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Utilizing Life Cycle Assessment (LCA) during Building design using Building Information Modelling (BIM) Case studies from Finland

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Background:

Since the construction industry is turning towards sustainability and aiming to profit from all available knowledge and technology with a view to achieve sustainable construction, a change in the construction industry is required in order to improve performance and achieve more sustainable approaches [1, 2]. Traditionally, buildings were constructed from local materials with low environmental impacts but in modern buildings, materials used on a global level (such as concrete, cement, aluminum, and PVC) are increasing the environmental impact and carbon footprint [3].

Life Cycle Assessment (LCA) is one of the most widely used methodology for evaluating environmental performance. It helps stakeholders to comprehend the various environmental impacts of the respective project during its different life-cycle phases [4]. Building Information Modelling (BIM) is a trending approach to plan, design, and manage a building in a digitalized way. Which combines the building geometry with all its relevant information throughout the whole life cycle of the building [5, 6]. BIM enables various construction parties to share information, combine it in only one model and visualize it. And as a result: eliminating the conflicts and errors, enhance work performance, early project delivery, and cost reduction are some of the benefits that occur from BIM implementation [7].

The integration of existing methods such as BIM and LCA is important for supporting sustainable design [8]. LCA evaluations are usually developed in the late project phases (after construction or during the operation phase). The results of the assessment are not as useful as they are in the early phases but unfortunately, there is a general lack of information in the early project phases. [9]. the early design phases have the highest influence on the project. The cost of implementing changes increases as the project evolves. Therefore, more effort should be devoted to the early design phases through integrating an exhaustive environmental analysis within BIM to improve performance, avoid wastage and generate a more sustainable design.

Finland was one of the leading countries in both BIM and LCA approaches development. A consortium of different companies in the architecture, engineering, and construction (AEC) industry in Finland (building smart Finland) published the Common BIM Requirements (COBIM) in 2012 to be national requirements for all stakeholders in the AEC industry value chain and for the whole lifecycle of the building [10].

Finland aims to achieve carbon neutrality by 2035 in all society sectors including the construction industry. In 2017 the Ministry of the Environment published a roadmap to low-carbon construction. It stated that the whole life carbon assessment of buildings must be incorporated in the building regulations by the mid-2020s. The Ministry of Environment in Finland published the first version of a method for the whole life carbon assessment of buildings (Rakennuksen vähähiilisyyden arviointimenetelmä) and will be further developed through a piloting period with industry cooperation. It is largely based on European standards, which provide a common framework for calculations. The 2019 Finnish Government program calls for accelerating the implementation of this roadmap. According to that, the assessment of the carbon footprint of building-type-specific emission limits is planned to be included in Finland's building regulations in the 2020s [11].

Research Question and Objectives:

This research paper will address the questions:

- How the LCA carbon emission calculation will be integrated with the Common BIM Requirements (COBIM) different IFC Models at different design processes?
- What is the analysis of comparing LCA calculation results between early and detailed design stages?
- How to develop the BIM requirements to enable assessing the variety of construction options and their embodied environmental impact?

The main purpose of this research is to investigate the effectiveness of employment Building Information Modeling (BIM) in the sustainable material selection at different design stages to make decision-making for a sustainable material selection easier for architects and designers in different design phases.

Methodology:

- Conduct an extensive literature review.
- The author will use the LCA carbon assessment method published by the Ministry of Environment in Finland as well as the emissions data form case studies construction projects and a tool for calculating carbon emissions (ex: one-click LCA tool).
- the Common BIM Requirements (COBIM) will be used in the case studies and will be assessed for future development.
- The BIM model will provide a design-specific bill of quantities and properties for the various building elements (e.g. amount, area and geometry) in the different design phases, while the LCA database provides information on the embodied impact per area of the building element.
- Interviews among professionals in the (AEC) industry and academics will be conducted.
- The construction industry is a project-based industry. Each project is unique and has its own characteristics, material, and components [12]. Therefore, three different case study projects in Finland will be used in this research.
- A comparative analysis of LCA calculation results will be conducted between the different design phases in the case studies projects to enhance the carbon requirements vision in the early design phases.
- Evaluating the accuracy of the early stage assumptions used by LCA calculation and the use of early-stage LCA calculations that are based on generated baseline building archetypes.
- Analysis of the case studies (visualization of LCA results, visualization of improvement potential, Discussion, and Conclusion).

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Abstract

Since the construction industry is turning towards sustainability, several international campaigns have called for creating sustainable roadmaps from global industry different stakeholders including governments and policymakers to achieve a net-zero carbon emission in the building environment sector by 2050. The Ministry of Environment in Finland has responded by defining a roadmap to include the building carbon assessment in the building permit legalizations process during mid-2020 and published a method for calculating the building carbon emission through its whole life cycle.

Life Cycle Assessment (LCA) is the most widely used Methodology for evaluating the building's environmental performance through its whole life cycle. Building Information Modelling (BIM) is a modern trending approach to design and manage the building information between different stakeholders to eliminate conflicts and enhance working performance. As the LCA outcome is highly reliable on the availability of the building elements material information, the integration between BIM and LCA represents a cutting-edge solution for fast and accurate building carbon assessment. The early design phase is the most beneficial timing for conducting the building LCA when the designers could change the high-carbon building elements while avoiding any costly consequences.

This research proposes a new approach to conduct the building life cycle assessment (based on the Ministry of Environment in Finland method) by extracting the building elements material information from the IFC building model which follows the common BIM requirements in Finland (COBIM) using Solibri software and calculate the carbon emission using a calculation tool. Three case study buildings from the Skanska construction company are used to give a realistic overview and a tangible understanding of the proposed approach benefits and the current LCA process problems. The case studies' outcome highlights the urgent need for environmental standardization in the building industry. The final part of the thesis conducts a comprehensive analysis between the COBIM and the Ministry method to reach an environmental standardization of the minimum material specifications required in the BIM model which could be used as a foundation for automatizing the LCA process.

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List of Abbreviations

LCA	Life Cycle Assessment
BIM	Building Information Modelling
COBIM	Common BIM Requirements
AEC	The Architecture, Engineering, and Construction
CO_2e	Carbon dioxide equivalent
EPD	Environmental Product Declaration
KWh	Kilowatt-hour
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership in Energy and Environmental Design
GWP	Global Warming Potential
ISO	International Organization for Standardization
IPCC	The Intergovernmental Panel on Climate Change
GHG	greenhouse gas
RTS	the Building Information Foundation in Finland (Rakennustietosäätiö)
NO_x	nitrogen oxides
CO_2	carbon dioxide
WorldGBC	World Green Building Council
CDP	Carbon Disclosure Project
IFC	The Industry Foundation Classes
UN	The United Nations
UNSDG	The United Nations Sustainable Development Goals
kg	Kilo gram
m^2	Square meter
HVAC	Heating, Ventilation, and Air Conditioning
VTT	the Technical Research Centre of Finland
BOQ	Bill of Quantities
TC350	Technical Committee 350
EN	European Standards
TR	Technical Report
LCI	Life-Cycle Inventory
LCIA	Life Cycle Impact Assessment

1. Introduction

1.1 Research background and problem definition

Global warming and climate change are two trending topics that have considerable attention worldwide. According to the 2007 & 2014 reports of The Intergovernmental Panel on Climate Change (IPCC), the Anthropogenic - human-based - greenhouse gas (GHG) emissions are the main driving factor for global climate change. The greenhouse gas (GHG) emissions are referring to the gasses that have a negative environmental impact such as nitrogen oxides (NO_x), and the carbon dioxide (CO_2) that has been tremendously increasing since the beginning of the industrial era (IPCC, 2007), (IPCC, 2014).

Recent researches indicated that the building industry is responsible for almost 40% of the global GHGs and produce the same percentage of the total waste worldwide as well as it consumes 40% of the world natural resource (Antón & Díaz, 2014), (Säynäjoki et al., 2012), (Hakaste & Kuittinen, 2017a). Therefore, many policymakers and building industry stakeholders are investing considerable effort to turn the industry into a more sustainable pattern (World Green Building Council, 2019).

A global network of building environment organizations from over 70 countries worldwide who are being addressed as the World Green Building Council (WorldGBC) has called for a faster response to achieve net-zero carbon emission in the building environment sector by 2050 (World Green Building Council, 2020). Appendix 1 simplifies the timeframe roadmap vision proposed by the WorldGBC latest report on September 2019 ‘’Bringing embodied carbon upfront’’. According to the WorldGBC roadmap, every main stakeholder (investors, policymakers, developers, designers, material manufacturers, and product vendors) should start in 2020 to develop short- and long-term strategies that support the main target of net-zero building carbon emission by 2050 (World Green Building Council, 2019).

Finland has a national target to be carbon-neutral by 2035 in all society sectors including the construction industry as well as achieving by 2050 an 80% cut in the 1990 greenhouse gas emissions benchmark (Kuittinen, 2019). In 2017, a roadmap to low-carbon construction has been published by the Finnish Ministry of the Environment which indicates that the building life carbon assessment will be required in the building permit process by 2025. In 2019, The Ministry of Environment in Finland published an initial version of a method for the building's life carbon assessment. This method will be further developed through a piloting period with industry cooperation to produce a reliable information database that supports developing the new environmental policies and legislation (Environmental management, 2013), (Ministry of Economic Affairs and Employment of Finland, 2020), (Kuittinen, 2019).

Life Cycle Assessment (LCA) is the most widely used Methodology for evaluating the potential environmental impacts of a product through its' life cycle. It helps stakeholders in the building industry to comprehend the various environmental characteristics performance of the respective project during its different life-cycle phases (Bayer et al., 2010). Building Information Modelling (BIM) is a modern trending approach to design and manage the building by combining building geometry with all building elements relevant information (Lee et al., 2012), (Tardif & Smith, 2009). BIM enables various construction parties to share information and visualize it in one model which eliminates conflicts, enhances work performance, delivers projects earlier, and reduces the project overall cost (Khatib et al., 2007).

The early design phases have the highest influence on the project. The cost of implementing changes increases as the project evolves. Performing the LCA in the late project phases (after construction or during the operation phase) is not as beneficial as it is in the early phases (Bayer et al., 2010). However, due to the general lack of building information in the early phases, designers and decision-makers face difficulties to perform an accurate LCA. Therefore, the integration between BIM and LCA represents a cutting-edge solution for the problem of lacking reliable data in the early phases. More effort should be devoted to developing standardization and a reliable environmental database that will help designers perform accurate LCA during the early design phases through integrating an exhaustive environmental analysis within BIM which will generate a more sustainable design.

Finland is one of the leading countries in developing both BIM and LCA approaches. The idea of integrating both approaches is important for supporting sustainable design.

The construction industry suffers from a lack of standardization among a large number of involved stakeholders (Antón & Díaz, 2014). The Common BIM Requirements (COBIM) was published in 2012 by Building Smart Finland (a collaboration forum founded by a consortium of different companies and organizations in the Finnish architecture, engineering, and construction (AEC) industry) to be national requirements for all stakeholders in the AEC industry value chain and the whole lifecycle of the building (BuildingSMART Finland, 2012a). This thesis investigates the required modification to the current COBIM to be used as an industry environmental standardization to achieve sustainable goals among all value chain stakeholders.

Skanska targets to be the world's leading environmentally efficient builder and aims to be carbon neutral by 2045. The intermediate target is to reduce carbon emissions by 50% by 2030. In 2019, Skanska achieved Leadership (A-) level in the climate change rating Carbon Disclosure Project (CDP) which indicates Skanska's ongoing efforts in tackling environmental and climate change problems (Skanska, 2020).

1.2 Research Questions

The main purpose of this research is to investigate the effectiveness of employing Building Information Modeling (BIM) in the building life cycle assessment ***process*** at different design stages to make decision-making for a sustainable material selection easier for architects and designers in early design phases. The thesis also investigates the required modification to the current COBIM to be used as the industry environmental standardization and the foundation for an automated LCA process.

This research thesis will address the following questions:

- What is the analysis of comparing LCA calculation results between early and detailed design stages?
- How can the LCA carbon emission calculation be integrated with the COBIM Requirements in different IFC Models at different design stages?
- How to modify the BIM requirements to enable assessing a variety of construction options and their embodied environmental impact during the design phase?

1.3 Scope of research

This thesis proposes a new industrial approach to assess the building life cycle by implementing the BIM methodology in the LCA process. Combining the two extensive literature fields (LCA & BIM) generates a huge amount of data that needs to be limited with a specific scope to support answering the research questions. The building material information will be extracted from the BIM models and based on it, the carbon assessment will be conducted. This approach is much faster and more accurate than the traditional way of performing the LCA based on the bill of quantities (BOQ). It would empower designers to evaluate the environmental impact of their chosen material immediately and consider changing it to a more sustainable material in the early design phases.

Three case studies were used in this thesis to have a more sensible understanding of how beneficial the usage of BIM would utilize the current carbon assessment process. The building IFC design models were not intended to be used in the LCA process. Therefore, there might be some minor defects (from an environmental perspective like misnaming the exact product material or extracting nonrelevant LCA material from the building model). However, Fixing the IFC files in their original design platform (Tekla/ArchiCAD) was not considered in the scope of this study.

The thesis focused on the LCA process and how it could be improved and utilized using BIM methodologies. It didn't focus on an LCA tool credibility or the defects of the used LCA method. It rather investigated the data management flow in the LCA process and what is missing to perform a faster and more automated carbon assessment while having an accurate outcome. The Common BIM requirements (COBIM) has been used as a baseline in the used IFC design models. The Ministry of Environment method for the whole life carbon assessment of a building 2019 was used during the case studies life cycle assessment. A comparative analysis between the COBIM and the Ministry method concluded the outcome and defined the research recommendations.

1.4 Research Methodology

The following steps have been conducted to answer the research questions and conclude the thesis outcome.

1. Conducting an extensive literature review and defining the main concepts in the Architecture, Engineering, and Construction (AEC) industry related to the scope of the research.

2. Solibri software was used to extract the building material information from the case studies IFC design Model and an LCA tool (ex: one-click LCA tool) was used to calculate the carbon emission for each building based on the Finnish Ministry of Environment method for the whole life carbon assessment of buildings.

    2.1. The BIM models will provide information for the different building elements (e.g. name, material, and volume) in the different design phases, while the one-click LCA database provides information on the embodied environmental impact for each material in the building.

    2.2. The first research question was answered by conducting a comparative analysis of the case studies' carbon assessment results between the different design phases to evaluate the accuracy of the carbon emission anticipation in the early design phases. The case studies will give a tangible sense of the main defects in the LCA process.

3. The second and third questions were answered by conducting a comprehensive comparative analysis between the (Common BIM Requirements (COBIM)) material minimum requirement and the materials mentioned in the Finnish Ministry of Environment method.

4. The conclusion was defined based on the comparison and the case studies result with a recommendation for modifying the COBIM from an environmental perspective.

1.5 Research structure

This research followed Labro & Tuomela (2010) diversification of research steps. The research has been categorized into three main phases (preparatory phase, fieldwork phase, and theorizing phase) alongside the introduction and conclusion parts. It starts with defining the problem and proposing a solution with related scope. For a clear understanding of the thesis topic and its relevant factors even for nonspecialized persons in the construction sector, an extensive literature review has been conducted along with a series of related definitions at the beginning of the research.

The first phase clarifies the general outcome benefit from the thesis in the building LCA process development timeframe. It starts by investigating the current LCA process and highlights its main defects. Then, clarifying the thesis approach to solve those defects and ends with anticipation of what would be the future building LCA process would look like.

The second phase answers the first thesis question by conducting three case study projects for carbon assessment that has been done entirely by the author and analyzing their outcome. The case studies give a realistic overview and a tangible understanding of how the current LCA process takes place in the industrial sector and how the use of Building Information Modelling could utilize this process. The Third chapter concludes that many defects in the LCA process could be solved by founding a standardization and a linking method between different industry stakeholders.

The third phase answers the second and third research questions as well as it represents the theoretical analysis of the report. It investigates the opportunities to conduct such standardization using the Common BIM requirements (COBIM) which defines the different design models minimum information requirements. It connects the Ministry of Environment in Finland Method for the whole life carbon assessment of the building 2019 with the COBIM through a series of tables. These tables highlight the environmental shortage in the 2012 COBIM standardization which could be simply fixed by publishing a new COBIM version that includes an environmental perspective. The research ends with the discussion, conclusion, recommendations, and further research questions. Figure 1 illustrates the thesis structure as described above.

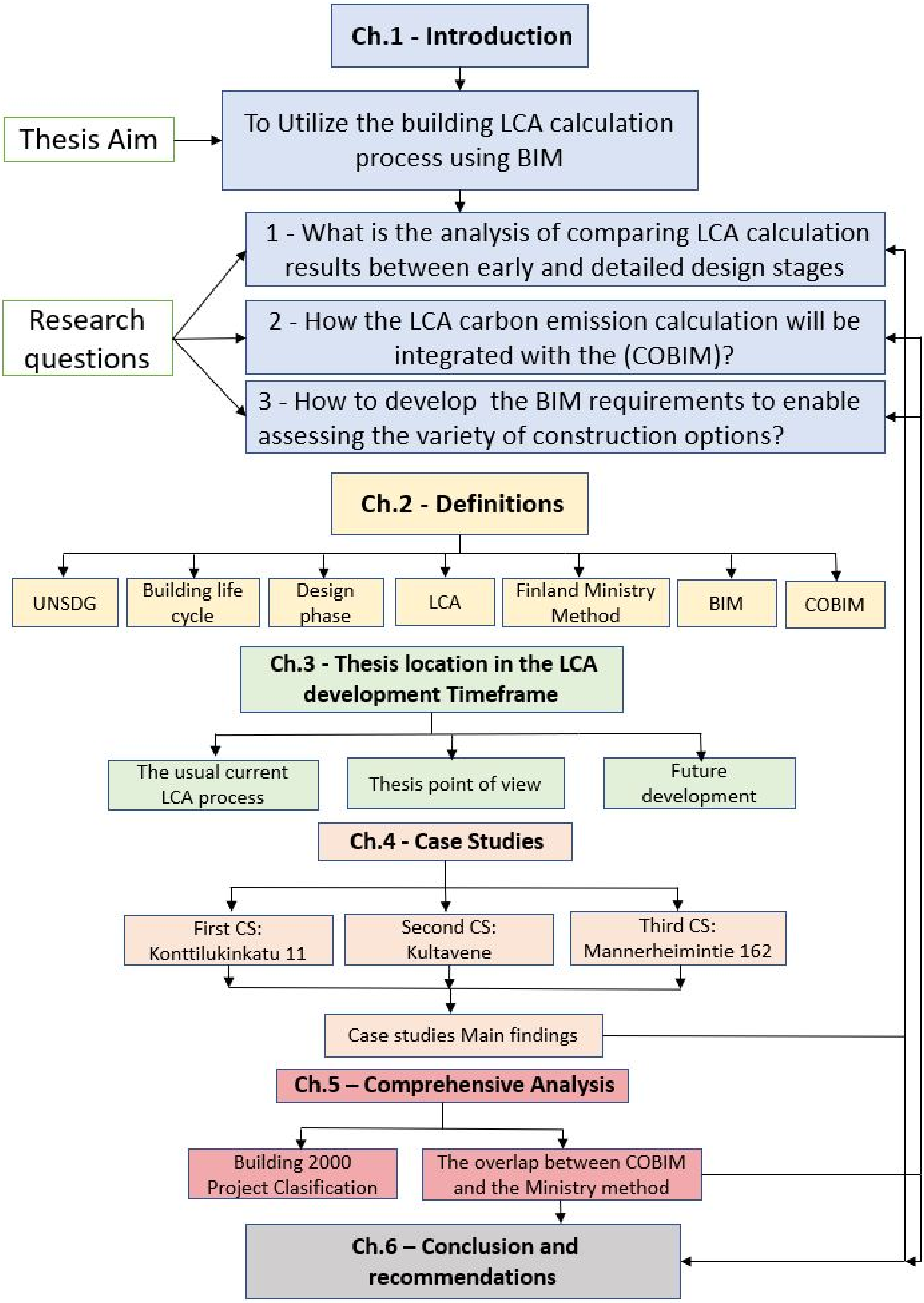


Figure 1: Thesis Structure and Methodology flow diagram

2 Literature study

2.1 The United Nations Sustainable Development Goals (UNSDG) and its Agenda 2030

The United Nations (UN) is an international intergovernmental organization founded after the devastation of the second world war in 1945, which is currently made up of 193 member countries. The aim is to maintain international peace and enhance international cooperation in many fields such as promote sustainable development, tackle climate change, protect human rights, deliver humanitarian aid, uphold international law, and more (United Nations, 2020a).

During the UN Sustainable Development Summit that took place in the UN headquarter in New York on 25-27th September 2015, the (Transforming our world: the 2030 Agenda for Sustainable Development) was adopted with its 17 Sustainable Development Goal (UNSDG) and 169 associated targets to be achieved by 2030. Addressing the global challenges, the 2030 UNSD Agenda main theme is achieving sustainable development in its three main dimensions – economic, social, and environmental – by all countries in a balanced and integrated manner, considering different national capacities and respecting national policies (United Nations Department of Economic and Social Affairs, 2020). Figure 2 illustrates the United Nations' different sustainable development goals (United Nations, 2020b).

Figure 2: The United Nations 17 Sustainable Development Goals
Source: (United Nations, 2020b).

Goal 1 - No Poverty
Goal 2 - Zero Hunger
Goal 3 - Good Health and Well-Being
Goal 4 - Quality education
Goal 5 - Gender equality
Goal 6 - Clean Water and Sanitation
Goal 7 - Affordable and Clean Energy
Goal 8 - Decent Work and Economic Growth
Goal 9 - Industry, innovation, and Infrastructure
Goal 10 - Reduced Inequalities
Goal 11 - Sustainable Cities and Communities
Goal 12 - Responsible Production and Consumption
Goal 13 - Climate Action
Goal 14 - Life Below Water
Goal 15 - Life on Land
Goal 16 - Peace, Justice and Strong Institutions
Goal 17 - Partnerships for the Goals

The World Green Building Council is a non-profit international councils' network from 70 countries worldwide representing the built environment and construction industry in achieving the United Nations Sustainable Development Goals (UNSDG). It has selected nine goals (as shown in figure 3 the goals numbers are 3, 7, 8, 9, 11, 12, 13, 15, and 17) where the role of the construction industry is noticeable (Czerwinska, 2017).

Figure 3: The World Green Building Council and the UNSDG
Source: (Czerwinska, 2017)

<u>This Thesis mainly addresses these two Sustainable Development Goals:</u>

<u>Goal 11</u>: Sustainable Cities and Communities

<u>Goal 13</u>: Climate Action

2.2 The Life cycle of a building

Birgisdóttir & Rasmussen (2016) clarifies in figure 4 the main elements of the building life cycle. It starts with the product stage where the building elements raw materials are extracted from the natural and manufactured followed by the construction and usage stages then the end-of-life stage when the building gets demolished and finally it ends with the recycling and reuse of the building material.

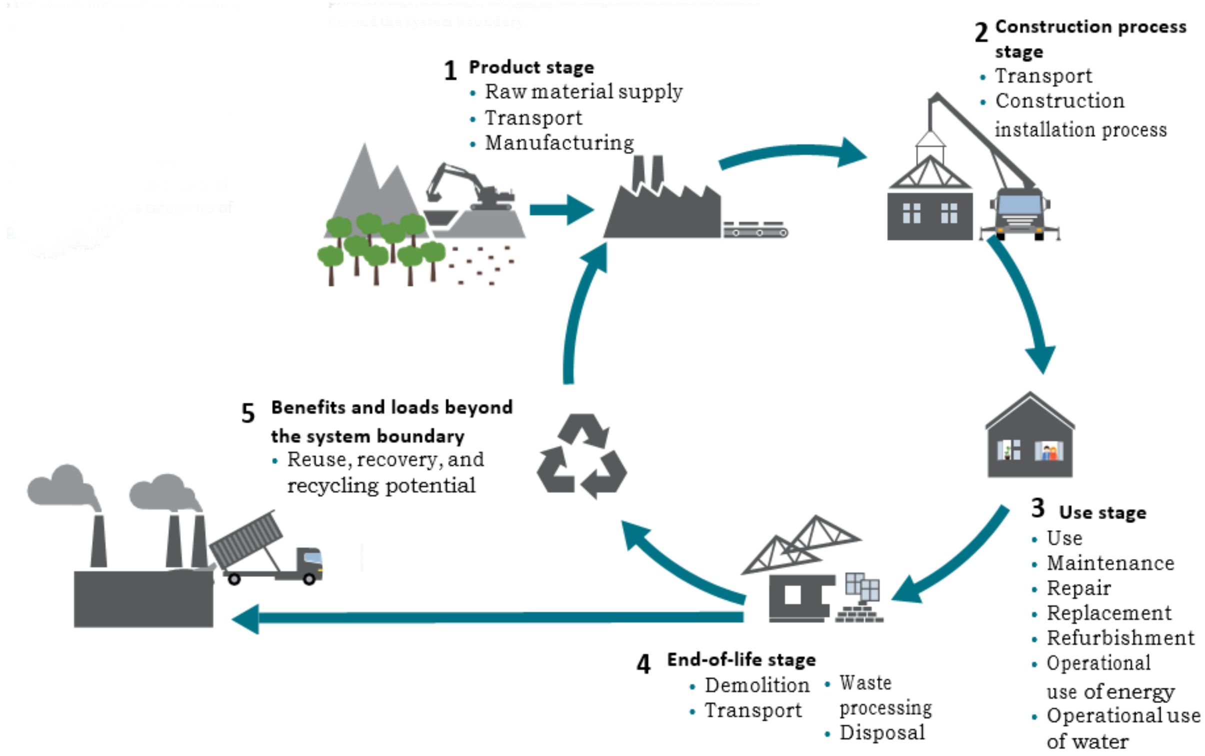


Figure 4: Illustration of a building life cycle process

Source: (Birgisdóttir & Rasmussen, 2016, p.05).

Figure 5 shows the building's main life cycle stages and its corresponding modules (A, B, C, D) defined by the European standard EN 15978:201. A single building life cycle stage has been defined in EN 15643-2 as ‘’Module’’ (Birgisdóttir & Rasmussen, 2016), (Kuittinen, 2019).

