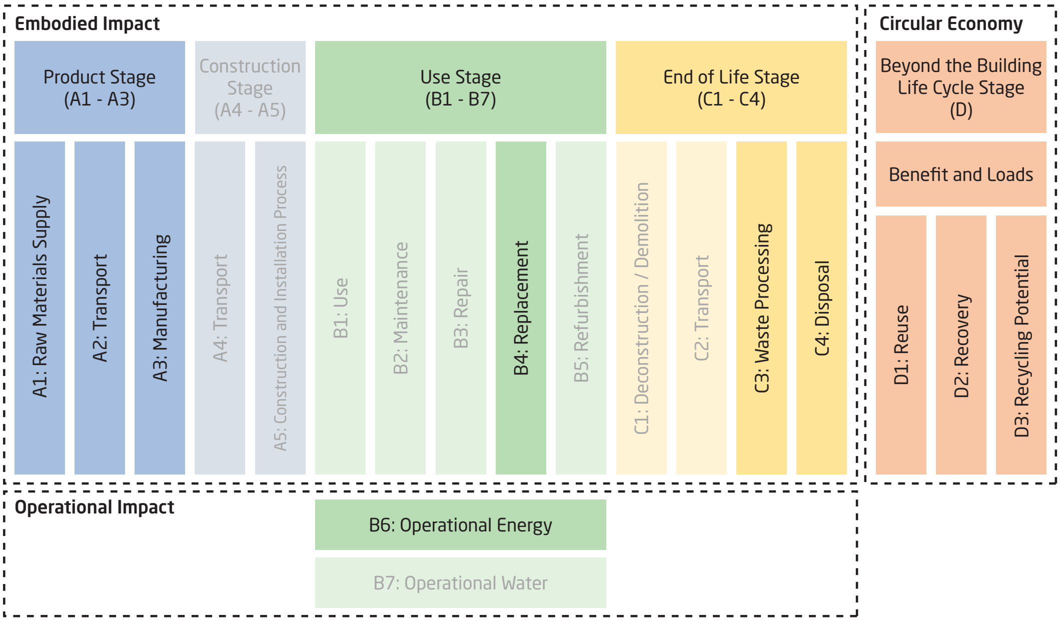

Figure 2.3: Building assessment stages based on the European Standard EN 15978. The highlighted stages are the mandatory stages of LCA, according to the BR23.

correspond to the actual values of the chosen material used in a building, also confirmed by Najjar et al. who mentions ”An LCA is only as valid as the data it uses” [14]. The dataset consists of an Environmental Product Declaration (EPD), an official environmental declaration for a specific product. If there is no EPD for the intended product, generic data is allowed to be used, which is averaged data based on EPD within that product category. There are many available databases, and it is essential to pick the most suitable one; for example, if a Danish LCA uses an American database, the results would likely be wrong since the processes of handling resources differ from country to country, for example, transportation of resources depends on where they are available, if a specific type of wood only is available in Canada, the American data would have less distance for transportation and therefore not be valid to use in a Danish context, of course, this also depends on the type of transportation, as a cargo ship is a lot more carbon efficient than a truck per km and so on. A study from Martínez-Rocamora, Solís-Guzmán, and Marrero presented a review of existing databases worldwide based on building material data. The databases were evaluated on six parameters: Territory, categories, variety, traceability, methodology, and documentation. The databases within Europe that scored highest were Ecoinvent and GaBi, which scored maximum points in all categories. However, both of the databases require a license. Another study from Huskinson et al. showed that different databases would give different results, even though the calculation method is the same. Therefore, it is essential to use the same databases when LCA are compared, especially when the law states the threshold of the GWP. In a Danish context, LCAbyg 5 uses the German database Ökobaudat, which is relatively close to Denmark but only has a total dataset of 954, in relation to Gabi and Ecoinvent, that has 6.513 and 11.302 datasets. [15].

2.2 Building information modeling

According to the international standard, ISO 19650, Building information modeling (BIM) is defined as ”the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions” [17]. According to the definition, BIM allows users from all disciplines to collaborate on a shared building model. Moreover, it is an efficient method of working as it eliminates a lot of manual tasks that could lead to mistakes.

2.2.1 Level of detail

Throughout the modeling phase, the detail level will continuously increase and, in the end, become as close as possible to the actual building. The metric ”Level of Detail” (LOD) is defined as the overall state of your information model at a particular point in its design process.” [18]. LOD can also refer to the Level of Development or Design, however, the definition stays the same. LOD ranges from 100 to 600 in 6 steps, presented in the following bullets and in fig. 2.4.

LOD 100 (Preparation and brief design): The model shows the requirements and site constraints. The model only consists of block models, including essential areas and volumes.

LOD 200 (Concept design): Is a conceptual level where the model consists of generic objects with approximate sizes, shapes, and locations.

LOD 300 (Developed design): The model contains exact quantities, sizes, locations, and orientation, with detailing, fabrication, assembly, and installation information.

LOD 400 (Technical design): Similar to level 300, but the model contains information on connection to other systems or components.

LOD 500 (Construction): The model contains sufficient information on fabrication and assembly to be handed over to suppliers to construct the building.

LOD 600 (As-built): The model has all sufficient information and geometry to support operations and maintenance throughout the building life cycle.

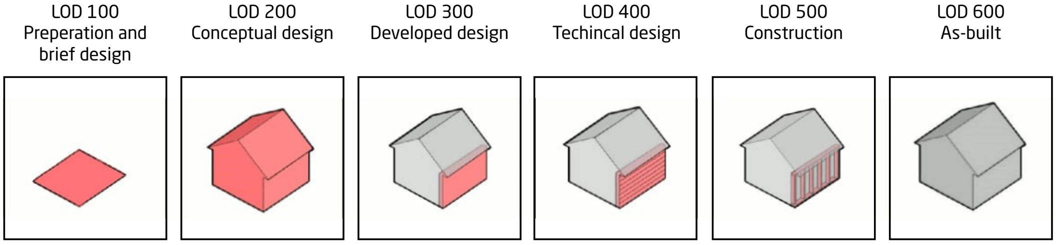

Figure 2.4: Levels of Detail / Development / Definition [19]

To achieve a reliable LCA result, the BIM model needs to have a sufficient LOD to minimize the information gap between the BIM model and the actual building. In the early design phase, LCA may be carried out with low LOD if the engineer or architect wants an initial idea of whether the building construction should be in concrete or steel. But in the later phases, the LCA has to be more reliable to ensure the building is delivering specific emissions in regards to the BR23 benchmarks and therefore requires higher LOD. Consequently, it is an excellent idea to iteratively carry out the LCA throughout the design phases as the results will keep becoming more precise and up to date [20].

2.2.2 Maturity levels

To achieve a high LOD, the collaboration of the BIM model plays an important role. The term 'maturity level' of a BIM model refers to the quality, repeatability, and degree of excellence within a BIM capability [21]. The maturity level is correlated to the collaboration of a BIM model and what means are used to leverage the partnership towards a more fluid and automatic process, resulting in fewer mistakes and more accessibility for each stakeholder. BIM is categorized into four levels of maturity. BIM Maturity level 0 represents low collaboration, using analogue tools such as drawing on paper, to level 3, which means full integration, such as using cloud-based BIM models. Each level is defined in fig. 2.5 and the following bullets.

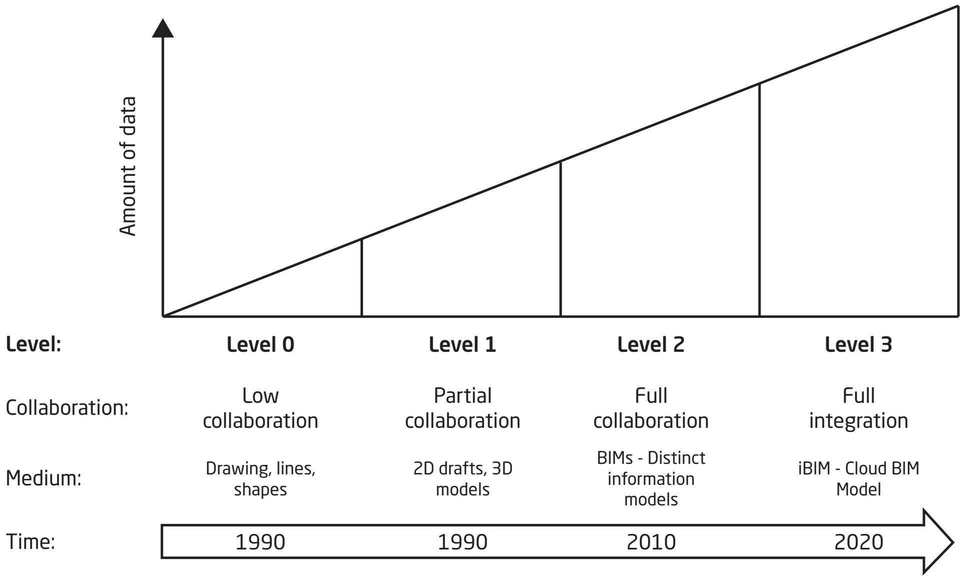

Figure 2.5: BIM Maturity levels from Succar, Sher, and Williams

BIM maturity level 0 (low collaboration): Represent the lowest level of collaboration. The main tool used is paper-based CAD, and the product is paper or electronic-based.

BIM maturity level 1 (partial collaboration): Represent the level where CAD utilize 2- and 3D modeling, whereas 3D is on a conceptual level and 2D is documentation. Data is shared through a common data environment (CDE) with each other but does not support a fully collaborative model.

BIM maturity level 2 (full collaboration): Represent streamlined and standardized models that allow collaboration between all stakeholders; however, every stakeholder has their own local 2- or 3D CAD model.

BIM maturity level 3 (full integration): Represent the highest level of collaboration, also referred to as ”Open BIM.” The model is based on a cloud-based environment, creating a single model that holds all information from every discipline, eliminating any conflicts that may interfere between the disciplines—also referred to as the single source of truth.

One of the most prominent countries regarding BIM is the UK and Germany, where the average maturity level is only at level 2. Hence to reach the next level, a report from Digital Built Britain presented some measures to levitate to level 3, named ”Level 3 Building Information Modelling - Strategic Plan”. Some of the key measures to do so are ”The creation of a set of new, international ’Open Data’ standards” to ensure an easy way of sharing data across the market and ”The establishment of a new contractual framework for projects” that potentially ensure consistency, avoid confusion and encourage, open collaborative work environment [22].

Another way of levitating the BIM maturity level from 2 to 3 is to introduce a common data environment that will enhance collaboration in a project.

2.2.3 Common data environment

A common data environment (CDE) is a centralized cloud-based platform that stores and manages information, also referred to as ’the single source of truth.’ The CDE enables all relevant stakeholders to access data from any given place at any time, with viewing or editing rights depending on their role. In a BIM context, the information can contain a wide range of data, such as schedules, contracts, reports, etc. A CDE is typically hosted through a cloud-based platform that ensures all information is up to date. This helps to reduce errors and misunderstandings and improve overall project efficiency [23].

One attempt at creating a CDE was the BIMServer.org [24], which is an open access open-sourced platform that provides an IFC[1] database to carry out model checks, versioning, and project structures, however, the platform was based on the IFC schema and therefore led to errors, and missing data [26]. Another attempt was Autodesk, who created Forge, a cloud platform that enables multiple of their products to be accessed with an API. However, the platform uses direct interoperability, which will later be explained, meaning that the software is closed and only allow file formats within the Autodesk environment [26].

Through Mikki Seidenschnur and Ali Kücükavci’s Ph.D., they have developed a cloud-based and open-source CDE called ”Virtual Commissioning Platform.” The platform is capable of running multiple microservices[2], with different functionalities, for instance, simulation of HVAC systems and performance measuring by connecting BIM models in Revit to third-party tools and services. However, the platform is missing a microservice capable of performing and storing an LCA of a building, which is part of the aim of this project.

Therefore, a literature review will be conducted to understand what BIM-LCA is, which state-of-the-art cloud and BIM-based LCA tools exist, and what a potential BIM-LCA tool

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[1] The Industry Foundation Classes (IFC) is a CAD data exchange data schema intended for description of architectural, building and construction industry data [25]

[2] A microservice is an architectural and organizational approach to software development where software is composed of small independent services that communicate over well-defined APIs. [27]

within the VC platform could look like. More on the CDE will be described in the Methodology chapter.

2.3 BIM-LCA

BIM-LCA is the combination of using an existing BIM model to assist in carrying out an LCA by utilizing the overlapping data stored in a BIM model and the data input needed for an LCA calculation to be carried out, often associated with a BIM-LCA tool; this concept is visualized in fig. 2.6. This concept has been used widely in the building industry due to its many advantages.

According to Soust-Verdaguer, Llatas, and García-Martínez, they acknowledge the potential of BIM combined with sustainable design, leading to an improved information flow, better performance, and quality. However, BIM–LCA is still at an early stage, and research on the topic is limited [29] (2020). The following section will attempt to review the state-of-the-art BIM-LCA tools and approaches.

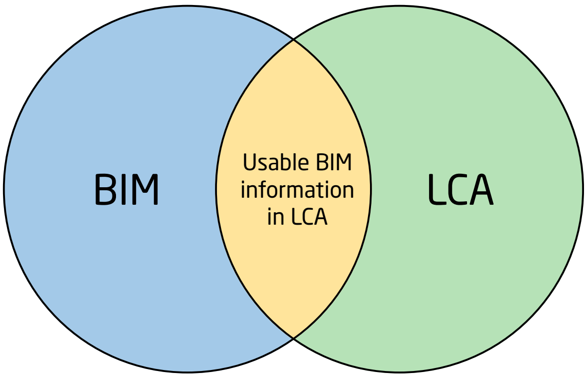

Figure 2.6: BIM data relative to the LCA data needed. The overlapping data show the usable data from BIM to LCA. Diagram inspired from Díaz and Antón [30].

BIM-LCA has undoubtedly been argued as remarkably better than LCA alone as it reduces the data input, helps decision-making, improves information flow, achieving better performance and quality [28]. This is shown in multiple papers; one example is Mah et al., who developed a method to estimate the CO_2 footprint on constructions based on the BIM model. Another example is Akbarnezhad, Ong, and Chandra, who invented a decision-making framework based on BIM that enables to recycle and reuse of building materials. Or summarized by Zimmermann, Bruhn, and Birgisdóttir who states, "BIM can simplify the establishment of the LCI for the LCA by eliminating the need to reenter information that is already available in the building model" which shows how the BIM-LCA approach can minimize time spent on redundant tasks.

2.3.1 Approaches to BIM-LCA tool

According to Hadjiiski et al., there are two main strategies 1) the first one extracts geometrical and possibly material data from the BIM model in the form of a bill of quantities[3] (BoQ), this data are then taken to a third-party LCA software to be carried out. 2) The

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[3] A bill of quantities is a document that provides project-specific measured quantities of the items identified in drawings and specifications for a built asset such as a building. [34]

second one adds LCA data to the BIM model and calculates the LCA from a plugin within the BIM software. From these two strategies, a set of five different BIM-LCA approaches have been defined by Wastiels and Decuypere.

The first approach is the ”enriched approach” where the LCA data is embedded in the BIM model; this minimizes the time manually entered to the LCA and the errors that arise when manually entering data and is easy to recalculate and LCA when the materials are in one place. However, there are some practical issues with implementing this LCA input in the BIM model, which may take longer than using the existing LCA software [35].

The second approach is the ”quantity take-off” approach which is the most commonly used. This basically extracts all the quantities from the BIM model and sends them to the LCA software. When carrying out multiple iterations, this method can be rather time-consuming.

Import of geometry into the LCA software is the third approach by Wastiels and Decuypere. It is based on the IFC schema that contains both the LCA material data and the building quantities, which can be directly exported to LCA software. This method is based on an open data format which will be discussed in the next section.

The fourth approach, the ’viewer,’ is similar to the previous one, as it also can match the IFC format. The approach is based in a 3D environment and allows users to display the data in 3D, which can contribute to another understanding of the data or results.

The final approach is the ’LCA Plugin,’ where the solution is built into the BIM software, which then can utilize the 3D viewer to match and show data directly within the BIM software. [35] The five approaches are also visualized in fig. 2.7.

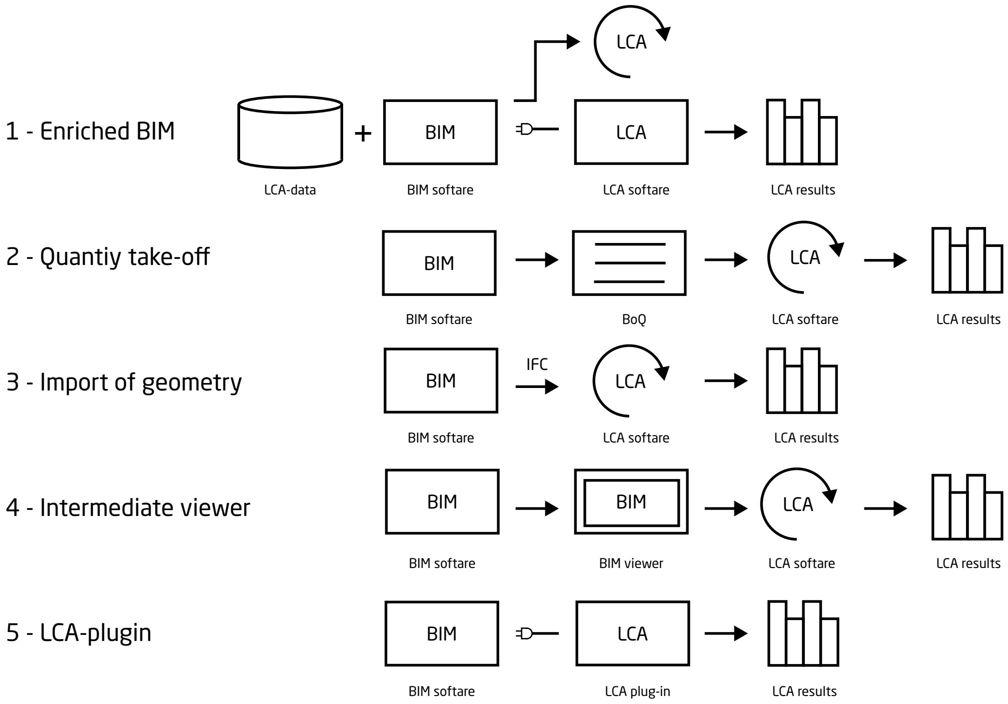


Figure 2.7: The 5 approaches of BIM-LCA according to Wastiels and Decuypere

An expert group of LCA practitioners from Belgium was brought together to evaluate these five approaches [33].

The group argues that from the structural-discipline perspective, any of the given approaches would be feasible, as the structural discipline has a low variety of materials and quantities that are relatively easy to specify. They suggest, however, creating a set of BIM objects containing LCA data with a limited amount of materials to implement in approach 5.
Another point from the group is a concern about using EPD data with BIM objects since the EPD is geographically specific and requires living near this area for the data to be usable. Secondly, the BIM objects can be scaled and changed, hence losing the validity of such an EPD.
The architectural part of the BIM model contains many different materials, yet in the early design phase, the level of detail is low. Therefore the suggestion is to use generic materials and LCA profiles. From an architectural perspective, the group suggests approach 5, LCA-plugin, as promising due to easy access to LCA data but also mentions the problem of the lack of LCA data from enriched BIM objects.

The central takeaways from the evaluation are that the most suitable workflow strongly relates to the objective of the LCA calculation, the stage of the project, and the discipline.

2.3.2 Data exchange

The five approaches contain different data flows, which impact the interoperability of other software. According to Zimmermann, Bruhn, and Birgisdóttir ”Interoperability is typically the goal within data management between software solutions, to allow for easy data exchange between software.”