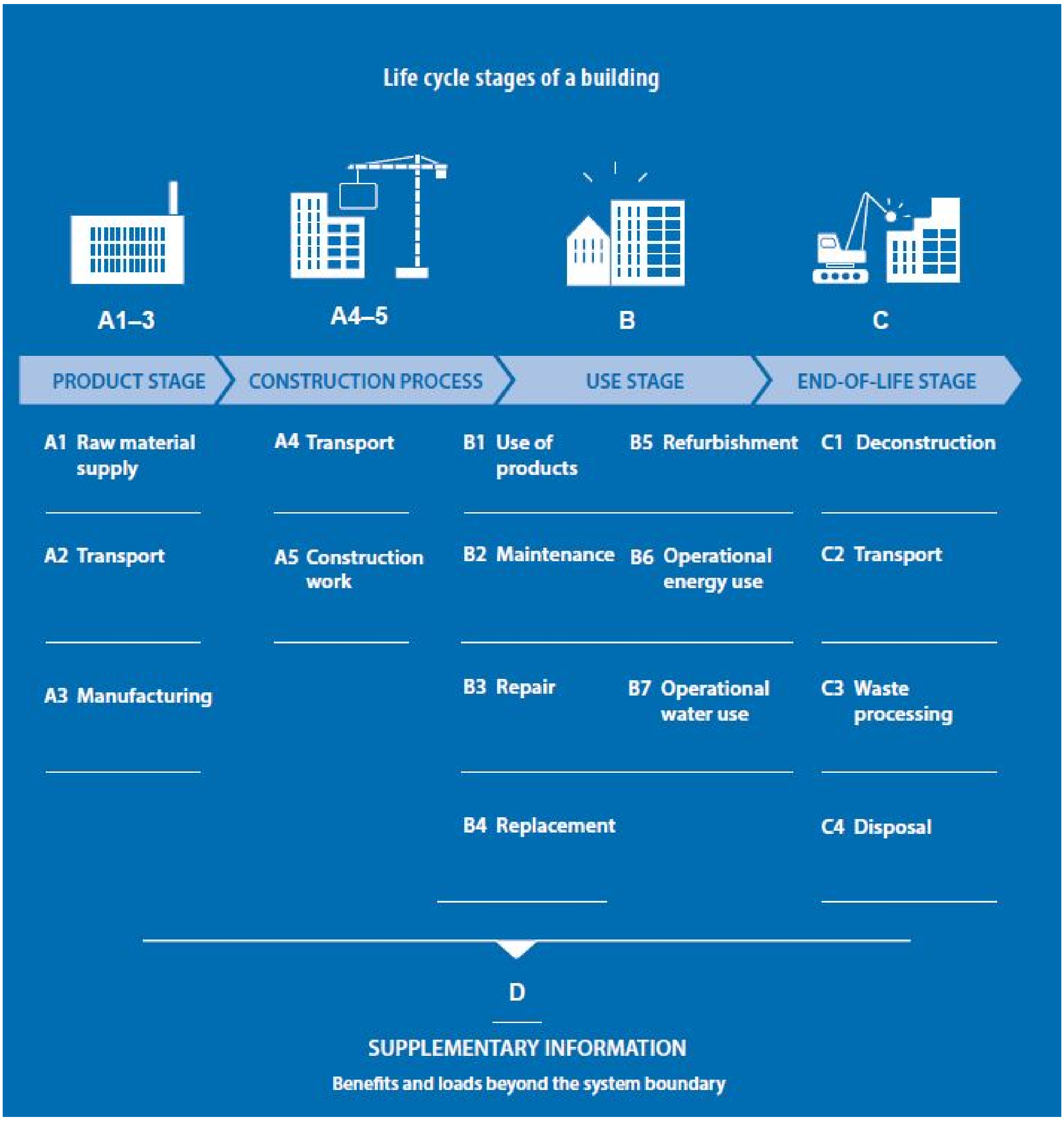


Figure 5: Building Life cycle stages and it's corresponding modules

Source: (Kuittinen, 2019, p.16)

The construction process (A4-5) contains more detailed phases. It starts with a feasibility study followed by conceptional planning and draft design, then a detailed design for the approved concept, and finally preparing the contracting and construction documents before starting the actual construction of the building. The quality of planning and design always controls the quality and cost of the construction overall process as clarified in the following chapter (chintis, 2019).

2.3 Design Phase Importance

The design phase importance could be understood by analyzing the well-known Patrick Macleamy graph in figure 6, which was initially drafted by Boyd Paulson in 1976 and gained its fame after being presented in an industrial meeting by Patrick Macleamy (Davis, 2013). The graph horizontal arrow represents the project time development phases while the vertical arrow represents the effort or effect that a specific task might have. The blue graph – indicated with number 1- shows that the ability to impact any changes to the project is the highest at the beginning of any project (in the pre-design, Schematic design, and design development phases) and this ability decreases with the development of the project as more of the design being documented and reaches the lowest at construction and operation phases. While the red graph – indicated in number 2 – shows that the cost of implementing changes to the project is the highest at the beginning of any project (design phases) and increases with the development of the project until it reaches its highest level after the construction phase (Nikles, 2013).

As a conclusion, the carbon assessment will have a higher positive impact if it is done in the design phase (mainly in the design development phase) when designer and decision-makers would have enough building information and higher flexibility to apply changes to the project design or change elements with high carbon emission while avoiding the high-cost consequences of these changes (Bayer et al., 2010).

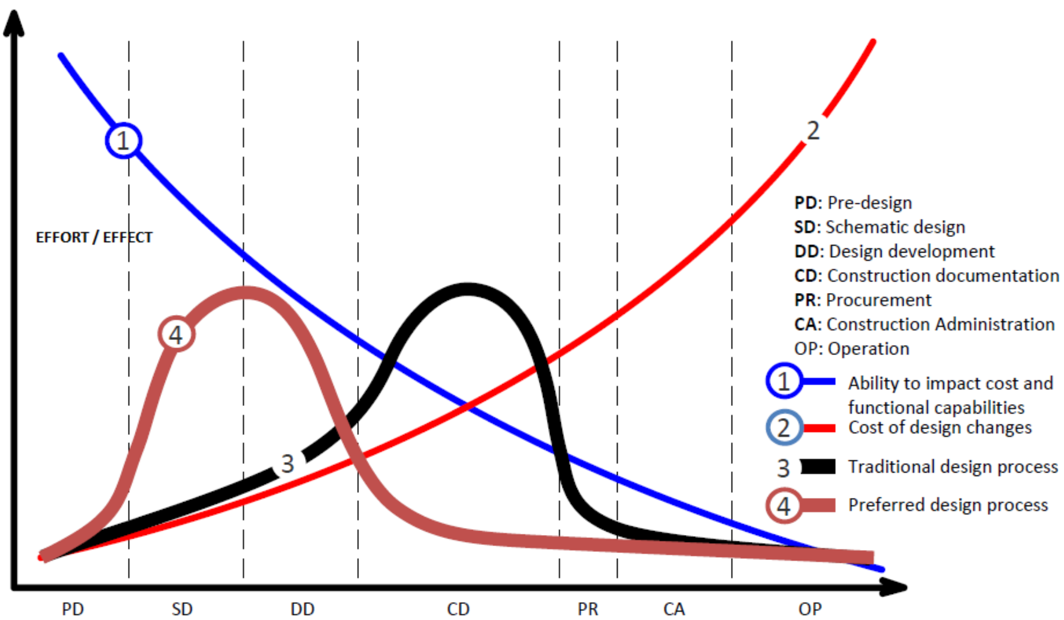


Figure 6: Patrick MacLeamy curve AIA/HOK, Effort over Time

Source: (Nikles, 2013)

2.4 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is an ISO standardized methodology (ISO 14040-14044) to calculate a product's potential environmental impact associated with its all life cycle stages (raw material extraction, manufacture, transport, usage, and end-of-life) (ISO, 2006). The ISO standards have defined four LCA phases: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and life cycle interpretation (Lee & Inaba, 2004). The LCA is a data-intensive method, to perform a building life cycle assessment there must be sufficient information about the building material type and volume along with a reliable material environmental database (like nationals Environmental Product Declaration (EPD)) and a calculating tool (Birgisdóttir & Rasmussen, 2016).
The Environmental Product Declaration (EPD) is a standardized environmental information database for materials or products during its whole life and it is usually valid for five years. Different public and private institutions provide it at a local level to enable designers to conduct a comparative analysis of the available materials based on their environmental impact. EPDs could be generated according to ISO 14040 or ISO 14044 or the International Standard ISO 14025 and in the case of European countries, it usually follows the EN 15804 standards for the construction sector developed by the European Committee for Standardization (Shaun, 2020b), (EPD International, 2020). The Finnish Environmental Product Declaration (EPD) database – provided by the Building Information Foundation Rakennustietosäätiö (RTS)- was used in this thesis (Bionova, 2018c). The RTS EPD database is defined according to the European standard EN 15804:2012+A1:2013 to present material environmental impact information in the building life cycle assessment (Rakennustietosäätiö, 2020).

In August 2017, the European Commission has published a common European sustainability framework (Level(s)) that provides measuring core-indicators for the environmental performance of office and residential buildings along their life cycle. The Level(s) framework has separate sections and instructions for different stakeholder groups, as it clarifies the author's perspective of the practical assessment of sustainable built environment proposed methodologies through six European environmental macro-objectives policies along with 9 related performance measuring indicators. It promotes the individual stakeholder life cycle thinking aspects towards a more holistic European use of Life Cycle Assessment (LCA) (Dodd et al., 2017).

During the last decade, there have been several publications related to construction products' environmental product declaration (EPD) by Technical Committee 350 (TC350) in the European Committee for standardization that has also issued other important environmental standards. Figure 7 clarifies the complex interaction between those standards (ISO & EN). However, most research relevant standards are ISO14040/44, EN 15978, EN 15804, and TR 15941 (Bre, 2016).

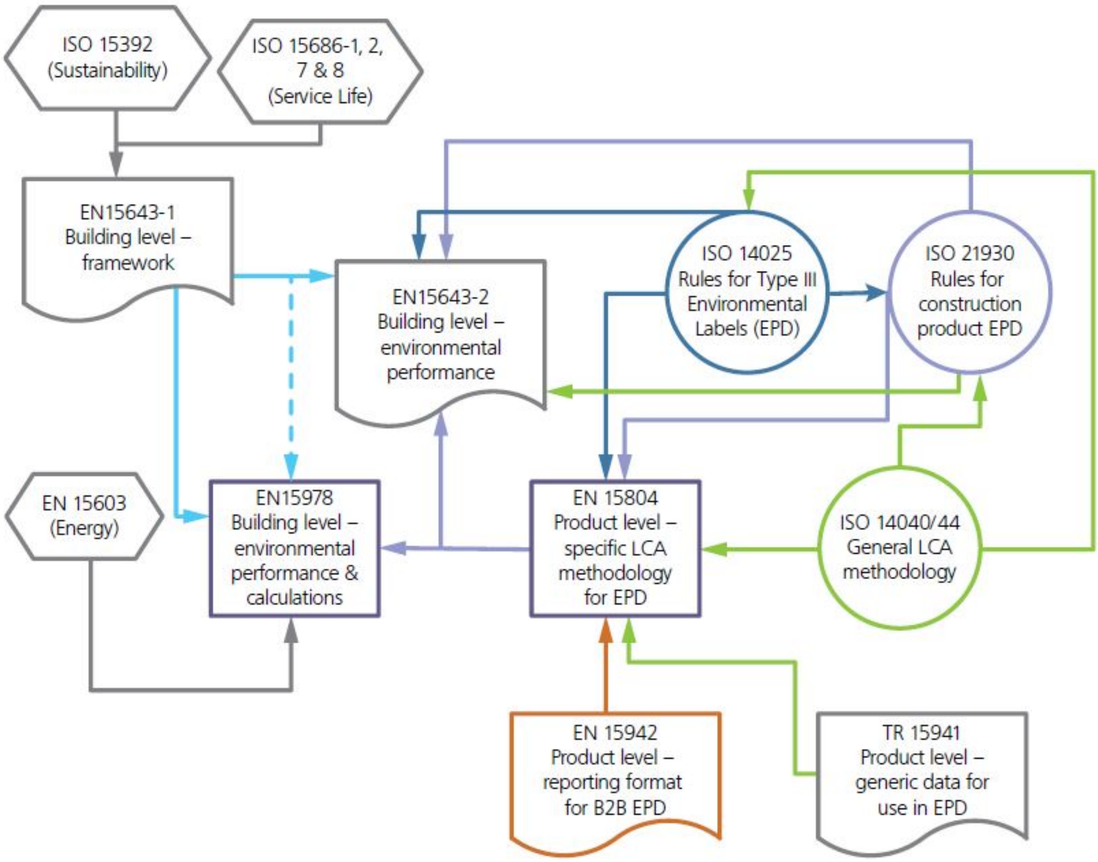


Figure 7: Dependency and interaction between TC350 EN and ISO standards
Source: (Bre, 2016, p.08).

there is a range of measurable indicators that could assess the building life cycle process. The Global Warming Potential (GWP) is the most relevant indicator of the thesis scope. The carbon emission definition used in the thesis is generally measured with the quantified indicator global warming potential (GWP) that is equal to one kilogram of carbon dioxide (1 kg CO_2 equivalent) and considered to be the main reason for global warming and climate change (Kuittinen, 2019), (Birgisdóttir & Rasmussen, 2016).

Traditionally, the energy factor had the greatest impact on the LCA results. There are two kinds of energy consumption and associated with the two main carbon emissions during the building life cycle. The first type is operational energy (associated with operational carbon which is estimated to be 28% of the global CO_2 emission) that is best defined as the energy used during the occupation/operation of the building lifetime (usage stage that includes heating, cooling, ventilation, etc.). The second type is embodied energy (associated with embodied carbon which is estimated to be 11% of the global CO_2 emission) which is the energy used in any other process than the usage stage, like construction, maintenance, and demolition of the building. The embodied energy also includes the energy used during the manufacturing of the building products and services (World Green Building Council, 2019), (Huang et al., 2018).

While there is a powerful future trend to optimize the operational energy by renewable sources, the embodied energy probably will have a higher influence on the building LCA and carbon emissions (Birgisdóttir & Rasmussen, 2016). Therefore, there should be more global efforts devoted to tackle the embodied carbon calculations as well. The 2019 LCA method of the Ministry of Environment in Finland focuses on the embodied carbon (World Green Building Council, 2019) (Kuittinen, 2019). Carbon footprint refers to the number of carbon emissions generated directly (like construction or transportation) or indirectly (like in extracting raw material or manufacturing products) through the whole life cycle of the project while the carbon handprint refers to the environmental impact benefits from the project construction like renewable energy and products recycling (Kuittinen, 2019), (World Green Building Council, 2019).

The LCA results are mostly calculated per square meter and the building service years. For example, 15 Kg CO_2 equivalent/m^2/year means that to get the total carbon emission we must multiply 15 * the building floor area * the number of building operating years). In Finland, the used area in the LCA calculation is mostly the heated net area which could be obtained from the building energy test or assumed to be 90% of the gross heated area. The gross heated area is equal to the building gross area minus the areas of the unheated premises. The gross building area could be calculated by multiplying the building area (external dimension/including the outer walls) by the number of floors (Shaun, 2020c).

2.5 Finland Ministry of Environment Method for the whole life carbon assessment of buildings 2019

The Ministry of Environment in Finland has created a roadmap for low-carbon construction in June 2017 which indicates that the building whole life carbon assessment will be monitored and included in the building permit process by the mid-2020s. The roadmap implementation requires different environmental expertise efforts in producing a reliable information database that supports developing the new environmental policies and legislation (Environmental management, 2013), (Ministry of Economic Affairs and Employment of Finland, 2020).

The Finnish 2019 government requested to speed up the implementation of the roadmap and develop a method for assessing the building's life cycle carbon footprint that is suitable for the Finnish environment (Kuittinen, 2020). The Ministry of Environment in Finland has published a method for the building whole life carbon assessment in 2019 by technical experts' extensive collaboration from different stakeholders along with researchers from Nordic and European countries and it is under development based on feedback obtained through regular consultation rounds in a piloting period (Kuittinen, 2019). It is generated based on the European Commission's Level(s) method and the European standards to provide a common framework for calculations (Hakaste & Kuittinen, 2017b).

The Ministry of Environment method supports all types of buildings (also both new building and building during refurbishment) and covers the entire building material and service systems during its entire life cycle (starting from building elements manufacture and transportation, passing by construction and usage until the demolition and recycling phase). However, it excludes the carbon calculation from vegetation, demolishing the site previous structures, soil restoration work, temporary scaffolding, and facilities during the construction phase.

Figure 8 summarizes the rules and restrictions of the Ministry of Environment in Finland method for building whole life carbon assessment in 2019. While figure 9 clarifies which input data used from each life cycle phase during the carbon analysis. It is recommended to use a carbon emission calculation tool with the Ministry method and take advantage of the tool material CO_2 database as the Ministry national database is still under development by the Finnish Environment Institute and its first version should be completed in 2020 (Kuittinen, 2019), (Ministry of the Environment, 2019).

Projects assessed	New buildings, extensive repairs	
Types of building assessed	1–2 Residential building 3 Office and health centre 4 Business premises, theatre, library, museum 5 Accommodation establishment, hotel, hostel, sheltered accommodation building, nursing home, care facility 6 Educational establishment and crèche 7 Sports centre (excluding swimming pools and ice rinks) 8 Hospital 9 Other	
Parts of a building assessed	*Assessed*	*Not assessed*
Site	Earth works, soil stabilisation and reinforcement elements, paved areas, site structures	Site equipment, vegetation, soil and bodies of water
Load-bearing structures	Foundations, ground floors, structural frame, façades, doors and windows, external decks, roofs	Separate fasteners
Supplementary structures	Interior walls, doors, stairs, surfaces, fittings, ducts and fireplaces, box units	Mouldings, surface materials and surface treatments, separate fasteners
Building systems	Energy systems, water and drainage systems, air conditioning systems, power distribution and operating systems, solar panels and collectors, lifts	Information systems, emergency power, escalators, separate machinery and equipment
Construction site	Energy consumed	Scaffolding and protective covers, temporary structures, moulds, life cycle of worksite facilities, site personnel traffic
Analysis period	Fifty years or design service life (if used as a basis for the design)	
Reference unit	1 m^2 of the building's heated net space / year	

Figure 8: The rules and restriction summarization Finland Ministry of Environment in method for the building whole life carbon assessment 2019.
Source: (Kuittinen, 2019, p.40)

Prior to use	Evaluation	Data used
A1-3 Product manufacture	+ Assessed	Only project-specific data
A4 Transportation to construction site	+ Assessed	Project-specific data or table of values
A5 Construction	+ Assessed	Project-specific data or table of values
During use	**Evaluation**	**Data used**
B1 Use of products	- Not assessed	
B2 Maintenance	- Not assessed	
B3-4 Repairs and replacements	+ Assessed	Project-specific data or table of values
B5 Refurbishment	Independent, separate analysis	
B6 Operational energy use	+ Assessed	Only project-specific data
B7 Water consumption	- Not assessed	
After use	**Evaluation**	**Data used**
C1 Demolition work	+ Assessed	Project-specific data or table of values
C2 Transportation for processing	+ Assessed	Project-specific data or table of values
C3 Waste processing	+ Assessed	Project-specific data or table of values
C4 Disposal	+ Assessed	Project-specific data or table of values
The implementation and review of the analysis		
Database	Not specified. National emissions database forthcoming.	
Tool	Not specified. Must be compatible with the assessment method.	
Competency requirements	Not specified. Requirements still under way.	
Revision of results	Not specified. Requirements still under way.	

Figure 9: Different input data used from each life cycle phase during the carbon analysis in the Ministry method.
Source: (Kuittinen, 2019, p.41).

The Ministry of Environment in Finland has assumed average figures for the carbon emission for each life cycle module as shown in Table 1. The assumption was made for projects in Finland with a 20% uncertainty factor and are given in kg CO_2e/m^2/year considering the building heated net area and its service lifetime to be 50 years. However, for modules A1-3 and B6 there is no assumption as their carbon emission must be calculated separately for each project (Kuittinen, 2019).

Typical emissions ($kgCO_2e/m^2$)		
A1–3 Manufacture		*(calculated only with project-specific data)*
A4 Transportation to site	10.20	Average transportation distance in Finland
A5 Functions at new construction site	27.30	Consumption of energy and fuel on the worksite
B3–4 Energy consumption of repairs[12]	2.16	The production of materials must be assessed separately
B6 Operational energy use		*(calculated only with project-specific data)*
C1 Functions at a demolition site	7.80	Consumption of energy and fuel on the worksite
C2 Transportation to further processing	10.20	Average transportation distance in Finland
C3–4 Waste processing and final disposal	15.60	
Total	73.26	$kgCO_2e/m^2$

Table 1: Average figures for different life cycle modules carbon emission in Finland Source: (Kuittinen, 2019, p.47).

The following sections will clarify the four main categories in the Ministry of Environment method (Material, Energy, Transportation, and Construction) linked with the related LCA stages and modules as shown in figure 10.

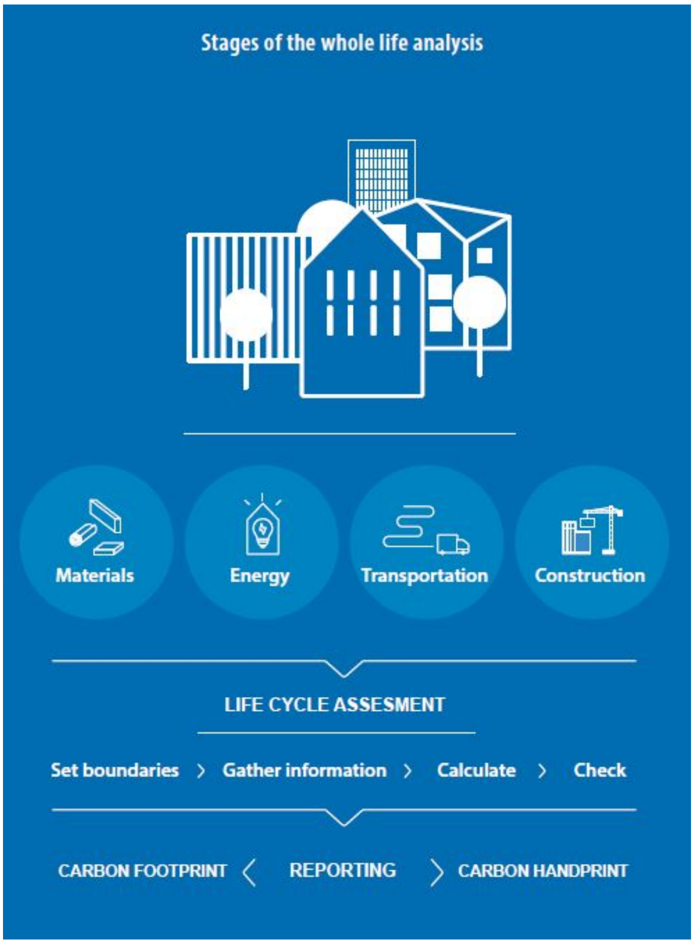


Figure 10: Stages of the whole life cycle analysis

Source: (Kuittinen, 2019, p.17).

2.5.1 Material carbon footprint

For the product stage in LCA (modules A1-3), the first step of conducting the Ministry building carbon assessment method is by creating a material list that includes carbon-related materials from the site, load-bearing structures, supplementary structures, and building systems (HVAC). Table 2 provides a general overview of which building materials are included and which are excluded in the Ministry method while appendix 2 clarifies the detailed elements nomenclature from the building 2000 classification system. In case of refurbishment, the materials included in the carbon footprint assessment will be restricted to the new building parts or elements that will be repaired and there is no consideration for any stages before the refurbishment (Kuittinen, 2019).

	Included in the analysis	Not included in the analysis
Site	+ Ground elements + Soil stabilisation and reinforcement elements– + Paved areas + Site structures	- Site equipment - Vegetation - Climate impacts of vegetation, soil or bodies of water
Load-bearing structures	+ Foundations + Ground floors + Structural frame + Façades, doors and windows + External decks + Roof structures	- Separate nails, screws, adhesives, seals, caulks and other fasteners, brackets, etc. that do not come with the products.
Supplementary structures	+ Interior walls and doors + Stairs + Surfaces + Normal fittings + Ducts and fireplaces + Prefabricated units	- Surface materials and mouldings - Surface treatment and paintwork - Separate nails, screws, adhesives, seals, caulks and other fasteners, brackets, etc. that do not come with the products.
Building systems	+ Heating systems + Water and drainage systems + Air conditioning systems + Cooling systems + Sprinklers + Electrical systems + Lifts	- Information systems - Building automation - Emergency power systems - Escalators - Separate machinery and equipment
Construction site	+ Energy consumed on the construction site	- Scaffolding and protective covers - Temporary structures, moulds and technical equipment - Life cycle of construction site facilities - Site personnel traffic

Table 2: An overview of the building elements included in the Ministry method for building carbon assessment.
Source: (Kuittinen, 2019, p.20).

If there is incomplete data on the building service systems (HVAC) which is usually the case during the early stages of the project, the average values in table 3 could be used to assess the carbon footprint of the building services system. These data have been developed by the Technical Research Centre of Finland (VTT) and the used m^2 is the heated room area which could be calculated as 18% less than the total floor area (Kuittinen, 2019).

Conventional systems (surface area indicated for each room area of the building)	
Lift	7 585.00 kg CO_2/each
Electrical installations and wiring	5.28 kg CO_2/m^2
Sprinkler system	5.85 kg CO_2/m^2
Water supply and sewage (surface area indicated for each room of the building)	
Water supply	2.70 kg CO_2/m^2
Piping	0.52 kg CO_2/m^2
Heating system (surface area indicated for each room of the building)	
Radiators	6.67 kg CO_2/m^2
District heating substation	0.53 kg CO_2/m^2
Ventilation system[10]	6.97 kg CO_2/m^2
Solar panels (surface area indicated for each solar panel collector)	
Crystalline silicon solar panel	242.00 kg CO_2/m^2
Thin-film solar panel	67.00 kg CO_2/m^2
Network inverter	22,00 kg CO_2/each

Table 3: Emission data for building service systems (HVAC).
Source: (Kuittinen, 2019, p.46).

In the case of the module B4 in the building life cycle (replacement of a product), the Ministry method has used the following formula shown in figure 11 to calculate the replacement time interval for products that will need replacement during the building lifetime. For example, windows with 20 years' life would be replaced 4 times during a 100-year lifetime building. These replaced products are not counted in module B5 (refurbishment of the building). The replacing products are always assumed to be new and all product relevant factors should be considered during estimating the product technical lifetime like conditions of use, abrasion resistance, and maintenance intervals (Kuittinen, 2019).

$$\text{Replacement interval} = \left[\left(\frac{\text{Building´s service life}}{\text{Product´s service life}} \right) - 1 \right]$$

Figure 11: Product replacement interval estimation formula.
Source: (Kuittinen, 2019, p.22)

For modules C3-C4 waste processing and disposal, a 15.6 $kgCO_2e/m^2$ assumption was issued in the Ministry of Environment method. As mentioned earlier, this number has with 20% uncertainty factor and consider the net building heated area and its service lifetime in years. There will be more detailed assumptions for each material category emission in the national emission database that will be published later that includes how much of each material could be used (Kuittinen, 2019).

2.5.2 Transportation carbon footprint

The transportation is a process integrated into all building life cycle categories like transportation of raw material during manufacturing A2, during construction A4, during repairing and replacement B3-4, and during the end of life stage C2. As mentioned earlier, with a 20% uncertainty factor the Ministry of Environment method has assumed a carbon emission mean value to be 10.2 $kgCo_2e/m^2$ (net heated area) for the transportation of the building products to the construction site and the transportation in the end life stage (modules A4 and C2). The assumed values consider an average transportation distance in Finland and distributed across the building service life ($kgCO_2e/m^2/year$) (Kuittinen, 2019).

Transportation carbon assessment includes the carbon emissions from transportation of materials and products to the construction site during construction or maintenance, transportation of large quantities of soil to or from the construction site, and transportation of all waste generated from the construction site. The Ministry of Environment method neglected the carbon emission from transporting construction machinery and labor. The load filling rate assumed to be 100% for soils taken away from the construction site, 80% for other outward journeys, and 0% for the return journeys (Kuittinen, 2019).