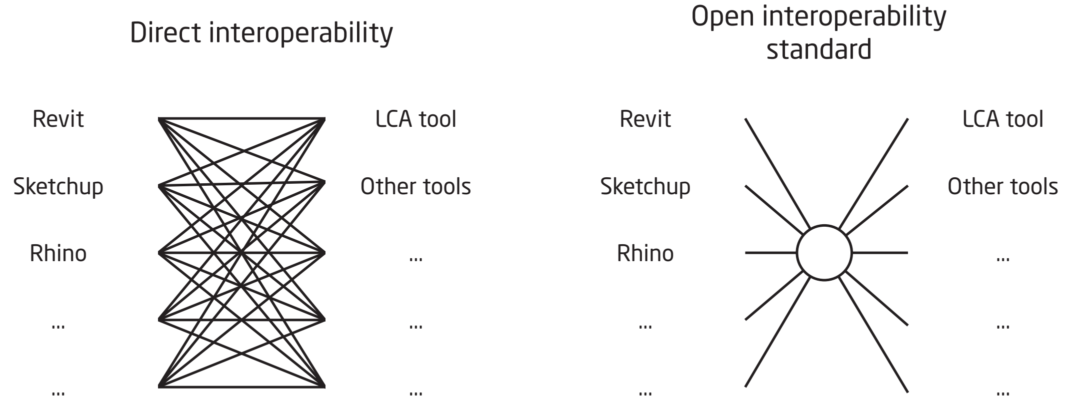


Figure 2.8: Data exchange of direct vs. open interoperability between BIM and LCA-tool

Looking at fig. 2.8 from Laakso and Kiviniemi, the interoperability can be divided into two parts; direct interoperability and open interoperability standard. When working with the open interoperability standard, the data has to be standardized to be compatible with all the relevant software. This process limits what can be included in the standard [36]; an example hereof is the CDE. However, using direct interoperability, the interoperability depends heavily on the software providers as they decide how compatible the file format is with other relevant software. Furthermore, if the data has to be handled in multiple different software, there might be a risk of losing data in the process of converting the data back and forth [36].

According to [28], one of the most significant challenges is to improve the interoperability between tools by ensuring compatible tools with the open file format rather than develop a plugin for specific BIM software. To provide complete interoperability throughout the whole design phase.

The software can also use an application programming interface (API) for data exchange; this is a direct way of communicating with software, but it depends on the data whether the interoperability is a natural or open standard. APIs allow custom solutions to meet specific needs, such as data transfer. These solutions can also be integrated with plugins into software, thereby extending its features. Standard plugins in BIM are Dynamo and Grasshopper, which uses visual programming language (VPL), frequently used in the AEC industry as building these custom solutions has become intuitive compared to programming and more flexible. One example is Nicolaj Langkjær, who created an early LCA workflow using Rhino and Grasshopper to match the building component with the environmental data and export these data to LCAbyg. Using Grasshopper, the workflow becomes dynamic and iterative, enabling producing LCA quickly. To wrap up, there has not been found the perfect BIM-LCA tool yet, but as Soust-Verdaguer, Llatas, and García-Martínez states, the challenge isn't uncomplicated to solve. "Several papers which analyzed the integration from a methodological point of view highlighted the software integration as one of the most important challenges."

2.3.3 Design stages

As previously addressed, a BIM model varies in detail throughout its design stages, as shown in fig. 2.4. In the beginning, not much information is contained in the model, and LCA results would be inaccurate, but the accuracy would increase as the LOD increases. Therefore, each design stage is translated to a specific LOD according to [38], whereas the early LCA is LOD 200, the preliminary LCA is LOD 300, and the final LCA is LOD 325.

In the early design phases, before knowing the specific material used in the BIM model, Röck et al. suggest using predefined components to generate the first iteration of results and thereby have a baseline result from the beginning. However, according to Durão et al., 60 % of the time is lost in the early stages as the same information has to be entered multiple times. Up to 7 times during a construction process. This shows the need for an LCA tool that allows for calculating LCA in an iterative workflow, replacing LCA data quickly and thereby removing the barrier of reentering data over and over — also, confirmed by Zimmermann, Bruhn, and Birgisdóttir, who argue that the complexity and time-consuming work related to LCA has often been considered a barrier.

According to a Danish architecture company named "Lendager" the founder, Anders Lendager, seeks an intuitive and dynamic LCA tool that, in 'real-time,' gives an overview of the building's climate footprint. Stating that the goal is to measure while designing and testing different solutions [41], which supports the iterative approach of LCA.

Conducting an LCA of a building is a challenging task due to the vast amount of information required, and the time-consuming nature of the method [42]. Most of the effort and time is spent creating the BoQ and locating the appropriate datasets in the building material LCA database. This results in a high cost for sustainability certification due to the significant effort involved in conducting an LCA. As a result, LCA of buildings is typically performed at the end of the design process, when the necessary information has been gathered. Still, it is too late to influence the design decision-making process [43]. While post-design evaluation through LCA is a step in the right direction, it alone is insufficient and does not improve the environmental performance of the design [44]. To reduce environmental impacts, it is crucial to integrate LCA into the architectural design process, particularly in the early design phases when decisions have the most significant impact [44].

2.4 State-of-the-art LCA-tools

Hollberg, Genova, and Habert created a BIM-LCA tool that uses the VPL Dynamo to extract building quantities and material data that is manually added to the native material database in Revit. Dynamo then calculates the LCA from this data, leading to many uncertainties as the material database does not include data on the technical components, for instance, and consists of many assumptions in the calculation. On the other side, Dynamo is used to colorize the BIM model from the results and create a history of the GWP during the modeling phase.

Kumanayake and Luo created another LCA tool that uses Object Oriented Programming C# in combination with SQL database to produce an LCA report based on generic data automatically. The LCA can be carried out in the cloud, allowing multiple users to see up-to-date results. However, the tool is based on manual user input, increasing the risk of error and delay.

According to Soust-Verdaguer, Llatas, and García-Martínez, research shows that user-friendly platforms that assist the integration of software are lacking. However, another LCA tool that supports BIM-LCA is One-Click LCA, a commercial automated LCA tool. The database uses multiple databases and allows users to choose their region for specific databases. It is also available through an API, making it accessible through third-party applications. Software such as Revit and Rhino already have plugins for One-Click LCA, creating a smoother transition from the early to late design phase [47].

Revit also has a built-in ”Tally” plugin that allows users to perform LCA. It uses BIM information to perform LCA quickly and efficiently. However, the material still has to be manually set for each component. Furthermore, the materials used are based on the GaBi database, which is not supported in the Danish standard, as the database is based on American geography. Since Tally is operated through direct interoperability, it doesn’t allow other tools to collaborate and, for example, use another database, unfortunately.

In the Danish context, LCAbyg 5.0 is currently the most widely used LCA tool and is approved to use by the building regulation. LCAbyg uses the German Ökobau LCA database, which is an integrated part of the software. It allows using other LCA data, which must be imported manually. Furthermore, LCAbyg does not interoperate with BIM and, therefore, is not an LCA-BIM tool, requiring additional manual inputs. However, it has the option to import JSON files, including all the necessary data to perform an LCA in LCAbyg, which would be able to replace many of the manual inputs if programmed correctly. Still, there isn’t any software available to export the LCAbyg JSON files yet.

2.5 Summary

An LCA involves a lot of parameters, and many current LCA tools require a lot of manual input. The validity of the results is, therefore, highly reliant on the data quality and an engineer inputting data. Furthermore, the LCI data can either come from an EPD or generic data, as there doesn't exist EPD for all materials; however, generic data can introduce uncertainty to the LCA results but may be faster and more flexible in applying. The LCI database also plays an important role, as some are larger than others or based in different countries, influencing the LCI data assumptions. These uncertainties also impact the LCA, and therefore, an LCA of a building will not always be completely accurate results.

BIM is a powerful tool for collaboration in an interdisciplinary team. BIM can be used in different maturity levels, from pen and paper to cloud-based models. The goal is to increase the maturity level by working towards a more collaborative workflow and using a CDE, which leads to fewer errors and better collaboration. Furthermore, BIM can be utilized in many fields, especially within LCA, as it holds relevant information, such as geometry and material data, known as BIM-LCA. However, it is essential to consider the LOD when using the BIM, as it constantly progresses during the design phases.

Literature has proven a great potential in BIM-LCA tools, as it can skip many of the manual tasks involved in the current LCA calculations and avoid human mistakes that would otherwise happen and thereby be faster and more accurate. Furthermore, combining BIM-LCA with a cloud platform enables users to perform an LCA from any location at any time, advancing the maturity level and allowing for better collaboration in interdisciplinary teams and performing LCA iteratively.

3 Problem Statement

As previously addressed, the thesis is conducted as the ongoing work of the open-source and cloud-based CDE, Virtual Commissioning platform (VC), which is missing a service to perform LCAs. Therefore, the scope of this project is to develop such a service that is integrated into the common data environment while also solving the problematics of LCA being time-consuming and inaccurate, which is an increasingly pressing challenge due to the new enforcement of BR23. The problem is attempted to be solved by developing a proof-of-concept tool that utilizes BIM-LCA in a cloud environment, as it allows to automatize many of the manual tasks that exist in the current workflow of LCA, which in theory would minimize the time spent and the human errors made.

3.1 Aim and goals

The thesis aim is to develop a proof-of-concept cloud-based BIM-LCA tool that holds the potential to reduce the time spent carrying out an LCA, while providing accurate results.

- Map the parameters needed to carry out an LCA calculation.
- Develop a cloud and BIM-based LCA tool that enable parsing the parameters from BIM to carry out an LCA.
- Apply the LCA tool on a BIM model and evaluate the results based on time and accuracy.

3.2 Reading guide

To achieve these aims and goals, the report will be carried out like following:

Chapter 1 presents a short introduction to the problem of the thesis and what a potential solution could be.

Chapter 2 addresses the background research conducted about LCA, BIM, and literature on state-of-the-art LCA-BIM tools And defines the aim and goals of the report.

Chapter 4 specifies the methodology employed in the tool development and any specific challenges encountered during this process.

Chapter 5 presents a case study in which the tool is applied to Building 118, where the accuracy and speed were measured. Next, a validation of the tool was conducted to evaluate its performance of the tool.

Chapter 6 discusses the results and methodology concerning the tool on the parameters of flexibility, extensibility, and usability, rounding off with a section outlining future developments.

Finally, in Chapter 7, the report concludes by assessing whether the stated aims and goals have been fulfilled throughout the research.

A final note for the thesis, in general, is that the objective of the thesis has been to develop code for a tool, which is not shown during the report's thesis, for the sake of clarity. However, if interested, the GitHub link below shows the entire code created during the thesis.

Github:

LCA tool (C#): https://github.com/oskargramnielsen/LCA_Tool/

LCA Web Application (Python): https://github.com/oskargramnielsen/WebApplication/

4 Methodology

This chapter will mainly focus on the development of the LCA tool, hereby the data structures and data exchange of Revit and LCAbyg, and furthermore, a short section on the evaluation and demonstration of the tool and the web application. But first, a brief overview of the methodology used in the process.

4.1 Methodology overview

The methodology of the project follows the Design science research approach, also known as design science methodology from Peffers, Tuunanen, and Rossi. The methodology is a systematic qualitative research approach in which the object of study is the design process. The aim of the process is to create and evaluate artifacts, such as the LCA tool. This method involves a series of iterative steps, including objectives of a solution, design & development, evaluation, and communication, with the goal of developing a novel artifact that can be used to improve the current state in the field of study. The artifact is typically evaluated in terms of its ability to meet the identified needs; in this case, the accuracy and time will be evaluated, whereas the flexibility, extensibility, and usability will be discussed, and finally, the future steps of the artifact. The methodology is illustrated in fig. 4.1 [48]. The first step in the design science research methodology is problem identification & motivation, which in this thesis is the manual and slow process of conducting LCA, leading to mistakes and consuming valuable time. The objectives of the solution would be to create an LCA tool that automatizes these processes leading to less time spent and better accuracy, according to theory. The actual design & development of the artifact would be the programming of the LCA tool that extract the components from Revit and generates an LCA automatically, with fewer manual tasks, saving time and human errors. Next, the demonstration of the artifact would be conducted in the case study on Building 118 on DTU Campus, where both the accuracy and time would be measured. Along with the demonstration of the tool on Building 118, a validation would also be conducted to evaluate the LCA tool further. Based on the evaluation, the problem identification of the solution would be either iterated back to design or, if the objectives were fulfilled. Once fulfilled, the thesis would be published.

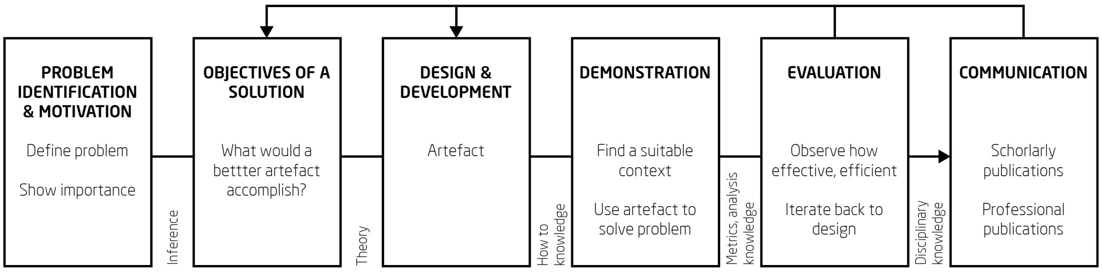


Figure 4.1: Design Science Research methodology according to Peffers, Tuunanen, and Rossi [48]

4.2 Development of the LCA tool

The following section will focus on the development of the LCA tool, thus understanding significant problems and choices made throughout the development and shaping the tool into a final artifact.

4.2.1 Context

Prior to the development of the tool, the findings from the background research revealed significant requirements that must be considered in the development process. These requirements establish the context for the tool, which is outlined in the following section.

The cloud- and BIM-based LCA tool will be integrated as one of the microservices within the existing CDE ”Virtual Commissioning” (VC) platform, as previously described. The platform was developed by Mikki Seidenschnur and Ali Kücükavci through their Ph.D. research hosted by Rambøll.

The chosen Building Information Modeling (BIM) tool is Revit 2021, as it is the most widely used BIM tool in Rambøll and the AEC industry, according to a survey conducted by Bips in 2014 [49]. Revit is a versatile software strongly integrated into the building industry, although it is not an open interoperability standard. However, it is suitable for the needs of this project.

Revit is typically utilized after the primary geometry and main materials have been defined, thus the use case of the tool will be after the conceptual design, which is mainly carried out in Rhino, but before the detailed design, hence the preliminary design stage, when a Revit model has been initiated. This also fits well with LCAbyg, since it operates at LOD 325, which corresponds to preliminary LCA at LOD 300.

The targeted user group for the tool is the Architect discipline, as the Revit model contains many different materials, thus providing more significant potential for the tool. However, since the tool is a proof-of-concept, only the building model of the LCA will be taken into account, including the walls, roof, ceilings, and floors.

The LCA materials will be sourced from a generic database named Ökobaudat, and LCA profiles will be created to better suit the preliminary design stage, with a focus on modeling and low detail level. The chosen BIM-LCA approach is number five, the LCA-plugin, for easy access to LCA data and the option of utilizing the 3D viewer and creating a more intuitive workflow.

LCAbyg is the most commonly used LCA tool in Denmark, as well as in Rambøll, and since it is based on the German Ökobaudat database, which has previously been shown to be a good choice of database, and since it supports an API-driven workflow, LCAbyg is chosen for the LCA calculations.

An Application Programming Interface (API) must be set up to initiate the LCA tool as a cloud-based tool. This will be done in Python, using a micro web framework called Flask, which will host the web application. Otherwise, the plugin for Revit will be coded in C# using objective-oriented programming.

The selection of requirements for the tool was derived from a thorough examination of the literature and analysis of the relevant requirements. It should be noted that they may not be the optimal choices in a long-term tool, but since BR23 regulations are enforced on January 1, 2023, a solution must be developed quickly to meet the needs of the industry, in this case, Rambøll, and the VC platform.

4.2.2 Workflow

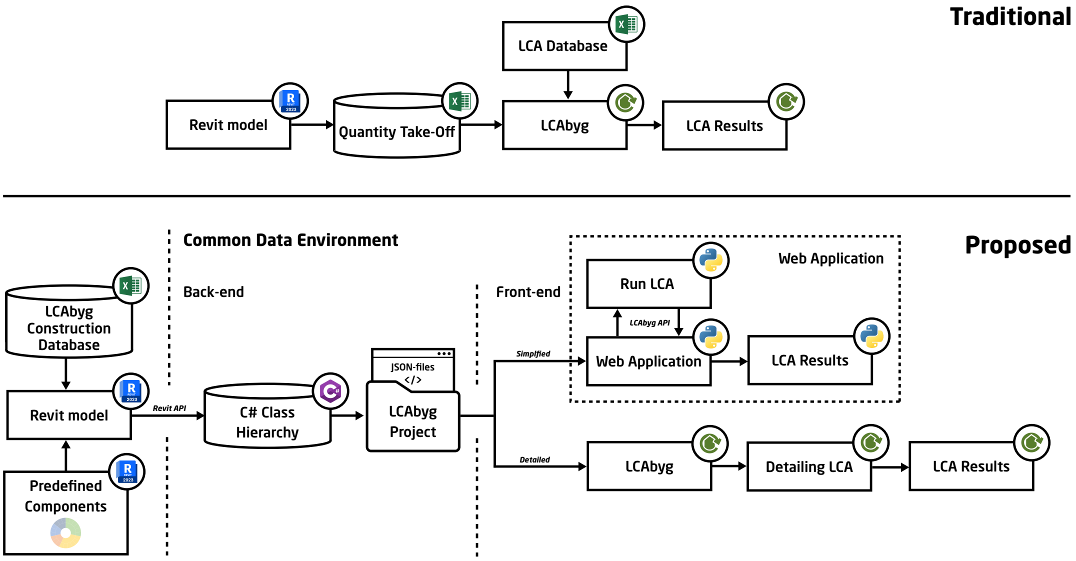


Figure 4.2: Traditional workflow of LCA (according to most common approach ”Quantity Take-off” [35]) and the proposed workflow of the LCA tool

The traditional and proposed workflow is illustrated in a flowchart in fig. 4.2; the proposed workflow is based on a Danish context and only takes into account the building model of LCA. The workflow starts in Revit, where each building component is either 1) defined from the construction library in the LCA database from LCAbyg or 2) modeled with a predefined building component, depending on the detail level desired. In Revit, an addin is created to export the necessary data from the building components through a C# class hierarchy to JSON. The JSON file is then restructured according to the LCAbyg JSON format. The next step is divided into two parts, the lower process shows the data being sent to the LCAbyg software, which allows adding further details to the LCA calculation, before running the LCA calculation and displaying the results, and the upper process shows the data being sent to the web application in the cloud and dynamically presenting the results in a browser, instead of having to open LCAbyg and thereby allowing a more iterative workflow. The traditional workflow of LCA varies from company to company, however, the most common approach is the Quantity Take-off approach, addressed in the background research [35]. The workflow is also based on the Danish context and the building model, and like the proposed workflow, it also starts in Revit. The building component is exported through spreadsheets, which are tables of quantities for each building component. These spreadsheets are then manually entered in LCAbyg, whereas the material is manually entered for each component. The results are automatically generated when all components have been entered into the LCAbyg project.

4.2.3 Data exchange between Revit and LCAbyg

For LCAbyg and Revit to coexist in the same environment, they must communicate in a mutual language, which is one of the key challenges with this tool. In fig. 4.3, a reference wall is used as an example to show the different data structures of building components in Revit and LCAbyg.