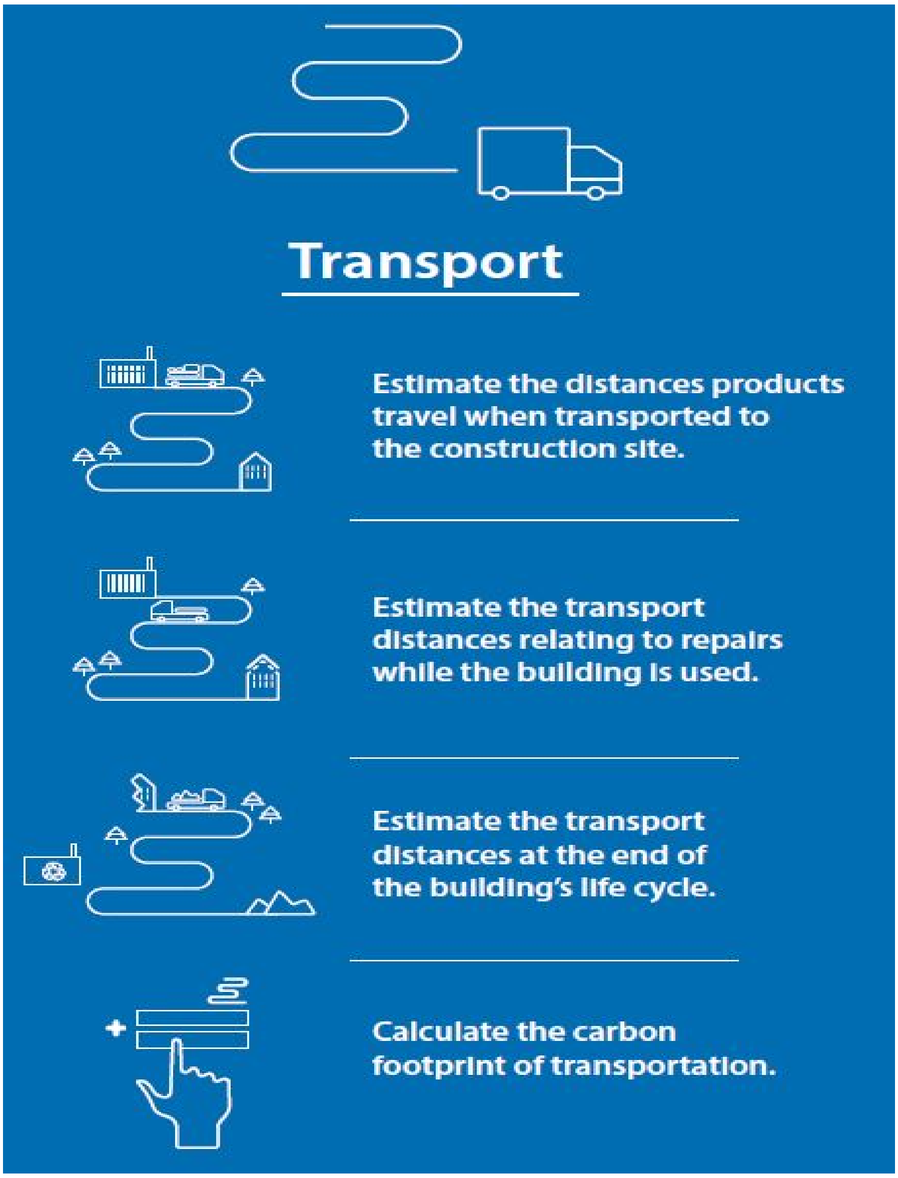


Figure 12: Transportation carbon emission main calculation steps.
Source: (Kuittinen, 2019, p.24).

2.5.3 Construction carbon footprint

The Ministry of Environment 2019 method for the whole life carbon assessment of the building assumed an amount of 27.3 $kgCO_2e/m^2$/year for the consumption of energy and fuel during new construction (modules A5) and an amount of 7.8 $kgCO_2e/m^2$/year for the consumption of energy and fuel during demolition (modules C1). The previous assumptions are made for the Finnish building environment with a 20% uncertainty factor and using the net heated area of the building (Kuittinen, 2019).

2.5.4 Energy carbon footprint

The Ministry of Environment method for the whole life carbon assessment of the building specified that the building energy should be estimated based on the Energy Performance Decree of new building 1010/2017. The energy carbon footprint is calculated by multiplying the emission coefficient by the estimated consumption of purchased energy supplied to the building. Table 4 provides the Ministry standardization emission coefficient for different forms of energy. The future anticipation based on the annual average CO_2 emissions from fuel consumption and energy consumption in Finland and the decreasing numbers reflects the different measures and researches taken by Finland's National Energy and Climate Strategy, Finland Ministry of Environment, and the Technical Research Centre of Finland (VTT) (Kuittinen, 2019).

	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120
Electricity	121	57	30	18	14	7	4	2	1	1	0
District heating	130	93	63	37	33	22	15	10	7	4	3
District cooling	130	93	63	37	33	22	15	10	7	4	3
Fossil fuels	260	260	260	260	260	260	260	260	260	260	260
Renewable fuels	0	0	0	0	0	0	0	0	0	0	0

Table 4: The Finnish Ministry of Environment standardized emission coefficient for different forms of energy.

Source: (Kuittinen, 2019, p.48)

2.5.5 Other considerations

The Ministry of Environment method also considers carbon handprint measures through the reuse or recycling the building materials and using renewable energy (Kuittinen, 2019). However, these measures are still in the reforming process during the pilot phase and will not be mentioned in detail as it is outside the thesis scope and integrated into the LCA one-click tool during performing the carbon assessment in the case studies.

2.6 Building Information Modeling (BIM)

Building Information Modelling (BIM) is the process and technologies to design and manage the building by combining the building geometry with all relevant information (Lee et al., 2012), (Tardif & Smith, 2009). It is an industry trending approach that enables various construction parties to share information and visualize it in a data-rich object-oriented model that represent the building physical and functional characteristics efficiently which eliminates the conflicts between project parties, enhances the work performance, delivers projects earlier, and reduce the overall project cost (Khatib et al., 2007). BIM is classified into different dimensions according to the level of usage and referred to as (n)D modeling; 3D modeling means to have a three-dimension model of the building that gives various 3D views. 4D BIM modeling is when the construction schedule is linked to the 3D model (visualizing the sequence of construction in a 3D view). 5D modeling is increasing cost to 4D modeling (estimating the bill of quantities and project cost within the model). While, 6D modeling refers to the management of the facility after construction (Smith, 2014). Figure 13 clarifies the development timeframe of adopting BIM since the first related research published in 1975. It gained considerable attention in the previous decade as the common BIM requirements in Finland (COBIM) has been issued in 2012 and by 2016, BIM has become mandatory in public projects in the UK (kiviniemi, 2019).

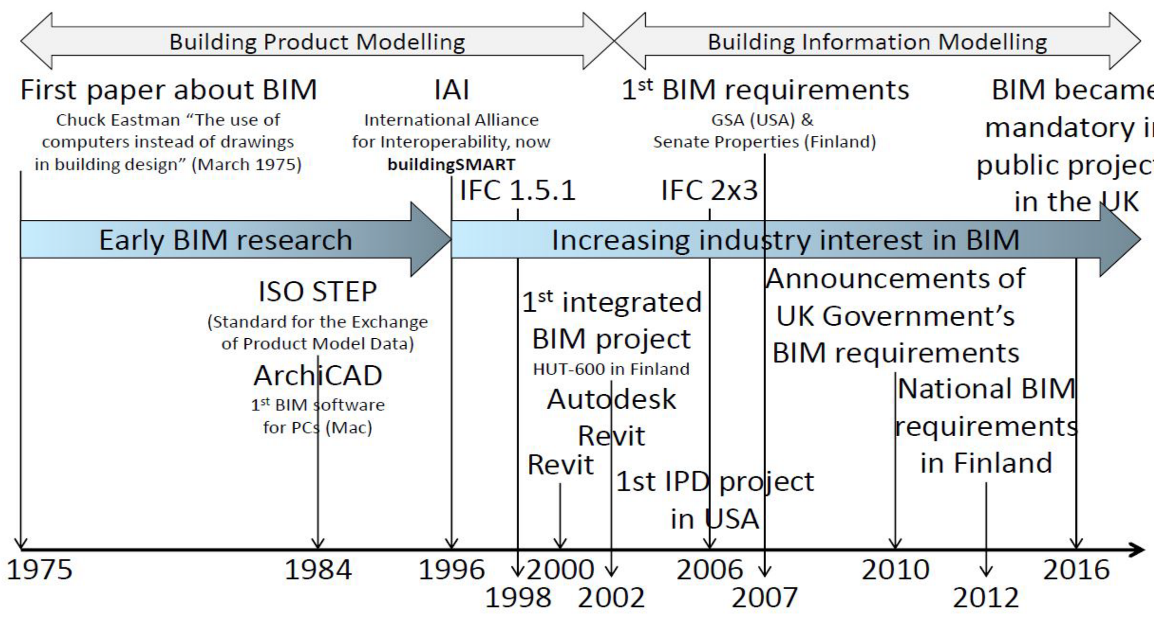


Figure 13: BIM development timeframe.

Source: (kiviniemi, 2019).

Azhar et al. (2008) conclude in their study research that the most noticeable obstacle preventing the widespread of BIM knowledge is the lack of training programs for engineers and architects as well as most owners and developers are aware of the benefits of implementing BIM. However, most companies in the united states seek to hire engineers with BIM skills rather than hiring others who lack BIM knowledge. As there is a general lacking in the numbers of BIM skilled engineers, (Livingston, 2008) argues that BIM should be considered in universities curricula.

The Industry Foundation Class (IFC) is a BIM data exchange international standard format. The IFC format represents a frozen copy of the original BIM design content, like PDF file format, to transfer the design information between project stakeholders. It could be used for many purposes like model viewing, clash detection, and cost estimation but shouldn't be edited (Baldwin, 2017). BIM software developers always provide the end-users with options in their software to import and export their work in IFC file format (buildingSMART International, 2020). The IFC schema has passed by several developing phases which improved its information quantity and quality. Figure 14 shows the development timeframe and that the currently used version is IFC 4 that has been released in 2013 while the IFC 5 is still under development (Majcher, 2019).

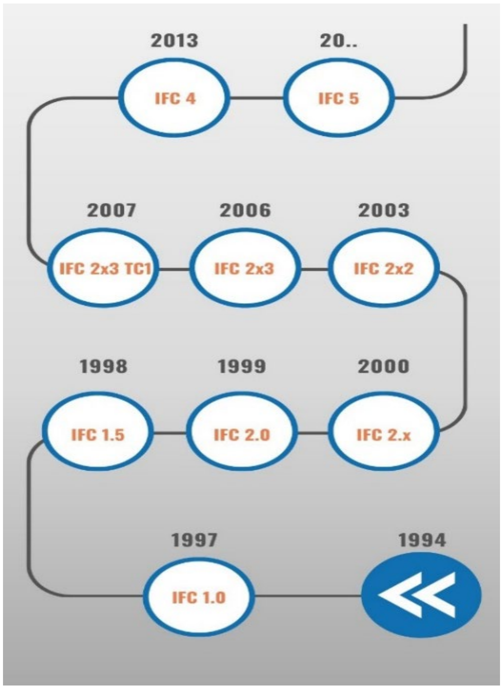


Figure 14: The IFC file format evolution.

Source: (Majcher, 2019).

2.7 Common BIM requirement (COBIM)

The Common BIM Requirements (COBIM) was published in 2012 by Building Smart Finland (a collaboration forum founded by a consortium of different public and private organizations in the Finnish architecture, engineering, and construction (AEC) industry. The Building Information Foundation (RTS) will serve as the project coordinator. The COBIM national requirements are for all stakeholders in the AEC industry value chain and the whole lifecycle of the building. It took approximately two years and was funded by a 250,000 Euro budget from 24 organizations and drafted by ten organizations (consultants, construction companies, research organizations, software enterprises, etc.) (European Commission, 2016), (BuildingSMART Finland, 2012a).

With the increasing demand for using building information modeling in the building sector, many organizations and companies created their BIM process and guidelines. Senate Properties, an enterprise owned by the government that owns the state buildings, had its own BIM guidelines in 2007 that has been used as a reference and foundation to generate the COBIM 2012 as clarified in figure 15 (Kiviniemi, 2016).

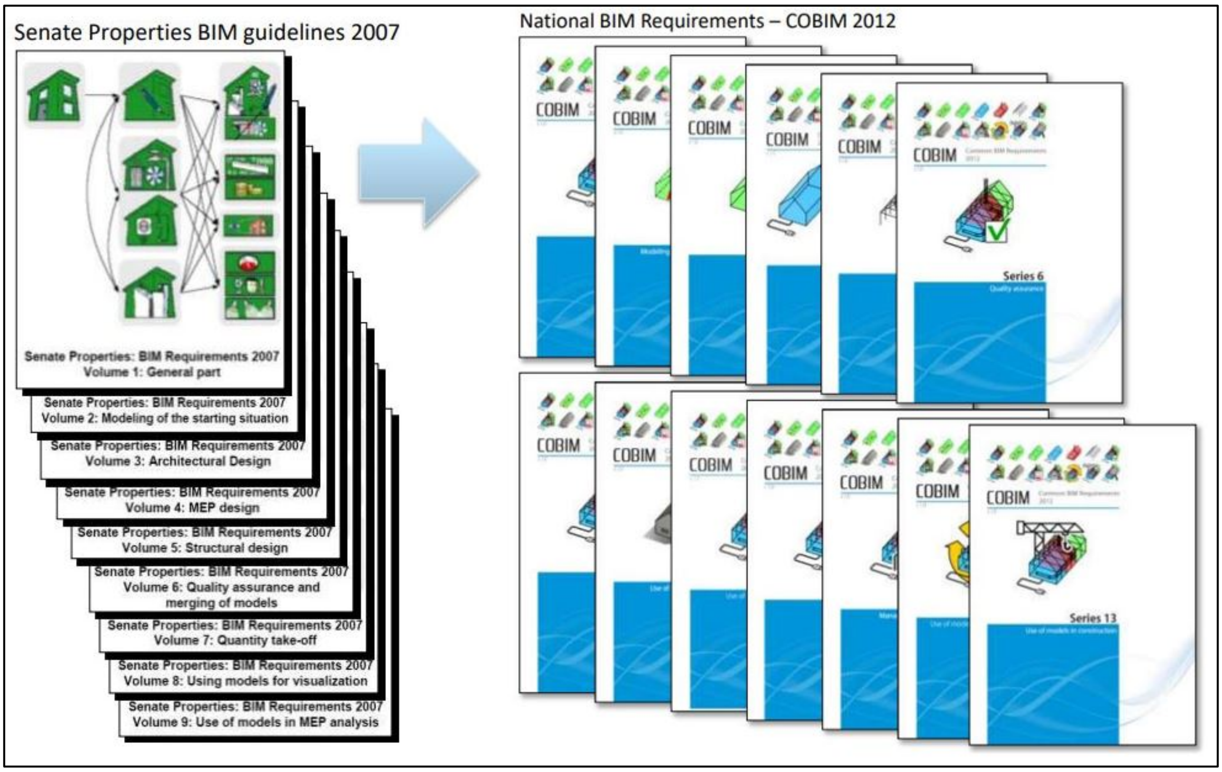


Figure 15: The development from the Senate Properties BIM guidelines 2007 to the National BIM Requirements COBIM in Finland 2012
Source: (Kiviniemi, 2016).

The COBIM consists of 14 series that are written, revised, and approved by a group of members from the participating companies and organization in the consortium. It contains the minimum required information to be modeled and how that should be done during the different phases of the construction project. It could be used for new construction and renovation projects as well as supports the building usage phase and building facility management. It supports all design and modeling software that has a minimum IFC 2*3 certification as agreed by the project management and based on the client demands (BuildingSmart Finland, 2012b). The COBIM 2012 series are:

1) General BIM Requirements
   It describes the basic concepts and principles that showed be followed during the BIM process and well as it contains the general definitions. It highlights that the BIM model could be a decision-making tool in case if modeling is required in the building permit process (Henttinen, 2012a).
2) Modeling of the Starting Situation
   The second series focuses on modeling the starting situation (the existing building if it is a renovation or the building site if it is a new project) to serve as information for design and construction purposes. It specifies the measurement requirements required to create an inventory model (Rajala, 2012).
3) Architectural Design
   Series 3 specifies the architect’s requirement in the BIM models. It is mandatory for all design phases in COBIM projects and is divided into three levels according to the different purposes of the model (Henttinen, 2012b).
4) MEP Design
   Series 4 is focusing on MEP design models. It contains prerequisites for enhancing the MEP system application for use and maintenance through the building's whole life cycle (Järvinen, 2012a).
5) Structural Design
   Series 5 is focused on the structure BIM scope, precision, and its relevant data. It has been broken down into design stages and each stage contains a list of relevant data that should be mentioned in the model (Kautto, 2012).
6) Quality Assurance
   Series 6 is specified for quality assurance. It describes how the BIM content could be managed in the other series to obtain the best usage as well as it contains practical guidelines and different assessment checklists (Kulusjärvi, 2012).

7) Quantity Take-off

Series 7 describes the BIM essential requirement for quantity take-off. It is drafted for every project stakeholder and should be conducted according to each design discipline requirement with a given level of details for each design stage (Tauriainen, 2012).

8) Use of Models for Visualization

Series 8 divided the usage of the BIM model for visualization into two types, rendering, and technical illustration. The usage of the BIM in rendering could be used for marketing while the technical model works as a supporting tool for communication in the design team (Henttinen, 2012c).

9) Use of Models in MEP Analyses

Series 9 describes how the BIM model could be used in analyzing the MEP design. It contains comparisons between different example analysis like lighting (Järvinen, 2012b).

10) Energy Analysis

Series 10 emphasizes the importance of energy analysis by giving it a whole part of the COBIM requirements. It clarifies the crucial tasks related to energy efficiency management that should be done during design and construction (Laine, 2012a).

11) Management of a BIM Project

Series 11 discuss the project management tasks and the perspective of the client on utilizing BIM. It describes the decision-making supportive decision that could be based on the BIM outcome at each stage of the project (Mäkelä, 2012).

12) Use of Models in Facility Management

Series 12 is focused on utilizing the use of BIM during the use and maintenance phases. It describes how the BIM would support the facility management throughout the whole construction value chain (Laine, 2012b).

13) Use of Models in Construction

Series 13 is focused on the implementation of BIM during the construction phase. It defines the related BIM tasks from the contractor's point of view (Kiviniemi & Peltomäki, 2012).

14) Use of Models in Building Supervision

Series 14 discuss the use of the BIM model in the supervision processes from the authorities’ point of view and it has been issued in 2014 (Lukkarinen, 2014).

The COBIM has been published to be the common ground between different project participants and could be used as appendices to the public and private construction contracts. Its main goal is to utilize the project data management and serve future sustainable development (European Commission, 2016). The beginning of each chapter defines that the designer of the BIM project that follows the COBIM must be aware of the general requirement (series 1) and Quality assurance principles (series 6). The COBIM also defines that the project client should have a copy of all designs and electronic documents (including the IFC files and the native design formats) at the end of the construction project (BuildingSmart Finland, 2012a). The Common BIM Requirements (COBIM) could be used as an industry standardization to achieve industry sustainable goals among all value chain stakeholders.

2.8 Utilizing LCA using BIM

Life cycle assessment is a data-intensive process that requires a huge reliable data inventory. therefore the idea of using BIM to utilize the life cycle assessment process is a cutting edge solution for the problem of lacking building material information (Röck et al., 2018). (Schlanbusch et al., 2016) has concluded that BIM is a smart solution for fast and accurate data management during the building life cycle assessment as it solves the problem of the poor building material information in the early design phases (like thickness or volume of the materials). Therefore, BIM could develop guidelines on extracting and sorting the LCA relevant data which will save time and improve the quality of the LCA inventory.

3. The Thesis location in the LCA development timeframe

This section clarifies the development timeframe of the LCA calculation process in the construction industry with the most common current process used in calculating the carbon emission and the effect of this thesis methodology in developing the current carbon assessment process as well as an anticipation of the future development that might happen in the coming years. This section also illustrates how the thesis approach would reduce the overall time required to conduct the carbon assessment for one project as well as reducing the number of engineering departments involved in conducting the LCA process which would decrease its overall cost and minimize faults probabilities by depending less on the human factor. Figure 16 illustrates the thesis attempt in the LCA calculation development timeframe as mentioned below.

3.1 The usual current process of carbon footprint calculation

Calculating the building's carbon footprint is highly depending on the availability of the building material information and related LCA factors. The author has investigated how the carbon assessment usually takes place in the construction industrial field nowadays. When the industrial company performs life cycle assessment they usually use the bill of quantities or other contractual documentation -probably from the cost control department- to extract the building element material information and start filtering these materials and conduct the carbon footprint calculation by the environmental department specialist based on the availability and quality of this information. Usually, they use LCA calculation excel sheets- then pass it back to the designer who should edit his design based on the LCA report to achieve a better carbon footprint target if required. The main fault of this process is that it would take more than four working days from the project engineer's time. Also, the problems of model inaccuracy, availability of required information, connection problems between different departments as well as involving several departments (cost control, environmental department, and design department) would result in higher cost of calculating the carbon emission for a single project.

3.2 Current thesis endeavor

This thesis aims to enhance the LCA carbon footprint calculation process by utilizing the usage of BIM software through the whole carbon assessment process which will generate a faster and more accurate outcome while including fewer departments in the operation (only the designer and environmental specialist) which will reduce the overall cost of conducting single project carbon assessment. The main idea is extracting the building material excel sheet from the IFC design models (that already complies with COBIM) through Solibri software then assess and filter the outcome on an accredited LCA calculation tool to calculate the carbon footprint based on the Ministry of Environment Method for the whole life carbon assessment of buildings.

3.3 Future development

Nowadays, many BIM software developers and consultants racing to reach a fast and accurate solution for the building carbon emission calculation as most construction industry stakeholders have a higher demand and interest than ever in assessing the environmental impact of their structures. There are ongoing attempts to utilize the CO_2 calculation inside the same design software so the designer could have an overview of the environmental impact of the chosen material alongside its financial impact during the design phase (SolibriInc, 2020).

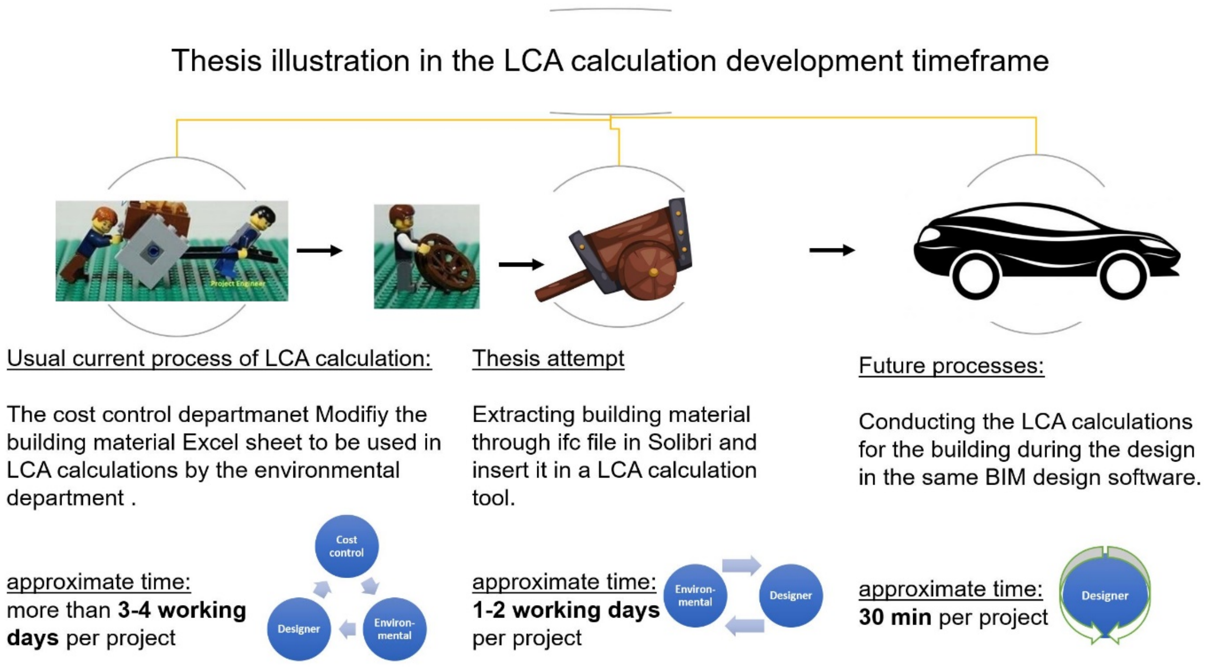


Figure 16: Illustration of the workflow and estimated time required to perform LCA according to the premise of this thesis.

4. Case studies overview

To validate the thesis approach and have a better understanding of its advantages in the carbon assessment process, three project design models were provided by Skanska company in Finland to be used as case studies in the thesis carbon assessment methodology. The three projects (Konttilukinkatu 11, Kultavene, and Mannerheimintie 162) are newly built multi-story residential buildings located in different parts of Finland and by different designers. Each project has a detailed Architecture and Structure design models except the structure model of the Kultavene project that was missing from the project database. For each case study project, a comparison of the carbon emission has been conducted between the results of the Carbon designer, Arch model only, Arch model + HVAC average standards, and combination of architecture model and required material information from the structural Model. Figure 17 illustrates the three case studies and their available models.

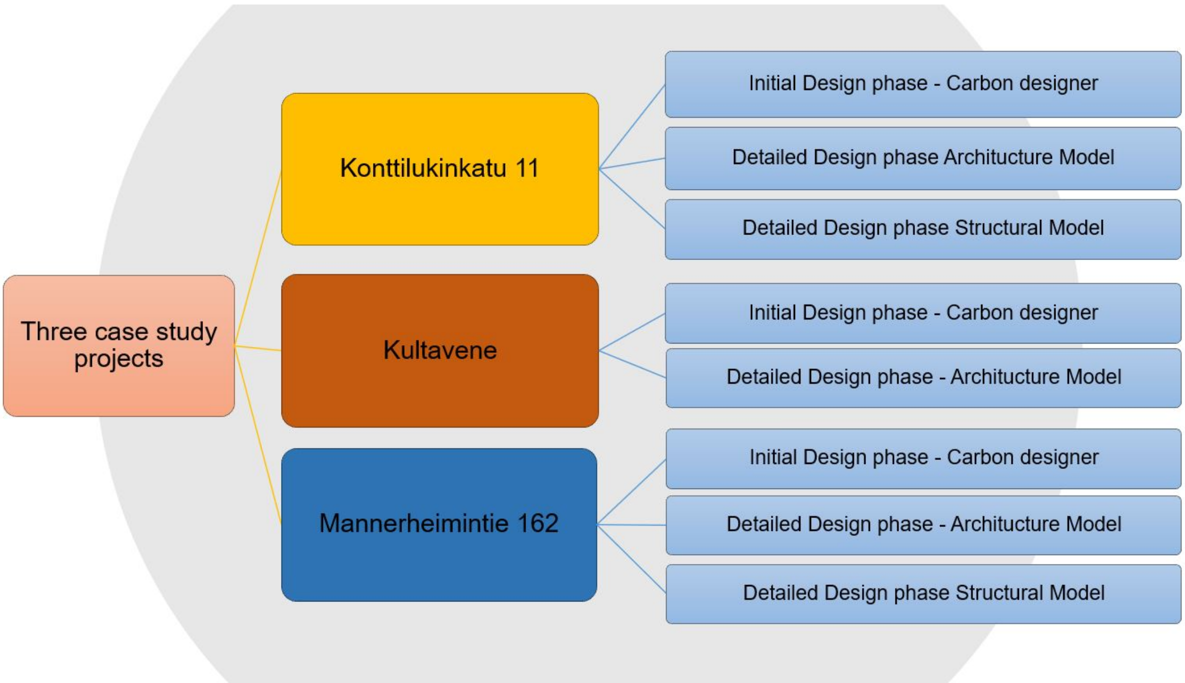


Figure 17: Case studies projects overview.

For the assessment of the environmental impact for each case study project, the Environmental Product Declaration (EPD) database provided by RTS (abbreviation for the building information foundation Rakennustietosäätiö in the Finnish language) were used through the direct integration in the LCA one-click tool when choosing the tool option to follow the Ministry of Environment method for the whole life carbon assessment of buildings (Bionova, 2018c). The RTS EPD database is based on the

EN standards 15804:2012+A1:2013 and following EN ISO 14044 (Rakennustietosäätiö, 2020). The Ministry of Environment Method for the whole life carbon assessment of buildings has set an average building lifetime of 50 years only to be processed in all carbon emission assessments using its method regardless of the designer wish for the building lifetime (Kuittinen, 2019).