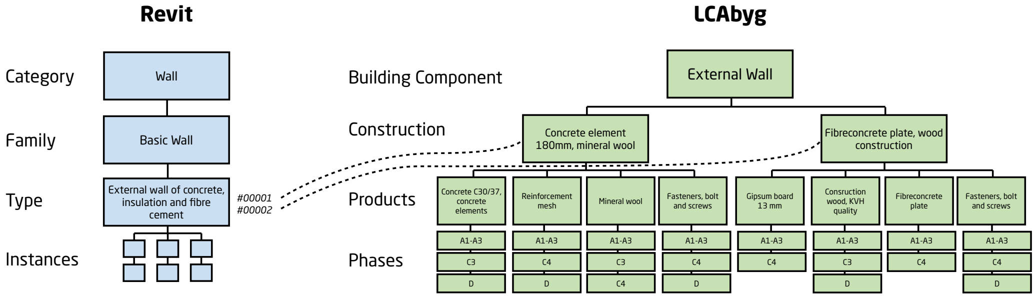


Figure 4.3: Building component structure of LCAbyg 5.2 and Revit 2021

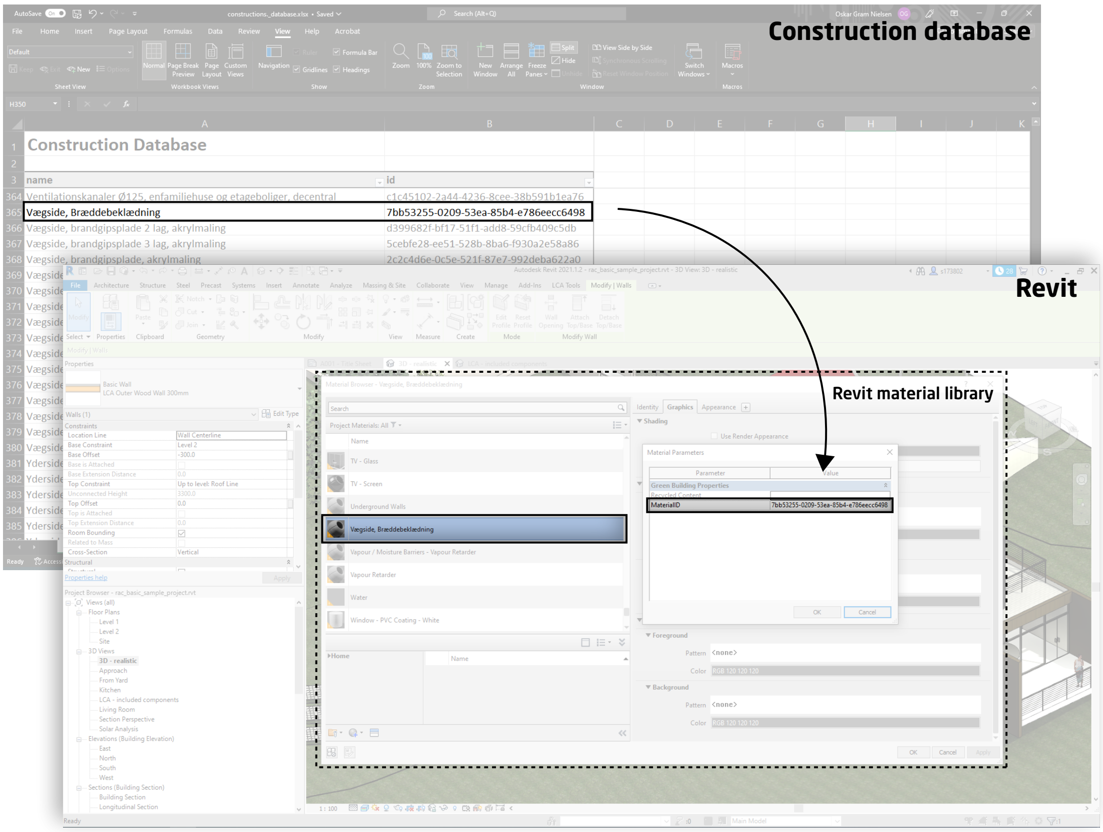
In the LCAbyg structure, the building components are typically divided into 1-3 constructions, each construction is then divided into the products, and lastly, each product is divided into the phases the product has been through. In the Revit structure, the building components are divided into categories, each category has different families, and these have different types. A type of component can finally have separate instances, for example, if the same component is placed in multiple locations, shown in fig. 4.3.

In this case, the tool will transfer building components from Revit to LCAbyg. In Revit, the components were chosen to be modified on a Type-level, as it allows to have multiple types of a family, for example, various walls with the same materials but with varying thicknesses. On the other hand, in LCAbyg, the components were chosen to be modified on Construction-level, which contains multiple products; for example, construction may have a steel construction with insulation and screws holding it together. This means that in Revit, components with Type-levels will have unique IDs that reference to constructions IDs in the construction database from LCAbyg; in this way, each component in Revit also has information about the LCA data. Of course, the IDs could also refer to a particular product instead (one level below construction), allowing more customized and detailed components; however, this would imply more IDs to input. Ideally, the user should be able to specify what detail level is necessary and then choose from that basis, but for the sake of simplicity, the Type-level (Revit) to Construction-level (LCAbyg), was the chosen datatypes, also shown in fig. 4.3 indicated by the dashed lines.

4.2.4 Import of LCA material data to Revit

The link between Revit and LCAbyg is based on the material ID inserted in Revit components, referring to the materials in the LCAbyg material library.

The material database from LCAbyg consists of several different databases depending on the building component level, as shown in fig. 4.3, hence building components, constructions, products, or phases. As mentioned previously, the Construction-level in LCAbyg is chosen, and therefore the Construction library in LCAbyg is used. The database consists of 399 different constructions, which is not much compared to the total number of constructions. The name and ID in the database are searchable, making it easier to find the desired construction. When the required materials are found, the material ID can be inserted into the Revit building components; an example is shown in fig. 4.4, where a ”Vægside, Bræddebeklædning” (trans. ”Wall side, Wooden cladding”) wall layer is added to the material library in Revit, from the Construction database. The Revit material now contains that ID that links to the specific construction; the material can then be applied to a wall layer in Revit as a wooden cladding; this is done for the remaining layers in the wall to create a complete wall.



Construction Database

	name	id
364	Ventilationskanaler Ø125, enfamiliehuse og etageboliger, decentral	c1c45102-2a44-4236-8cee-38b591b1ea76
365	Vægside, Bræddebeklædning	7bb53255-0209-53ea-85b4-e786eecc6498
366	Vægside, brandgipsplade 2 lag, akrylmaling	d399682f-bf17-51f1-add8-59cfb409c5db
367	Vægside, brandgipsplade 3 lag, akrylmaling	5cebfe28-ee51-528b-8ba6-f930a2e58a86
368	Vægside, brandgipsplade, akrylmaling	2c2c4d6e-0c5e-521f-87e7-992deba622a0

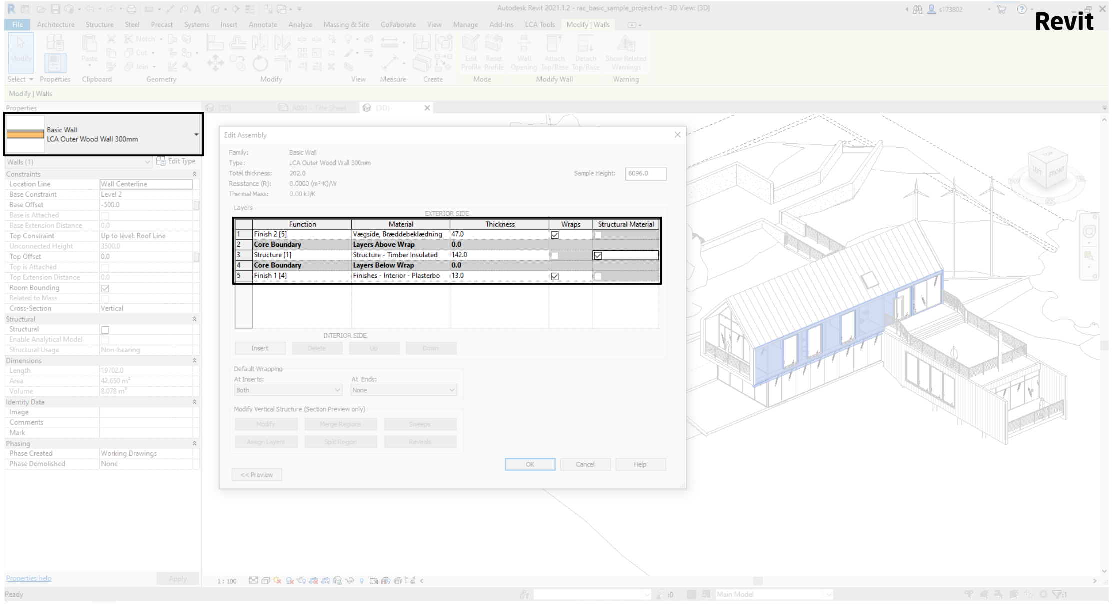
Material Parameters

Parameter	Value
Green Building Properties	
Recycled Content	
MaterialID	7bb53255-0209-53ea-85b4-e786eecc6498

Figure 4.4: Creating custom construction from the LCAbyg Constructions database to the Revit material database.

A family can be completed when all the relevant material layers have been created in Revit. An example is shown in fig. 4.5. Here the family wall has been made that consists of 3 constructions and the wall family, shown in the material layers window in the middle. To the top left, the wall family ”LCA Outer Wood Wall 300mm” is selected, also highlighted in blue in the 3D model, which now can be used in the LCA calculation.

The process of manually entering the Construction ID into the Revit material library seems like a time-consuming task, and why replace manual tasks with another manual task? The answer is that this is a time-consuming task at the beginning of a project as all the components in the Revit model would have to be added manually from the Construction database; however, once a component type is created, it can be reused over and over again, and for the following projects ahead. This is illustrated in fig. 4.6, where the x-axis represents time, and the y-axis represents the number of construction added to the Revit



Basic Wall
LCA Outer Wood Wall 300mm

Walls (1)

Constraints	
Location Line	Wall Centerline
Base Constraint	Level 2
Base Offset	-500.0
Base is Attached	☐
Base Extension Distance	0.0
Top Constraint	Up to level: Roof Line
Unconnected Height	3500.0
Top Offset	0.0
Top is Attached	☐
Top Extension Distance	0.0
Room Bounding	☑
Related to Mass	☐
Cross-Section	Vertical
Structural	
Structural	☐
Enable Analytical Model	☐
Structural Usage	Non-bearing
Dimensions	
Length	19702.0
Area	42.650 m²
Volume	8.078 m³
Identity Data	
Image	
Comments	
Mark	
Phasing	
Phase Created	Working Drawings
Phase Demolished	None

Edit Assembly

Family: Basic Wall
Type: LCA Outer Wood Wall 300mm
Total thickness: 202.0
Resistance (R): 0.0000 (m²·K)/W
Thermal Mass: 0.00 kJ/K
Sample Height: 6096.0

Layers

EXTERIOR SIDE

	Function	Material	Thickness	Wraps	Structural Material
1	Finish 2 [5]	Vægside, Bræddebeklædning	47.0	☑	☐
2	**Core Boundary**	**Layers Above Wrap**	**0.0**		
3	Structure [1]	Structure - Timber Insulated	142.0	☐	☑
4	**Core Boundary**	**Layers Below Wrap**	**0.0**		
5	Finish 1 [4]	Finishes - Interior - Plasterbo	13.0	☑	☐

INTERIOR SIDE

Default Wrapping
At Inserts: Both
At Ends: None

Figure 4.5: Completed wall family in Revit with embedded LCA Construction IDs

material database. After adding a material ID to the Revit material database, the database will be increasingly populated, and over time, previous materials can be reused. At one point, the Revit material would all have a Construction ID added, the database would be up to date, as illustrated in the dotted line, and only new materials would have to be added.

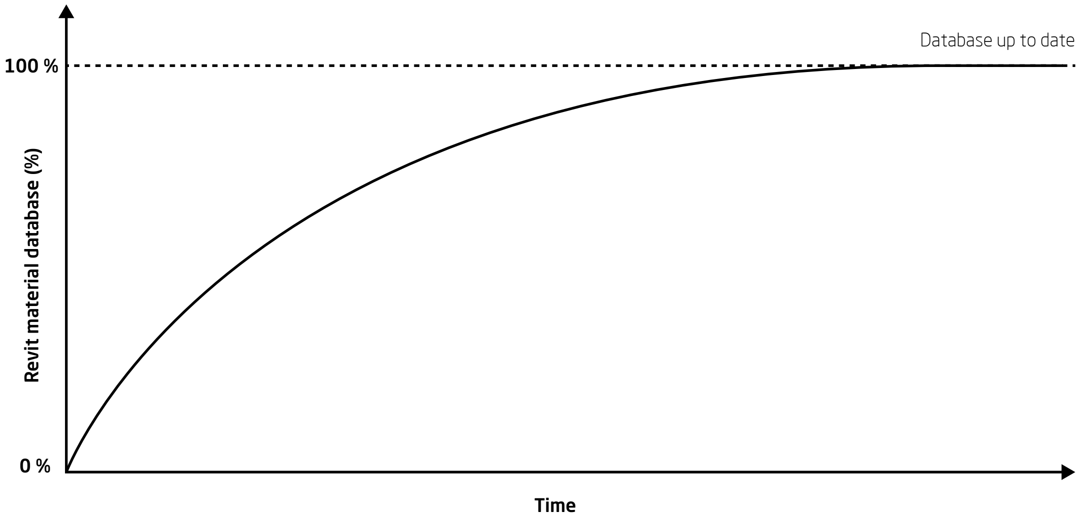


Figure 4.6: LCA material data added to Revit material database (%) over time

Adding material IDs to each layer of a building component allows the creation of tailor-made components and a better fit for the desired materials. However, in the preliminary phases, an exact fit is not always needed, therefore, a collection of predefined components has been created to speed up the modeling. The method of using the predefined components with LCA data embedded is backed up by a Belgium team, who recommended predefining components in the early stages, shown in the literature study in the background section. The predefined components include external and internal walls, ground slab, deck, and roof. In fig. 4.7, a diagram shows the possible options for each building component in Revit; this is only to show the proof-of-concept, as the diagram could be expanded for a wider variety of components.

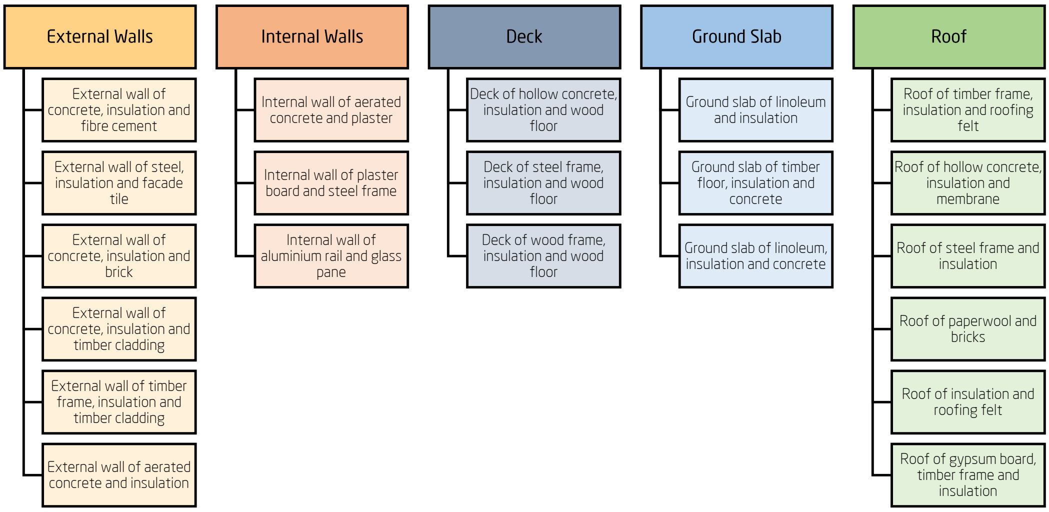


Figure 4.7: Predefined building components collection

After adding all relevant building components to the Revit project with their appropriate material IDs, the necessary data can be exported to the CDE by either using the predefined components or creating new ones. To get an overview of the included components in the LCA, a view in Revit has been created for easy representation. The view is shown in fig. 4.8, whereas the building components with embedded material IDs included are automatically highlighted with a transparent green for a more intuitive workflow, as requested by Anders Lendager from Lendager Group.

Not all component categories in the Revit model are included in the export; in the next section, the exact component categories will be defined.

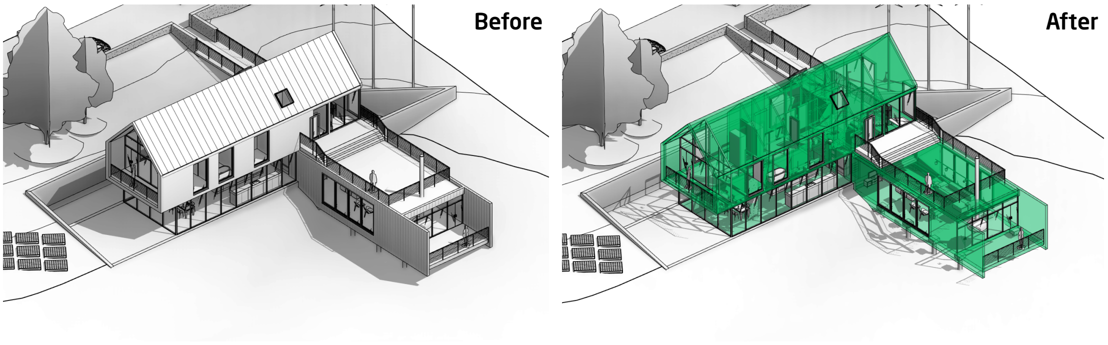


Figure 4.8: Revit view highlights building components containing LCA data before and after.

4.2.5 LCA Parameters

The LCA parameters required to be included in an LCA according to the BR23 demands and the included parameters in the tool are illustrated in fig. 4.9. The parameters are grouped in boxes for a better overview. The green boxes represent groups of parameters where all the parameters are mandatory, the yellow is only partly mandatory, and the red none mandatory. Similarly, the boxes with a circumference of a line show the group of parameters included in the tool, and those with a dotted line are not included. Most of the required parameters are included in the tool, but as the tool is a proof of concept, only the most impact-heavy on the LCA has been chosen. As previously addressed, the tool focuses on the building model quantity extraction and not the usage and energy from the building model. If those were taken into account, there would be some issues with extracting data such as energy data; this would ideally come from a separate energy analysis and other components like mechanical components, which are rarely accurately placed in a Revit model.

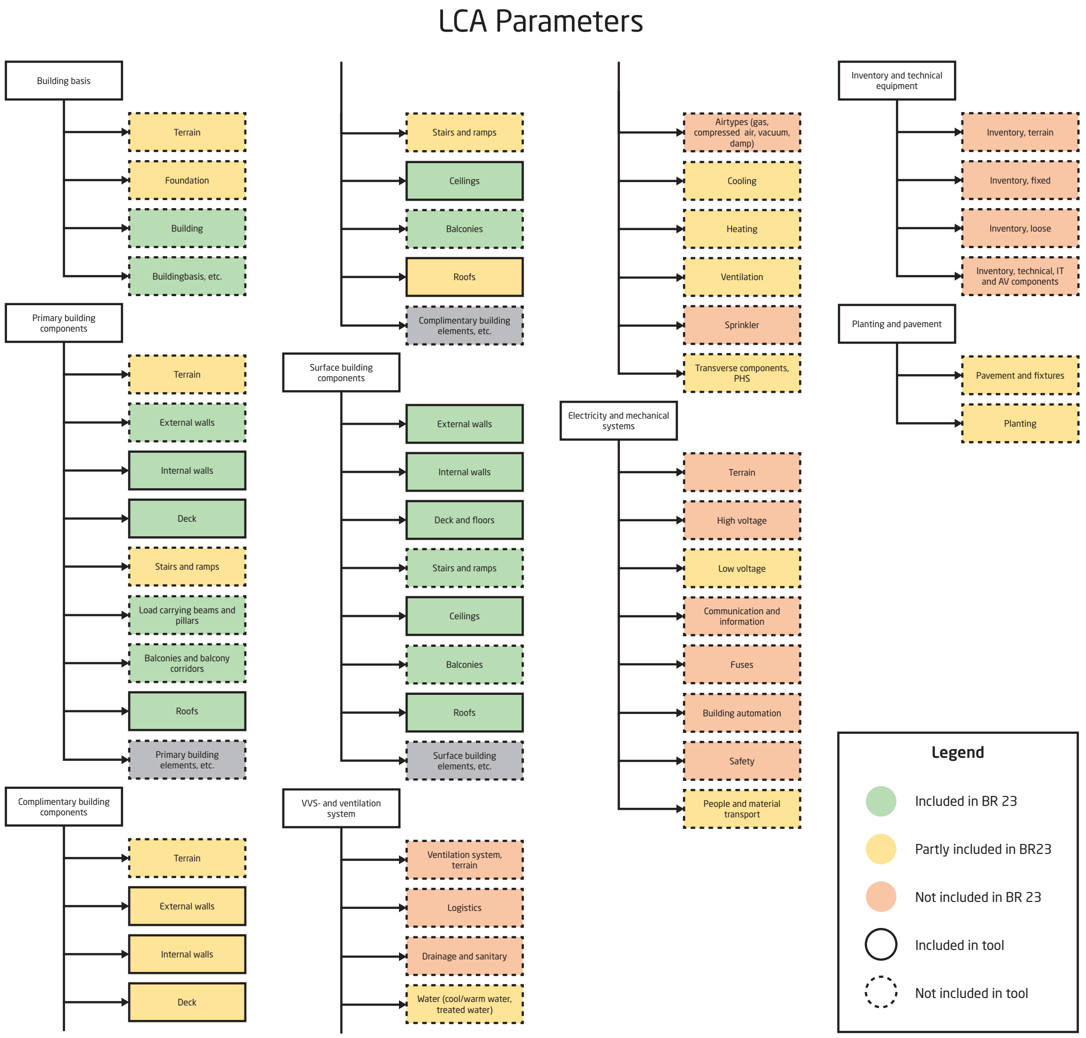


Figure 4.9: LCA parameters categorized from BR23 demands (from Arkitema and COWI in cooperation with DK-GBC and Housing and the Danish Planning Agency) and included model parameters in the tool.

4.2.6 Export of data from Revit to CDE

The data stored in a Revit project can be accessed through the Revit API. The API allows users to program scripts to automate repetitive tasks. The API is compatible with several programming languages, such as VB.NET, C#, and CCLI, the chosen language was C# as it allows to use of object-oriented programming. In the C# class hierarchy, classes are created for each building component. The classes use the Revit API to extract the relevant attributes necessary to conduct an LCA, such as component type, unique ID, component number, layer number, material name, area, and material ID. These attributes are parsed to JSON dictionaries by the C# Class hierarchy. An example of the data structure is shown in listing 4.1; the example shows a selection of wall components from the JSON dictionary; each branch in the dictionary is a layer in a component; for instance, these three branches specify one wall component, as it contains three layers since their component ID is the same and the layer ID counts from one to three. For all layers, the unique material ID from the Construction database is included, together with area, name, and thickness.

To extract all of the relevant attributes from Revit, the classes iterate through all components in the Revit file using the Revit API. When a desired component is found, all necessary attributes are extracted and inserted into a constructor. The constructor then parses the attributes of the component to a JSON dictionary, which can later be used to create the LCAbyg JSON.

```
[
  {
    "Type": "Walls",
    "ComponentId": 1,
    "LayerId": 1,
    "MaterialId": "f2ce8b16-7c8e-56e0-8a85-136a20d3bb26",
    "Name": "Internal wall side, Wood cladding",
    "Area": 165.2,
    "Thickness": 25
  },
  {
    "Type": "Walls",
    "ComponenttId": 1,
    "LayerId": 2,
    "MaterialId": "nf32e5136-105d-566b-a761-8dba8a44f6b9",
    "Name": "Middle part, concrete element 180mm, mineral wool",
    "Area": 165.2,
    "Thickness": 180
  },
  {
    "Type": "Walls",
    "ComponentId": 1,
    "LayerId": 3,
    "MaterialId": "b4aa08e3-fd38-514e-b32b-fb107e112a23",
    "Name": "External wall side, fibercement board, front wall",
    "Area": 165.2,
    "Thickness": 35
  },
  ...
]
```

Listing 4.1: Example of JSON file of the raw data export from Revit

4.2.7 Export from CDE to LCAbyg

This section will address translating the JSON dictionaries in the CDE to an LCAbyg project. First, the LCAbyg data structure will briefly be explained.

LCAbyg data structure

LCAbyg organizes the individual projects in a central folder; each LCAbyg project consists of a folder with individual JSON files structured in a tree hierarchy, shown in fig. 4.10. Each JSON file is based on nodes and edges. Nodes could be any component in the project, from the complete building to a brick in the wall. Since the nodes are structured in a tree hierarchy, all nodes can be connected to the main building as the starting node. The building node then branches out to the walls, wall layer, construction layer, and product in construction, such as a brick. The edges connect the nodes depending on their relationship in the system. The overall structure of the nodes and edges is shown in fig. 4.11.

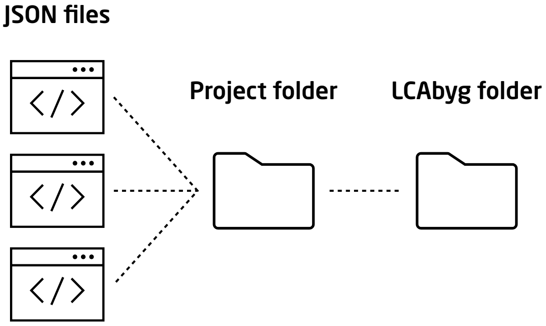


Figure 4.10: Structure of files in LCAbyg

One example could be that a wall is connected to the building it is part of, and construction layers are attached to the wall it is part of, the material layers are connected to the construction it is part of, and so on. This is also known as a parent-child tree structure hierarchy, shown in fig. 4.11. This data structure creates an extensive network of nodes related to the project it is part of.

The raw JSON file, for example, of a building, is shown in listing 4.2. The JSON file describes the building node for the main building of the LCAbyg project, where the building data can be inserted, such as floor area, story height, and energy class. The edge below the node then links the main building to the following nodes in the hierarchy, such as the component Categories. To ensure that the nodes are connected correctly, all nodes carry a unique ID that ensures the nodes are pointing to the correct nodes. By inserting the data through a JSON format like this, LCAbyg can interpret it, and it allows to be able to be programmed instead of manually inputting the data into the software.

Translation of data to LCAbyg

To create the JSON files for the building model, a lot of nodes and edges have to be generated, as each construction of each component has its node and edge. Therefore an automated script has been created. The script iterates through all the keys in the JSON dictionary and fills out all the data required for each component into a new JSON in the LCAbyg format. For example, from listing 4.1, the first key to be registered would be the type of component, and the script would define the node as a Wall type; by parsing the

```json
[
    {
        "Node": {
            "Building": {
                "id": "6d766aa5-50aa-4005-ab35-29f2fb82ddad",
                "name": {
                    "Danish": "Test eksempel"
                },
                "address": "Testvej 1, 1111 Testby",
                "owner": "Test",
                "description": "",
                "building_type": "Other",
                "heated_floor_area": 0,
                "gross_area": 0,
                "gross_area_above_ground": 0,
                "storeys_above_ground": 0,
                "storeys_below_ground": 0,
                "storey_height": 0,
                "initial_year": 2015,
                "calculation_timespan": 50,
                "calculation_mode": "SC",
                "lca_advisor": "Test",
                "building_regulation_version": "BR2018",
                "plot_area": 0,
                "outside_area": 0,
                "energy_class": "LowEnergy"
            }
        }
    },
    {
        "Edge": [
            {
                "MainBuilding": "15867192-86b7-40a8-9936-83d9e998516d"
            },
            "e9e6e798-390e-4419-a1fa-3b46a8ba5b8d",
            "6d766aa5-50aa-4005-ab35-29f2fb82ddad"
        ]
    },
...
]
```

Listing 4.2: Example of JSON file from LCAbyg showing the main Building node including its edge.

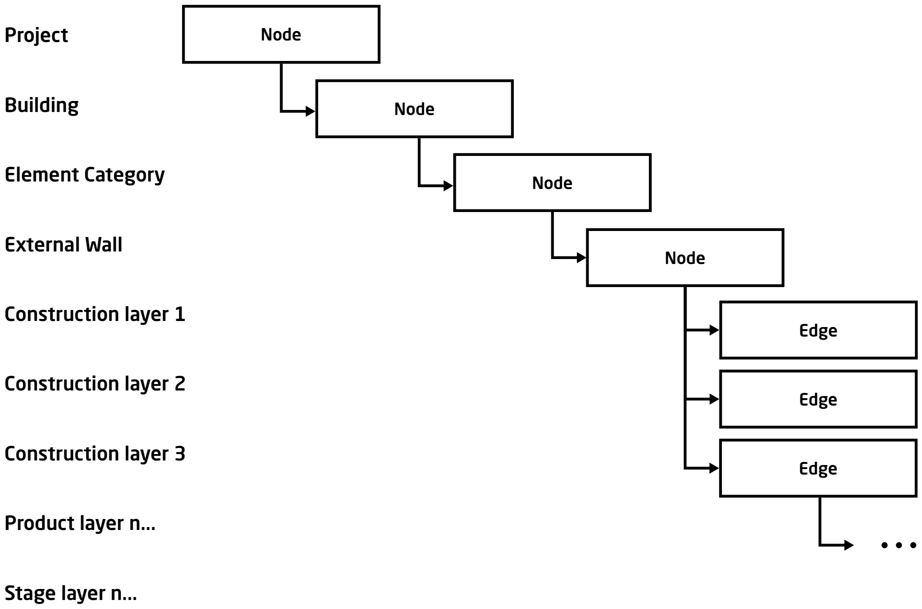


Figure 4.11: Data structure of LCAbyg

ID for a wall, next, it would search for the layers within that component and fill out the Construction ID, e.g., 'Wood cladding,' area and thickness. This would be done for all the components in the JSON and, by the end, create multiple new JSON files in the LCAbyg format. The JSON files would then be located in the project folder, with the corresponding JSON files matching the project of LCAbyg for LCAbyg to open it smoothly with all building components filled out. The processes mentioned above have been programmed to execute when pressing the button "Export" in the Revit plugin shown in fig. 4.12; the other button, "LCAbyg" simply executes the LCAbyg program and enables to open of the newly created project from the current data from Revit.

4.2.8 Web Application

Parallel to the LCAbyg workflow, another addition to the tool is the web application, a user interface that allows performing the necessary operation to carry out the LCA directly from a web browser. This service enables users to run an LCA through a web-based application from a REST API, making the LCA more iterative and intuitive for architects without LCA backgrounds. A REST API is a joint abbreviation, whereas an API stands for application programming interface; it is a method of retrieving information or performing a function from a system, one example is retrieving the weather forecast from a weather service, if you request the weather forecast with a given zip code to the weather service API, the API would respond with the current weather forecast for that zip code. In this case, the API instead runs the LCA and responds with the results [50]. The REST stands for representational state transfer which is a set of architectural constraints, it means that when a request is made through a REST API, it responds with a representation of the state of the resource to the requester [50].

The API is hosted through a micro web framework, "flask" enabling users to run the customized script. In this case, three scripts have been made: "update data from Revit", "run the LCA" and "show results from the LCA". These scripts are visualized in an HTML script

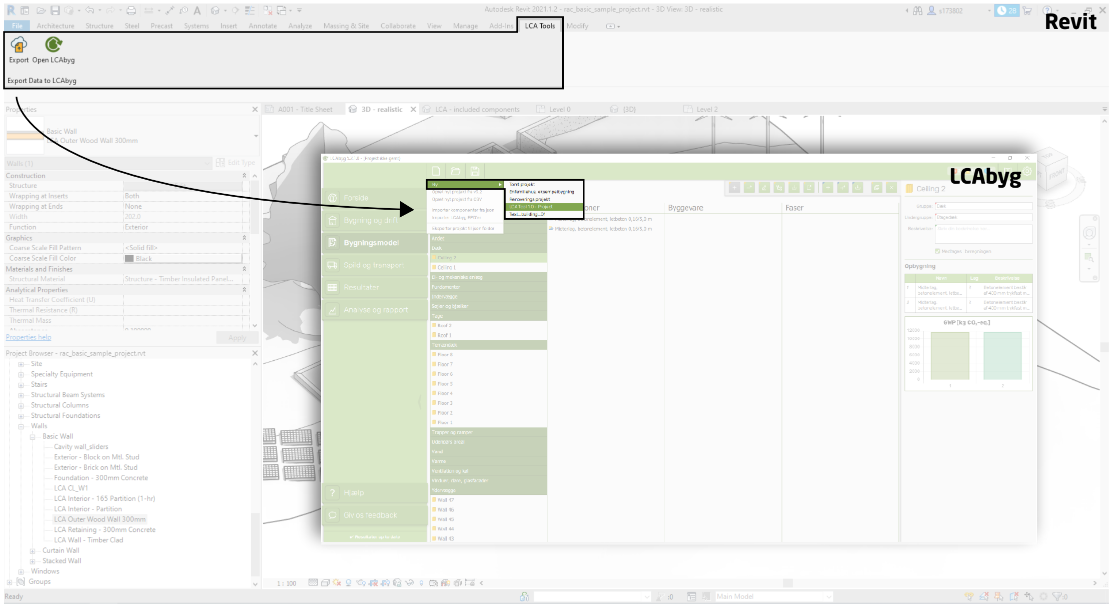


Figure 4.12: Data export from Revit through addin, first button (1) export the data, second button opens LCAbyg. In LCAbyg, all the building components are filled out according to the data from Revit when importing the according to the project.

that allows the users to interact with the website, shown in fig. 4.13. To run the LCA, the updated data are sent to the LCAbyg API, another API hosted by LCAbyg that performs the LCA calculation from the JSON data. This enables users to run the LCA calculation in the cloud instead of opening the software on the computer. The results are then stored in the CDE, and the 'show result' script can be run, visualizing the data in a bar chart. This way, the LCA can be carried out in an iterative manner, as requested by Anders Lendager mentioned in the background chapter. As the Web Application is limited to the three scripts, it does not yet allow editing the LCA from the Web Application. However, this addition to the tool hasn't been included in the evaluation process and is therefore seen as a supplement to the tool since it does not allow editing the LCA. However, it is the first step towards a higher maturity level, a more iterative approach to LCA, and more flexibility for the users.

4.3 Analysis

According to the design science research methodology, the next step is demonstrating the tool in a suitable context.

4.3.1 Demonstration

The LCA tool is demonstrated in Building 118 on DTU Campus. A Revit model was given by the Campus Service at DTU. The Revit model was assessed using predefined components or modeling from scratch. The first option was selected, as the LOD of the Revit model was too low to create customized building components since the components had too little information contained. The four main building component categories were each matched with the best-fitting predefined components. After the matching process, the components were changed in Revit and exported through the plugin in Revit. The LCAbyg project was created with all building components filled out. Finally, the last general infor-

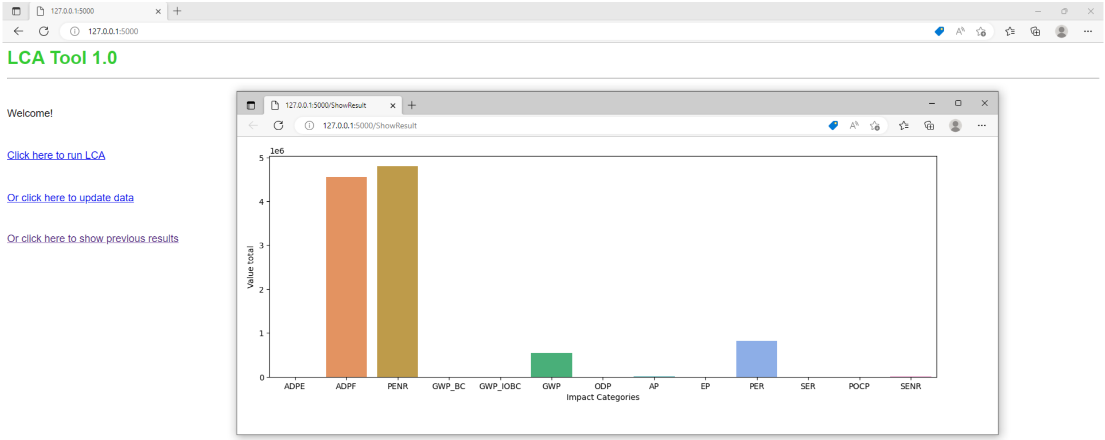


Figure 4.13: Web Application ”LCA Tool 1.0” interface.

mation about the building was inputted, and the results were ready. The results were compared to a case study of 22 office buildings from a report by Zimmermann et al. The report summarized the LCA of 60 buildings, whereas 22 were office buildings. The GWP of the 22 LCA results was then compared to the GWP of Building 118. An additional metric was included in a statement from Andreas Sørensen, Sustainability Consultant from Rambøll. The statement divides the time carrying out an LCA into three parts based on building 118; here, a simplified calculation was made to quantify the time saved with the new LCA tool.

4.3.2 Evaluation

The evaluation of the tool was conducted through a validation of the predefined components. The components in the predefined component collection, also used in the previous demonstration on Building 118, were validated on their accuracy of GWP. The components were recreated according to the description of the components in a report ”LCA-profiler for bygningsdele” (trans. ”LCA-profiles for building components”) from Statens Byggeforskningsinstitut et al. The resulting GWP of the recreated components was then compared to the components from the report. The deviations of each component were calculated to evaluate the accuracy of the predefined components used in the component collection. A deviation within 25 % was chosen as the acceptable limit since the tool is created for the preliminary stage and therefore doesn’t need 100 % accurate results.

4.4 Summary

A new proposed BIM and cloud-based LCA tool are presented with a new workflow that plugs into the current VC platform. The workflow is based on the building model and ignores the remaining data input to the LCA. The workflow starts in Revit, where the LCI data from the Økobau database is inserted into each relevant building component. For faster modeling but compromising accuracy, predefined components are available instead of inserting each material ID in each building component. Then, a plugin in Revit is created that automatically exports the necessary data for the LCA from all of the building components to an LCAbyg JSON format based on the parent-child hierarchy with edge and node network. After the export, the LCAbyg can be opened, and a newly created project has been created for all the building components from the Revit model. An additional web application has been added to the workflow that allows users to run the LCA in the cloud and access the results from a web application instead of opening the LCAbyg software; however, it doesn't allow further detail of the LCA but supports the iterative workflow.

5 Analysis

This chapter demonstrates and evaluates the performance of the LCA tool by applying it to the case study of an office building, Building 118, on the DTU Campus. First, the results of Building 118 are compared to reference office buildings from a BUILD Report from 2021 [51] on accuracy. The LCA tool is also evaluated on the speed of carrying out an LCA with a statement from sustainability consultant Andreas Sørensen from Rambøll. Next, the tool will be validated on the accuracy of the predefined components based on reference data from a Report from Aalborg University, Henning Larsen, and Rambøll.

5.1 Case study: Building 118

The case study is based on Building 118, an office building located on Brovej 118, 2800 Kongens Lyngby, at DTU Campus. The building is from 1970 and is 5.800 square meters divided into three stories and a basement. The structure consists mainly of concrete and bricks.

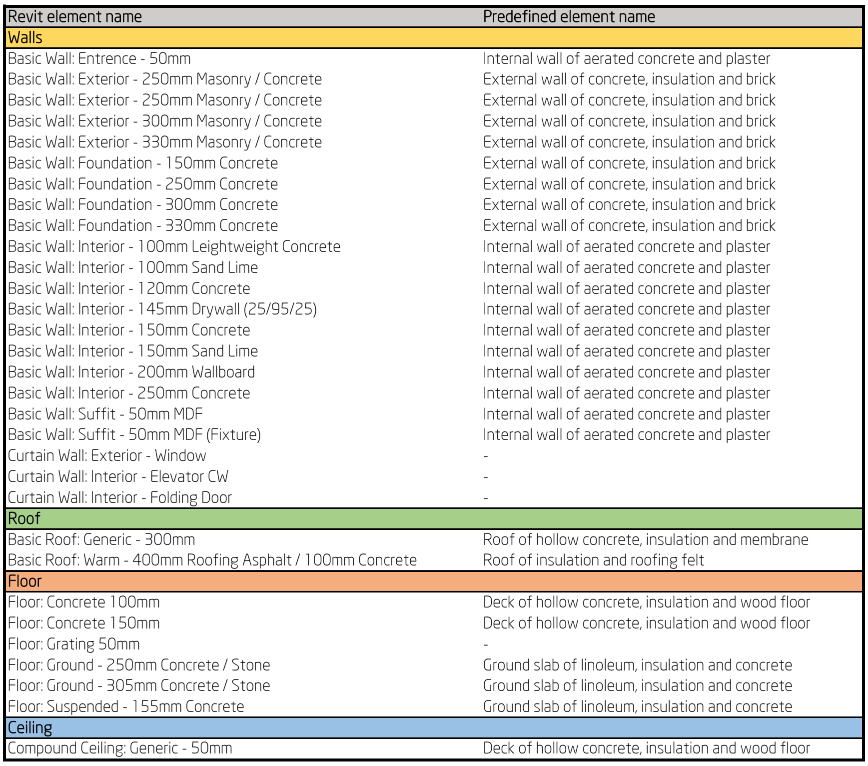
5.1.1 Model setup

A Revit file of Building 118 has been retrieved from the DTU BIMlab, a platform that facilitates content for educational use. The Revit model is at a preliminary stage, approximately between LOD 200-300, as the building components are generic, but the sizes and quantities are accurate.

As previously stated, there are two ways of modeling the components in Revit with the LCA tool; the first is to use the predefined component, which is useful when the Revit model has a low detail level since the predefined component has already embedded the data; which speeds up the modeling phase. On the other hand, if the model has a higher detail level, it may be a better option to model the component manually from the material ID, however, it is slower but able to give a more precise result. In this case, the first option of using a predefined component is chosen since the model only uses generic components, thereby increasing the modeling speed.

The list in fig. 5.1 shows two columns, and the left shows the different types of families in the Revit model for each of the chosen building component categories; walls, roofs, floors, and ceilings. The right column shows the corresponding predefined building components (previously shown in the diagram in fig. 4.7) that fit the component types from the Revit model the best; however, since the options of predefined components are limited, the matching is likely to cause deviations between the Revit model components and the predefined components. A few building components were not considered to fit the predefined components, like 50 mm grating and curtain walls, instead marked with ”-”.