It is crucial to understand the importance of analyzing different design models in the LCA carbon assessment to obtain more accurate results. In the case studies, both architecture and structural models were used to know the exact building material information naming and type. The structural IFC model has a better definition for the structural bearing material elements like; concrete exact material type or sandwich walls that could consist of different elements. The architectural model should have much more information than the structural one related to all information other than the bearing elements like; windows and doors material type. It is also understandable not to duplicate materials from both models, for example; the columns will exist in both models but its material definition should be extracted from the structural model (which is based on COBIM it should have a better material definition) and neglected from the architectural model.

4.1 About the used BIM software (Solibri)

Operates in more than 70 countries, the Solibri software company has a Scandinavian root as it was initially founded in Helsinki back in 1996 (SOLIBRI , 2020a). Solibri is a BIM software that supports quality control and quality assurance in the design and pre-construction phases through checking the different disciplines model clashes and errors so the project stakeholders could have a better understanding of the design issues which have a positive impact on the design process coordination. It is also used in the material quantities take-off from the models that can be used in many ways like cost control and procurement (SOLIBRI, 2020b). Figure 18 shows an example of Solibri software capabilities by combining three discipline models (architecture, structure, and HVAC) and the related clash detection with the information box on the left down corner.

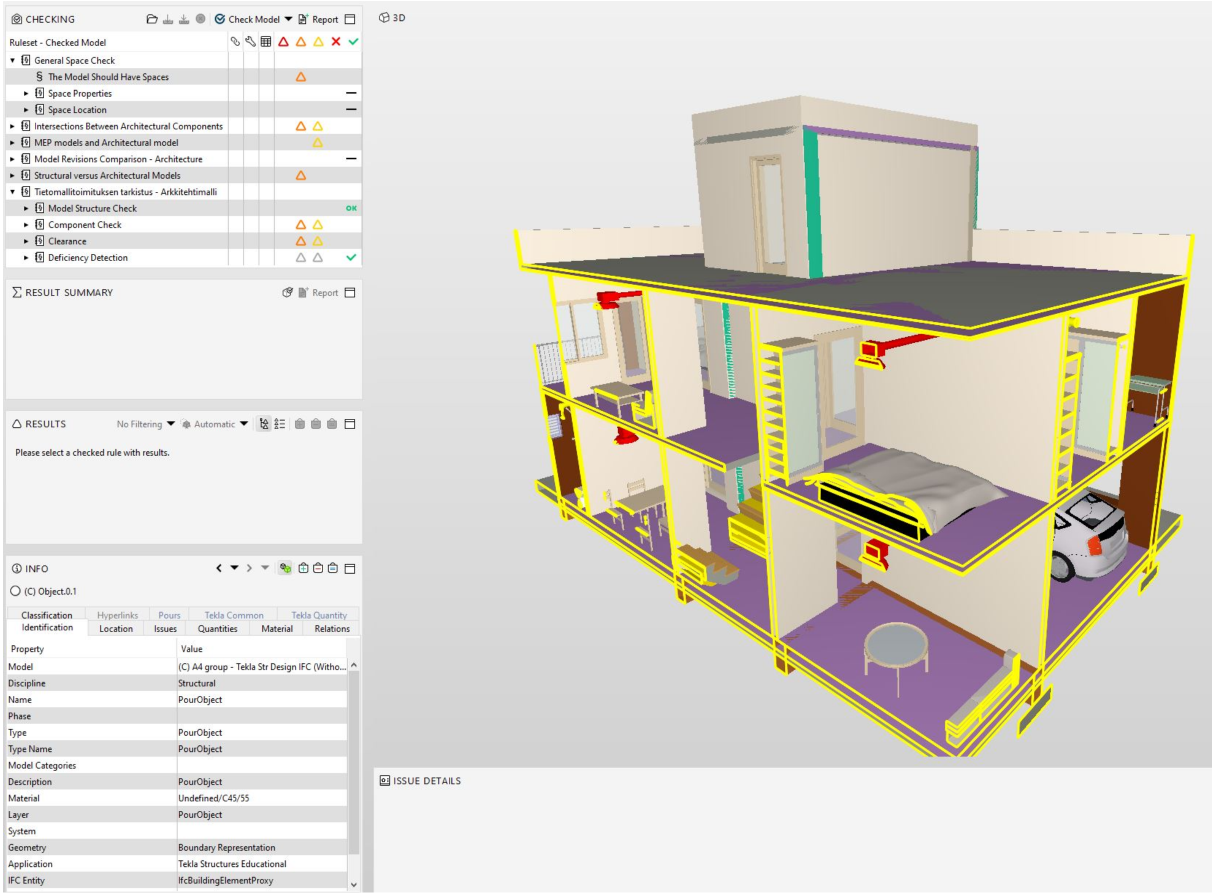


Figure 18: Solibri different capabilities example

Solibri offers good visualization options with an information box where the user can find all relevant information about the selected building element in the IFC model like Name, type, description, material, classification, and Quantities. It is critical to mention the importance of the quality of this information in the model for conducting the LCA and carbon assessment, as calculating the carbon footprint based on the model quantities take-off requires a high quality of the extracted material data from the model.

4.2 About the used LCA tool (One Click LCA)

It is crucially important to clarify that this thesis doesn't assess the quality or credibility of the chosen LCA tool. It rather investigates the LCA process defaults and obstacles and BIM could enhance the life cycle assessment process regardless of the used LCA tool. The LCA One-Click tool has been chosen as it is following the Finnish building code and it is widely used by different industrial field professionals in Finland (Bionova, 2018a).

Developed in 2011 by Bionova company in Helsinki city, One-Click LCA is an automated LCA tool that calculates the environmental carbon footprints quicker and easier than the normal procedures of using spreadsheets (Bionova, 2018e). One-Click LCA tool is used in more than 50 countries worldwide and complies with ISO and EN standards as well as it could be used to achieve credits from many certification systems such as BREEAM, LEED, and other global certification systems as shown in figure 19 (Bionova, 2018d), (one-click LCA, 2018a).

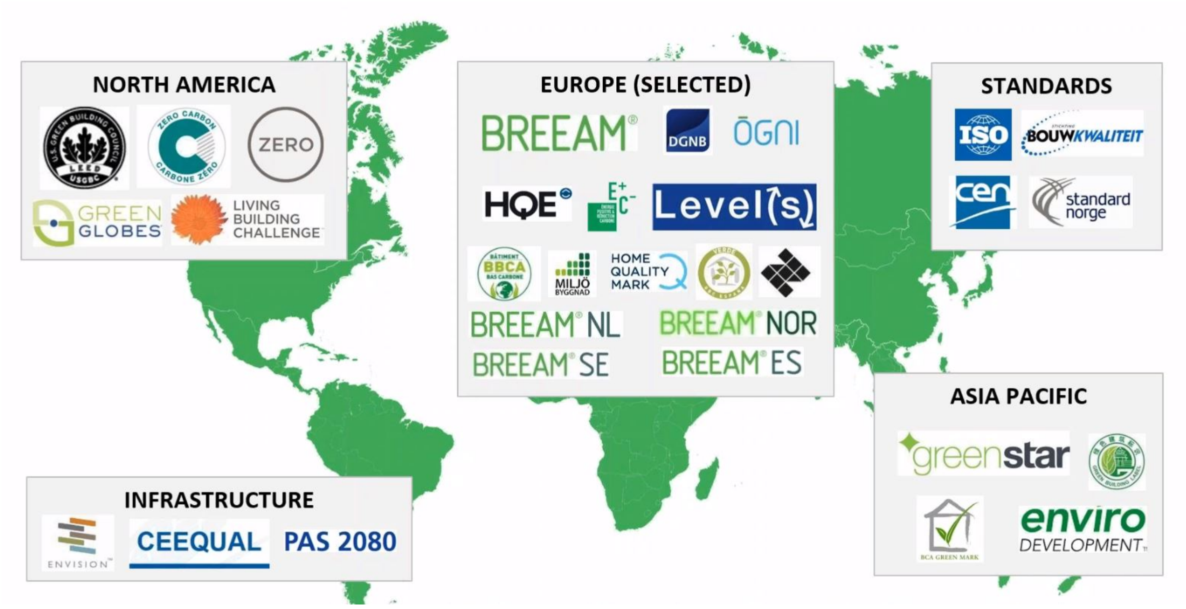


Figure 19: Integrated certification systems in the one-Click LCA tool.
Source: (one-click LCA, 2018a)

The tool is operated through a configuration-driven web cloud platform for easier future updates adoption (Shaun, 2020a). The tool allows integration with different BIM design software and different file formats through plugins to help its user extracting the relevant data in any suitable way. The tool developers provide different supporting videos and tutorials on how the integration process works step by step for a wide range of software and file formats such as Autodesk Revit, Solibri, ArchiCAD, Tekla Structure, SketchUp, IFC file formats, and Excel sheets as shown in figure 20 (Bionova, 2018F).

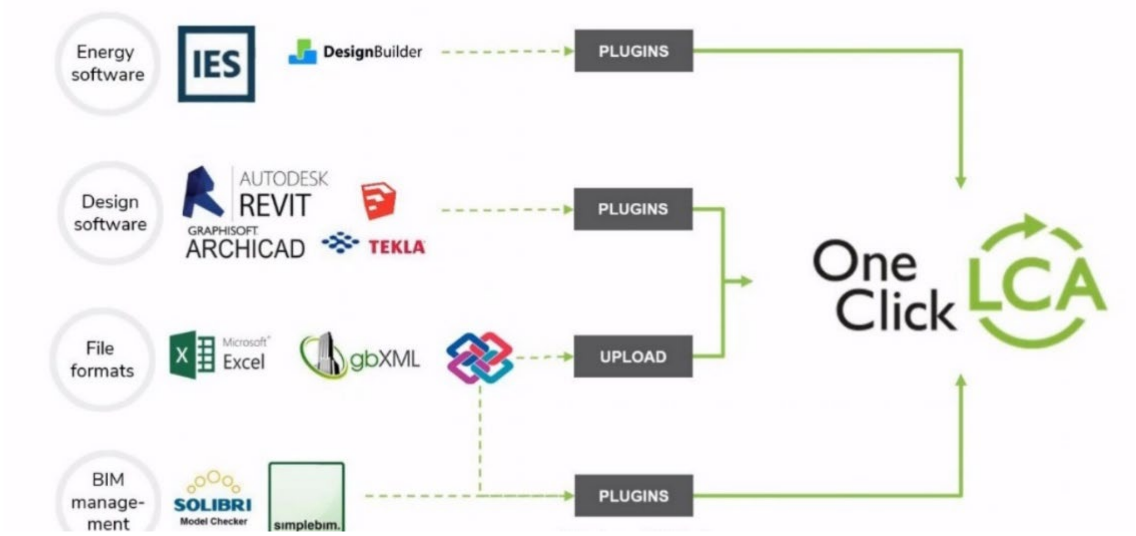


Figure 20: BIM integration options in the one-Click LCA tool.
Source: (one-click LCA, 2018a).

The LCA one-click tool has comprehensive materials carbon emission databases from various public and private sources that are subjected to a strict verification using a building research establishment reviewing process to ensure accurate results based on the designer's needs and the project location. Figure 21 summarizes some of the integrated databases in the LCA one-click tool (Bionova, 2018G).

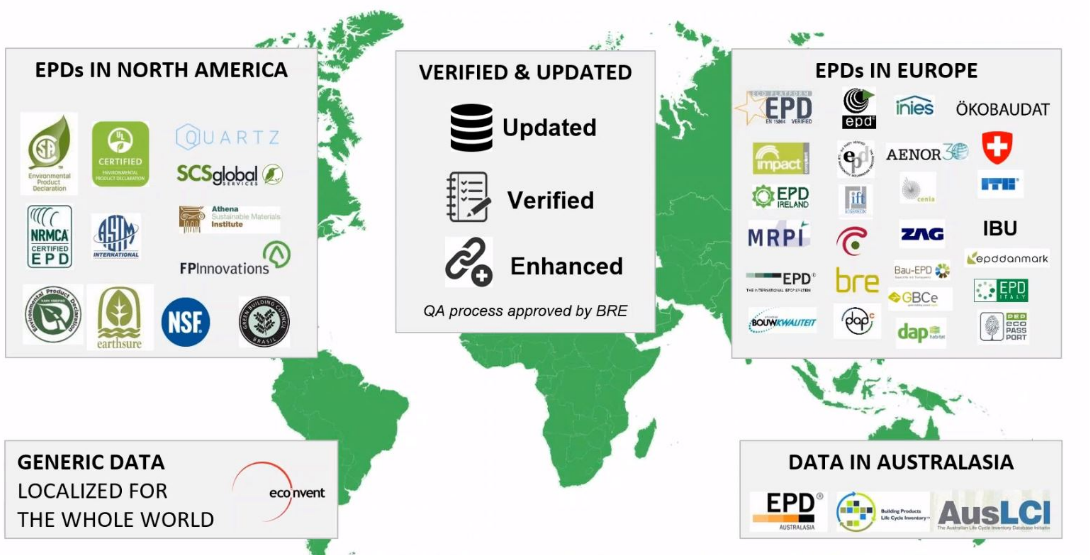


Figure 21: One-Click LCA tool integrated databases.
Source: (one-click LCA, 2018a).

4.3 What is Carbon Designer

Carbon designer is an option in the LCA One-Click tool to generate a rough estimation of the building overall carbon emission based on the general database in the LCA one-click tool and the early phases of building information's like the building type (residential, office, etc.), Gross floor area, the number of floors above the ground floor and other similar related factors. It is a very useful outcome in the building idea conception phase (very early phases) when there is a general lack of information about the building designs or material, which would help designers and decision-makers to decide whether to execute the project considering that initial rough estimation of carbon or investigating other alternatives. However, the creditably of the Carbon Designer results is the full responsibility of the software company (Bionova, 2018a).

The Carbon Designer was used in the case studies as a baseline and put it in a comparison with the carbon emission out of the detailed design building models to understand the capabilities and options that could be available in the early phases (Idea conception/formulation) compiling with the Finnish Ministry of Environment Method for the whole life carbon assessment of buildings. Figure 22 gives an example for the building different information that could be required in the Carbon Designer baseline (the information on the right side of the picture are standard automatically generated based on the information filled in the right side which is mentioned in the previous paragraph), while figure 23 shows that the designers can change the building elements properties of materials from the previously selected database in LCA one-click tool and Test different design options environmental impacts quickly to control the accuracy of the Carbon Designer outcome like if the upper floors have less floor area than the ground floor for example. In such a way, the owners and decision-makers will be able to consider the environmental impact of the building alongside its financial one in the early project phases, when plans can still be easily adjusted (Bionova, 2018b), (one-click LCA, 2018a).

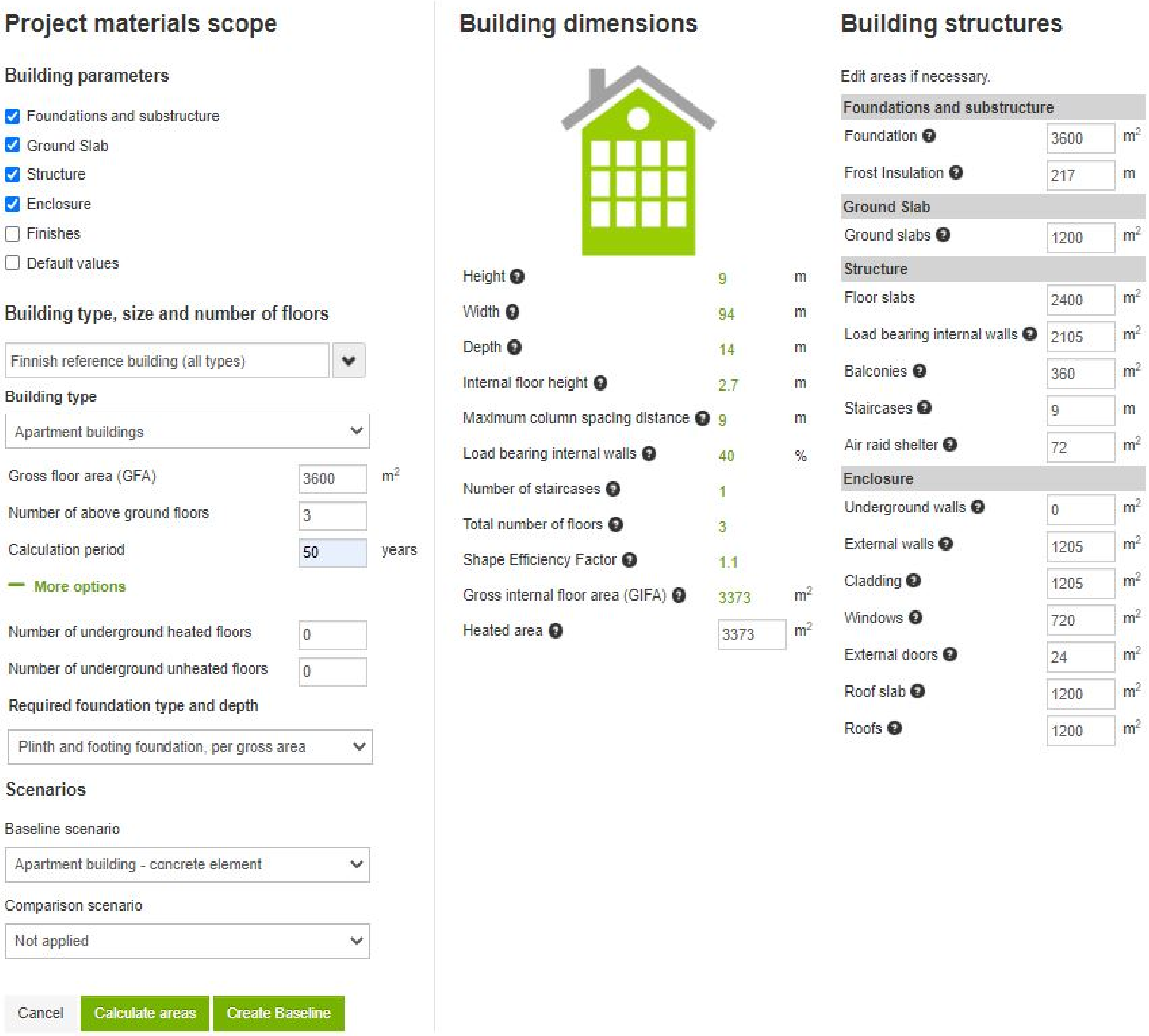


Figure 22: Carbon Designer different required options example.

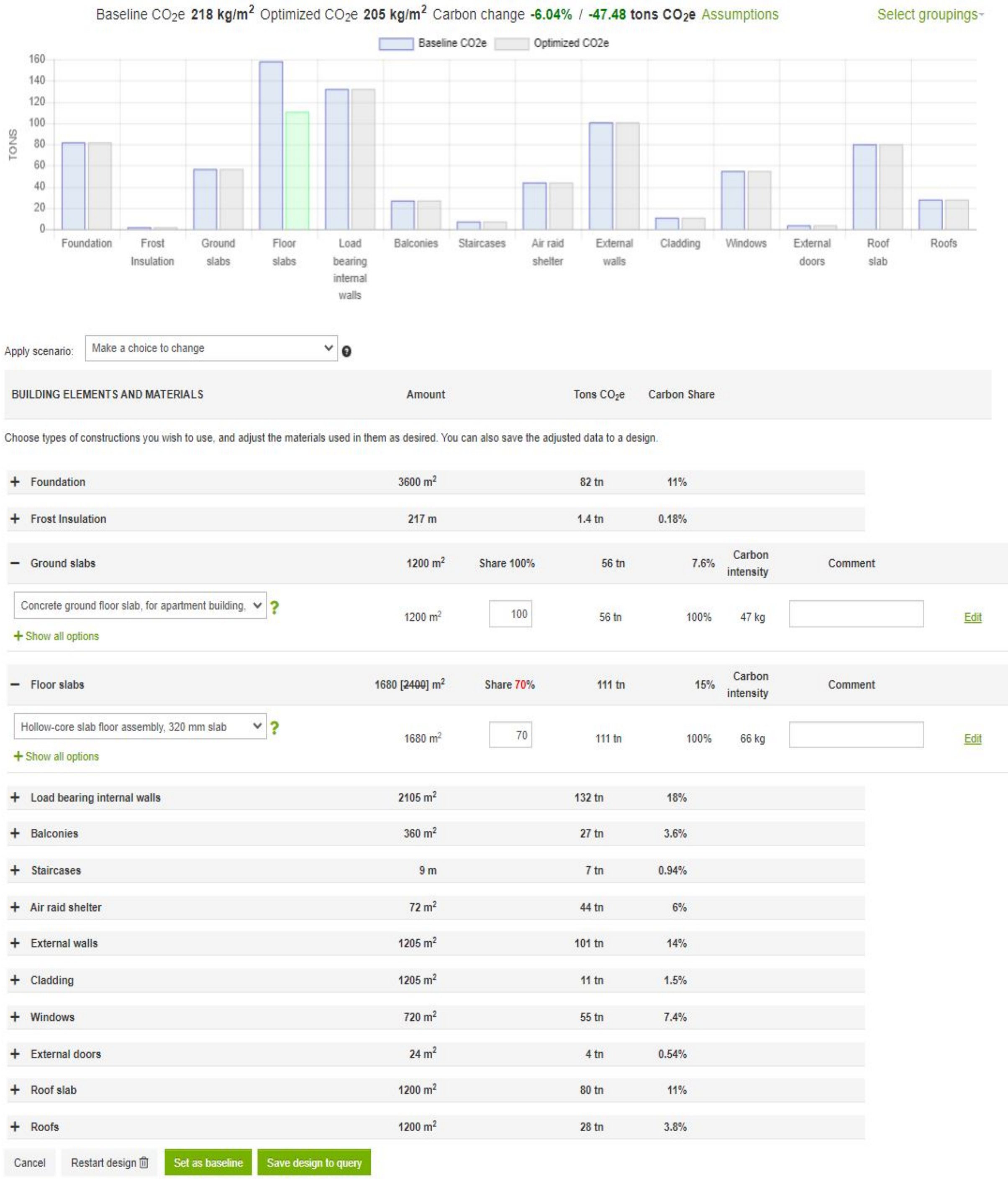


Figure 23: Carbon Designer advanced options example.

4.4 Detailed case studies technical Process

As mention previously, the thesis technical approach is utilizing LCA calculation using Building Information Modelling (BIM). That is done through extracting the building material excel sheet out of the IFC design model in Solibri software and insert this excel sheet into an LCA calculation tool to calculate the carbon emission of the current design of the building. The IFC model should comply with the COBIM and the LCA tool should include the material carbon database and its options adjusted that the generated outcome is based on the Ministry of Environment Method for the whole life carbon assessment of buildings. This proposed process will save the overall time and cost required to conduct a project carbon assessment. Figure 24 simplifying the thesis process through sketching and in the following pages there will be a detailed clarification of every step.

Figure 24: Illustration Sketch of the thesis attempt process.

The following pages contain a detailed clarification of the two main steps that have been done to calculate the carbon emission for the following case studies:

4.4.1 First step: Extracting the building material excel sheet

The initial step applied in every case study is getting the building material required information for conducting the LCA assessment. Solibri software was used to extract the building material information in the excel sheet form through the software available option of information takeoff. As clarified in figure 25 and 26 the detailed steps for extracting the excel sheet are as followed (one-click LCA, 2018b):

1- Inserting the LCA one-click tool plugin extension (available in the tool developing company website) into the Solibri information takeoff.
2- Press on Takeoff all
3- Choose Report to extract your information in a plain excel sheet report.

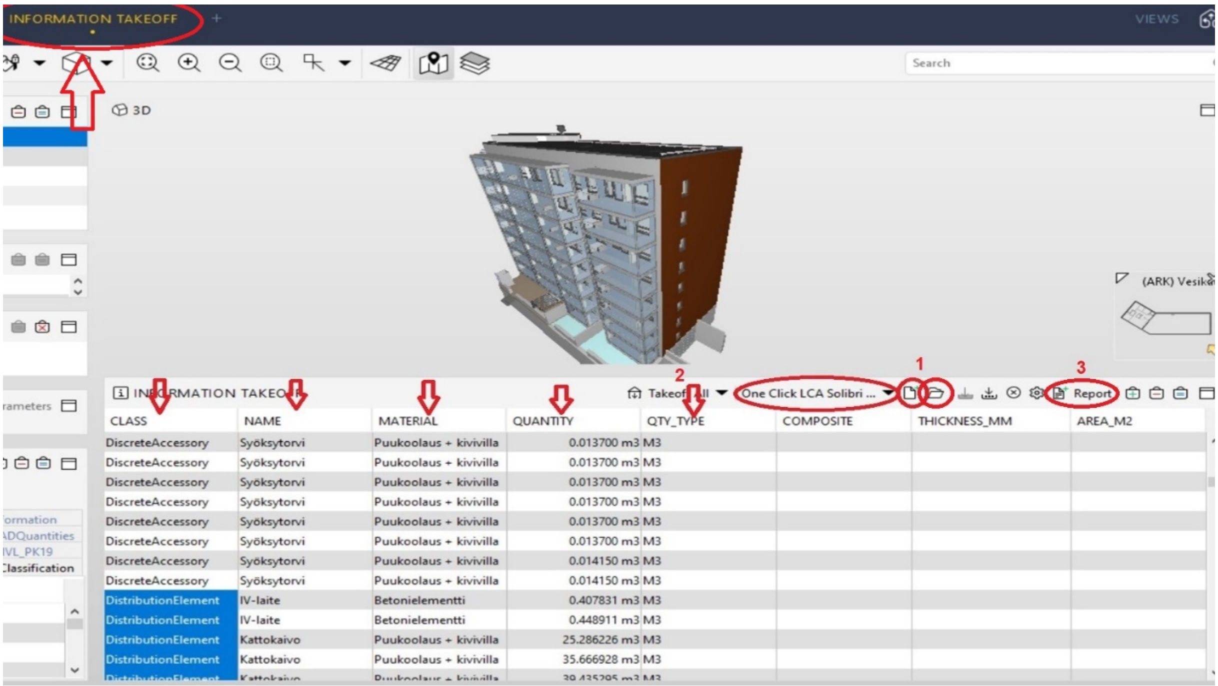


Figure 25: Steps of extracting the building material excel sheet of Solibri software part 1.

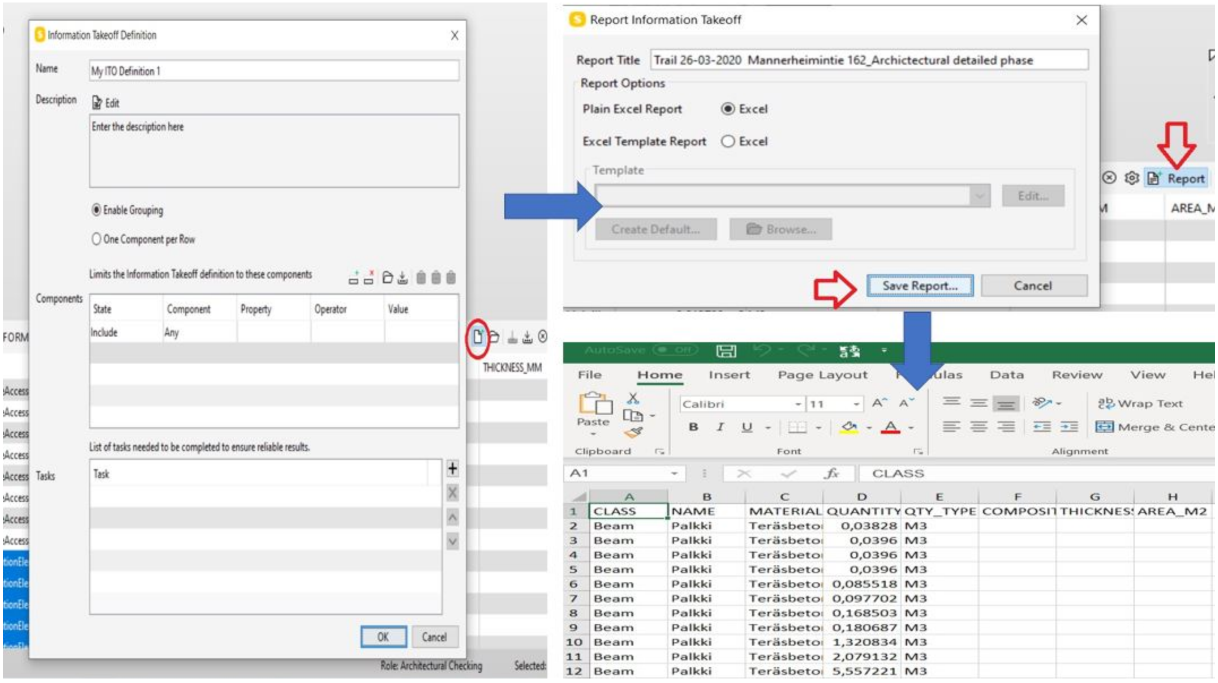


Figure 26: Steps of extracting the building material excel sheet of Solibri software part 2.