After changing all the relevant building components in Revit to the corresponding predefined components, a 3D visualization is shown in fig. 4.8 from Revit. The upper model shows the building before being mapped with predefined components, and the lower model shows the model after. In addition, the building component mapped with LCA materials is marked with a transparent green to visualize better which components are



Revit element name	Predefined element name
Walls	
Basic Wall: Entrence - 50mm	Internal wall of aerated concrete and plaster
Basic Wall: Exterior - 250mm Masonry / Concrete	External wall of concrete, insulation and brick
Basic Wall: Exterior - 250mm Masonry / Concrete	External wall of concrete, insulation and brick
Basic Wall: Exterior - 300mm Masonry / Concrete	External wall of concrete, insulation and brick
Basic Wall: Exterior - 330mm Masonry / Concrete	External wall of concrete, insulation and brick
Basic Wall: Foundation - 150mm Concrete	External wall of concrete, insulation and brick
Basic Wall: Foundation - 250mm Concrete	External wall of concrete, insulation and brick
Basic Wall: Foundation - 300mm Concrete	External wall of concrete, insulation and brick
Basic Wall: Foundation - 330mm Concrete	External wall of concrete, insulation and brick
Basic Wall: Interior - 100mm Leightweight Concrete	Internal wall of aerated concrete and plaster
Basic Wall: Interior - 100mm Sand Lime	Internal wall of aerated concrete and plaster
Basic Wall: Interior - 120mm Concrete	Internal wall of aerated concrete and plaster
Basic Wall: Interior - 145mm Drywall (25/95/25)	Internal wall of aerated concrete and plaster
Basic Wall: Interior - 150mm Concrete	Internal wall of aerated concrete and plaster
Basic Wall: Interior - 150mm Sand Lime	Internal wall of aerated concrete and plaster
Basic Wall: Interior - 200mm Wallboard	Internal wall of aerated concrete and plaster
Basic Wall: Interior - 250mm Concrete	Internal wall of aerated concrete and plaster
Basic Wall: Suffit - 50mm MDF	Internal wall of aerated concrete and plaster
Basic Wall: Suffit - 50mm MDF (Fixture)	Internal wall of aerated concrete and plaster
Curtain Wall: Exterior - Window	-
Curtain Wall: Interior - Elevator CW	-
Curtain Wall: Interior - Folding Door	-
Roof	
Basic Roof: Generic - 300mm	Roof of hollow concrete, insulation and membrane
Basic Roof: Warm - 400mm Roofing Asphalt / 100mm Concrete	Roof of insulation and roofing felt
Floor	
Floor: Concrete 100mm	Deck of hollow concrete, insulation and wood floor
Floor: Concrete 150mm	Deck of hollow concrete, insulation and wood floor
Floor: Grating 50mm	-
Floor: Ground - 250mm Concrete / Stone	Ground slab of linoleum, insulation and concrete
Floor: Ground - 305mm Concrete / Stone	Ground slab of linoleum, insulation and concrete
Floor: Suspended - 155mm Concrete	Ground slab of linoleum, insulation and concrete
Ceiling	
Compound Ceiling: Generic - 50mm	Deck of hollow concrete, insulation and wood floor

Figure 5.1: Building 118 Revit families grouped on walls, roofs, floors, and ceilings, and the corresponding predefined components from fig. 4.7.

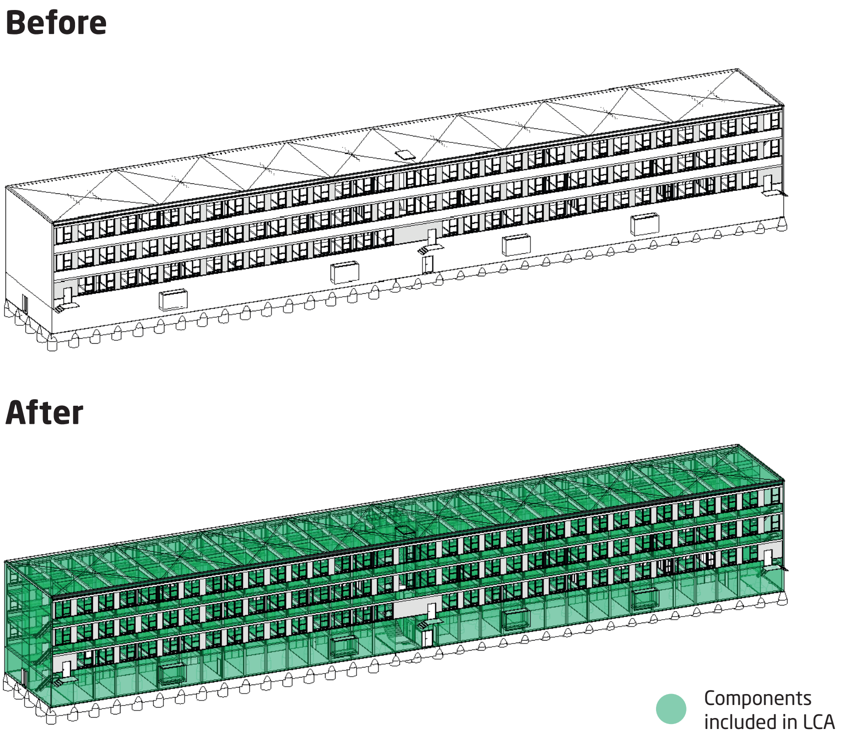
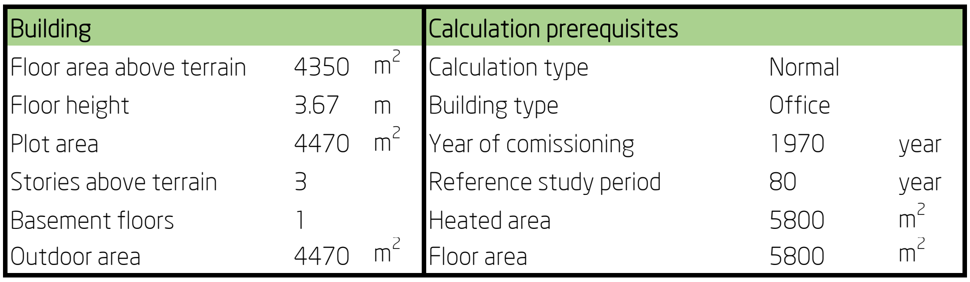


Figure 5.2: View in Revit before and after mapping components with material IDs

taken into account in the LCA, creating a better overview and making the modeling phase of LCA components more intuitive.

When the building components are exported to LCAbyg, additional information needs to be input into the project, such as the calculation type, reference study period, gross floor area, and building type; however, only regarding the building model and not the usage phases and energy data. The calculation type is set to Normal; other types could be DGNB or voluntary sustainability class. The type of building is set to an office, as this consists mainly of the professor's offices. The gross floor area is set to 5.800 m^2, which originates from the BBR database, and the reference study period is set to 50 years to compare it with reference data, however, offices usually have higher RSP, as it SBi states a typical 80-year RSP for offices. [53].



Building		
Floor area above terrain	4350	m^2
Floor height	3.67	m
Plot area	4470	m^2
Stories above terrain	3	
Basement floors	1	
Outdoor area	4470	m^2

Calculation prerequisites		
Calculation type	Normal	
Building type	Office	
Year of comissioning	1970	year
Reference study period	80	year
Heated area	5800	m^2
Floor area	5800	m^2

Figure 5.3: Prerequisite project settings LCAbyg

5.2 Results of case study

5.2.1 Accuracy

The mapped materials are exported to LCAbyg, through the plugin in Revit, where the LCA is carried out. The building components are compared to the report "WHOLE LIFE CARBON ASSESSMENT OF 60 BUILDINGS POSSIBILITIES TO DEVELOP BENCHMARKS VALUES FOR LCA OF BUILDINGS" [51] from Aalborg University, where 60 different buildings are assessed on carbon emissions, whereas 22 of them are office buildings. Of these offices, 13 of them are medium size (1.000-10.000 m^2), and 8 of them are large (>10.000 m^2). The construction type of the buildings is categorized as 'heavy' when choosing between light or heavy. Heavy buildings are defined as having load-bearing structures with internal walls or concrete components, while light buildings have load-bearing structures with skeleton constructions. [53]. Building 118 belongs to the medium size category with a GFA of 4.350 m^2 and is a heavy building as it mainly contains brick and concrete.

A boxplot is shown in fig. 5.4 together with the results from Building 118. Only the categories "floor", "wall" and "roof" are shown, as there was no comparison of the ceiling in the report.

According to fig. 5.4, the floor of Building 118 is one of the lowest GWPs of all buildings at 0.65 kg CO_2-eq / m^2 / year. On the other hand, the wall has a GWP much higher than the highest of the facilities at over 2 kg CO_2-eq / m^2 / year, while the roof of Building 118 is just below the 4th quartile at 1.5 kg CO_2-eq / m^2 / year. There may be several reasons for these deviations; one significant impact is the Construction database that uses bundles

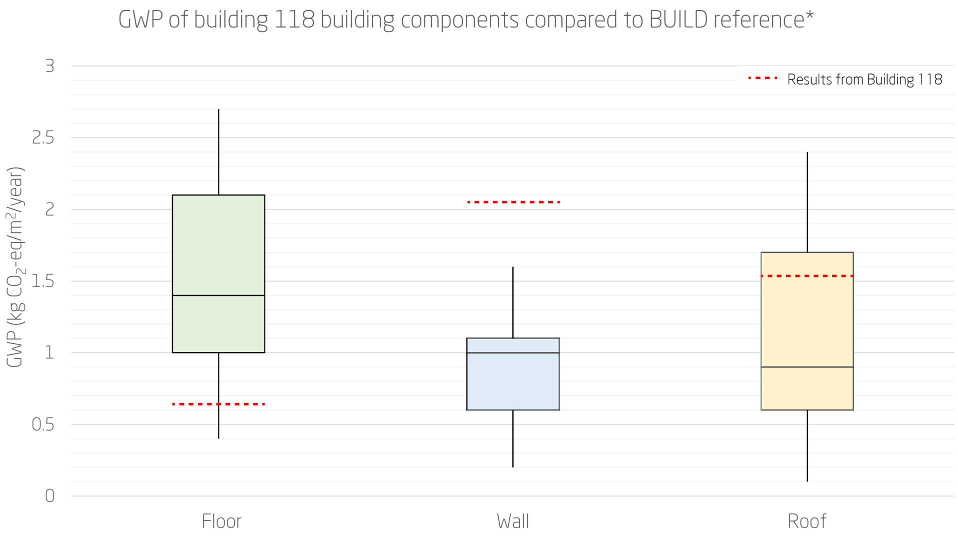


Figure 5.4: Boxplot of carbon assessment from 22 office buildings from the BUILD report [51] compared to the results from the case study of Building 118, resembled with red dotted lines.

of materials, and for some products, may result in redundant materials in the analysis, for instance, if the ID for plywood is added to a wall, there may be excessive materials following such as construction wood and screws, which results in higher GWP. Another reason is the poor quality of the Revit model; often, a component is modeled, and the genetic material is set as 100 % concrete, which may not be correct and creates a false basis for the predefined component fit. Also, the thickness of the components occasionally seems inaccurate, e.g., the floor was in the model set to 14 cm thickness, whereas the typical floor thicknesses range from 30-35 cm [54]. The selection of predefined components was limited, leading to many materials being unavailable in the limited selection. Therefore materials such as aerated concrete had to replace materials such as MDF and drywall, which led to a lot of heavy inner walls, and due to the fact there are 116 offices, this led to a lot of inner walls with GWP higher than they should have been, explaining the higher GWP for walls. Also, most buildings from the Build Report 2021 originate from DGNB, the German Sustainable Building Council, which, based only on guessing, may have chosen some better-performing buildings regarding GWP. Generally, this could also be explained by the age difference in the buildings. For example, Building 118 is from 1970, and the buildings from the report are roughly from 2010-2020, therefore using more modern materials that are more eco-friendly than in 1970. Another point worth mentioning is that the intended point of the tool is not to backwardly assess the carbon emission of a building from a finished Revit model like this case study has done. Instead, the intended way of using the tool is to model the LCA information as the Revit model develops since many choices could benefit the LCA throughout the designing phase. This is where the web application would be utilized as it can fluently run the LCA in the cloud and do many iterations of the LCA while making decisions on what type of predefined components to use.

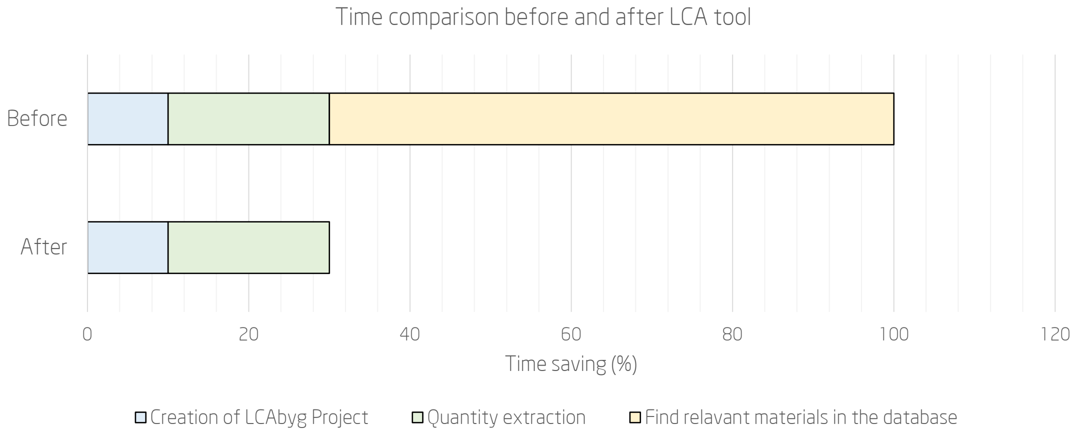


Figure 5.5: Time consumption before and after new tool, according to statement from Sørensen.

5.2.2 Time

To measure the reduction of time the new tool provides, Andreas Sørensen, a sustainability consultant from Rambøll, was asked how long an LCA would take based on Building 118 as a case. His answer was that the time depends on many different things, especially waiting for input from other disciplines and stakeholders and the size of the project. Also, they each have different methodologies, whether renovation or new construction. The conclusion was that it could vary from as little as 10 hours to 100+ hours. However, the LCA was broken down into three steps for a better comparison from before and after.

The result is shown in fig. 5.5, where the time is illustrated in a bar chart before and after the tool. The time is shown in percent, where 100 % is the time it takes to conduct an LCA today. The upper bar is the time an LCA takes based on the three steps from Sørensen's answer, whereas the quantity extraction is clearly the major time-consuming step of 70 %. He mentions other significant steps regarding the LCA as preliminary consultancy, settlement of goals, and interpretation of results. However, these three steps were chosen as the main ones in the actual LCA calculation of the building model. At the bottom of the diagram is the new estimated LCA time, where the quantity extraction is removed, as it has now been automated with a click of a button. The other two steps, "creation of LCAbyg project" and "finding relevant materials in the database" still have to be carried out. To quantify these numbers according to the time basis from 10 to 100+ hours, the actual time saving is shown below.

$$\text{Min. time saving per LCA} = 10 \text{ hours} \cdot 70\% = 7 \text{ hours}$$

$$\text{Max. time saving per LCA} = 100\text{+ hours} \cdot 70\% = 70\text{+ hours}$$

This simplified time estimation shows that there is great potential in saving time when carrying out an LCA when eliminating the quantity extraction step from 7 to over 70 hours, however, this is a simplified calculation, and as Sørensen mentioned, the LCA includes more processes.

All in all, the case study showed how the LCA tool could be used to assess the GWP of the building components of a large office building. The mapping of components showed out to be the most challenging part, as the Revit model had a poor explanation of the building components, with little information about what the layers were included, hence; therefore, used the predefined parts as it made no sense to manually model these components from the information background. Another challenge was the limited choice of predefined components, as it didn't cover all the materials from the Revit components. According to a rough calculation based on a statement from Sørensen, the tool's speed also proved that the time saving of the new method could be reduced by 70 % resulting in a time saving per LCA at 7 to over 70 hours. Overall the results show that the LCA tool still needs many improvements to achieve more stable results, however, the time-saving evaluation shows great potential to save a lot of time in the whole process.

5.3 Validation

Part of the thesis's aim was to ensure the tool provides accurate results, which this section seeks to validate by comparing components created through the tool to reference components. According to the international standard ISO 14040, the accuracy has to be "adequate for the intended purpose of the study" and since the intended purpose relies on the individual project and the information available, the definition remains open. However, the context of the tool is to provide results of the building model at the preliminary stage based on the Revit model, and for this case, the accepted accuracy is set to a deviation of less than 25 % from the reference results.

The predefined components are based on a report "LCA-profiler for bygningsdele" (trans. "LCA-profiles for building components") from the Statens Byggeforskningsinstitut, Aalborg Universitet, Henning Larsen Architects, and Rambøll. The report shows a collection of predefined building components and each component's GWP. Next, these components are recreated in Revit as close as possible to the predefined components, and each component's GWP is calculated. The results are then compared to the report to validate how well the tool can create a desired component. Finally, the results are visualized in the three bar charts in fig. 5.7, fig. 5.8, and fig. 5.9.

An example of such a reconstruction in LCAbyg is shown in fig. 5.6; here, a predefined external wall is shown from the report with five different materials in the left column. The recreation in the right column includes seven materials; one reason is that the steel mesh and the mineral wool are gathered in one component in the report and not in LCAbyg. Another reason is that the chosen LCAbyg material database is based on the Construction-level, which includes bundles of materials in one construction. Therefore unwanted materials may be included in the component, like in fig. 5.6 the 13 mm gypsum board in layer 2 is excessive and will influence the GWP of the component. This is also marked in the table, whereas the LCAbyg has three construction layers, marked with one, two, and three. The following bar chart will compare the reference GWP to the recreated components to validate how well the component's GWP is modeled.

From fig. 5.7, most of the wall components reconstructed in LCAbyg show a good correspondence with the reference components, where five out of eight have a deviation below 25, but due to the remaining three, the average deviation is 34 %. A few of the compo-

Reference*	LCAbyg reconstruction	
180 mm steel reinforced concrete with paint	180 mm betonelement C30/C37	***1***
300 mm mineral wool with steel frame	Steel mesh	
8 mm fiber cement board	300 mm mineral wool	
Wooden battens	Fasternes / screws	
25 mm larch wood cladding	13 mm gipsum board	***2***
-	Construction wood	
-	Fiber cement board	
-	Fasternes / screws	
-	15 mm Pine cladding	***3***
-	Fasternes / screws	
1.14 [kg CO_2 eqv / m^2 / year]	1.30 [kg CO_2 eqv / m^2 / year]	

Figure 5.6: Example of an external wall from the report ”LCA-profiler for bygningsdele” to the left, and the reconstruction of the wall in LCAbyg on the right.

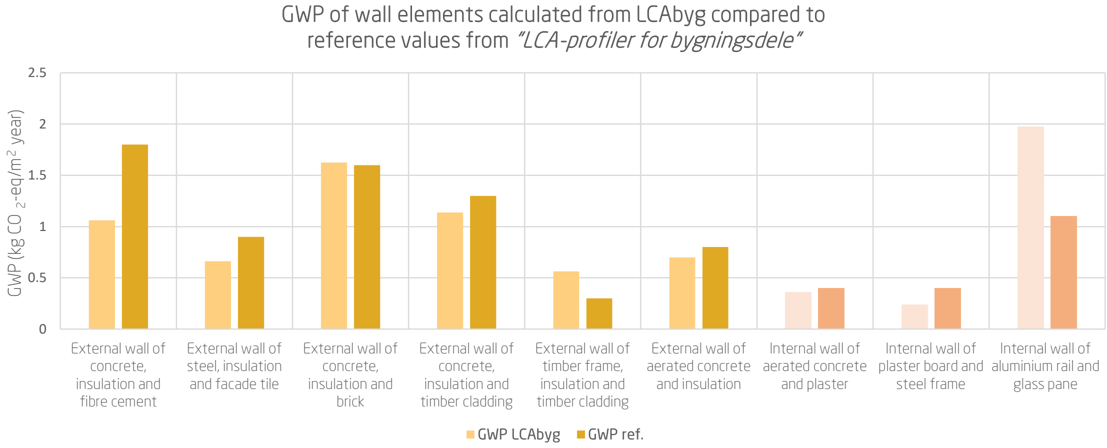


Figure 5.7: Validation of walls reconstructed from the report ”LCA-profiler for bygningsdele” (trans. ”LCA-profiles for building components”). The GWP of the walls compared to the LCA tools result and the report.

nents that deviate from the references are the ”External wall of concrete, insulation and fiber cement” and the ”Internal wall of aluminum rail and glass pane”. One explanation for this higher deviation could be the limitation of the Construction database and the fact that the less common materials are harder to find. One example is the aluminum glass pane, which isn’t available in the Construction database, as it only contains 399 constructions. So instead, a replacement has to be found, which is not always a fair match in terms of GWP.