The Use of the Plugin tool is just to extract the material excel sheet in the format that will be readable in the LCA one-click tool later when inserting it in the tool (the excel sheet columns are Class, Name, Material, Quantity, and Quantity Type). Therefore, there is an option to create your format of the excel sheet rather than selecting the LCA one-click plugin tool in case of using another tool or another methodology to calculate the carbon footprint in the second step. It worth to mention that there is some known limitation to the LCA one-click plugin tool as it is a BETA version like the exported data are in metric units only as it doesn’t support exporting in imperial units and the building services (HVAC) are not exported (Shaun, 2020d).

As shown in figure 26, each row in the excel sheet represents a building material with identified class, name, material, and quantity. Logically, the takeoff option extracts the building material excel sheet out of the Solibri IFC model in such a detailed way that would have many elements with the same name and material that should be combined and treated as a single material with an aggregated volume value of the extracted material. For example, if the building has 100 doors (all having the same material, manufacture, and other LCA related characteristics), they will be represented in the excel sheet in 100 rows but they should be combined and treated as a single material with an aggregated volume of the sum equivalent values of the 100 door during calculating that door carbon equivalent value.

4.4.2 Second step: calculating the building carbon emission

The second step in importing the excel sheet into the LCA one-click tool. Figure 27 clarifies the importing steps of the excel sheet into the tool while figure 28 shows the three tool steps: filtering the irrelevant material, combining the repeated amounts of similar materials, and finally the mapping phase where there is a manual fixation of the misnamed material in the extracted excel sheet of the design model. It is worthy to mention that the mapping stage could consume a huge amount of time in case the model has a bad material naming quality (one-click LCA, 2018b). Figure 27 also clarifies the current rich building material carbon emission EPD database – provided by the Building Information Foundation Rakennustietosäätiö (RTS) - in the one-click LCA tool.

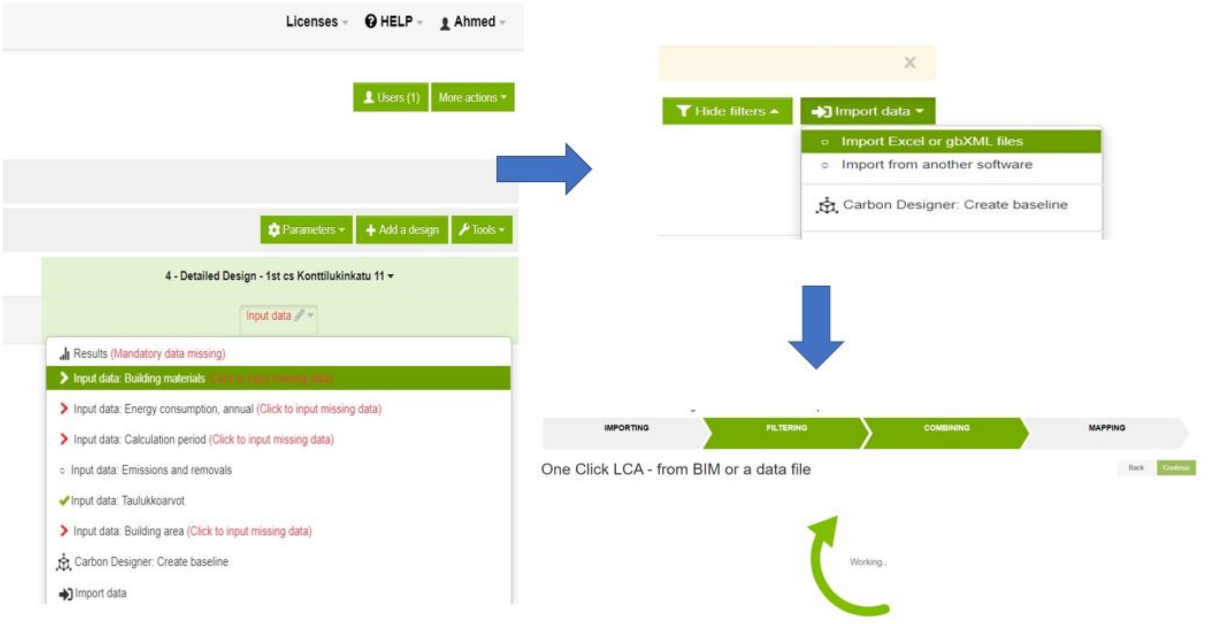


Figure 27: Steps of importing the building material excel sheet into the LCA one-click tool part 1

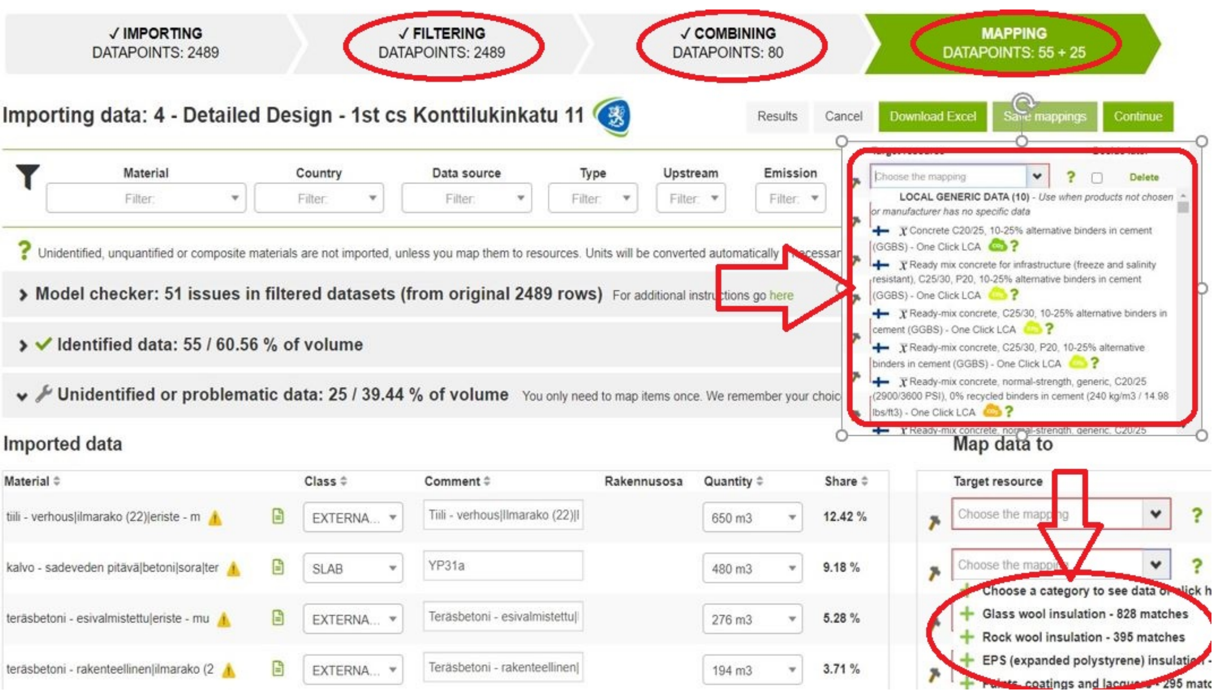


Figure 28: Steps of importing the building material excel sheet into the LCA one-click tool part 2

4.5 First case study: Konttilukinkatu 11

The Konttilukinkatu 11 project is a residential building consist of six upper floors other than the ground and the roof floor. It is located in the city of Tampere, Finland with 5200 m^2 gross area and 61 apartments. Figure 29 and 30 gives an overview of the building shape and structure.

Figure 29: First case study project Konttilukinkatu 11
Source: (Myllyniemi, 2019)

Figure 30: First case study building plan overview.
Source: (Myllyniemi, 2019).

The material excel sheet extracted from the design models using Solibri software has a total number of 4890 and 22925-row material extracted from the architecture and structural models respectively which makes the Konttilukinkatu 11 project has the biggest amount of extracted material information in this thesis case studies. However, the material excel sheet shows many design faults (from LCA and carbon calculation perspective) that required manual editing before uploading the excel sheet in the one-click LCA tool. Figure 31 summarizes some of these design mistakes as followed:

- 1998 rows (40.7 %) show {No Material} at the material row (or Tyhjä in the Finnish language), highlighted in light green color, that has taken considerable effort to be identified through the process of the carbon assessment. Several meetings have been scheduled with the model designer and the project responsible engineers to identify each missing building element material. This situation highlights the need to have an environmental standardization for all designers to correctly identify the building elements material name.

- 1013 rows (20.7%) should be deleted at Arch Model highlighted in yellow color:
    - Doors or windows spaces: This is an empty place reserved in the model to prevent any kind of construction in the space when the door opens.
    - basepoint virtual representation: (modeled in the Finnish language: Origo) an element modeled to indicate the building basepoint (0,0,0).
    - Electrical Appliance: (modeled in Finnish language Kp-PPK varaus) an empty space reserved for the washing machine.
- Many duplicated Materials need to be specified manually in more detail through contacting the project engineer, highlighted in purple color.

1	CLASS	NAME	MATERIAL	QUANTITY
870	Door	älä laske	[NO MATERIAL]	0.048
871	Door	älä laske	[NO MATERIAL]	0.048
872	Door	älä laske	[NO MATERIAL]	0.048
873	Door	älä laske	[NO MATERIAL]	0.048
1045	ElectricAppliance	PPK varaus	Tyhjä	0.055116
1046	ElectricAppliance	PPK varaus	Tyhjä	0.055116
1047	ElectricAppliance	PPK varaus	Tyhjä	0.055116
1048	Opening	ASO	[NO MATERIAL]	0.43248
1049	Opening	ASO	[NO MATERIAL]	0.43248
257	Column	ORIGO	ORIGO 459193	0,208586
258	Column	ORIGO	ORIGO 459193	0,27
259	Column	ORIGO	ORIGO 459193	0,27
260	Column	ORIGO	ORIGO 459193	0,27
3771	Wall	VS105	Kipsilevy 296111805 | Teräsranka 390047285 | Kipsilevy 296111805	0,361174
3772	Wall	VS105	Kipsilevy 296111805 | Teräsranka 390047285 | Kipsilevy 296111805	0,361174
3773	Wall	VS105	Kipsilevy 296111805 | Teräsranka 390047285 | Kipsilevy 296111805	0,361174
3774	Wall	VS105	Laatta sauma 268899148 | Kipsilevy 296111805 | Teräsranka 390047285 | Kipsilevy 296111805	0,151195
3775	Wall	VS105	Laatta sauma 268899148 | Kipsilevy 296111805 | Teräsranka 390047285 | Kipsilevy 296111805	0,151195
3776	Wall	VS105	Laatta sauma 268899148 | Kipsilevy 296111805 | Teräsranka 390047285 | Kipsilevy 296111805	0,151195

Figure 31: First case study building material excel sheet highlighted problems.

After reviewing and manually editing the extracted material excel sheet, the next step is to upload the modified excel sheet to the one-click LCA tool where there is a second layer of filtering of unrelated materials and combining similar ones. The LCA tool shows a detailed report of the second filtering phase and recommended actions that should be taken for the first case study material excel sheet as shown in figure 32.

Type	Issue	# in model	% in model	Recommended action
	Implausible thickness ?	1	0.03 %	Check or correct defined thicknesses
	Unconventional class ?	74	2.56 %	Review material classes
	Composite materials ?	1623	56.14 %	Verify highlighted datapoints
	Non-material objects ?	1998	69.11 %	No action. These are automatically removed

Figure 32: First case study automated filtering of the building material excel sheet done by the one-click LCA tool.

As mentioned earlier, both discipline IFC design models (architecture and structural) are used to complete each other to obtain the exact materials information in the building. Figures 33 and 34 clarifies that the structural model shows the existence of construction piles which is not shown in the architecture model, while the architecture model shows details of windows and doors. It worth mentioning that there were some challenges in appointing the exact material information in the LCA one-click tool and had to be manually edited like: internal walls were classified as external walls by the LCA one-click tool.

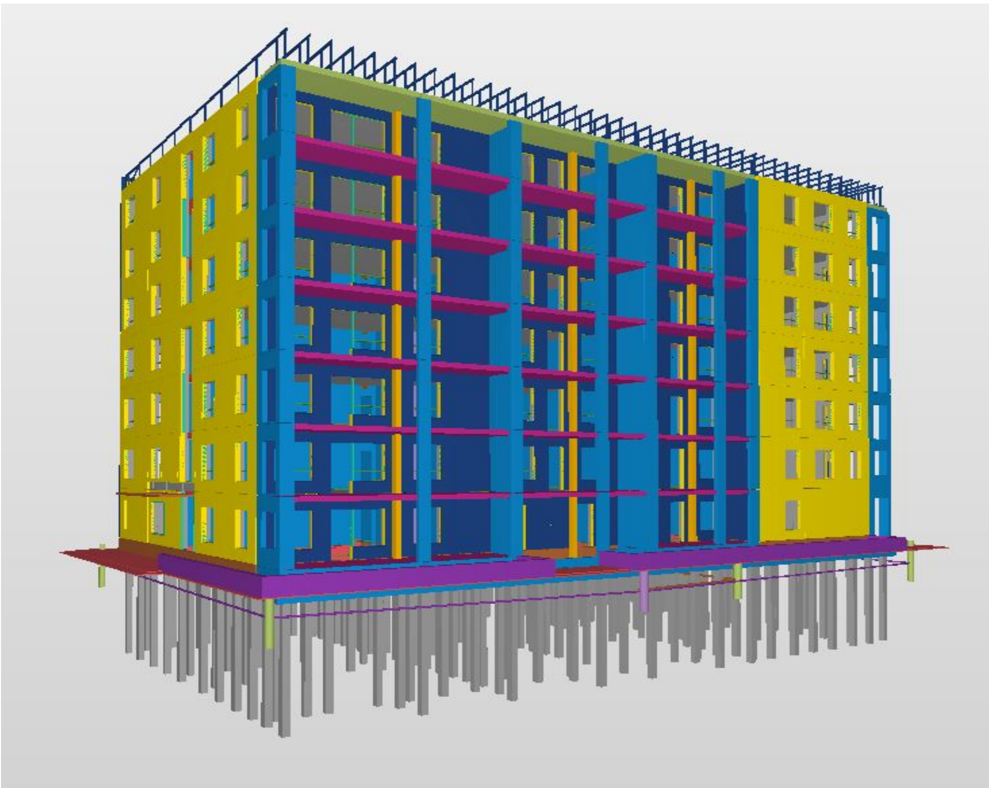


Figure 33: First case study structural IFC model view in Solibri.

Figure 34: First case study architecture IFC model view in Solibri.

The Carbon Designer baseline estimated that the total carbon emission of the building would be 14.63 Kg of CO^2 per m^2 per year. So, the total amount of carbon estimated by the Carbon Designer for the whole building (heated net area) and service lifetime (50 years) is (14.63*5200*0.9*50) = 3423420 kg CO^2. The final carbon assessment comparison clarified in figure 35, shows that the carbon designer baseline carbon emission anticipation was a bit accurate in comparison with the detailed design models material excel sheets.

Figure 35: First case study comparison of different design models final carbon emission results.

The LCA one-click tool provides a pie chart of the building embodied carbon distribution for the different LCA stages and modules as shown in figure 36. Based on the figure, The first case study (Konttilukinkatu 11) has 83% of its embodied carbon from the production stage (Modules A1-A3) and 13% from the replacement of products during the use stage (modules B4-B5) while only 4% from the end of life stage (modules C1-C4).

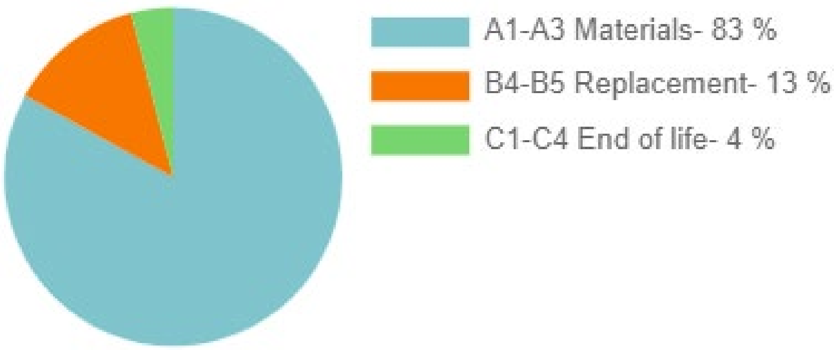


Figure 36: Distribution of the embodied carbon through different LCA stages for the first case study.

Figure 37 shows a percentage distribution of the building embodied carbon based on the building elements. Based on the figure, the vertical structures and facades have the highest percentage of the building embodied carbon with 58%, then the horizontal structures (like beams, floor slabs, and roofs) are responsible for 28% of the building embodied carbon.

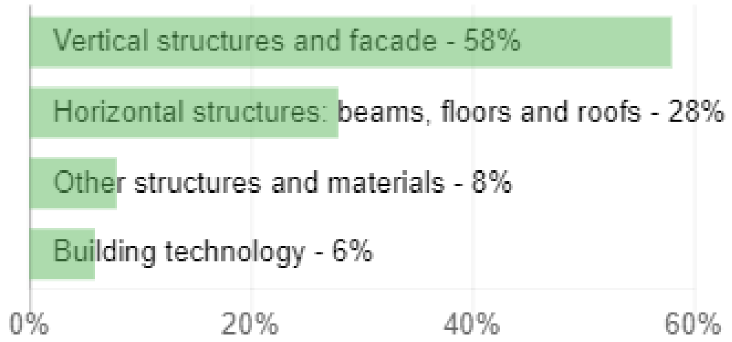


Figure 37: Distribution of the embodied carbon by the different structural elements for the first case study.

While figure 38 clarifies a visualization of the building carbon emission distributed by the different building elements in each design phase (based on the input data quality from the model) that has been generated by the LCA one-click tool. It is clear from the figure that district heat use is the highest contributor to the building carbon emission.

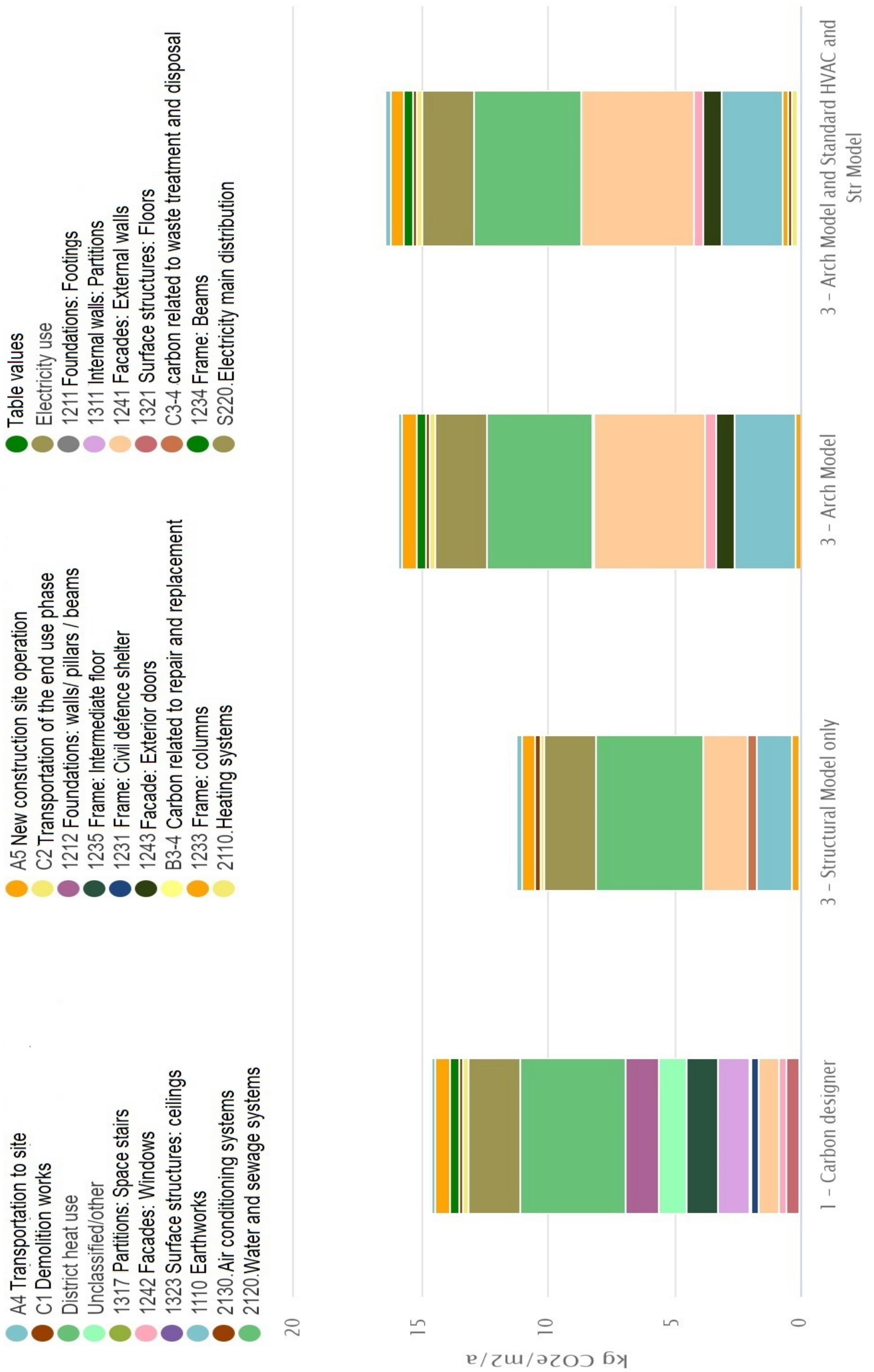


Figure 38: First case study visualization of the building elements carbon emission in each design phase.

4.6 Second case study: Kultavene

The Kultavene project is a residential project consist of three buildings connected with a common ground slab, each has three upper floors other than the ground and the roof floor. There is also a basement that extends under two buildings only. Kultavene project is located in Helsinki, the capital city of Finland with a 2960 m^2 gross area.

Figure 39: Second case study Kultavene project.
Source: (Rönkä, 2019).

Figure 40: Second case study Kultavene project Plan view.
Source: (Rönkä, 2019).

As mentioned earlier, this project is missing the structural design model from the project database, so the carbon assessment was done based on the arch model material information only. The material excel sheet extracted from the architecture design model using Solibri software has a total number of 6328 rows of material. Compared to the first case study (Konttilukinkatu 11), the designer of the second case study had a worse material naming and specification. Like the first case study, the material excel sheet had many design faults (from LCA and carbon calculation perspective) that required manual editing before uploading the excel sheet in the one-click LCA tool for combining the similar building materials and calculating the building carbon emission. Figure 41 combines some screenshots from these design faults that have been found in the excel sheet and could be summarized as followed:

- 2194 rows (35 %) show {No Material} at the material row (or Tyhjä in the Finnish language), highlighted in light green color, that has taken considerable effort to be identified through the process of the carbon assessment. Several meetings have been scheduled with the model designer and the project responsible engineers to identify each missing building element material. This situation highlights the need to have an environmental standardization for all designers to correctly identify the building elements material name.

- 1380 rows (21.8 %) should be deleted, highlighted in yellow color:
    - Air Terminal (modeled in the Finnish language: US-AV, Kuori yleinen) an empty place reserved for a ventilation unit that will be fixed later to prevent any kind of construction in this place.
    - Opening: (also modeled as Aso-Aukko-FA00 or codes like FU_1) an empty place reserved for different reasons (like windows) to prevent any kind of construction in this place.
    - Walls of basement storage rooms: (modeled in the Finnish language: Verkkokomero) or windows metal lower frame (Vesipelti) that could be neglected as it hasn't a reliable CO_2 database available for it and the designer didn't mention what kind manufacturer of metal used.
- Many duplicated Materials need to be specified manually in more detail through contacting the project engineer, highlighted in purple color.

1	CLASS	NAME	MATERIAL	QUANTITY
5327	Wall	parvekelasitus	Kuori lasi	0,019514
5328	Wall	parvekelasitus	Kuori lasi	0,019515
5329	Wall	säilytysjärjestelmä liukuovi	Sisä kaluste	0,01237
5330	Wall	säilytysjärjestelmä liukuovi	Sisä kaluste	0,01237
3639	Wall	US17_paksunnos	Kuori tiili|Kuori ilmarako|Kuori eriste kova|Runko betoni	15,270022
3640	Wall	VERKKOKOMERO	Kuori teräs	0,002697
3641	Wall	VERKKOKOMERO	Kuori teräs	0,008825
3642	Wall	VERKKOKOMERO	Kuori teräs	0,015069
812	Opening	FS_6	[NO MATERIAL]	1.939637
813	Opening	FU_1	[NO MATERIAL]	1.120912
814	Opening	FU_1	[NO MATERIAL]	1.120922
6053	Window	vesipelti	[NO MATERIAL]	0.001316
6054	Window	vesipelti	[NO MATERIAL]	0.001316
6055	Window	vesipelti	[NO MATERIAL]	0.001316

Figure 41: Second case study building material excel sheet highlighted problems.

After reviewing and manually editing the extracted material excel sheet, the next step is uploading the modified excel sheet to the one-click LCA tool where there is a second layer of filtering of unrelated materials and combining similar ones. The one-click LCA tool shows a detailed report of the second filtering phase and recommended actions that should be taken for the second case study material excel sheet as shown in figure 42.

Type	Issue	# in model	% in model	Recommended action
	Unconventional class ?	161	3.9 %	Review material classes
	Composite materials ?	1799	43.54 %	Verify highlighted datapoints
	Non-material objects ?	2194	53.1 %	No action. These are automatically removed

Figure 42: Second case study automated filtering of the building material excel sheet done by the one-click LCA tool.

Figures 43 and 44 are two different views of the second case study architectural model in Solibri which clarifies the extension of one floor under two buildings only out of three. Compared with the first case study project, Kultavene has a worse naming and specification for type and material. Due to using the architectural model only, the foundation and structural information were missing for a complete carbon assessment. Like earlier case study, there were some minor mistakes in the LCA one-click tool material identification that had to be manually edited like: internal walls were classified as external walls, and combining similar material doors and windows didn't go ideally.