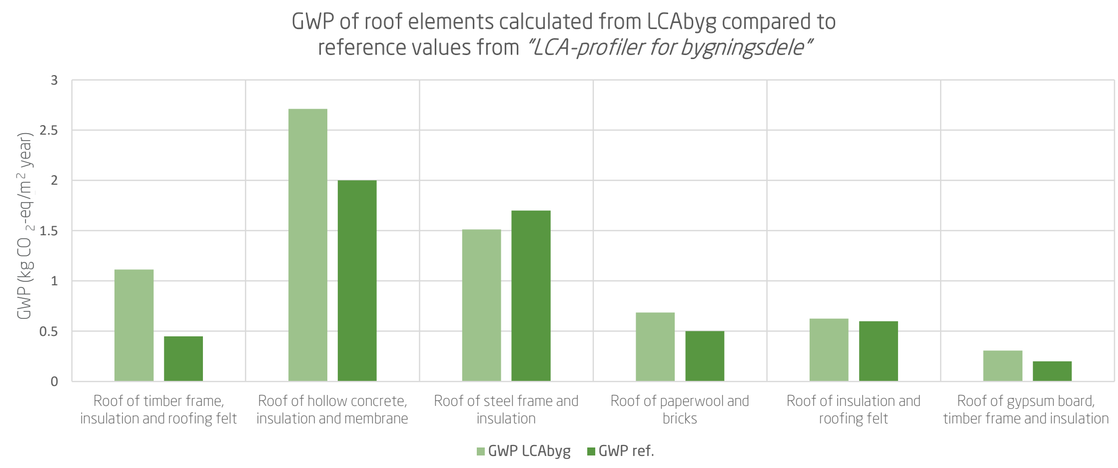


Figure 5.8: Validation of roofs reconstructed from the report ”LCA-profiler for bygningsdele” (trans. ”LCA-profiles for building components”). The GWP of the walls compared to the LCA tools result and the report.

Next, fig. 5.8 shows again a good correspondence with the reference components, with only two components that deviate significantly, which is the ”Roof of timber frame, insulation, and roofing felt” that has a GWP of more than double the reference data and an average deviation of 48 % on all the components in the category. Even though all of the materials are included in the database, the construction does not allow adjustment of the thickness of the materials, which is another factor to take into account. The most common material has a few different thicknesses but is limited.

Finally, slabs and decks were validated according to the reference data. Here, the components deviated more than the previous component categories with an average 101 % deviation. In fact, only the ”Ground slab of linoleum and insulation” and ”Deck of hollow concrete insulation and wood floor” has a good approximation, whereas the remaining components did not. One explanation could be the lack of material in this specific group, as categories like walls and roofs have a more comprehensive selection of materials within the database. However, the larger percentage deviation can also seem a lot higher due to some of the small emissions since an 0.1 kg CO_2-eq / m^2 / year deviation from the ”Ground slab of timber floor, insulation, and void”, does not seem as much, but when the reference value is 0.2 kg CO_2-eq / m^2 / year the deviation is 100 % off, which quickly results in high deviations, especially for the ”Deck of wood frame, insulation, and wood floor”.

Wrapping up the validation of components in five categories; external walls, inner walls, roofs, ground decks, and decks. The majority of the component has a good approximation

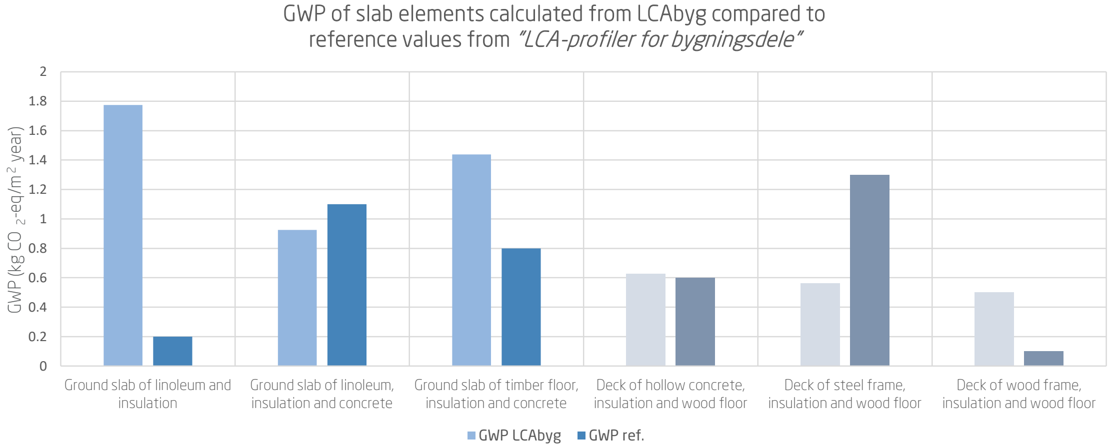


Figure 5.9: Validation of slabs reconstructed from the report "LCA-profiler for bygningsdele" (trans. "LCA-profiles for building components"). The GWP of the walls compared to the LCA tools result and the report.

within 25 % deviation and is perhaps sufficient for an early-stage LCA. However, a few components had deviations up to 400 % deviation which would be catastrophic for an LCA if such a component was used. The average deviation of all the components in total was 57 % which is over double the acceptable percent of 25 %; if the component of 400 % is removed, the final average deviation is 40 %. However, the number of components within the acceptable percent was 11 out of 21, which is just above half. Therefore, the way the tool models components through the Construction LCI database must be reconsidered.

According to the methodology used in the thesis, design science research, from [48], the learnings from the evaluation should be iterated back to the objective and development of the artifact, "LCA tool". As it is an iterative process, this should be done until the initial problem has been sufficiently solved. However, due to the limited time of the thesis, the learnings will instead be explained in the discussion chapter.

5.4 Summary

The case study of Building 118 showed that the results of the LCA tool performed inconsistently, which could be explained in a number of ways. One of the main causes is due to the limited Construction database in LCAbyg and the number of predefined components available. According to the time saving, there is great potential in the tool, however, a number of modifications to the tool have to be made. Later, the validation showed more consistent results, and many of the predefined components showed a good fit to the reference data, however, a few components did not, resulting in an average deviation of 57 %, which is double the acceptable percent of 25 % and 11 of the 21 predefined components had a deviation less than 25 %. The modeling of components through the Construction LCI database must therefore be reconsidered.

6 Discussion

In the previous chapter, the tool's efficacy was demonstrated through its implementation in Building 118 and the validation of pre-specified components. This chapter will focus on the methodology employed, present the findings, and examine three crucial metrics - flexibility, extensibility, and usability - that highlight the decisions made throughout the thesis and some of the weaknesses and strengths of the LCA tool. Finally, the learning will inform future iterations of the LCA tool.

6.1 Results

6.1.1 Case Study

The case study conducted on Building 118 at DTU Campus aimed to showcase the practical application of the tool. The first step involved assessing the level of detail in the Revit model in order to determine whether to utilize the predefined components or to manually model the building components. Given that the detail level in the Revit model was low, it was decided to employ the predefined components. A schedule was created for each building component family, and the corresponding predefined components were selected to achieve the best fit. However, the available options for predefined components were limited, which resulted in some inaccuracies in the selection process (as depicted in fig. 5.1). The process of changing each building component to the corresponding family was relatively straightforward, as the view in fig. 5.2 provided a visual representation of the changes made. Once complete, the components were exported to the CDE, and the LCAbyg tool was able to open and display the results. This process was relatively effortless, especially considering that the changing of components could have been avoided if the Revit model had been created with the desired components from the outset.

The carbon emissions were calculated for each component group and compared to 22 other office buildings from the report "WHOLE LIFE CARBON ASSESSMENT OF 60 BUILDINGS POSSIBILITIES TO DEVELOP BENCHMARKS VALUES FOR LCA OF BUILDINGS" [51] from Aalborg University. However, it must be noted that comparing the results from one building to 22 other buildings is challenging due to the presence of various discrepancies between the two buildings that may impact the results. For instance, most of the buildings in the comparison were 10 to 15 years old, whereas Building 118 was built in 1970. Furthermore, the availability of a Revit model with a pre-conducted LCA and concrete results to compare to was not possible.

A sustainability consultant from Rambøll, Andreas Sørensen, was consulted regarding the amount of time an LCA typically requires. According to Sørensen, the time taken for an LCA is dependent on several factors and could range anywhere between 10 to 100+ hours. The process of conducting an LCA was divided into three stages, namely, the creation of the LCAbyg project, quantity extraction, and the retrieval of relevant material from the database. Results indicated that the majority of the time, approximately 70 %, was consumed by the quantity extraction stage. This step has been automated by the new tool, which could potentially reduce the overall time taken to conduct an LCA. Although this approach is rather basic and only based on the experience of a single individual, it does align with literature, which suggests that 60 % of the time is lost in early stages due to the repetition of data entry, as reported by Durão et al. However, Sørensen also acknowledges that there are several other critical steps involved in conducting an LCA such as preliminary consultancy, setting objectives, and interpretation of results, among others. As a result, the time estimate remains subject to some degree of uncertainty.

6.1.2 Validation

The validation process involved a comparison of 21 different building components, including nine different wall types, six different roof types, three different slab types, and three different deck types based on the report ”LCA-profiler for bygningsdele” (trans. ”LCA-profiles for building components”). The validation consisted of recreating these building components in Revit using the construction material library in an attempt to achieve the best possible representation. However, this approach was heavily dependent on the construction materials utilized, and the options may not always fit the components, leading to subjective guessing and introducing significant bias. Most of the time, the choice was straightforward, resulting in some accurate approximations. However, if new material, such as Hempcrete[4], constituted the majority of the building, the results would have been less satisfactory, as the product is rarely used and not widely available in the database unless a specific EPD was imported. The validation showed that there is potential for approximating existing building components with varying degrees of precision and that the accuracy could be improved by utilizing a more extensive database and transitioning from Construction-level data to product-level data.

6.2 Methodology

The methodology adopted in this research was rooted in the design science research methodology proposed by Peffers, Tuunanen, and Rossi. This methodology is characterized by an iterative approach, where the process of identifying the objective of a solution and publishing it in an academic article is repeated until a satisfactory resolution of the initial problem is achieved. However, in this study, the process was only executed once, which may be viewed as a limitation as further iterations of the tool could have led to significant modifications. Nevertheless, these potential modifications will be documented for future reference in the following sections.

6.2.1 Flexibility

> *”The ability to change or be changed easily according to the situation”* [55]

The tool is a proof-of-concept aimed at addressing the LCA of building components such as walls, floors, ceilings, and roofs. These components have a common characteristic of being layer structures and are connected to the material database in the Revit software, enabling the configuration of multiple LCA materials on a single wall. However, certain building components such as stairs and curtain walls may present challenges in material volume calculation; for example, how do you measure the volume of material of the metal

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[4] ”Hempcrete or hemplime is biocomposite material, a mixture of hemp hurds and lime, sand, or pozzolans, which is used as a material for construction and insulation”

on the railings on a staircase? For a wall, it is an easier calculation as the width and area of the insulation in a given wall are known; the volume is simply the product of the two. The Revit API, which provides the information extracted from the BIM used in the tool, may also result in limitations in accuracy. For example, if the volume of a wall component was extracted, the volume may not have considered the pipes running inside, which should have been subtracted. Other problems may arise for mechanical components, as Revit models rarely contain the actual mechanical component, according to Winther (restated from a meeting with Frederik Blum Winther), which could lead to the wrong components that may have a significant impact on the LCA. This is another reason to aim for a high maturity level to ensure the HVAC engineers have inserted the correct components with the valid LCA material ID.

The tool was developed in alignment with the Danish building regulation BR23 and was based on the Danish software LCAbyg and the German Ökobau database for materials. This resulted in basing the entire tool on regulation from BR23, which minimizes the operability in other countries. The tool is based on the Danish software LCAbyg, which uses the German Ökobau database for materials and therefore suits the calculation of LCA in Denmark very well. However, the software has some limitations that impact the flexibility of the tool. First of all, the software is only in Danish, secondly, the material library is limited to Ökobau, but the import of external EPD is an option, however, it hasn't been the focus as generic data from Ökobau is acceptable in BR23. Recently, LCAbyg released the API which enables the calculation of LCA in the cloud and bypasses the program. This allows the tool a lot more flexibility as a plugin from Revit can be coded to directly pass the data needed for the LCA to the API and retrieve the results directly from a web application, but the options from there are endless, more on how utilization of the API can extend the possibilities for the tool in the section ”Future Work”.

The CDE facilitates accessibility to data through the use of an open data format, such as JSON. This allows for easier utilization of data, as demonstrated in the ”Open Interoperability Standard” illustrated in 4.3. This level of openness provides added flexibility, as the data can be accessed by tools beyond LCAbyg. The implementation of the CDE also enhances collaboration among stakeholders and reduces errors by promoting a single source of truth in the BIM process, contributing to the advancement of BIM maturity levels.

6.2.2 Extensibility

> *”the quality of being designed to allow the addition of new capabilities or functionality”* [56]

Before creating a Revit model, there has already been a design stage where the initial ideas of the design should be, for instance, in Rhino. When the design is settled, it minimizes the option of changing it later, which becomes a barrier for LCA if it isn't included in the early phase. Rhino is a common 3D modeling software used in the early design phase; if the tool could connect to the same database and parse the LCA data to the tool, their barrier would disappear. In fact, Nicolaj Langkjær created such a tool in Rhino / Grasshopper that uses predefined building components in the model and parses the data to LCAbyg, which essentially is the same concept for this tool, instead the software is using Revit. In order to utilize models are create in different software very useful data format is the IFC. The IFC schema is a standardized, digital description of the built asset; this is an open data schema that can create a frozen copy of a model in one software and open it in another, for example, with the LCA data embedded. This bridge could have been implemented in the tool, as it adds a lot of flexibility when working in multiple BIM software, however, there are a few obstacles to using OFC, as editing an IFC after export can be difficult. The concept of using IFC is similar to the CDE, which also creates an open data schema and enables to store specific BIM data in an accessible format, in this case, JSON, which allows everyone to use and manipulate it.

EPD is crucial for a reliable LCA result, especially in the later phases of designing, as it gives a specific dataset of the actual product used. LCAbyg allows EPD to be imported into a project, however, the EPD has to be in a certain file format that only LCAbyg can import. The EPDs are only available through EPD-Denmark, which is a Danish EPD database. The database is currently working on collaborating with more databases globally to create a larger database, but currently, it is only EPD-Denmark that is available to import to LCAbyg [57]. On top of that, LCAbyg only allows importing one EPD at a time, making it very time-consuming for larger construction projects. Hopefully, this process will be more fluid in the future, allowing to use of materials from external databases.

The tool has shown how to extract quantities from a Revit model through an API to a database, however, there still are some gaps in data needed to carry out an LCA. E.g., the energy data of the building, which isn't typically available in Revit. An energy software that provides an API could easily be implemented in the tool for a completely automized LCA calculation. Another option is to utilize the existing services on the VC CDE, which already have an HVAC simulator; if such a service could parse the heating and cooling loads to the LCA tool, the tool could be even more automized. Taking a step further, AI could even be implemented in such a system. Suppose the data is accessible to train such a model. In that case, the tool could estimate an LCA result without having all the necessary data available, but existing data give an estimated guess on what the final LCA result would be. This could be an interesting method through all the design phases, and the more information on the LCA there would become, the more certain the model prediction would be.

6.2.3 Usability

> *"The ability to change or be changed easily according to the situation"* [58]

User-friendliness has not been the top priority in the early phases of the development of the LCA tool. The workflow contains a series of steps before being able to export the relevant information from Revit to LCAbyg, as there haven't been created a graphical user interface (GUI) for all the steps. For example, when adding the material ID, a separate Excel spreadsheet has to be opened before being able to search for the required material. If a window with an overview of the materials were integrated into Revit, the process would have been intuitive and user-friendly. However, a few places have prioritized making such a GUI for better usability. One example is the "LCA tool" tab integrated into the Revit menu, seen in fig. 4.12. Two buttons have been created that 1) transfer the building components to LCAbyg and 2) open LCAbyg. Another example is the web-based application where the necessary operations for conducting an updated LCA have been created, shown in fig. 4.13. The website contains three links, ”Run LCA”, ”Update data” and ”Show results”, which all are programmed scripts that communicate with the BIM data and LCAbyg API.

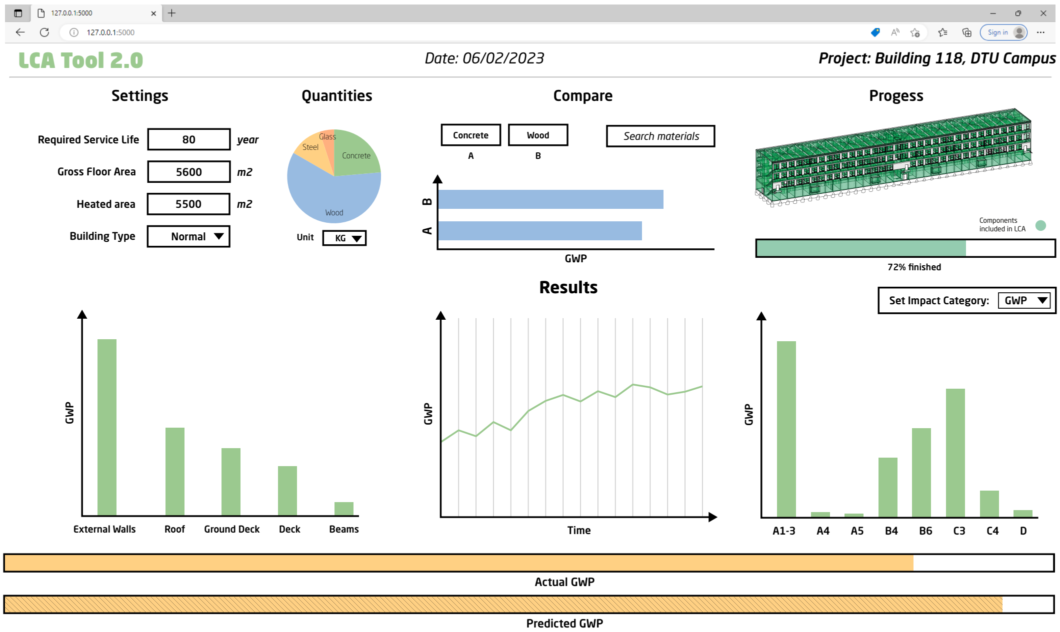
Another measure to increase the usability of the tool was to implement the predefined components so that the components could be used without needing background knowledge of the materials' properties. Since the tool is developed with the focus of the architects, they would, in theory, be able to create the majority of the building with predefined components, as they contain a realistic composition of materials. Later on, other disciplines would be able to edit these compositions to their specific needs.

Finally, the last measure of improving the usability of the tool was the 3D model view in Revit, which visualize what component in the model has been added material IDs. The view is simply filtering the materials that contain the material IDs and highlights these in a slightly transparent green. As the process of adding material to the building, more and more of the model would turn green, shown in fig. 5.2, where most of the materials are green after the material IDs have been added to the corresponding components. In addition to the view could be a bar from 0 to 100 % that would more clearly show the percentage amount of components left needed to have added material IDs. However, though actions have been made to improve the usability of the LCA tool, in regard to an architect, still some steps are missing before a new user would be able to use the tool without explanation.

6.3 Future Work

As the LCA tool is still in the development phase and the tool just showed a proof-of-concept, there are obviously many steps before the tool would be ready to be implemented in a professional environment. One of the major improvements to the tool is to reprogram the data structure of the tool so that each material in Revit would, instead of referring to a construction, refer to a product; of course, this means that more products have to be inputted to the model, however, it allows a lot more flexibility and accurate components, instead of the predefined, that showed out to not very accurate and instead create new predefined components that would, in theory, be a lot more precise, if the data structure would be on the product level, as it would avoid excess materials in the components.

As the tool only takes into account the building model components an obvious improvement would be to extend the tool to include the operation of energy and usage. Data like these could be imported from an external energy frame software, for example, Be18, which holds information on data such as heating, cooling water usage, etc. The web application currently only holds three operations, however, there is great potential to create more beneficial extensions. If the web application had options for the early design phases of, for example, changing all constructions material to wood, steel, or concrete and being able to compare these. This would add a lot of flexibility to the tool and improve the tool as a designing tool for optimizing the LCA. Furthermore, the web application could evolve into an interactive dashboard, where different data could be used to enhance usability. For example, the costs of the project, the project timeline, and when the expected dead-



Required Service Life 80 year

Gross Floor Area 5600 m2

Heated area 5500 m2

Building Type Normal

Unit KG

Set Impact Category: GWP

Figure 6.1: Proposed interactive dashboard for future work of the LCA tool. Note that this is only an illustration and is created based on the original web application shown in fig. 4.13.

line for the project is finished. The result page could also be more detailed; instead of only showing the traditional impact categories, it also shows the impact over time, the impacts on individual building categories, and the impact on embodied vs. operational emissions. These ideas have been implemented in a proposed interactive dashboard shown in fig. 6.1.

Using modern technologies such as machine learning (ML) to predict final LCA results based on the initial data from the model and constantly update throughout the development of the model. This, of course, requires a lot of training data for a model to become usable, however, a software called "Sustainable Minds tool" have already implemented ML in their LCA tool, enabling the creation of comprehensive LCA results from the design phase inputs.[59] Furthermore, artificial intelligence could be added to make suggestions on material choice or geometry based on the lowest impact while keeping the properties sufficient.

6.4 Summary

The learnings of the case study and validation, including accuracy and time spent, were critically discussed, highlighting the tool's strengths and weaknesses. The methodology used in the study was briefly examined, but due to constraints on the thesis, the second iteration of the Design Science Method was executed in written form, focusing on the three key aspects of flexibility, extensibility, and usability. Finally, the potential future works of the tool were outlined, including enhancements to its capabilities that are illustrated in the proposed interactive dashboard (as depicted in fig. 6.1).

7 Conclusion

The aim of the thesis was to develop a proof-of-concept cloud-based BIM-LCA tool that holds the potential to reduce the time spent carrying out an LCA while providing accurate results. The tool was developed using a combination of C# and Python programming languages, enabling the extraction of relevant data from a Revit model to a CDE accessible in the cloud, and thereby both BIM- and cloud-based.

To address whether or not the tool holds the potential to reduce the time spent carrying out an LCA, Sørensen, LCA Consultant in Rambøll, was asked to estimate the contribution of three aspects of the LCA process: creation of the LCAbyg project, finding relevant materials in the database, and quantity extraction, which he estimated to be 10 %, 20 % and 70 %, based on the case study for Building 118. Since the tool automatizes the quantity approach, the step is neglected and thereby only contains the creation of the LCAbyg project and finding relevant materials in the database that together consist of 30 %, hence an argument that the tool holds the potential to reduce the time spent carrying out an LCA of 70 %. Additionally, the time spent carrying out an LCA today, is between 10 to 100+ hours, according to Sørensen, which leads to a potential reduction from 7 to over 70 hours per LCA. However, the calculation is greatly simplified and the LCA does contain more nuances than these three steps. The time of carrying out an LCA also depends on what approach is used and with which tools. Only asking one person gives a more one-sided result.

To ensure the LCA tool provided accurate results the tool was both evaluated in the case study of Building 118 and later validated based on the proposed predefined components. The case study on Building 118, showed inconsistent results, and especially the wall component category deviated significantly from the comparing 22 office buildings, yet the floor and roof component categories were within the min and max bounds of the reference office buildings. However, these results may not accurately reflect the accuracy of the tool, since the 22 reference buildings aren't entirely comparable to Building 118.

Therefore a validation was conducted based on the predefined components. These components were compared to a report "LCA-profiler for bygningsdele" (trans. "LCA-profiles for building components"), which contained concrete GWP data of each component, and was, therefore, more comparable. The components were categorized into external walls, internal walls, roofs, slabs, and decks. Overall 11 of 21 components were within the accepted deviation of 25 %, which is just above half. The other half contained components that were deviating a lot since the database didn't contain all of the materials and therefore substitutes were replaced, which resulted in a few highly deviating components, resulting in an average deviation of 57 % of all the components and 40 % if neglecting the outlier, hence above the accepted accuracy of 25 % deviation.

In conclusion, while the tool demonstrated potential in reducing the time spent on LCA, with a potential time saving of 70 % or 7 to over 70 hours per LCA, the accuracy of the results was not found to be accurate, with a 57 % average deviation larger than the acceptable limit of 25 % deviation.

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A Appendix

Validation results from LCAbyg of predefined components

Beskrivelse	Navn	Total Udskiftninger	Total GWP ex_c3 kg CO_2-eq.	Total GWP ex_c4 kg CO_2-eq.	Total GWP ex_d kg CO_2-eq.	Total GWP a1_3 kg CO_2-eq.	Total GWP a4 kg CO_2-eq.	Total GWP a5 kg CO_2-eq.	Total GWP b4 kg CO_2-eq.	Total GWP b6 kg CO_2-eq.	Total GWP c3 kg CO_2-eq.	Total GWP c4 kg CO_2-eq.	Total GWP d kg CO_2-eq.
Sum	Bygning		0.00E+00	0.00E+00	0.00E+00	7.78E-03	0.00E+00	0.00E+00	5.99E-03	0.00E+00	5.12E-03	1.13E-03	-3.70E-03
Sum	Drift		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Driftforbrug el	El (Fremskrivning 2020-2040)		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Driftforbrug varme	Naturgas (Fremskrivning 2020-2040)		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Byggeproces			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Opførelse / montering			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bygge- og anlægsmaskiner			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	Drift		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Driftforbrug el	El (Fremskrivning 2020-2040)		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Driftforbrug varme	Naturgas (Fremskrivning 2020-2040)		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	Bygningsdel		0.00E+00	0.00E+00	0.00E+00	7.78E-03	0.00E+00	0.00E+00	5.99E-03	0.00E+00	5.12E-03	1.13E-03	-3.70E-03
Gruppe	Dæk		0.00E+00	0.00E+00	0.00E+00	-4.03E-05	0.00E+00	0.00E+00	4.70E-04	0.00E+00	1.24E-03	1.19E-05	-5.20E-04
Undergruppe	Etagedæk		0.00E+00	0.00E+00	0.00E+00	-4.03E-05	0.00E+00	0.00E+00	4.70E-04	0.00E+00	1.24E-03	1.19E-05	-5.20E-04
Bygningsdel	Etagedæk af beton huldæk, isolering og trægulv		0.00E+00	0.00E+00	0.00E+00	2.97E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.26E-04	2.87E-07	-1.55E-04
Konstruktion	Dæk, betonelement, forspændt huldæk 0,18/7,0		0.00E+00	0.00E+00	0.00E+00	5.17E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.57E-06	6.14E-08	-6.94E-05
Byggevare	Armeringsnet	0	0.00E+00	0.00E+00	0.00E+00	6.15E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.14E-08	-3.54E-05
Byggevare	Beton C45/55, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	4.55E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.57E-06	0.00E+00	-3.41E-05
Konstruktion	Gulv, trægulv på strøer		0.00E+00	0.00E+00	0.00E+00	-2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-04	2.26E-07	-8.52E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-3.12E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-05	0.00E+00	-1.13E-05
Byggevare	Mineraluld, alm.	0	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Træ, fyrretræ (12% fugt / 10,7% H2O)	0	0.00E+00	0.00E+00	0.00E+00	-2.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E-04	0.00E+00	-7.16E-05
Bygningsdel	Etagedæk af stålskelet, isolering og trægulv		0.00E+00	0.00E+00	0.00E+00	-2.07E-05	0.00E+00	0.00E+00	2.57E-04	0.00E+00	3.18E-04	6.38E-06	-1.36E-04
Konstruktion	Gulv, trægulv på strøer		0.00E+00	0.00E+00	0.00E+00	-2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-04	2.26E-07	-8.52E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-3.12E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-05	0.00E+00	-1.13E-05
Byggevare	Mineraluld, alm.	0	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Træ, fyrretræ (12% fugt / 10,7% H2O)	0	0.00E+00	0.00E+00	0.00E+00	-2.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E-04	0.00E+00	-7.16E-05
Konstruktion	Loft, gipsplader på stålprofiler		0.00E+00	0.00E+00	0.00E+00	1.27E-04	0.00E+00	0.00E+00	1.44E-04	0.00E+00	4.52E-07	5.74E-06	-2.55E-05
Byggevare	Afretningslag, cementbaseret	0	0.00E+00	0.00E+00	0.00E+00	2.75E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E-06	0.00E+00
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	1	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	8.53E-10	-4.53E-06
Byggevare	Gipskartonplade 13 mm, hulplade	1	0.00E+00	0.00E+00	0.00E+00	3.41E-05	0.00E+00	0.00E+00	3.73E-05	0.00E+00	0.00E+00	3.19E-06	0.00E+00
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	2.33E-05	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Overflade, Facademaling, akryl maling	5	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	5.04E-05	0.00E+00	0.00E+00	7.13E-08	-2.69E-07
Byggevare	Stål, valsede profiler og plader	1	0.00E+00	0.00E+00	0.00E+00	2.81E-05	0.00E+00	0.00E+00	2.82E-05	0.00E+00	4.61E-08	0.00E+00	-2.07E-05
Konstruktion	Loft, nedhængt demonterbart systemloft		0.00E+00	0.00E+00	0.00E+00	7.19E-05	0.00E+00	0.00E+00	1.13E-04	0.00E+00	7.92E-07	4.14E-07	-2.52E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	1	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	8.53E-10	-4.53E-06
Byggevare	Mineraluld, trykfast til tagsystem	2	0.00E+00	0.00E+00	0.00E+00	3.93E-05	0.00E+00	0.00E+00	8.09E-05	0.00E+00	7.46E-07	4.13E-07	0.00E+00
Byggevare	Stål, valsede profiler og plader	1	0.00E+00	0.00E+00	0.00E+00	2.81E-05	0.00E+00	0.00E+00	2.82E-05	0.00E+00	4.61E-08	0.00E+00	-2.07E-05
Bygningsdel	Etagedæk af træskelet, isolering og trægulv		0.00E+00	0.00E+00	0.00E+00	-3.17E-04	0.00E+00	0.00E+00	2.13E-04	0.00E+00	5.97E-04	5.25E-06	-2.30E-04
Konstruktion	Gulv, trægulv på strøer		0.00E+00	0.00E+00	0.00E+00	-2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-04	2.26E-07	-8.52E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-3.12E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-05	0.00E+00	-1.13E-05
Byggevare	Mineraluld, alm.	0	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Træ, fyrretræ (12% fugt / 10,7% H2O)	0	0.00E+00	0.00E+00	0.00E+00	-2.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E-04	0.00E+00	-7.16E-05
Konstruktion	Loft, gipsplader på trælægter		0.00E+00	0.00E+00	0.00E+00	-9.74E-05	0.00E+00	0.00E+00	2.13E-04	0.00E+00	2.80E-04	5.02E-06	-1.45E-04
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	1	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	8.53E-10	-4.53E-06
Byggevare	Gipskartonplade 13 mm, hulplade	1	0.00E+00	0.00E+00	0.00E+00	3.41E-05	0.00E+00	0.00E+00	3.73E-05	0.00E+00	0.00E+00	3.19E-06	0.00E+00
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	1	0.00E+00	0.00E+00	0.00E+00	-1.93E-04	0.00E+00	0.00E+00	8.68E-05	0.00E+00	2.80E-04	0.00E+00	-1.40E-04
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	2.33E-05	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Overflade, Facademaling, akryl maling	5	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	5.04E-05	0.00E+00	0.00E+00	7.13E-08	-2.69E-07
Byggevare	Overflade, Facademaling, grunder, dispersion	5	0.00E+00	0.00E+00	0.00E+00	2.14E-06	0.00E+00	0.00E+00	1.09E-05	0.00E+00	0.00E+00	3.56E-08	-1.54E-07
Byggevare	Puds, kalk-gips, inde	0	0.00E+00	0.00E+00	0.00E+00	2.21E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-06	0.00E+00
Gruppe	Tage		0.00E+00	0.00E+00	0.00E+00	2.32E-03	0.00E+00	0.00E+00	3.01E-03	0.00E+00	1.60E-03	4.43E-05	-8.77E-04
Undergruppe	Tage		0.00E+00	0.00E+00	0.00E+00	2.32E-03	0.00E+00	0.00E+00	3.01E-03	0.00E+00	1.60E-03	4.43E-05	-8.77E-04
Bygningsdel	Tag af beton huldæk, isolering og membran		0.00E+00	0.00E+00	0.00E+00	1.60E-03	0.00E+00	0.00E+00	1.08E-03	0.00E+00	2.93E-05	1.11E-05	-9.53E-05
Konstruktion	Midterlag, forspændt huldæk 0,18/7,0 m		0.00E+00	0.00E+00	0.00E+00	1.60E-03	0.00E+00	0.00E+00	1.08E-03	0.00E+00	2.93E-05	1.11E-05	-9.53E-05
Byggevare	Armeringsnet	0	0.00E+00	0.00E+00	0.00E+00	1.08E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-07	-6.19E-05
Byggevare	Beton C45/55, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	4.47E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.39E-06	0.00E+00	-3.34E-05
Byggevare	Mineraluld, trykfast til tagsystem	1	0.00E+00	0.00E+00	0.00E+00	1.05E-03	0.00E+00	0.00E+00	1.08E-03	0.00E+00	1.99E-05	1.10E-05	0.00E+00
Bygningsdel	Tag af gipsplade, træskelet og isolering		0.00E+00	0.00E+00	0.00E+00	1.30E-05	0.00E+00	0.00E+00	1.27E-04	0.00E+00	1.66E-04	1.14E-06	-4.83E-05
Konstruktion	Efterisolering af skrå loft indefra, mineraluld		0.00E+00	0.00E+00	0.00E+00	1.30E-05	0.00E+00	0.00E+00	1.27E-04	0.00E+00	1.66E-04	1.14E-06	-4.83E-05
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	1	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	1.19E-05	0.00E+00	6.95E-06	0.00E+00	-6.86E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-1.08E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.57E-04	0.00E+00	-3.92E-05
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	7.56E-05	0.00E+00	0.00E+00	7.77E-05	0.00E+00	1.35E-06	7.49E-07	0.00E+00
Byggevare	Mineraluld, løsfyld	1	0.00E+00	0.00E+00	0.00E+00	3.60E-05	0.00E+00	0.00E+00	3.71E-05	0.00E+00	7.01E-07	3.88E-07	0.00E+00
Bygningsdel	Tag af isolering og tagpap		0.00E+00	0.00E+00	0.00E+00	1.91E-04	0.00E+00	0.00E+00	4.23E-04	0.00E+00	1.66E-06	1.20E-05	0.00E+00
Konstruktion	Ren. Indvendig efterisolering af kviste (isolering)		0.00E+00	0.00E+00	0.00E+00	9.29E-05	0.00E+00	0.00E+00	9.55E-05	0.00E+00	1.66E-06	9.21E-07	0.00E+00
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	9.29E-05	0.00E+00	0.00E+00	9.55E-05	0.00E+00	1.66E-06	9.21E-07	0.00E+00
Konstruktion	Tagbelægning, tagpap		0.00E+00	0.00E+00	0.00E+00	9.80E-05	0.00E+00	0.00E+00	3.27E-04	0.00E+00	0.00E+00	1.11E-05	0.00E+00
Byggevare	Tagpap, bitumen toplag, skiferbestrøet	3	0.00E+00	0.00E+00	0.00E+00	6.71E-05	0.00E+00	0.00E+00	2.20E-04	0.00E+00	0.00E+00	6.15E-06	0.00E+00
Byggevare	Tagpap, bitumen undermembran	3	0.00E+00	0.00E+00	0.00E+00	3.09E-05	0.00E+00	0.00E+00	1.08E-04	0.00E+00	0.00E+00	4.96E-06	0.00E+00
Bygningsdel	Tag af papiruld til tagrum med teglsten		0.00E+00	0.00E+00	0.00E+00	-1.90E-04	0.00E+00	0.00E+00	3.27E-04	0.00E+00	5.56E-04	8.53E-10	-3.06E-04
Konstruktion	Efterisolering af loft i tilgængelig tagrum,		0.00E+00	0.00E+00	0.00E+00	-3.16E-04	0.00E+00	0.00E+00	1.24E-04	0.00E+00	4.40E-04	0.00E+00	-2.74E-04
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	1	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	1.19E-05	0.00E+00	6.95E-06	0.00E+00	-6.86E-06
Byggevare	Papiruldsisolering, løsfyld	1	0.00E+00	0.00E+00	0.00E+00	-3.21E-04	0.00E+00	0.00E+00	1.12E-04	0.00E+00	4.33E-04	0.00E+00	-2.67E-04
Konstruktion	Tagbelægning, tegl		0.00E+00	0.00E+00	0.00E+00	1.26E-04	0.00E+00	0.00E+00	2.02E-04	0.00E+00	1.16E-04	8.53E-10	-3.26E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-7.72E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-04	0.00E+00	-2.80E-05
Byggevare	Tagsten, tegl	1	0.00E+00	0.00E+00	0.00E+00	1.98E-04	0.00E+00	0.00E+00	2.02E-04	0.00E+00	3.78E-06	0.00E+00	-2.31E-06
Bygningsdel	Tag af stålskelet og isolering		0.00E+00	0.00E+00	0.00E+00	8.29E-04	0.00E+00	0.00E+00	5.53E-04	0.00E+00	1.20E-04	7.74E-06	-1.96E-04
Konstruktion	Loft, gipsplader på stålprofiler		0.00E+00	0.00E+00	0.00E+00	1.27E-04	0.00E+00	0.00E+00	1.44E-04	0.00E+00	4.52E-07	5.74E-06	-2.55E-05
Byggevare	Afretningslag, cementbaseret	0	0.00E+00	0.00E+00	0.00E+00	2.75E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E-06	0.00E+00
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	1	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	8.53E-10	-4.53E-06