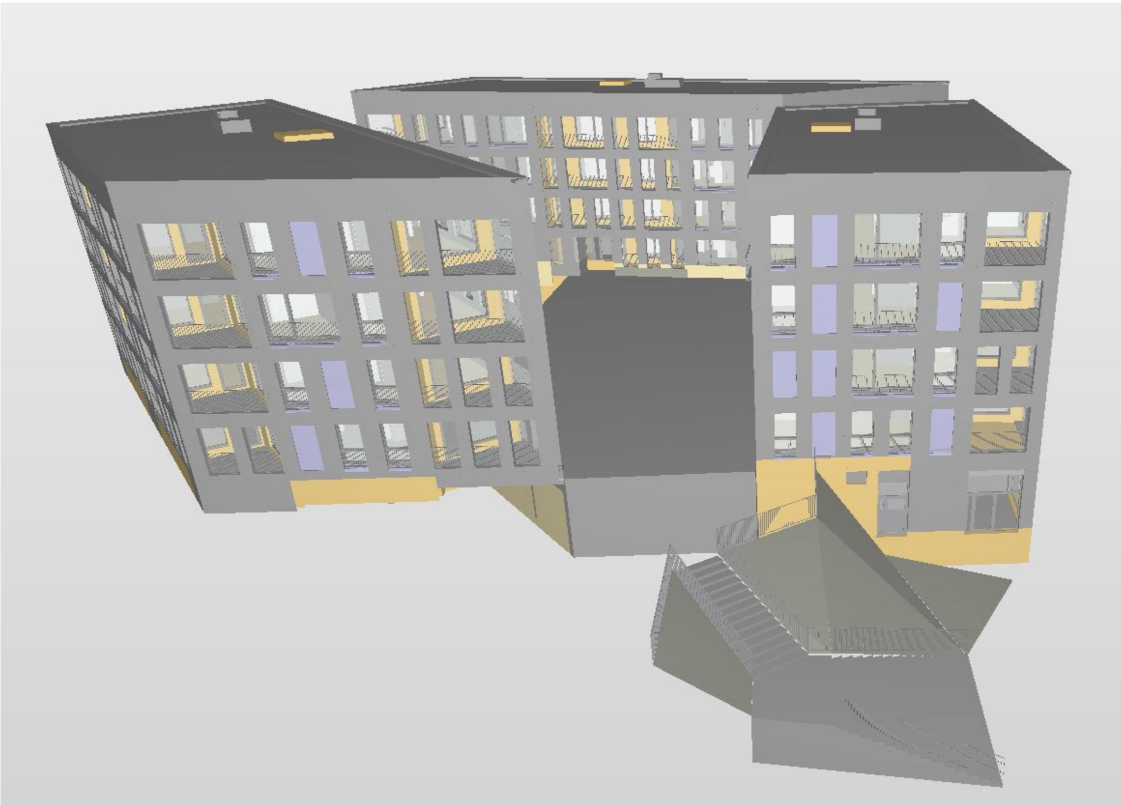


Figure 43: Second case study architecture IFC model first view in Solibri.

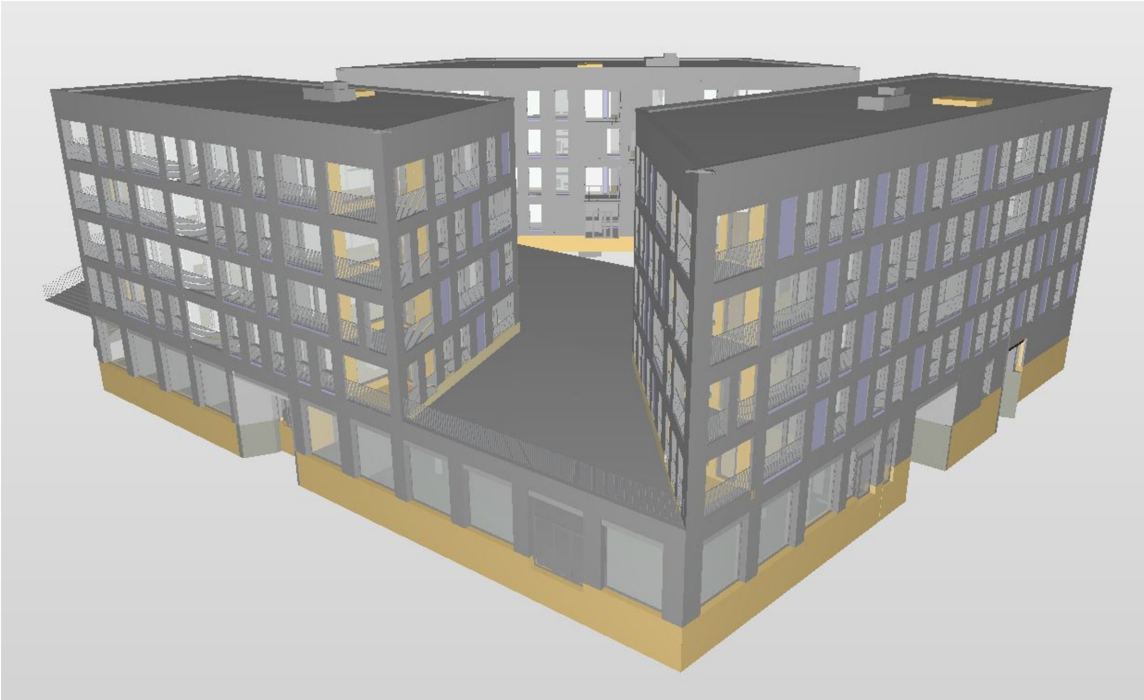


Figure 44: Second case study architecture IFC model second view in Solibri.

The Carbon Designer baseline estimated that the total carbon emission of the building would be 15.49 Kg of CO_2 per m^2 per year. As the method of the Ministry of Environment in Finland for the whole life carbon assessment of buildings defined a standard 50 years as an average lifetime of the building, so the total amount of carbon estimated by the Carbon Designer for the whole building (heated net area) and lifetime is (15.49*2960*0.9*50)= 2063268 kg CO_2.

The second case study project carbon assessment comparison for different design phases clarified in figure 45 shows that the carbon designer baseline had very accurate anticipation for the carbon emission compared with the numbers obtained from the detailed material excel sheets of the architectural design model and the architectural design model with the standard HVAC values.

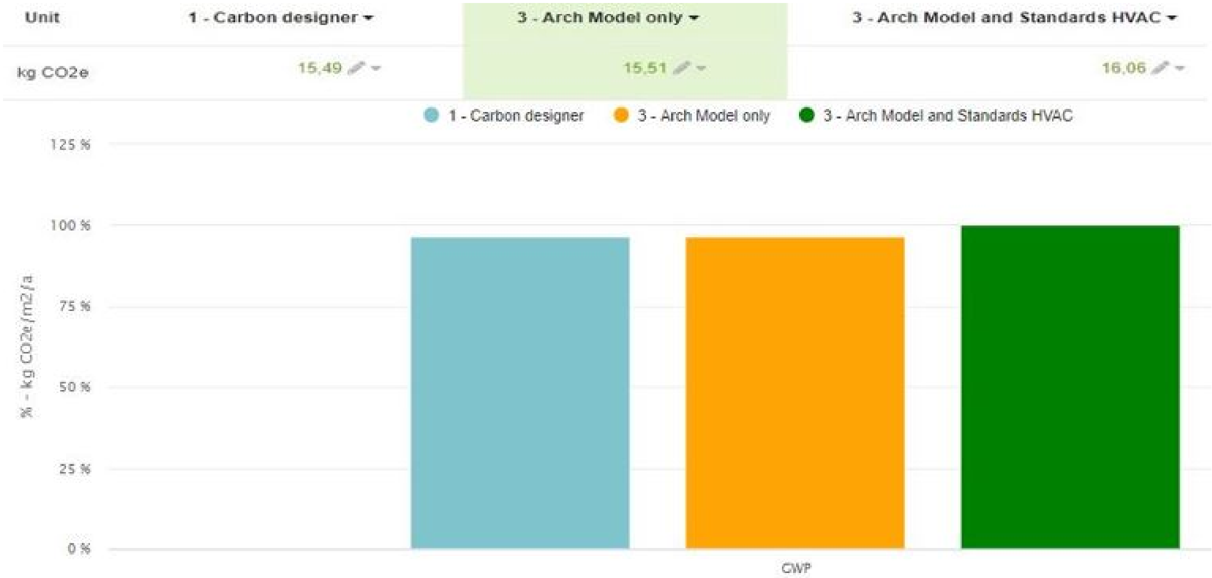


Figure 45: Second case study comparison of different design models final carbon emission results.

The LCA one-click tool provides a pie chart of the building embodied carbon distribution for the different LCA stages and modules as shown in figure 46. Based on the figure, The second case study (Kultavene) has 83% of its embodied carbon from the production stage (Modules A1-A3) and 12% from the replacement of products during the use stage (modules B4-B5) while only 5% from the end of life stage (modules C1-C4).

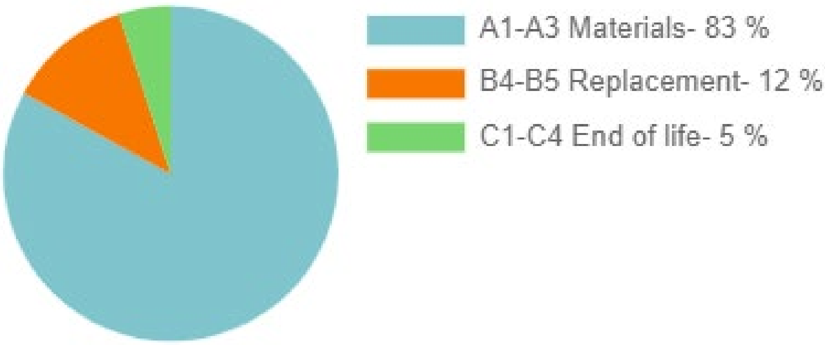


Figure 46: Distribution of the embodied carbon through different LCA stages for the second case study.

Figure 47 shows a percentage distribution of the building embodied carbon based on the building elements. Based on the figure, the horizontal structures (like beams, floor slabs, and roofs) have the highest percentage of the building embodied carbon with 47%, then the vertical structures and facades are responsible for 36% of the building embodied carbon.

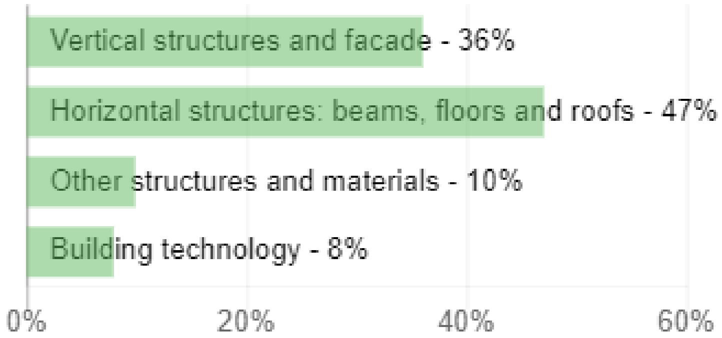


Figure 47: Distribution of the embodied carbon by the different structural elements for the second case study.

While figure 48 clarifies a visualization of the building carbon emission distributed by the different building elements in each design phase (based on the input data quality from the model) that has been generated by the LCA one-click tool. It is clear from the figure that district heat use is the highest contributor to the building carbon emission.

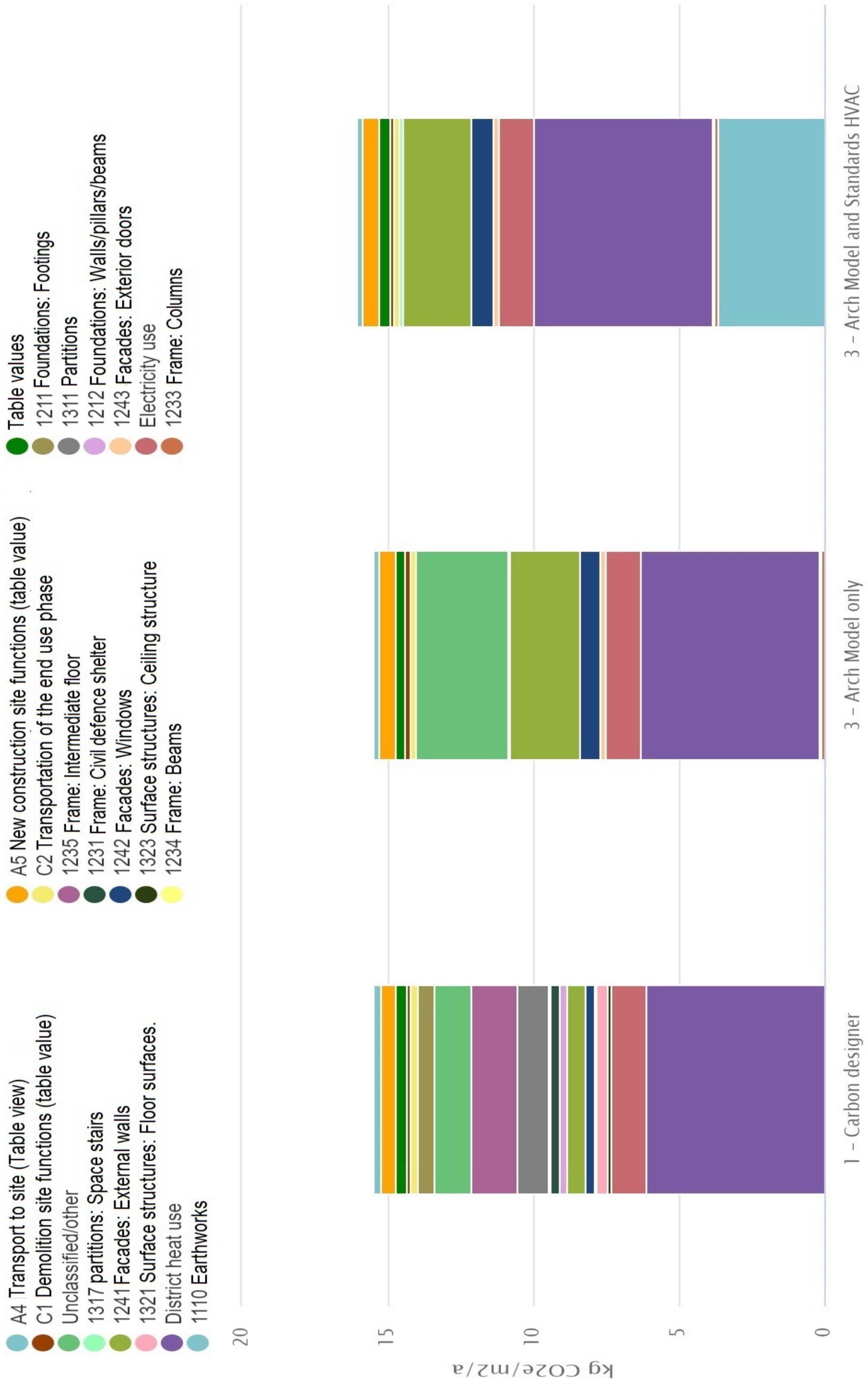


Figure 48: Second case study visualization of the building elements carbon emission in each design phase.

4.7 Third case study: Mannerheimintie 162

The Mannerheimintie 162 project is a residential building consist of seven upper floors other than the ground and the roof floor. It is located at the heart of Helsinki (the capital city of Finland) with an overall building area of 3670 m^2 with a remarkable façade architecture that aims to engage in dialogue with the surroundings of Tilkka Military Hospital.

Figure 49: Third case study project Mannerheimintie 162 Bird-eye view.
Source: (Lindfors, 2019)

Figure 50: Third case study project building Mannerheimintie 162 Plan view. Source: (Lindfors, 2019)

Like the previous case studies, the material excel sheet extracted from the design models using Solibri software has a total number of 4594-row material extracted from the architecture model and 2682 rows of material extracted from the structural model. In the same case as before, the material excel sheet had many design faults (from LCA and carbon calculation perspective) that required manual editing before uploading the excel sheet in the one-click LCA tool for combining the similar building materials and calculating the building carbon emission. Figure 51 combines some screenshots from these design faults that have been found in the excel sheet and could be summarized as followed:

- 1541 rows (33.5 %) show {No Material} at the material row (or Tyhjä in the Finnish language), highlighted in light green color, that has taken considerable effort to be identified through the process of the carbon assessment. Several meetings have been scheduled with the model designer and the project responsible engineers to identify each missing building element material. This situation highlights the need to have an environmental standardization for all designers to correctly identify the building elements material name.
- 1526 rows (33.2 %) should be deleted, highlighted in yellow color:
    - Opening: (also modeled as codes like LT): an empty place reserved for different reasons (like windows) to prevent construction in this place.

    - Sanitary Terminal: a space reserved for the toilet seats to prevent any kind of construction in their places.
    - Electric Appliance (modeled in the Finnish language as Kuivausrumpu or Pyykinpesukone): an empty space reserved for the washing machine.
    - Discrete accessory or distribution element represent elements that are not related to the LCA calculation and therefore deleted.
- Many duplicated Materials need to be specified manually in more detail through contacting the project engineer, highlighted in purple color.

<table>
<tr><th>1</th><th>CLASS</th><th>NAME</th><th>MATERIAL</th><th>QUANTITY</th><th>QTY_TYPE</th></tr>
<tr><td>385</td><td>Column</td><td>Pilari</td><td>Teräsbetoni - rakenteellinen</td><td>1.24</td><td>M3</td></tr>
<tr><td>386</td><td>CurtainWall</td><td>Parvekelasitus</td><td>Yleinen - rakenteellinen</td><td>0</td><td>M3</td></tr>
<tr><td>510</td><td>DiscreteAccessory</td><td>ILP sisäyksikkö</td><td>Betonielementti</td><td>0.054</td><td>M3</td></tr>
<tr><td>511</td><td>DiscreteAccessory</td><td>IV-kone</td><td>Betonielementti</td><td>0.474375</td><td>M3</td></tr>
<tr><td>854</td><td>DistributionElement</td><td>Suihku</td><td>Betonielementti</td><td>0.001633</td><td>M3</td></tr>
<tr><td>855</td><td>DistributionElement</td><td>Vesipiste</td><td>Betonielementti</td><td>0.000951</td><td>M3</td></tr>
<tr><td>856</td><td>Door</td><td>ATO</td><td>marako|Tyhjä|Ilmarako|Ilmarako|Tyhjä|Tyhjä|Pehmeä eristevilla|Tyhjä|Ilmarako|Kov</td><td>0.90086</td><td>M3</td></tr>
<tr><td>857</td><td>Door</td><td>HS-1</td><td>Tyhjä|Tyhjä</td><td>0.023793</td><td>M3</td></tr>
<tr><td>858</td><td>Door</td><td>IV-O</td><td>yhjä|Tyhjä|Tyhjä|Ilmarako|Kova eriste|Ilmarako|Ilmarako|Ilmarako|Tyhjä|Ilmarako|T</td><td>0.090108</td><td>M3</td></tr>
<tr><td>2251</td><td>Opening</td><td>VO</td><td>[NO MATERIAL]</td><td>0.176649</td><td>M3</td></tr>
<tr><td>4137</td><td>Window</td><td>LT</td><td>Tyhjä|Tyhjä|Tyhjä|Ilmarako|Kova eriste|Ilmarako|Ilmarako|Ilmarako|Tyhjä|Tyhjä|Pe</td><td>0.03244</td><td>M3</td></tr>
</table>

Figure 51: Third case study building material excel sheet highlighted problems.

After reviewing and manually editing the extracted material excel sheet, the next step is uploading the modified excel sheet to the one-click LCA tool where there is a second layer of filtering of unrelated materials and combining similar ones. The one-click LCA tool shows a detailed report of the second filtering phase and recommended actions that should be taken for the material excel sheet as shown in figure 52.

Type	Issue	# in model	% in model	Recommended action
⚠	Implausible thickness ?	7	0.28 %	Check or correct defined thicknesses
⚠	Unconventional class ?	565	22.7 %	Review material classes
⚠	Composite materials ?	1017	40.86 %	Verify highlighted datapoints
✓	Non-material objects ?	2071	83.21 %	No action. These are automatically removed

Figure 52: Third case study automated filtering of the building material excel sheet done by the one-click LCA tool.

As mentioned earlier, both discipline IFC design models (architecture and structural) are used to complete each other to obtain the exact materials information in the building. Figure 52 and 53 clarifies that the structural model shows the bearing structural elements materials in a more detailed way than the architecture model, while the architecture model shows material details of all other building elements like windows and doors.

Figure 53: Third case study architecture IFC design model view in Solibri.

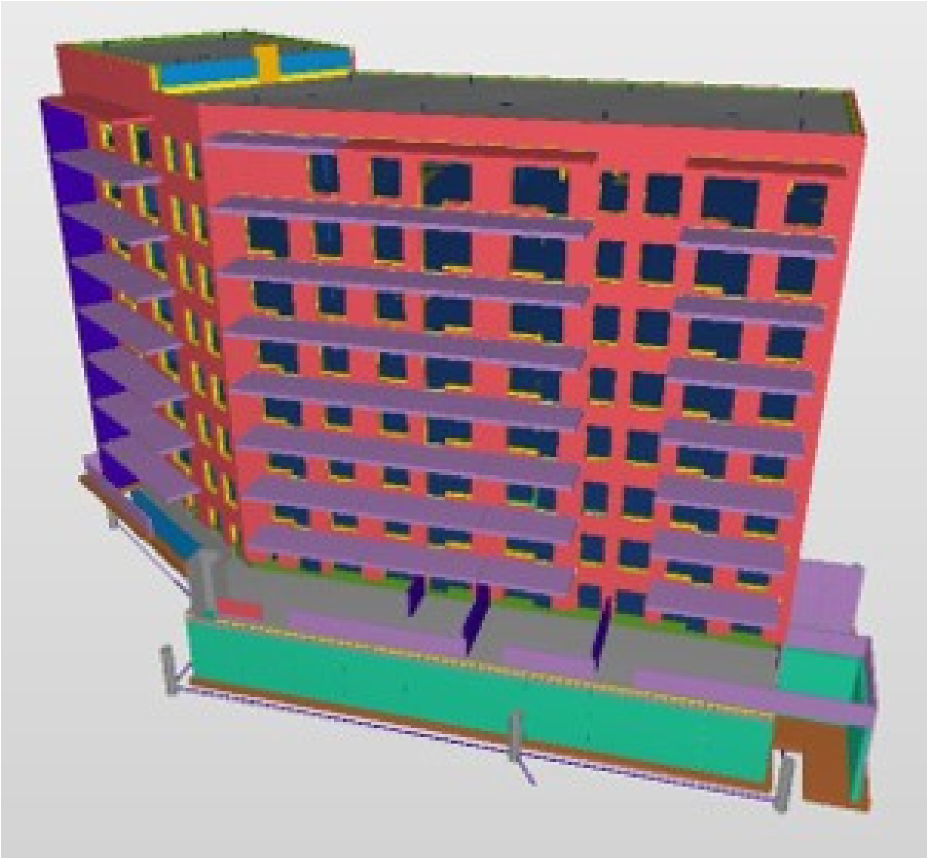


Figure 54: Third case study structural IFC design model view in Solibri.

The carbon designer baseline estimated that the total carbon emission of the building would be 14.06 Kg of CO_2 per m^2 per year (the method of the Ministry of Environment in Finland for the whole life carbon assessment of buildings estate that the average lifetime of the building is 50 years) so the total amount of carbon estimated by the Carbon Designer for the whole building area (heated net area) and lifetime is (14.06*3670*0.9*50)= 2322009 kg CO_2.

The third case study project carbon assessment comparison for different design phases clarified in figure 55 shows unexpected outcomes with the structural model having a higher carbon emission than the architecture model with standard HVAC values. After a detailed investigation, the reason for such a result was that some materials quantities in the structural models were identified in the wrong way by the designer, and fixing that should be done in Tekla software which is outside the thesis scope.

Figure 55: Third case study comparison of different design models final carbon emission results.

The LCA one-click tool provides a pie chart of the building embodied carbon distribution for the different LCA stages and modules as shown in figure 56. Based on the figure, The third case study (Mannerheimintie 162) has 77% of its embodied carbon from the production stage (Modules A1-A3) and 18% from the replacement of products during the use stage (modules B4-B5) while only 5% from the end of life stage (modules C1-C4).

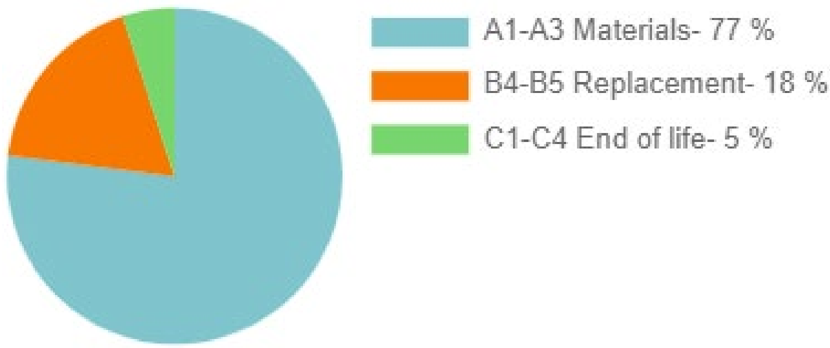


Figure 56: Distribution of the embodied carbon through different LCA stages for the third case study.

Figure 57 shows a percentage distribution of the building embodied carbon based on the building elements. Based on the figure, the horizontal structures (like beams, floor slabs, and roofs) have the highest percentage of the building embodied carbon with 64%, then the vertical structures and facades are responsible for 28% of the building embodied carbon while the foundation and substructure contribute to 8% of the building embodied carbon emission.

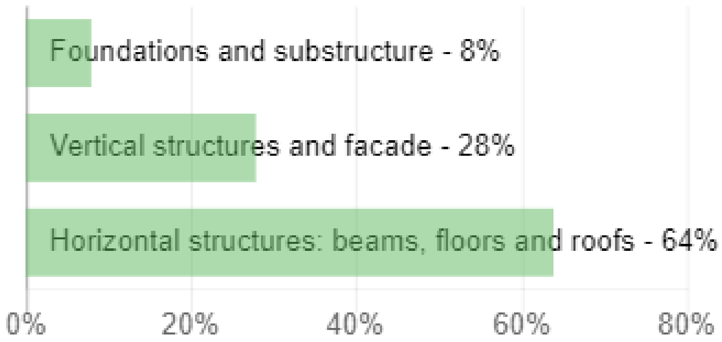


Figure 57: Distribution of the embodied carbon by the different structural elements for the third case study.

While Figure 58 clarifies a visualization of the building carbon emission distributed by the different building elements in each design phase (based on the input data quality from the model) that has been generated by the LCA one-click tool. It is clear from the figure that district heat use is the highest contributor to the building carbon emission. The following high carbon elements are the foundation that only appears in the structural model carbon assessment.