Byggevare	Gipskartonplade 13 mm, hulplade	1	0.00E+00	0.00E+00	0.00E+00	3.41E-05	0.00E+00	0.00E+00	3.73E-05	0.00E+00	0.00E+00	3.19E-06	0.00E+00
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	2.33E-05	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Overflade, Facademaling, akryl maling	5	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	5.04E-05	0.00E+00	0.00E+00	7.13E-08	-2.69E-07
Byggevare	Stål, valsede profiler og plader	1	0.00E+00	0.00E+00	0.00E+00	2.81E-05	0.00E+00	0.00E+00	2.82E-05	0.00E+00	4.61E-08	0.00E+00	-2.07E-05
Konstruktion	Midterlag, ståldæk		0.00E+00	0.00E+00	0.00E+00	5.77E-04	0.00E+00	0.00E+00	2.07E-04	0.00E+00	4.22E-06	2.00E-06	-1.38E-04
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	2.02E-04	0.00E+00	0.00E+00	2.07E-04	0.00E+00	3.61E-06	2.00E-06	0.00E+00
Byggevare	Stål, valsede profiler og plader	0	0.00E+00	0.00E+00	0.00E+00	3.73E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11E-07	0.00E+00	-1.37E-04
Konstruktion	Tagbelægning, tegl		0.00E+00	0.00E+00	0.00E+00	1.26E-04	0.00E+00	0.00E+00	2.02E-04	0.00E+00	1.16E-04	8.53E-10	-3.26E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-7.72E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-04	0.00E+00	-2.80E-05
Byggevare	Tagsten, tegl	1	0.00E+00	0.00E+00	0.00E+00	1.98E-04	0.00E+00	0.00E+00	2.02E-04	0.00E+00	3.78E-06	0.00E+00	-2.31E-06
Bygningsdel	Tag af træskelet, isolering og tagpap		0.00E+00	0.00E+00	0.00E+00	-1.27E-04	0.00E+00	0.00E+00	5.00E-04	0.00E+00	7.28E-04	1.23E-05	-2.30E-04
Konstruktion	Loft, gipsplader på trælægter		0.00E+00	0.00E+00	0.00E+00	-9.74E-05	0.00E+00	0.00E+00	2.13E-04	0.00E+00	2.80E-04	5.02E-06	-1.45E-04
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	1	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	8.53E-10	-4.53E-06
Byggevare	Gipskartonplade 13 mm, hulplade	1	0.00E+00	0.00E+00	0.00E+00	3.41E-05	0.00E+00	0.00E+00	3.73E-05	0.00E+00	0.00E+00	3.19E-06	0.00E+00
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	1	0.00E+00	0.00E+00	0.00E+00	-1.93E-04	0.00E+00	0.00E+00	8.68E-05	0.00E+00	2.80E-04	0.00E+00	-1.40E-04
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	2.33E-05	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Overflade, Facademaling, akryl maling	5	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	5.04E-05	0.00E+00	0.00E+00	7.13E-08	-2.69E-07
Byggevare	Overflade, Facademaling, grunder, dispersion	5	0.00E+00	0.00E+00	0.00E+00	2.14E-06	0.00E+00	0.00E+00	1.09E-05	0.00E+00	0.00E+00	3.56E-08	-1.54E-07
Byggevare	Puds, kalk-gips, inde	0	0.00E+00	0.00E+00	0.00E+00	2.21E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-06	0.00E+00
Konstruktion	Midterlag, bjælkespær, ventileret, skrå tage,		0.00E+00	0.00E+00	0.00E+00	-2.95E-05	0.00E+00	0.00E+00	2.87E-04	0.00E+00	4.48E-04	7.30E-06	-8.56E-05
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	1	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	1.19E-05	0.00E+00	6.95E-06	0.00E+00	-6.86E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	6.67E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-09	-3.39E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-1.94E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.82E-04	0.00E+00	-7.05E-05
Byggevare	Krydsfinérplade	0	0.00E+00	0.00E+00	0.00E+00	-1.10E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-04	0.00E+00	-4.87E-06
Byggevare	Mineraluld, alm.	1	0.00E+00	0.00E+00	0.00E+00	1.96E-04	0.00E+00	0.00E+00	2.02E-04	0.00E+00	3.52E-06	1.95E-06	0.00E+00
Byggevare	Mineraluld, løsfyld	1	0.00E+00	0.00E+00	0.00E+00	3.60E-05	0.00E+00	0.00E+00	3.71E-05	0.00E+00	7.01E-07	3.88E-07	0.00E+00
Byggevare	Tagpap, bitumen undermembran	1	0.00E+00	0.00E+00	0.00E+00	3.09E-05	0.00E+00	0.00E+00	3.59E-05	0.00E+00	0.00E+00	4.96E-06	0.00E+00
Gruppe	Terrændæk		0.00E+00	0.00E+00	0.00E+00	1.61E-03	0.00E+00	0.00E+00	1.82E-03	0.00E+00	1.12E-03	1.03E-03	-1.48E-03
Undergruppe	Terrændæk		0.00E+00	0.00E+00	0.00E+00	1.61E-03	0.00E+00	0.00E+00	1.82E-03	0.00E+00	1.12E-03	1.03E-03	-1.48E-03
Bygningsdel	Terrændæk af linoleum, beton, isolering		0.00E+00	0.00E+00	0.00E+00	7.96E-04	0.00E+00	0.00E+00	1.68E-05	0.00E+00	6.08E-05	4.52E-05	-6.68E-05
Konstruktion	Gulv, beton slidlag		0.00E+00	0.00E+00	0.00E+00	2.77E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.48E-05	-1.20E-06
Byggevare	Afretningslag, cementbaseret	0	0.00E+00	0.00E+00	0.00E+00	2.75E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E-05	0.00E+00
Byggevare	EPS isolering til lofter / gulve og kælderydervæg /	0	0.00E+00	0.00E+00	0.00E+00	2.02E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.29E-06	-1.20E-06
Konstruktion	Gulv, linoleum		0.00E+00	0.00E+00	0.00E+00	1.93E-04	0.00E+00	0.00E+00	1.68E-05	0.00E+00	5.18E-05	2.03E-05	-1.58E-05
Byggevare	Afretningslag, cementbaseret	0	0.00E+00	0.00E+00	0.00E+00	2.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-05	0.00E+00
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	0	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.95E-06	0.00E+00	-3.43E-06
Byggevare	EPS isolering til lofter / gulve og kælderydervæg /	0	0.00E+00	0.00E+00	0.00E+00	2.02E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.29E-06	-1.20E-06
Byggevare	Linoleum gulvbelægning (tykkelse 0,0025 m)	1	0.00E+00	0.00E+00	0.00E+00	-4.06E-05	0.00E+00	0.00E+00	4.24E-06	0.00E+00	4.48E-05	0.00E+00	-1.11E-05
Byggevare	Overflade, Indendørsmaling, emulsions maling,	2	0.00E+00	0.00E+00	0.00E+00	6.23E-06	0.00E+00	0.00E+00	1.25E-05	0.00E+00	0.00E+00	3.56E-08	-7.71E-08
Konstruktion	Terrændæk, beton, 120 mm		0.00E+00	0.00E+00	0.00E+00	3.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.02E-06	3.07E-08	-4.98E-05
Byggevare	Armeringsnet	0	0.00E+00	0.00E+00	0.00E+00	3.08E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E-08	-1.77E-05
Byggevare	Beton C25/30, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	2.96E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.02E-06	0.00E+00	-3.21E-05
Bygningsdel	Terrændæk af trægulv, beton og isolering		0.00E+00	0.00E+00	0.00E+00	1.61E-04	0.00E+00	0.00E+00	6.01E-04	0.00E+00	3.56E-04	3.29E-04	-4.72E-04
Konstruktion	Ex. Terrændæk, uarmeret beton 100 mm		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.51E-06	0.00E+00	-2.68E-05
Byggevare	Beton C25/30, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.51E-06	0.00E+00	-2.68E-05
Konstruktion	Gulv, trægulv på strøer		0.00E+00	0.00E+00	0.00E+00	-2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-04	2.26E-07	-8.52E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-3.12E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-05	0.00E+00	-1.13E-05
Byggevare	Mineraluld, alm.	0	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Træ, fyrretræ (12% fugt / 10,7% H2O)	0	0.00E+00	0.00E+00	0.00E+00	-2.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E-04	0.00E+00	-7.16E-05
Konstruktion	Underlag, isolering EPS 350 mm og singels		0.00E+00	0.00E+00	0.00E+00	3.81E-04	0.00E+00	0.00E+00	6.01E-04	0.00E+00	3.24E-05	3.29E-04	-3.60E-04
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	1	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	1.19E-05	0.00E+00	6.95E-06	0.00E+00	-6.86E-06
Byggevare	EPS isolering til vægge og tage 035	1	0.00E+00	0.00E+00	0.00E+00	2.60E-04	0.00E+00	0.00E+00	5.89E-04	0.00E+00	0.00E+00	3.29E-04	-3.47E-04
Byggevare	Grus 2-32 mm, tørret	0	0.00E+00	0.00E+00	0.00E+00	1.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.55E-05	0.00E+00	-7.12E-06
Bygningsdel	Terrændæk af trægulv, isolering og beton		0.00E+00	0.00E+00	0.00E+00	4.87E-04	0.00E+00	0.00E+00	6.01E-04	0.00E+00	3.58E-04	3.29E-04	-4.95E-04
Konstruktion	Gulv, trægulv på strøer		0.00E+00	0.00E+00	0.00E+00	-2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-04	2.26E-07	-8.52E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-3.12E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-05	0.00E+00	-1.13E-05
Byggevare	Mineraluld, alm.	0	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Træ, fyrretræ (12% fugt / 10,7% H2O)	0	0.00E+00	0.00E+00	0.00E+00	-2.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E-04	0.00E+00	-7.16E-05
Konstruktion	Terrændæk, beton, 120 mm		0.00E+00	0.00E+00	0.00E+00	3.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.02E-06	3.07E-08	-4.98E-05
Byggevare	Armeringsnet	0	0.00E+00	0.00E+00	0.00E+00	3.08E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E-08	-1.77E-05
Byggevare	Beton C25/30, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	2.96E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.02E-06	0.00E+00	-3.21E-05
Konstruktion	Underlag, isolering EPS 350 mm og singels		0.00E+00	0.00E+00	0.00E+00	3.81E-04	0.00E+00	0.00E+00	6.01E-04	0.00E+00	3.24E-05	3.29E-04	-3.60E-04
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	1	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	1.19E-05	0.00E+00	6.95E-06	0.00E+00	-6.86E-06
Byggevare	EPS isolering til vægge og tage 035	1	0.00E+00	0.00E+00	0.00E+00	2.60E-04	0.00E+00	0.00E+00	5.89E-04	0.00E+00	0.00E+00	3.29E-04	-3.47E-04
Byggevare	Grus 2-32 mm, tørret	0	0.00E+00	0.00E+00	0.00E+00	1.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.55E-05	0.00E+00	-7.12E-06
Bygningsdel	Terrændæk af trægulv, isolering og krybekælder		0.00E+00	0.00E+00	0.00E+00	1.61E-04	0.00E+00	0.00E+00	6.01E-04	0.00E+00	3.49E-04	3.29E-04	-4.46E-04
Konstruktion	Gulv, trægulv på strøer		0.00E+00	0.00E+00	0.00E+00	-2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-04	2.26E-07	-8.52E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-3.12E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-05	0.00E+00	-1.13E-05
Byggevare	Mineraluld, alm.	0	0.00E+00	0.00E+00	0.00E+00	2.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-07	2.25E-07	0.00E+00
Byggevare	Træ, fyrretræ (12% fugt / 10,7% H2O)	0	0.00E+00	0.00E+00	0.00E+00	-2.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E-04	0.00E+00	-7.16E-05
Konstruktion	Underlag, isolering EPS 350 mm og singels		0.00E+00	0.00E+00	0.00E+00	3.81E-04	0.00E+00	0.00E+00	6.01E-04	0.00E+00	3.24E-05	3.29E-04	-3.60E-04
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	1	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	1.19E-05	0.00E+00	6.95E-06	0.00E+00	-6.86E-06
Byggevare	EPS isolering til vægge og tage 035	1	0.00E+00	0.00E+00	0.00E+00	2.60E-04	0.00E+00	0.00E+00	5.89E-04	0.00E+00	0.00E+00	3.29E-04	-3.47E-04
Byggevare	Grus 2-32 mm, tørret	0	0.00E+00	0.00E+00	0.00E+00	1.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.55E-05	0.00E+00	-7.12E-06
Gruppe	Ydervægge		0.00E+00	0.00E+00	0.00E+00	3.90E-03	0.00E+00	0.00E+00	6.89E-04	0.00E+00	1.15E-03	4.25E-05	-8.24E-04
Undergruppe	Ydervægge		0.00E+00	0.00E+00	0.00E+00	3.90E-03	0.00E+00	0.00E+00	6.89E-04	0.00E+00	1.15E-03	4.25E-05	-8.24E-04
Bygningsdel	Ydervæg af beton, isolering og fibercement		0.00E+00	0.00E+00	0.00E+00	9.19E-04	0.00E+00	0.00E+00	8.99E-05	0.00E+00	4.24E-05	6.42E-06	-1.12E-04
Konstruktion	Midterdel, betonelement 180mm, mineraluld		0.00E+00	0.00E+00	0.00E+00	8.27E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-05	2.68E-06	-1.02E-04
Byggevare	Armeringsnet	0	0.00E+00	0.00E+00	0.00E+00	9.23E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.21E-08	-5.31E-05
Byggevare	Beton C30/37, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	4.93E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-05	0.00E+00	-4.82E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Mineraluld, løsfyld	0	0.00E+00	0.00E+00	0.00E+00	2.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.67E-06	2.59E-06	0.00E+00
Konstruktion	Yderside, fibercementplade, underkonstruktion i		0.00E+00	0.00E+00	0.00E+00	9.14E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	2.42E-05	3.73E-06	-9.44E-06

Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	6.67E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-09	-3.39E-06
Byggevare	Fibercementplade	1	0.00E+00	0.00E+00	0.00E+00	8.74E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	0.00E+00	2.44E-06	0.00E+00
Byggevare	Gipskartonplade 13 mm, imprægneret	0	0.00E+00	0.00E+00	0.00E+00	1.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-06	0.00E+00
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-1.67E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-05	0.00E+00	-6.04E-06
Bygningsdel	Ydervæg af beton, isolering og murværk		0.00E+00	0.00E+00	0.00E+00	1.59E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.60E-05	5.16E-06	-1.08E-04
Konstruktion	Midterdel, betonelement 180mm, mineraluld		0.00E+00	0.00E+00	0.00E+00	8.27E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-05	2.68E-06	-1.02E-04
Byggevare	Armeringsnet	0	0.00E+00	0.00E+00	0.00E+00	9.23E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.21E-08	-5.31E-05
Byggevare	Beton C30/37, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	4.93E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-05	0.00E+00	-4.82E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Mineraluld, løsfyld	0	0.00E+00	0.00E+00	0.00E+00	2.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.67E-06	2.59E-06	0.00E+00
Konstruktion	Yderside, Teglsten, formur		0.00E+00	0.00E+00	0.00E+00	7.66E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-05	2.48E-06	-5.42E-06
Byggevare	Mørtel, fliseklæber	0	0.00E+00	0.00E+00	0.00E+00	5.25E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.48E-06	-4.32E-07
Byggevare	Teglsten, formur	0	0.00E+00	0.00E+00	0.00E+00	7.14E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-05	0.00E+00	-4.99E-06
Bygningsdel	Ydervæg af beton, isolering og træbeklædning		0.00E+00	0.00E+00	0.00E+00	7.74E-04	0.00E+00	0.00E+00	1.28E-04	0.00E+00	2.27E-04	6.42E-06	-2.11E-04
Konstruktion	Midterdel, betonelement 180mm, mineraluld		0.00E+00	0.00E+00	0.00E+00	8.27E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-05	2.68E-06	-1.02E-04
Byggevare	Armeringsnet	0	0.00E+00	0.00E+00	0.00E+00	9.23E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.21E-08	-5.31E-05
Byggevare	Beton C30/37, fabriksbeton og betonelementer	0	0.00E+00	0.00E+00	0.00E+00	4.93E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-05	0.00E+00	-4.82E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Mineraluld, løsfyld	0	0.00E+00	0.00E+00	0.00E+00	2.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.67E-06	2.59E-06	0.00E+00
Konstruktion	Vægside, Bræddebeklædning		0.00E+00	0.00E+00	0.00E+00	-1.45E-04	0.00E+00	0.00E+00	3.79E-05	0.00E+00	1.85E-04	4.26E-10	-9.88E-05
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Træ, fyrretræ (12% fugt / 10,7% H2O)	1	0.00E+00	0.00E+00	0.00E+00	-1.47E-04	0.00E+00	0.00E+00	3.79E-05	0.00E+00	1.85E-04	0.00E+00	-9.76E-05
Konstruktion	Yderside, fibercementplade, underkonstruktion i		0.00E+00	0.00E+00	0.00E+00	9.14E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	2.42E-05	3.73E-06	-9.44E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	6.67E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-09	-3.39E-06
Byggevare	Fibercementplade	1	0.00E+00	0.00E+00	0.00E+00	8.74E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	0.00E+00	2.44E-06	0.00E+00
Byggevare	Gipskartonplade 13 mm, imprægneret	0	0.00E+00	0.00E+00	0.00E+00	1.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-06	0.00E+00
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-1.67E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-05	0.00E+00	-6.04E-06
Bygningsdel	Ydervæg af porebeton og isolering		0.00E+00	0.00E+00	0.00E+00	5.83E-04	0.00E+00	0.00E+00	8.99E-05	0.00E+00	3.20E-05	7.31E-06	-1.17E-05
Konstruktion	Midterlag, beton, porebetonblok 100mm,		0.00E+00	0.00E+00	0.00E+00	4.91E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.87E-06	3.57E-06	-2.28E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Mineraluld, løsfyld	0	0.00E+00	0.00E+00	0.00E+00	2.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.67E-06	2.59E-06	0.00E+00
Byggevare	Mørtel, fliseklæber	0	0.00E+00	0.00E+00	0.00E+00	2.08E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.82E-07	-1.71E-07
Byggevare	Porebeton 380 kg/m3	0	0.00E+00	0.00E+00	0.00E+00	2.28E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-06	0.00E+00	-9.76E-07
Konstruktion	Yderside, fibercementplade, underkonstruktion i		0.00E+00	0.00E+00	0.00E+00	9.14E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	2.42E-05	3.73E-06	-9.44E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	6.67E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-09	-3.39E-06
Byggevare	Fibercementplade	1	0.00E+00	0.00E+00	0.00E+00	8.74E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	0.00E+00	2.44E-06	0.00E+00
Byggevare	Gipskartonplade 13 mm, imprægneret	0	0.00E+00	0.00E+00	0.00E+00	1.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-06	0.00E+00
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-1.67E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-05	0.00E+00	-6.04E-06
Bygningsdel	Ydervæg af stålskelet, isolering og skærmtegl		0.00E+00	0.00E+00	0.00E+00	4.38E-04	0.00E+00	0.00E+00	1.88E-04	0.00E+00	3.44E-05	1.10E-05	-4.89E-05
Konstruktion	Midterdel, stålskelet, mineraluld		0.00E+00	0.00E+00	0.00E+00	2.71E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-05	1.72E-06	-3.79E-05
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	0	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.95E-06	0.00E+00	-3.43E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Mineraluld, alm.	0	0.00E+00	0.00E+00	0.00E+00	1.74E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.11E-06	1.72E-06	0.00E+00
Byggevare	Stål, valsede profiler og plader	0	0.00E+00	0.00E+00	0.00E+00	8.76E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-07	0.00E+00	-3.22E-05
Konstruktion	Vægside, gipskartonplade 2 lag, akrylmaling		0.00E+00	0.00E+00	0.00E+00	7.60E-05	0.00E+00	0.00E+00	9.85E-05	0.00E+00	0.00E+00	5.55E-06	-1.55E-06
Byggevare	Afretningslag, cementbaseret	0	0.00E+00	0.00E+00	0.00E+00	2.75E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E-06	0.00E+00
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Gipskartonplade 13 mm, hulplade	1	0.00E+00	0.00E+00	0.00E+00	3.41E-05	0.00E+00	0.00E+00	3.73E-05	0.00E+00	0.00E+00	3.19E-06	0.00E+00
Byggevare	Overflade, Facademaling, akryl maling	5	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	5.04E-05	0.00E+00	0.00E+00	7.13E-08	-2.69E-07
Byggevare	Overflade, Facademaling, grunder, dispersion	5	0.00E+00	0.00E+00	0.00E+00	2.14E-06	0.00E+00	0.00E+00	1.09E-05	0.00E+00	0.00E+00	3.56E-08	-1.54E-07
Konstruktion	Yderside, fibercementplade, underkonstruktion i		0.00E+00	0.00E+00	0.00E+00	9.14E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	2.42E-05	3.73E-06	-9.44E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	6.67E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-09	-3.39E-06
Byggevare	Fibercementplade	1	0.00E+00	0.00E+00	0.00E+00	8.74E-05	0.00E+00	0.00E+00	8.99E-05	0.00E+00	0.00E+00	2.44E-06	0.00E+00
Byggevare	Gipskartonplade 13 mm, imprægneret	0	0.00E+00	0.00E+00	0.00E+00	1.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-06	0.00E+00
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-1.67E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-05	0.00E+00	-6.04E-06
Bygningsdel	Ydervæg af træskelet, isolering og		0.00E+00	0.00E+00	0.00E+00	-4.09E-04	0.00E+00	0.00E+00	1.93E-04	0.00E+00	7.79E-04	6.15E-06	-3.34E-04
Konstruktion	Midterdel, træelement, papiruld		0.00E+00	0.00E+00	0.00E+00	-4.85E-04	0.00E+00	0.00E+00	9.48E-05	0.00E+00	7.79E-04	6.05E-07	-3.32E-04
Byggevare	Dampspærre PE (tykkelse 0,0002 m)	0	0.00E+00	0.00E+00	0.00E+00	4.99E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.95E-06	0.00E+00	-3.43E-06
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	4.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.53E-10	-2.26E-06
Byggevare	Konstruktionstræ, KVH-kvalitet (15% fugt / 13%	0	0.00E+00	0.00E+00	0.00E+00	-2.80E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-04	0.00E+00	-1.01E-04
Byggevare	Mineraluld, løsfyld	0	0.00E+00	0.00E+00	0.00E+00	5.60E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-06	6.04E-07	0.00E+00
Byggevare	Papiruldsisolering, løsfyld	1	0.00E+00	0.00E+00	0.00E+00	-2.71E-04	0.00E+00	0.00E+00	9.48E-05	0.00E+00	3.65E-04	0.00E+00	-2.25E-04
Konstruktion	Vægside, gipskartonplade 2 lag, akrylmaling		0.00E+00	0.00E+00	0.00E+00	7.60E-05	0.00E+00	0.00E+00	9.85E-05	0.00E+00	0.00E+00	5.55E-06	-1.55E-06
Byggevare	Afretningslag, cementbaseret	0	0.00E+00	0.00E+00	0.00E+00	2.75E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E-06	0.00E+00
Byggevare	Fastgørelsesmidler/skruer i galvaniseret stål	0	0.00E+00	0.00E+00	0.00E+00	2.22E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-10	-1.13E-06
Byggevare	Gipskartonplade 13 mm, hulplade	1	0.00E+00	0.00E+00	0.00E+00	3.41E-05	0.00E+00	0.00E+00	3.73E-05	0.00E+00	0.00E+00	3.19E-06	0.00E+00
Byggevare	Overflade, Facademaling, akryl maling	5	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	5.04E-05	0.00E+00	0.00E+00	7.13E-08	-2.69E-07
Byggevare	Overflade, Facademaling, grunder, dispersion	5	0.00E+00	0.00E+00	0.00E+00	2.14E-06	0.00E+00	0.00E+00	1.09E-05	0.00E+00	0.00E+00	3.56E-08	-1.54E-07

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