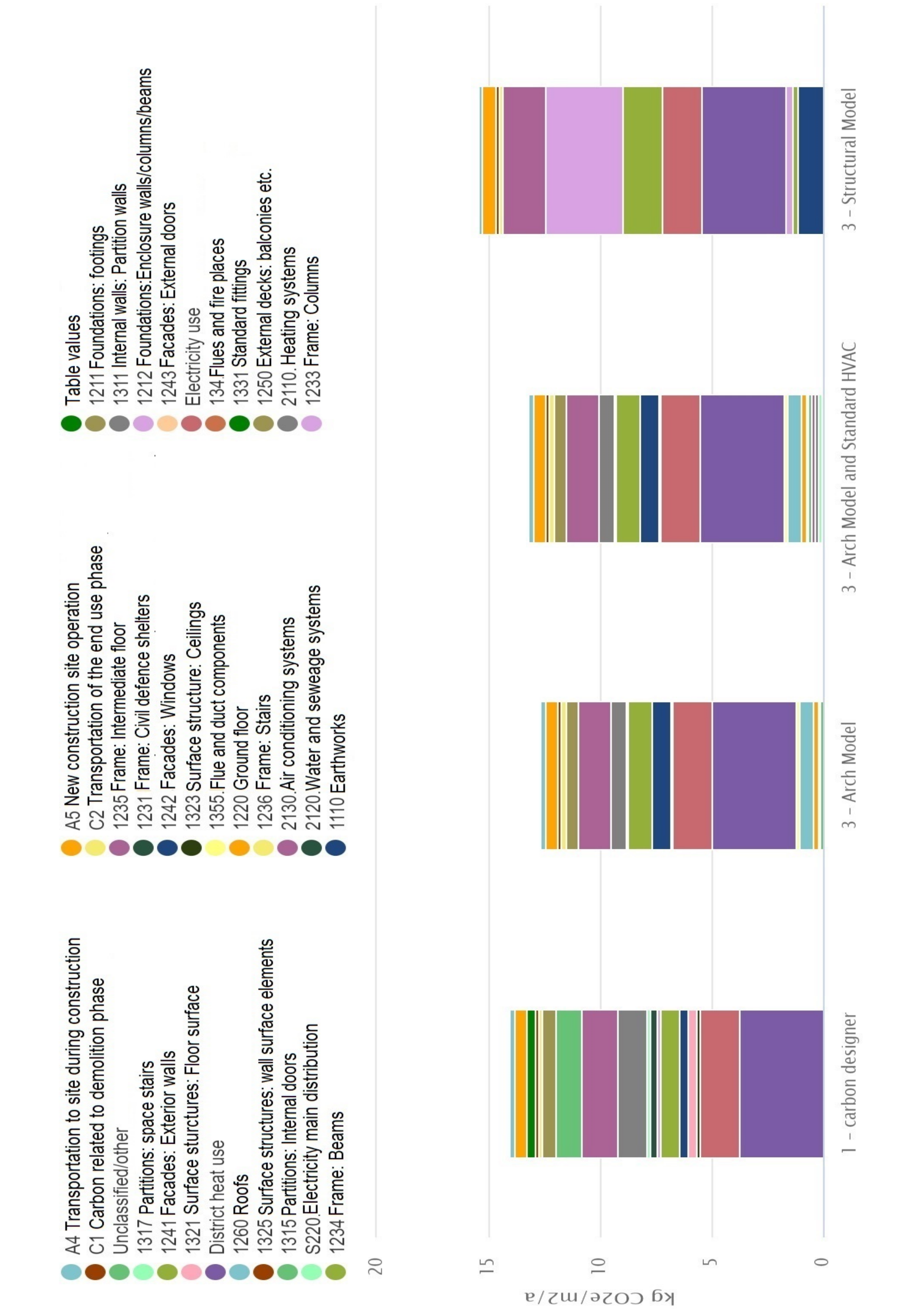


Figure 58: Third case study visualization of the building elements carbon emission in each design phase.

4.8 case studies main findings

The thesis proposed process has proved its efficiency while conducting the carbon assessment in the case studies. The main defects were that the models were not intended to be used for carbon assessment and the designer didn't consider defining the exact material name and volume. Therefore, there were many irrelevant building elements extracted from the model and many building elements didn't have the exact material name.

There were three main filtering phases in each case studies which made the process of LCA take much longer time than expected. The first filtering phase was deleting irrelevant building elements from the extracted excel sheets (like toilets, washing machines, and openings) as shown previously in figures 31, 41, and 51. The second filtering phase was done automatically by the LCA One-Click tool, as the tool highlights these issues while combined similar materials and gives a recommended action to be implemented as shown in figures 32, 42, and 52. The third filtering phase was the most time consuming as it required the information of each building element exact material to be allocated to the relevant database material in the LCA One-Click tool. That required direct contact with the model architect or the project manager to know the exact material type and name for many unnamed materials. Figure 59 shows the third filtering phase in the LCA One-Click tool.

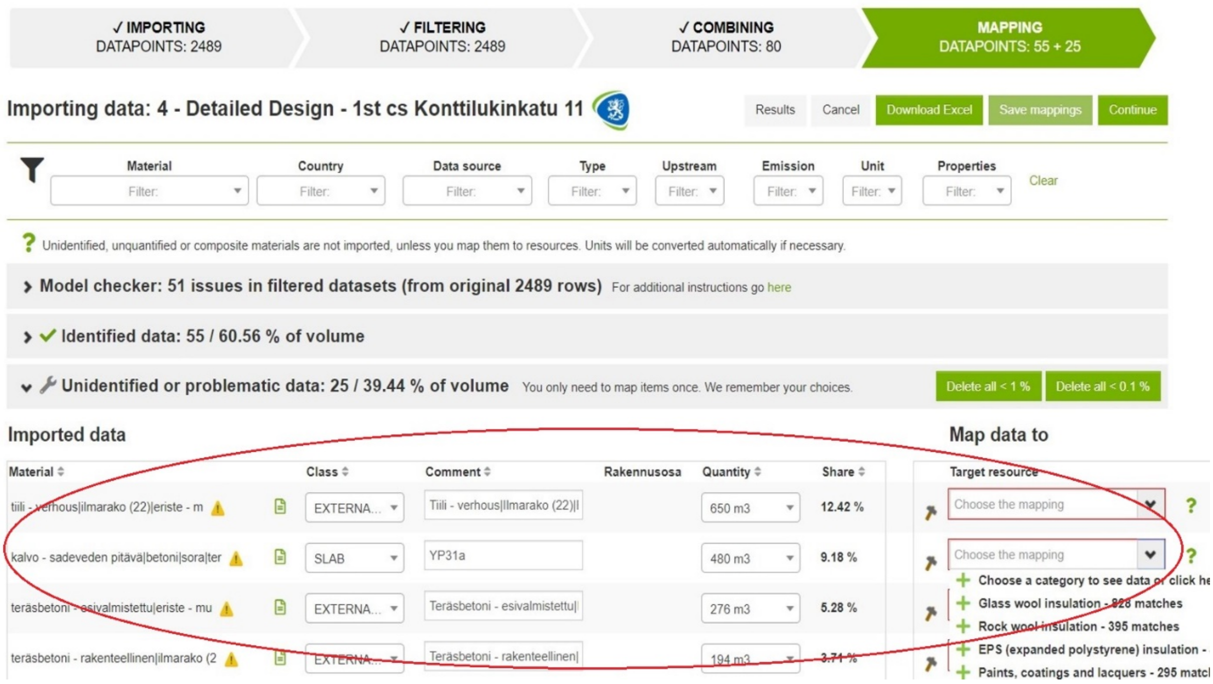


Figure 59: The third filtering phase – mapping the building elements to the related material carbon database.

5. The comprehensive analysis:

Although the three case study projects were designed by different designers, the same three filtering phases took place with almost equal time for each case study and same model defects (unspecified building elements exact material naming, source, classification, dimensions, and volume). This chapter investigates the reasons behind the design model defects (from the environmental perspective) and the analysis of the case studies' outcome.

The COBIM defines the minimum information required to be included in the design model which represents the foundation and main guiding reference for designers to follow when designing the model in the Finnish construction industry. A comprehensive comparative analysis had to be done for the building elements minimum information defined by the COBIM and the building elements specified by the Ministry of Environment.

5.1 Building 2000 Project classification

Compatible with ISO 12006-2 framework standards, the building 2000 project classification system is a Finnish set of grouping tables for the building materials that distribute the building material into a readable breakdown structure to be used in different ways like BIM models in the design operation, planning, and cost estimation. It breaks down the building elements based on many perspectives like:

- Space classification: to comply with the Finnish target price estimating method that is mainly based on the structure spaces.
- Building elements: that is used in the building specification and bill of quantities.
- Project management: that breaks the project down based on construction management and design tasks.
- Production: for procurement and production operations purposes.
- Resources: the breakdown considers labors, site equipment, and overhead pricing.

Appendix 3 clarifies that the building 2000 project classification could be used by owners in pre-contracting and tendering phases, by designers in BIM models, by contractors in cost control and estimation, and by scientists in data management and information statistics (Rakennustieto Oy, 2020), (Rakennustieto Oy, 2010).

5.2 The overlap between the COBIM and the Finnish Ministry of Environment LCA Method 2019

In the scope of this thesis, the implementation difficulties that would face the method of the building's life carbon assessment - developed by the Ministry of Environment in Finland in 2019 - when it is implemented by the different stakeholders in the construction industry have been investigated. As stated in the COBIM, most engineers in Finland required to design their work based on the common BIM national requirements (COBIM) (BuildingSmart Finland, 2012b). On the other hand, the method of the whole LCA assessment don’t consider all building elements, it specifies some specific elements of the building in their carbon assessment. Both parties (COBIM and the LCA method) have considered the same project classification (Building 2000 or in Finnish version Talo2000) for naming and coding different materials used in the project (Rakennustieto Oy, 2010).

The tables in appendix 4 are a comparison between the different minimum requirements for the building model material information in the COBIM series and the material used in the LCA Finnish Ministry of Environment method in both architecture and structural disciplines. These COBIM series have been used in the comparison (BuildingSmart Finland, 2012b):

- COBIM series 3 Architectural design.
- COBIM series 5 Structural Design.
- COBIM series 7 Quantity take-off (for both Architectural and Structural models).
- COBIM Supplementary Annex for series 3: Architectural Design Modeling accuracy.
- COBIM Supplementary Annex for series 5: Structural Design Modeling accuracy.

The design development phase has been chosen to be the main focus phase in this research as it is where the designer would have gained a better vision of the different project materials information that would be used in his design and still before the building permit. The COBIM series number 7 quantity take-off shows the different minimum information extracted from the Architecture and structural IFC models. The COBIM supplementary annex for series 3 architectural design and series 5 structural design shows what kind of information should be specified in the models (like naming and ID, Gross, and net area, the volume of the material… etc.). It is worth to mention that the volume of the material is the most critical information the project engineer needs for conducting the life carbon assessment (BuildingSmart Finland, 2012b).

The symbols in the table are different from one series to another because every COBIM series have a different specialized author who might use different symbols to express his vision. The author of COBIM series 3: architecture design, Tomi Henttinen, used the abbreviations M & O to categorize the importance of the model building materials, the letter (M) is referred to mandatory tasks and the letter (O) is referring to optional tasks. While the author of COBIM series 5: structural design, Tero Kautto, used the abbreviations P & S, The letter (P) is referred to primary tasks, and the letter (S) is referred to secondary tasks which might be defined based on the project special needs by the project team or the facility owner. Both mandatory and optional tasks in series 3: (architecture design) are followed by the number of the recommended content level (1, 2, or 3). The project phase and the IFC model prospective usage are the main elements for determining the content level requirement 1, 2, or 3 (Henttinen, 2012), (Kautto, 2012).

- Level 1: refers that the building elements are descriptively named and used when the model is still in the communication and collaboration phase between the designers and other stakeholder engineers.
- Level 2: refers that the building elements are correctly named that the cost estimation can read the related essential information from the model and used in the pre-design, energy analysis, and bidding quantity take-off phase.
- Level 3: refers that the building elements are detailed described that the contractor can perform the required purchase based on the related information from the model and used in scheduling and contractor purchasing.

The comparison tables in appendix 4 give a clear understanding of why there was the same defects in each case study design model. The designers have followed the COBIM instructions for the required modeled information while the table includes the building elements specified in the Ministry of Environment in Finland method to give a better understanding of which of its building elements information should be included in the model and which materials information doesn’t have any current obligation to be modeled.

As an analysis of the comparison tables above, it is obvious that there is a general lack of the current minimum required material information in the design models to perform the LCA carbon assessment. Let's take for example the external doors (its code is 1.2.4.3 in the building 2000 classification) neither the architecture COBIM nor the structural one has specified that the designer showed allocate the related material volume information. The same happens with windows (code number 1.2.4.2) which forces the environmental specialist to open the model and calculate all windows volume manually before starting the carbon footprint assessment process.

It worth to mention that in the HVAC building services elements (code number 2 in building 2000 classification system) the COBIM quantity takeoff -COBIM 7- has followed the building 2000 classification system and specified some related requirement (like elements coded in 2.1.2.3 or 2.1.2.4) while the Finnish Ministry of Environment method has followed a mix between building 2000 classification system and different classification systems (LVI2010 nomenclature & S2010 electricity nomenclature or in Finnish language S2010-sähkönimikkeistön) which made it very difficult to connect the related information with the COBIM to make a standard requirement from both discipline engineering designers.

Regarding using the same classification system, the following notes have been observed which could be fixed in future versions of the COBIM. Some elements have been mentioned in COBIM series 7 (quantity takeoff) but haven't been mentioned in the building 2000 classification system like elements 2.1.6 Civil defense shelter. Other elements haven't been mentioned in the detailed design phase for architecture or structural COBIM, but it is required to be extracted from the model quantity take-off COBIM series 7 like element 1.2.3.7 structure frame stairs for example.

6. Conclusion

The carbon neutrality timeframe target that has been taken by many governments and organization based on the world green building council recommendation (Finland has a national target to be carbon-neutral by 2035 and Skanska aims to be the first carbon-neutral construction company worldwide by 2045) is very challenging and requires a fast and effective innovative solution. Each government and organizations (public or private) would donate much effort and cost to tackle the problems of global warming in the best sustainable way.

The integration between The Building Information Modelling (BIM) and the Life Cycle Assessment (LCA) has proven its efficiency in utilizing the LCA process by enhancing its speed and improving the carbon assessment outcome accuracy by depending less on the human factor. As well as it decreases the overall cost of the carbon assessment process by decreasing the number of involved engineering departments in each company (only the environmental and design department rather than the current status of involving the three departments of cost control, environmental, and design).

The early design phases have the highest influence and ability to apply changes in the project while avoiding the high-cost consequences of these changes in the later phases like the construction and the operation phases. The early design stages suffer the issue of lacking the building detailed information that would enable an accurate LCA evaluation. Therefore, more effort should be allocated to enhance the availability of the building information in the early design phases that would enable the architects and decision-makers to take critical changing decisions to the project scope and characteristics at a much lower cost.

The three case studies give a tangible sense and a better understanding of the thesis proposed enhancement to the building LCA process. The first research question (What is the analysis of comparing LCA calculation results between early and detailed design stages?) has been answered by conducting the carbon emission comparison between the different design phases and different design models for each case study. The case studies analysis clarifies that there were design problems in the models { the materials of the different building elements were not named efficiently to allocate its exact carbon emission in the tool database (the Finnish RTS EPD) and there were many extracted elements that were irrelevant to the LCA calculations} which resulted in three filtering phases of the extracted material information excel sheets { as specified in section (4.8) } that revealed the complicity of the LCA process and consumed an enormous amount of time.

The common BIM requirement (COBIM) is considered to be the standardization for design BIM modeling in the Finnish construction industry and the national requirement for all industry stakeholders. Considering that the last version of COBIM was published in 2012, the authors of COBIM probably didn't consider the future requirements of the carbon assessment or environmental impact in their publication. Therefore, there have been several defects (from an environmental perspective) and a shortage of related material information available in the IFC models for conducting the carbon assessment based on the Finnish Ministry of Environment method.

<u>The second and third research questions</u> (How the LCA carbon emission calculation will be integrated with the COBIM different IFC models? How to develop the BIM requirements to enable assessing the variety of construction options and their embodied environmental impact?) were answered by conducting the comparative analysis tables. It reviews the current environmental defects in the COBIM, and it reveals the urgent need for updating the COBIM to enrich the minimum requirements of the building elements modeled information with special attention to materials specified in the Finnish Ministry of Environment LCA method and special attention to the design development phase (the final phase of design and before requesting the building permit from officials) which will eventually support the Finnish Ministry of Environment target of initiating the environmental building permit by 2025.

It is crucial to highlight that to perform a carbon assessment in an automated model-based process, the material exact name and volume is the most important information that needs to be identified clearly in the BIM design models. The design models should also have the same naming standardization to best identify the material between industry stakeholders in the LCA tools in an automated way with less manual interference. Therefore, any future publication of the common BIM requirements (COBIM) and any future carbon assessment method should follow the same project classification (like building 2000 in the Finnish construction industry), which we could identify as a common ground or the same language between BIM and LCA, otherwise, it would be impossible to link the LCA carbon assessment method and the BIM design models through the COBIM.

For an accurate LCA carbon assessment, the different models (architecture and structure) information should complement each other. The COBIM should clearly define and separate the responsibilities between the two different models regarding LCA related information. For example, the structural engineer should be responsible for the detailed description of all load-bearing structural elements (columns, slabs, etc.) in a way that the building carbon assessment could be easily done afterward based on his model information (concrete type, amount of steel bars used in each element, …), while the architect should be responsible for every other material definition like windows and doors. There should be a mutual understanding and harmony between the design team to define any material that could play a mutual role in both models, like internal non-bearing walls and the outer layers of the slabs or columns could be defined by the architect rather than the structural engineer.

Based on the comprehensive analysis tables all value chain engineers should be capable of checking their designs to have the minimum requirement of the information stated by the COBIM. They also would have a better understanding of the material information and the ***data management*** required for conducting the life cycle assessment based on the materials specified in the method of the Finnish Ministry of Environment 2019. As well as, the COBIM authors should consider processing any defects and shortage of material information required for conducting the carbon assessment based on the Finnish Ministry of Environment method in their future publication of COBIM. Finally, the Finnish Ministry of Environment method authors would consider expanding the scope of selected materials based on the available information in the COBIM different series and IFC models.

6.1 Recommendation

The building Life Cycle Assessment (LCA) is still a very complex process. This thesis represents the foundation for the automated LCA process and an initial step for considerable future scientific research that would also require the industrial field extensive cooperation along the whole value chain. It highlights the environmental shortage in the current COBIM version of 2012 and its updating opportunities.

To achieve the Ministry of Environment in Finland's goal of issuing an environmental building permit, effective industrial material environmental standardization is essential. The Ministry of Environment in Finland could issue a new legal obligation for the building products vendors and manufactures to specify its carbon footprint through its whole life cycle (starting from the raw material extraction phase until it's end-life time phase including its recycling probabilities) before marketing and distributing it in the Finnish construction market. This information should be available for designers in a huge national database to be used during design and construction under the observation of the local consulting engineering offices. The carbon designer (preliminary rough carbon emission calculation) is a very beneficial tool that will enable decision-makers to define whether to construct the project or not in the feasibility study or idea conceptional phase. More effort should be allocated to enhance the carbon designer options and creditability.

6.2 Future research questions

Besides the ongoing efforts to standardize a national LCA method along with developing carbon assessment tools and developing the material database, the LCA process requires more future research to be done in a fully automated way. These questions could be the next challenges in the building environment field that needs more effort from future researchers to answer and enrich the construction industry's environmental perspective.

- How the thesis output would develop the Ministry of Environment method to meet Finland's building environmental regulations targets in mid-2020s?
- How the Common BIM requirements (COBIM) would be developed to integrate the environmental perspective?

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Helsinki, Finland
28, October 2020

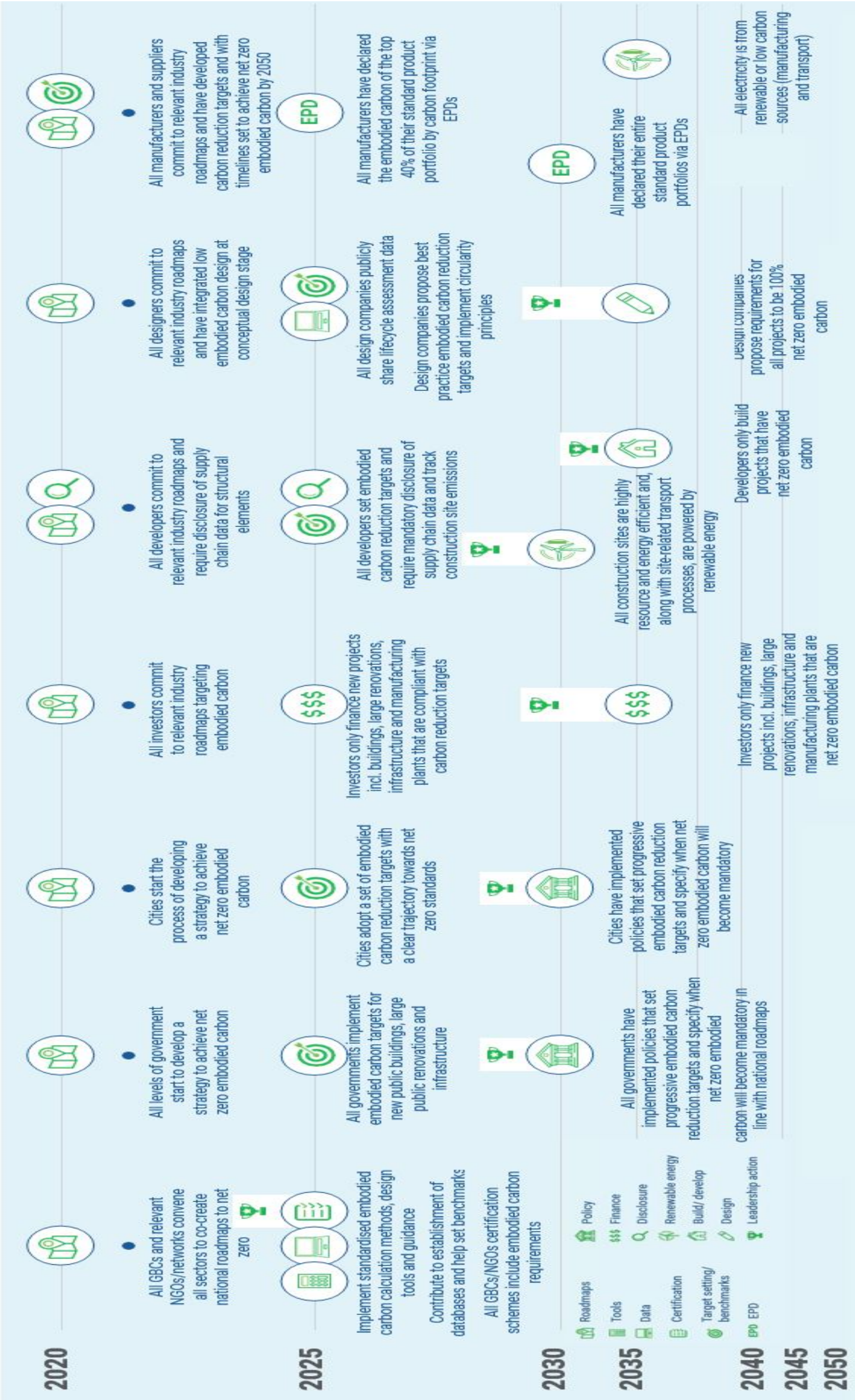
Location, Date

Signature of the student

Appendix

Appendix 1

the World Green Building Council (WorldGBC) roadmap vision (World Green Building Council, 2019).



Appendix 2

Detailed building elements that should be included during conducting the ministry of environment method for the whole building life carbon assessment and its equivalence nomenclature form building 2000 classification system (Kuittinen, 2019).

Assessed parts of building	Building 2000 classification system equivalence
Site	
Earth works	1111 Clearing elements 1112 Trenches 1113 Channels 1114 Filling on site 1115 Embankments 1116 Draining elements
Soil stabilisation and reinforcement elements	1121 Piles 1122 Permanent soil stabilisation 1123 Reinforcement elements
Paved areas on the site	1131 Traffic area pavings 1132 Parking area pavings 1133 Leisure and play area pavings
External structures and their foundations on the site	1151 Outdoor storage 1152 Yard sheds and pergolas 1154 Stairs, ramps/embankments and terraces
Load-bearing structures	
Building foundations and dewatering	1211 Footings 1212 Enclosure walls, and foundation columns and beams
Ground floors	1221 Ground floor slabs 1222 Ground floor channels/ducts
Structural frame	1231 Civil defence shelters 1232 Bearing walls 1233 Columns 1234 Beams 1235 Intermediate floors 1236 Structural frame stairs
Façades	1241 External walls 1242 Windows 1243 External doors
External decks	1251 Balconies 1252 Shelters and pergolas 1253 Special external decks
Roofs	1261 Roof substructures 1262 Eaves 1263 Roofings 1265 Glass roof structures 1266 Skylights and hatches
Light structures	
Interior walls	1311 Partitions 1312 Glass partitions 1315 Internal doors 1316 Special doors 1317 Space stairs
Surface elements	1321 Floor surface elements 1323 Ceiling surface elements 1325 Wall surface elements
Fixtures	1331 Standard fittings

Assessed parts of building	Building 2000 classification system equivalence
Light structures	
Flues and fireplaces	134 Flues and fireplaces
Box units	1351 Box unit bathrooms 1353 Box unit saunas 1354 Box units for building service systems 1355 Flue and duct components
Heating, ventilation and air conditioning systems and their corresponding LVI2010 nomenclature	
Heating systems	2111 Central units: boiler installations, burner systems, flues, geo-thermal and aerothermal heat pumps, solar thermal equipment 2112 Transmission components: exchange systems, heat transfer fluids, air ducts 2113 Terminal parts: radiators, radiant heaters, underfloor heating pipes, supply air heaters 2114 Local area parts: networks, thermal power stations, pipes, fuel stores, equipment for solar, heat pump and combined heating systems, heat storage equipment, pipework
Water and drainage systems	2122 Transmission components: tanks and storage appliances 2123 Terminal parts: mixers, taps, lavatory pans, urinals, baths, shower trays and cabins 2124 Local area parts, building pipework, site conduits, sewers, inspection chambers, runoff gullies, storm drains
Air conditioning systems	2131 Central units: appliances and their parts, air extractors, air recirculation systems, supply ventilation systems, waste air purification equipment 2132 Transmission components: pipes and ducts 2133 Terminal parts: exhaust air windows 2134 Local area parts: external and waste air gaps and ducts, heat recovery systems, filter units, outdoor air and exhaust equipment
Cooling systems	2141 Central units: appliances, equipment, pumps, steam gene-ra-tors, heat exchange units, condensers, tanks 2142 Transmission components: pipes 2143 Terminal parts radiators, air-conditioners, chilled beams 2144 Local area parts: network, central units, pipework
Fire-fighting systems	2152 Transmission components: Conduits, sprinkler pipes
Electricity systems and their corresponding S2010 nomenclature	
Production and connection	S212 Electricity generation systems and equipment
Main distribution	S221 Medium voltage power distribution system S222 Main distribution system
Electrification	S231 Electrification of a property's equipment and appliances S231 Electrification of heating, ventilation and air conditioning equipment and appliances S231 Electrification of a user's equipment and appliances
Lighting systems	S251 Internal lighting S252 External lighting S253 Local area lighting system
Electrical heating systems	S261 Building's electrical heating system S262 Underfloor heating
Mechanical elements	
Transporters	2511 Lifts

Appendix 3

Main categories in the building 2000 classification system (Rakennustieto Oy, 2020).

Construction 2000
Project Classification

1 BUILDING ELEMENTS

11 Site elements
111 Ground elements
112 Soil stabilisation and reinforcement elements
113 Paved and green areas
114 Site equipment
115 Site constructions

12 Building elements
121 Foundations
122 Ground floors
123 Structural frame
124 Facades
125 External decks
126 Roofs

13 Internal space elements (infills)
131 Internal dividers
132 Space surfaces
133 Internal fixtures
134 Other internal space elements (infills)
135 Box units

2 SERVICES ELEMENTS

21 Plumbing elements

22 Air conditioning elements

23 Electrical elements

24 Data transfer elements

25 Mechanical elements

3 PROJECT-RELATED TASKS

31 Project management tasks
311 Construction project preparation
312 Site supervision
313 Project administration

32 Design tasks
321 Spatial design
322 Building design
323 Expert tasks in design
324 Project information tasks

33 Construction management tasks
331 General construction management
332 Site management tasks

34 Site tasks
341 Site services
342 Site equipment operations

4 PROPERTY MANAGEMENT TASKS

41 Site tasks
411 Plot tasks
412 Connections
413 Site development

42 Financing and marketing
421 Financing tasks
422 Marketing tasks

5 USER TASKS

51 Space equipment
511 Movables
512 Business devices and machines

52 Maintenance of operation
521 Temporary activity
522 Taking into use

6 PROJECT PROVISIONS

61 Document and price level changes
611 Document changes
612 Price level changes

62 Other provisions
621 Risks
622 Special provisions

Appendix 4

Comparative analysis between COBIM 2012 and the Finnish Ministry of Environment Method of the whole life carbon assessment of buildings 2019

A) Architecture Model

Building 2000 Project classification		COBIM serious		COBIM Supplementary Annex for Part 3 Arch Design Modeling accuracy - Data content in the IFC template					Method of the whole life carbon assessment of buildings 2019 (Ympäristöministeriö Miljöministeriet Ministry of the Environment)
		3 - Arch – Design Development phase	7 -Arch model Quantity take-off	Type / name/ ID	building2000 classification	Gross & Net area	Length, width, height	Volume	
Code	Name								
1.1	Site elements (Site BIM)								
1.1.1	Ground elements		S						
1.1.1.1	Clearing elements		S						Clearing elements
1.1.1.2	Trenches		S						Trenches
1.1.1.3	Channels		S						Channels
1.1.1.4	Filling on site		S						Filling on site
1.1.1.5	Embankments		S						Embankments
1.1.1.6	Draining Elements		S						Draining elements
1.1.1.7	Other ground elements		S						
1.1.2	Soil stabilization and reinforcement elements								
1.1.2.1	Piles								Piles
1.1.2.2	Soil stabilization elements								Permanent soil stabilization
1.1.2.3	Reinforcement elements								Reinforcement elements
1.1.2.4	Other soil stabilization and reinforcement elements								
1.1.3	Paved and green areas		P	X	X	X			
1.1.3.1	Traffic area pavings		P						Traffic area pavings
1.1.3.2	Parking area pavings		P						Parking area pavings
1.1.3.3	Leisure and play area pavings		P						Leisure and play area pavings
1.1.3.4	Green areas		P						
1.1.3.5	Special area pavings		P						
1.1.4	Site equipment		P	X	X				
1.1.4.1	Building equipment		P						
1.1.4.2	Leisure equipment		P						
1.1.4.3	Play equipment		P						
1.1.4.4	Site signage		P						
1.1.4.5	Other site equipment		P						
1.1.5	Site construction		P						
1.1.5.1	Yard sheds	M1	P	X	X	X			Outdoor storage

1.1.5.2	Yard shelters and pergolas	O1	P	X	X	X			Yard sheds and pergolas
1.1.5.3	Fences and retaining walls	O1	P	X	X	X	X		
1.1.5.4	Site stairs, ramps and terraces	O1	P	X	X				Stairs, ramps, and terraces
1.1.5.5	Site parking facilities		P	X	X	X			
1.1.5.6	Other site constructions		P						
1.2	Building elements								
1.2.1	Foundations			X	X				
1.2.1.1	Footings (based on the structural BIM)								Footings
1.2.1.2	Enclosure walls, foundation columns, foundation beams	M1							Enclosure walls, foundation columns, and beams
1.2.1.2	Enclosure walls								
1.2.1.2	Foundation beams								
1.2.1.2	External surfaces								
1.2.1.3	Special foundations								
1.2.2	Ground floors		S						
1.2.2.1	Ground floor slabs	M1		X	X	X	X		Ground floor slabs
1.2.2.2	Ground floor ducts	O1							Ground floor channels/ducts
1.2.2.3	Special ground floors								
1.2.3	Structural frame		S						
1.2.3.1	Civil defense Shelters (Ground floor str, …)		S	X	X	X	X		Civil defense shelters
1.2.3.1	Shelter floors	M1	S	X	X	X	X		
1.2.3.1	Shelter walls	M1	S	X	X	X	X		
1.2.3.1	Shelter roof structure	M1	S	X	X	X	X		
1.2.3.1	Shelter closed space, emergency exit corridors and openings	M1	S	X	X	X	X		
1.2.3.1	Shelter protective doors and hatches	M1	S	X	X	X	X		
1.2.3.1	Shelter ladders and ventilation equipment	O1	S	X	X	X	X		
1.2.3.1	Shelter crises-time and other equipment	O1	S	X	X	X	X		
1.2.3.2	Bearing walls	M2	S	X	X	X	X		Bearing walls
1.2.3.3	Columns	M1	S	X	X		X		Columns
1.2.3.4	Beams	M1	S	X	X		X		Beams
1.2.3.5	Intermediate floors	M1	S	X	X	X	X		Intermediate floors
1.2.3.6	Roofing decks	M1	S	X	X	X	X		
1.2.3.7	Structure frame stairs		S	X	X				Structural frame stairs
1.2.3.7	Structural frame stairs and landings	M1							
1.2.3.7	Structural frame stairs railings	O1							
1.2.3.8	Other structural elements	O1							
1.2.4	Facades		P						
1.2.4.1	External walls	M2	S	X	X	X	X		External walls
1.2.4.2	Windows	M1	P	X	X	X			Windows
1.2.4.2	Window fittings and locks (information)								
1.2.4.2	Window cover strips								
1.2.4.3	External doors	M1	P	X	X				External doors

1.2.4.3	External doors fittings and locks (information)								
1.2.4.4	Facade attachments		P	X	X				
1.2.4.5	Other facade structures (including curtain wall structures)	O1	P						
1.2.5	External decks								
1.2.5.1	Balconies			X	X	X	X		Balconies
1.2.5.1	Balcony slabs and roofs	M1							
1.2.5.1	Balcony railings	M1							
1.2.5.1	Balcony glazing	O1							
1.2.5.2	External shelters and pergolas	M1		X	X	X	X		Shelters and pergolas
1.2.5.3	Special external decks								Special external decks
1.2.5.3	External decks and stairs	M1							
1.2.5.3	External deck railings	O1							
1.2.5.3	External deck glazing	O1							
1.2.6	Roofs		P						
1.2.6.1	Roof substructures	M1	S						Roof substructures
1.2.6.1	Fire compartmentation of roofing deck	M1							
1.2.6.1	Roof catwalks	O1							
1.2.6.1	Roof hatches	M1							
1.2.6.2	Eaves	O1	S	X	X		X		Eaves
1.2.6.2	Cover strips and other details of eaves								
1.2.6.3	Roofing		P	X	X	X	X		Roofings
1.2.6.3	Roofing outlets	O1							
1.2.6.4	Roof safety products	O1	P	X	X				
1.2.6.5	Glass roof structures	M1	P	X	X	X	X		Glass roof structures
1.2.6.5	Glass roof fittings (information)								
1.2.6.5	Wall-like root structure of glass roof	M1							
1.2.6.5	Maintenance platforms for glass roofs								
1.2.6.6	Skylights and hatches	M1	P	X	X	X			Skylights and hatches
1.2.6.6	Fittings of skylights and hatches (information)								
1.2.6.6	Wall-like root structure of skylights and hatches	M1							
1.2.6.7	Special roof substructures		P						
1.3	Internal space elements (infills)								
1.3.1	Internal dividers								
1.3.1.1	Partitions	M1	P	X	X	X	X		Partitions
1.3.1.2	Glass partitions	M1	P	X	X	X	X		Glass partitions
1.3.1.3	Special partitions		P	X	X	X	X		
1.3.1.4	Balustrades and raillings		P	X	X		X		
1.3.1.5	Internal doors	M1	P	X	X				Internal doors
1.3.1.5	Fittings and locking of internal doors (information)								
1.3.1.6	Special doors		P	X	X				Special doors
1.3.1.7	Space stairs and landings	M1	P	X	X				Space stairs
1.3.1.7	Railings of space stairs	M1							
1.3.1.8	Other Internal dividers		P						
1.3.2	Space surfaces		P						
1.3.2.1	Floor surface elements		P	X	X	X			Floor surface elements

1.3.2.2	Flooring		S	X	X	X			
1.3.2.3	Ceiling surface elements	M1	P	X	X	X	X		Ceiling surface elements
1.3.2.4	Ceiling finishings	M1	S	X	X				
1.3.2.5	Wall surface elements		P	X	X	X	X		Wall surface elements
1.3.2.6	Wall finishings		S	X	X	X			
1.3.2.7	Other space surfaces		S	X	X				
1.3.3	Internal fixtures		S						
1.3.3.1	Standard fittings	M1	P	X	X		X		Standard fittings
1.3.3.2	Special fittings	O1		X	X		X		
1.3.3.3	Accessories	O1		X	X				
1.3.3.4	Standard appliances	M1		X	X				
1.3.3.5	Internal signage								
1.3.3.6	Other internal fixtures								
1.3.3.6	Sanitary fixtures	M1							
1.3.3.6	Sanitary equipment	O1							
1.3.4	Other internal space elements (infills)		P						
1.3.4.1	Maintenance platforms and catwalks		P	X	X				
1.3.4.1	Maintenance platforms and catwalks including stairs and treads	O1							
1.3.4.1	Maintenance platform frame structures separate from the building frame	O1							
1.3.4.1	Maintenance platform railings	O1							
1.3.4.2	Fireplaces and flues	M1	S	X	X				Flues and fireplaces
1.3.4.3	Other Special Internal space elements (infills)		S						
1.3.5	Box units								
1.3.5.1	Box unit bathrooms			X	X	X	X		Box unit bathrooms
1.3.5.2	Box unit refrigeration rooms			X	X	X	X		
1.3.5.3	Box unit saunas			X	X	X	X		Box unit saunas
1.3.5.4	Box units for services systems								Box units for building service systems
1.3.5.5	Flue and duct components			X	X		X		Flue and duct components
1.3.5.6	Other box units								
2	Services elements								
2.1	Plumbing elements								
2.1.1	Heating systems								
2.1.1.1	Central units: boiler installations, burner systems, flues, geothermal and aerothermal heat pumps, solar thermal equipment								Central units: boiler installations,…...
2.1.1.2	Transmission components: exchange systems, heat transfer fluids, air ducts								Transmission components….
2.1.1.3	Terminal parts: radiators, radiant heaters, underfloor heating pipes, supply air heaters								Terminal parts: radiators, …..
2.1.1.4	Local area parts: networks, thermal power stations, pipes, fuel stores, equipment for solar, heat pump, and combined								Local area parts: networks, ….

	heating systems, heat storage equipment, pipework								
2.1.2	Water and Drainage systems								
2.1.2.2	Transmission components: tanks and storage appliances								Transmission components….
2.1.2.3	Terminal parts: mixers, taps, lavatory pans, urinals, baths, shower trays, and cabins		S						Terminal parts: mixers, taps, ….
2.1.2.4	Local area parts, building pipework, site conduits, sewers, inspection chambers, runoff gullies, storm drains								Local area parts, building pipework, site conduits, ….
2.1.3	Air conditioning systems								
2.1.3.1	Central units: appliances and their parts, air extractors, air recirculation systems, supply ventilation systems, waste air purification equipment								Central units: appliances and their parts, air extractors, ….
2.1.3.2	Transmission components: pipes and ducts								Transmission components: pipes and ducts
2.1.3.3	Terminal parts: exhaust air windows		S						Terminal parts: exhaust air windows
2.1.3.4	Local area parts: external and waste air gaps and ducts, heat recovery systems, filter units, outdoor air, and exhaust equipment								Local area parts: external and waste air gaps and ducts, ….
2.1.4	Cooling systems								
2.1.4.1	Central units: appliances, equipment, pumps, steam generators, heat exchange units, condensers, tanks								Central units: appliances, equipment, pumps, ….
2.1.4.2	Transmission components: pipes								Transmission components: pipes
2.1.4.3	Terminal parts radiators, air-conditioners, chilled beams		S						Terminal parts radiators, air-conditioners, chilled beams
2.1.4.4	Local area parts: network, central units, pipework								Local area parts: network, central units, pipework
2.1.5	Fire-fighting systems								
2.1.5.2	Transmission components: Conduits, sprinkler pipes								Transmission components: Conduits, sprinkler pipes
2.1.5.4	Fire prevention area components		S						
2.1.6	Civil defence shelter HVAC system								
2.1.6.1	Civil defence shelter HVAC system central components								
2.1.6.2	Civil defence shelter HVAC system transfer components								
2.1.6.3	Civil defence shelter HVAC system terminal units		S						
2.1.6.4	Civil defence shelter HVAC system area components		S						
2.2	Air conditioning elements								

2.3	Electrical elements								
2.4	Data transfer elements								
2.5	Mechanical elements								
2.5.1	Transportation equipment								
2.5.1.1	Lifts			X	X				Lifts
2.5.1.2	Escalators and conveyors								
2.5.1.3	Other transportation equipment's								
S2	Electricity systems and their corresponding S2010 nomenclature								
S2.1	Production and connection								
S2.1.2	Electricity generation systems and equipment								Electricity generation systems and equipment
S2.2	Main distribution								
S2.2.1	Medium voltage power distribution system								Medium voltage power distribution system
S2.2.2	Main distribution system								Main distribution system
S2.3	Electrification								
S2.3.1	Electrification of a property's equipment and appliances								Electrification of a property's equipment and appliances
S2.3.1	Electrification of heating, ventilation, and air conditioning equipment and appliances								Electrification of heating, ….
S2.3.1	Electrification of a user's equipment and appliances								Electrification of a user's equipment and appliances
S2.5	Lighting systems								
S2.5.1	Internal lighting								Internal lighting
S2.5.2	External lighting								External lighting
S2.5.3	Local area lighting system								Local area lighting system
S2.6	Electrical heating systems								
S2.6.1	Building's electrical heating system								Building's electrical heating system
S2.6.2	Underfloor heating								Underfloor heating
9	Areas and volumes								
9.1	Program areas								
9.1.1	Program area of building elements								
9.1.1.1	Program area of the site								
9.1.1.2	Program area of the building								
9.1.1.3	Program area of the rooms and spaces								
9.1.2	Program area of technical elements								
9.2	Site areas								
9.2.1	Area of the plot	O2							
9.2.2	Area of the block								
9.2.3	Area of building								
9.2.4	Area of the traffic areas								
9.2.9	Other areas								

9.3	Total areas of the building								
9.3.1	Gross area	M2		X	X	X			
9.3.2	Total floor area	O2		X	X	X			
9.3.3	Area of apartments and departments	O2		X	X	X			
9.3.4	Space group areas	O2							
9.3.5	Net areas of rooms	M2		X	X	X			
9.3.5.1	Areas of room sections that are lower than 1600 mm	O2							
9.3.6.1	Areas of the load-bearing structures								
9.3.6.2	Areas of the non-bearing structures								
9.4	Departments								
9.4.1.1	Areas of the fi re departments								
9.5	Volumes								
9.5.1	Volume of the buildings	O2		X	X			X	

Table 5: Architecture comparison between COBIM 2012 and the Finnish Ministry of Environment Method of the whole life carbon assessment of buildings 2019

B) Structural Models

Building 2000 Project classification		COBIM serious		COBIM Supplementary Annex for Part 5 Structural Design Modeling accuracy - Data content in the IFC template					Method of the whole life carbon assessment of buildings 2019 Ympäristöministeriö Miljöministeriet Ministry of the Environment
		5 - Str – Detailed Design phase	7 - Str model Quantity take-off	Name / Material / ID	building2000 classification	Gross & Net area	Length, width, height	Volume	
Code	Name								
1.1	Site elements (Site BIM)								
1.1.1	Ground elements		S						
1.1.1.1	Clearing elements		S						Clearing elements
1.1.1.2	Trenches		S	X	X	X	X		Trenches
1.1.1.3	Channels		S						Channels
1.1.1.4	Filling on site		S						Filling on site
1.1.1.5	Embankments		S						Embankments
1.1.1.6	Draining Elements		S	X	X			X	Draining elements
1.1.1.7	Other ground elements		S	X	X			X	
1.1.2	Soil stabilization and reinforcement elements		P						
1.1.2.1	Piles	M	P	X	X	X	X	X	Piles
1.1.2.2	Soil stabilization elements		P	X	X	X	X	X	Permanent soil stabilization
1.1.2.3	Reinforcement elements		P						Reinforcement elements

1.1.2.4	Other soil stabilization and reinforcement elements		P						
1.1.3	Paved and green areas								
1.1.3.1	Traffic area pavings								Traffic area pavings
1.1.3.2	Parking area pavings								Parking area pavings
1.1.3.3	Leisure and play area pavings								Leisure and play area pavings
1.1.3.4	Green areas								
1.1.3.5	Special area pavings								
1.1.4	Site equipment								
1.1.4.1	Building equipment								
1.1.4.2	Leisure equipment								
1.1.4.3	Play equipment								
1.1.4.4	Site signage								
1.1.4.5	Other site equipment								
1.1.5	Site construction		S						
1.1.5.1	Yard sheds		S	X	X	X	X	X	Outdoor storage
1.1.5.2	Yard shelters and pergolas		S	X	X	X	X	X	Yard sheds and pergolas
1.1.5.3	Fences and retaining walls		S	X	X	X	X	X	
1.1.5.4	Site stairs, ramps, and terraces		S	X	X	X	X	X	Stairs, ramps, and terraces
1.1.5.5	Site parking facilities		S						
1.1.5.6	Other site constructions		S						
1.2	Building elements								
1.2.1	Foundations		P						
1.2.1.1	Footings (based on the structural BIM)	M	P	X	X	X	X	X	Footings
1.2.1.2	Enclosure walls, foundation columns, foundation beams	M	P	X	X	X	X	X	Enclosure walls, foundation columns and beams
1.2.1.2	Enclosure walls	M	P	X	X	X	X	X	
1.2.1.2	Foundation beams	M	P	X	X	X	X	X	
1.2.1.2	External surfaces		P	X	X	X	X	X	
1.2.1.3	Special foundations		P						
1.2.2	Ground floors		P						
1.2.2.1	Ground floor slabs	M	P	X	X	X	X	X	Ground floor slabs
1.2.2.2	Ground floor ducts	M	P	X	X	X	X	X	Ground floor channels/ducts
1.2.2.3	Special ground floors	M	P	X	X	X	X	X	
1.2.3	Structural frame		P						
1.2.3.1	Civil defense Shelters (Ground floor str, …)	M	P	X	X	X	X	X	Civil defense shelters
1.2.3.1	Shelter floors								
1.2.3.1	Shelter walls								
1.2.3.1	Shelter roof structure								
1.2.3.1	Shelter closed space, emergency exit corridors and openings								
1.2.3.1	Shelter protective doors and hatches								
1.2.3.1	Shelter ladders and ventilation equipment								
1.2.3.1	Shelter crises-time and other equipment								
1.2.3.2	Bearing walls	M	P	X	X	X	X	X	Bearing walls

1.2.3.3	Columns	M	P	X	X	X	X	X	Columns
1.2.3.4	Beams	M	P	X	X	X	X	X	Beams
1.2.3.5	Intermediate floors	M	P	X	X	X	X	X	Intermediate floors
1.2.3.6	Roofing decks		P	X	X	X	X	X	
1.2.3.7	Structure frame stairs		P	X	X	X	X	X	Structural frame stairs
1.2.3.7	Structural frame stairs and landings		P	X	X	X	X	X	
1.2.3.7	Structural frame stairs railings		P	X	X	X	X	X	
1.2.3.8	Other structural elements	M	P	X	X	X	X	X	
1.2.4	Facades								
1.2.4.1	External walls	M	P	X	X	X	X	X	External walls
1.2.4.2	Windows								Windows
1.2.4.2	Window fittings and locks (information)								
1.2.4.2	Window cover strips								
1.2.4.3	External doors								External doors
1.2.4.3	External doors fittings and locks (information)								
1.2.4.4	Facade attachments								
1.2.4.5	Other facade structures (including curtain wall structures)	O							
1.2.5	External decks								
1.2.5.1	Balconies	M		X	X	X	X	X	Balconies
1.2.5.1	Balcony slabs and roofs								
1.2.5.1	Balcony railings								
1.2.5.1	Balcony glazing								
1.2.5.2	External shelters and pergolas	O		X	X	X	X	X	Shelters and pergolas
1.2.5.3	Special external decks	O		X	X	X	X	X	Special external decks
1.2.5.3	External decks and stairs								
1.2.5.3	External deck railings								
1.2.5.3	External deck glazing								
1.2.6	Roofs								
1.2.6.1	Roof substructures	O	P	X	X	X	X	X	Roof substructures
1.2.6.1	Fire compartmentation of roofing deck								
1.2.6.1	Roof catwalks								
1.2.6.1	Roof hatches								
1.2.6.2	Eaves	O	S	X	X	X	X	X	Eaves
1.2.6.2	Cover strips and other details of eaves								
1.2.6.3	Roofing								Roofings
1.2.6.3	Roofing outlets								
1.2.6.4	Roof safety products								
1.2.6.5	Glass roof structures	O		X	X	X	X	X	Glass roof structures
1.2.6.5	Glass roof fittings (information)								
1.2.6.5	Wall-like root structure of glass roof								
1.2.6.5	Maintenance platforms for glass roofs								
1.2.6.6	Skylights and hatches			X	X	X	X	X	Skylights and hatches
1.2.6.6	Fittings of skylights and hatches (information)								

1.2.6.6	Wall-like root structure of skylights and hatches								
1.2.6.7	Special roof substructures								
1.3	Internal space elements (infills)								
1.3.1	Internal dividers								
1.3.1.1	Partitions	O		X	X	X	X	X	Partitions
1.3.1.2	Glass partitions			X	X	X	X	X	Glass partitions
1.3.1.3	Special partitions								
1.3.1.4	Balustrades and raillings								
1.3.1.5	Internal doors								Internal doors
1.3.1.5	Fittings and locking of internal doors (information)								
1.3.1.6	Special doors								Special doors
1.3.1.7	Space stairs and landings			X	X	X	X	X	Space stairs
1.3.1.7	Railings of space stairs								
1.3.1.8	Other Internal dividers								
1.3.2	Space surfaces								
1.3.2.1	Floor surface elements	M		X	X	X	X	X	Floor surface elements
1.3.2.2	Flooring	M							
1.3.2.3	Ceiling surface elements	M							Ceiling surface elements
1.3.2.4	Ceiling finishings	M							
1.3.2.5	Wall surface elements	M							Wall surface elements
1.3.2.6	Wall finishings	M							
1.3.2.7	Other space surfaces	O							
1.3.3	Internal fixtures								
1.3.3.1	Standard fittings								Standard fittings
1.3.3.2	Special fittings								
1.3.3.3	Accessories								
1.3.3.4	Standard appliances								
1.3.3.5	Internal signage								
1.3.3.6	Other internal fixtures								
1.3.3.6	Sanitary fixtures								
1.3.3.6	Sanitary equipment								
1.3.4	Other internal space elements (infills)								
1.3.4.1	Maintenance platforms and catwalks			X	X	X	X	X	
1.3.4.1	Maintenance platforms and catwalks including stairs and treads								
1.3.4.1	Maintenance platform frame structures separate from the building frame								
1.3.4.1	Maintenance platform railings								
1.3.4.2	Fireplaces and flues		S	X	X	X	X	X	Flues and fireplaces
1.3.4.3	Other Special Internal space elements (infills)								
1.3.5	Box units								
1.3.5.1	Box unit bathrooms			X	X	X	X	X	Box unit bathrooms
1.3.5.2	Box unit refrigeration rooms			X	X	X	X	X	
1.3.5.3	Box unit saunas			X	X	X	X	X	Box unit saunas
1.3.5.4	Box units for services systems			X	X	X	X	X	Box units for building service systems

1.3.5.5	Flue and duct components			X	X	X	X	X	Flue and duct components
1.3.5.6	Other box units								
2	Services elements								
2.1	Plumbing elements								
2.1.1	Heating systems								
2.1.1.1	Central units: boiler installations, burner systems, flues, geothermal and aerothermal heat pumps, solar thermal equipment								Central units: boiler installations,…...
2.1.1.2	Transmission components: exchange systems, heat transfer fluids, air ducts								Transmission components….
2.1.1.3	Terminal parts: radiators, radiant heaters, underfloor heating pipes, supply air heaters								Terminal parts: radiators, …..
2.1.1.4	Local area parts: networks, thermal power stations, pipes, fuel stores, equipment for solar, heat pump, and combined heating systems, heat storage equipment, pipework								Local area parts: networks, ….
2.1.2	Water and Drainage systems								
2.1.2.2	Transmission components: tanks and storage appliances								Transmission components….
2.1.2.3	Terminal parts: mixers, taps, lavatory pans, urinals, baths, shower trays, and cabins								Terminal parts: mixers, taps, ….
2.1.2.4	Local area parts, building pipework, site conduits, sewers, inspection chambers, runoff gullies, storm drains		S						Local area parts, building pipework, site conduits, ….
2.1.3	Air conditioning systems								
2.1.3.1	Central units: appliances and their parts, air extractors, air recirculation systems, supply ventilation systems, waste air purification equipment								Central units: appliances and their parts, air extractors, ….
2.1.3.2	Transmission components: pipes and ducts								Transmission components: pipes and ducts
2.1.3.3	Terminal parts: exhaust air windows								Terminal parts: exhaust air windows
2.1.3.4	Local area parts: external and waste air gaps and ducts, heat recovery systems, filter units, outdoor air, and exhaust equipment								Local area parts: external and waste air gaps and ducts, ….
2.1.4	Cooling systems								
2.1.4.1	Central units: appliances, equipment, pumps, steam generators, heat exchange units, condensers, tanks								Central units: appliances, equipment, pumps, ….
2.1.4.2	Transmission components: pipes								Transmission components: pipes
2.1.4.3	Terminal parts radiators, air-conditioners, chilled beams								Terminal parts radiators, air-

									conditioners, chilled beams
2.1.4.4	Local area parts: network, central units, pipework								Local area parts: network, central units, pipework
2.1.5	Fire-fighting systems								
2.1.5.2	Transmission components: Conduits, sprinkler pipes								Transmission components: Conduits, sprinkler pipes
2.1.5.4	Fire prevention area components								
2.1.6	Civil defence shelter HVAC system								
2.1.6.1	Civil defence shelter HVAC system central components								
2.1.6.2	Civil defence shelter HVAC system transfer components								
2.1.6.3	Civil defence shelter HVAC system terminal units		S						
2.1.6.4	Civil defence shelter HVAC system area components		S						
2.2	Air conditioning elements								
2.3	Electrical elements								
2.4	Data transfer elements								
2.5	Mechanical elements								
2.5.1	Transportation equipment								
2.5.1.1	Lifts								Lifts
2.5.1.2	Escalators and conveyors								
2.5.1.3	Other transportation equipment's								
S2	Electricity systems and their corresponding S2010 nomenclature								
S2.1	Production and connection								
S2.1.2	Electricity generation systems and equipment								Electricity generation systems and equipment
S2.2	Main distribution								
S2.2.1	Medium voltage power distribution system								Medium voltage power distribution system
S2.2.2	Main distribution system								Main distribution system
S2.3	Electrification								
S2.3.1	Electrification of a property's equipment and appliances								Electrification of a property's equipment and appliances
S2.3.1	Electrification of heating, ventilation, and air conditioning equipment and appliances								Electrification of heating, ….
S2.3.1	Electrification of a user's equipment and appliances								Electrification of a user's equipment and appliances
S2.5	Lighting systems								
S2.5.1	Internal lighting								Internal lighting
S2.5.2	External lighting								External lighting
S2.5.3	Local area lighting system								Local area lighting system

S2.6	Electrical heating systems								
S2.6.1	Building’s electrical heating system								Building’s electrical heating system
S2.6.2	Underfloor heating								Underfloor heating
9	Areas and volumes								
9.1	Program areas								
9.1.1	Program area of building elements								
9.1.1.1	Program area of the site								
9.1.1.2	Program area of the building								
9.1.1.3	Program area of the rooms and spaces								
9.1.2	Program area of technical elements								
9.2	Site areas								
9.2.1	Area of the plot								
9.2.2	Area of the block								
9.2.3	Area of building								
9.2.4	Area of the traffic areas								
9.2.9	Other areas								
9.3	Total areas of the building								
9.3.1	Gross area								
9.3.2	Total floor area								
9.3.3	Area of apartments and departments								
9.3.4	Space group areas								
9.3.5	Net areas of rooms								
9.3.5.1	Areas of room sections that are lower than 1600 mm								
9.3.6.1	Areas of the load-bearing structures								
9.3.6.2	Areas of the non-bearing structures								
9.4	Departments								
9.4.1.1	Areas of the fi re departments								
9.5	Volumes								
9.5.1	Volume of the buildings								

Table 6: Structural comparison between COBIM 2012 and the Finnish Ministry of Environment Method of the whole life carbon assessment of buildings 2019.

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