Metropolia
University of Applied Sciences

Hochschule für Technik
und Wirtschaft Berlin
University of Applied Sciences

Life Cycle Assessment of a Low Energy/Carbon Building Using BIM Tools

Master Thesis

Construction and Real Estate Management

Faculty of Engineering

from

Homa Javadi

Date:

Berlin, 18.07.2021

1st Supervisor: Sergio Rossi

2nd Supervisor: Dieter Bunte

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Homa Javadi

Berlin, July 2021

To my beloved parents

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International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia Helsinki and HTW Berlin

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Energy analysis of a nearly zero-energy building (ZEB) using BIM tools

(2) Examination Commission

Chairperson	Prof. Dr. Dieter Bunte
1. Supervisor	Lecturer Mr. Sergio Rossi
2. Supervisor	Prof. Dr. Dieter Bunte

(3) Thesis Period

Date of Issue	01. 07.2020
Closing Date Deadline	02.07.2021

Berlin, 29. JUNI 2020
Signature of the Chairperson of the Examination Board

2. Issue of the Topic of the Master Thesis

Date of Issue 29. JUNI 2020 issued by

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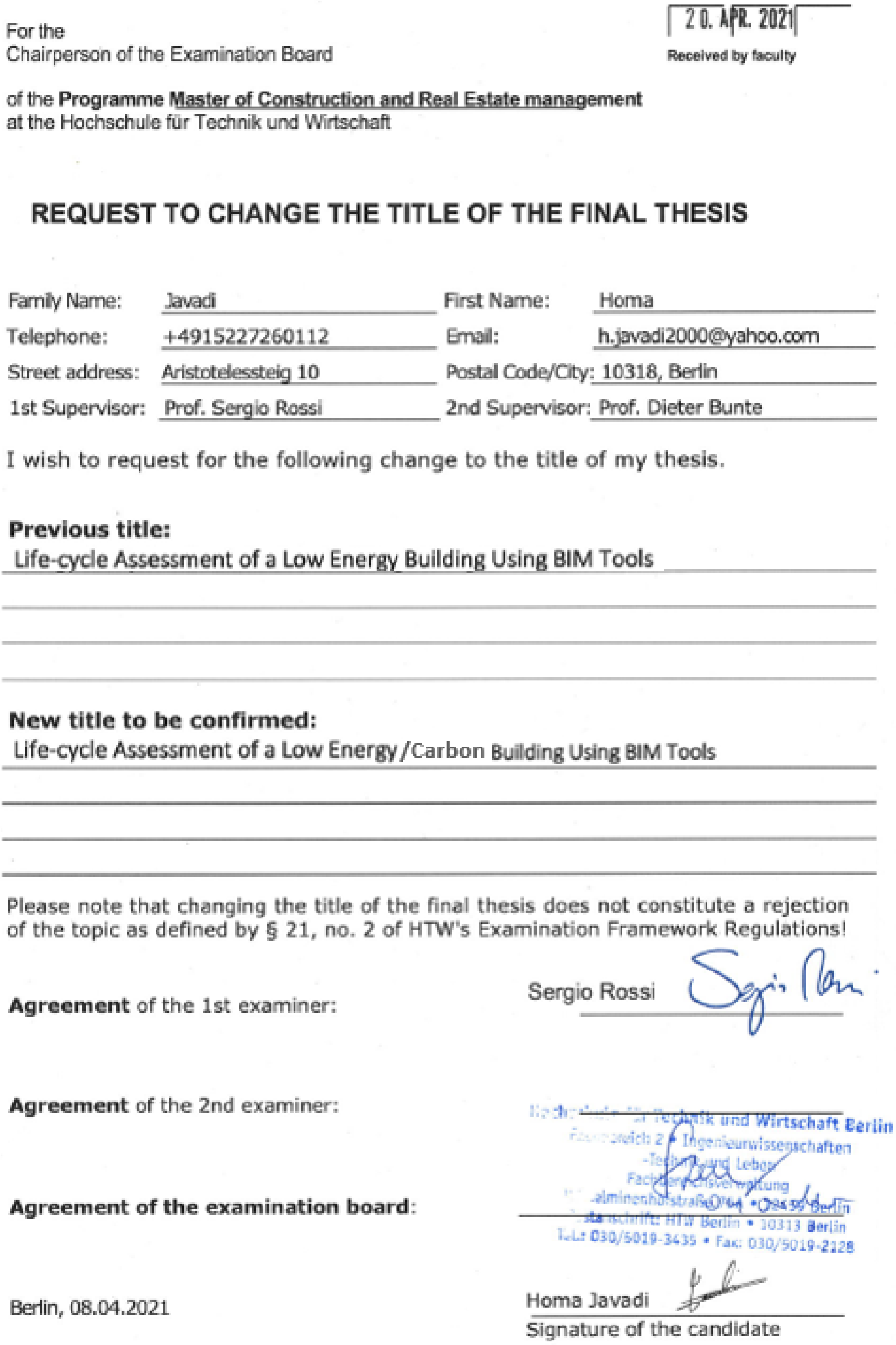

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REQUEST TO CHANGE THE TITLE OF THE FINAL THESIS

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I wish to request for the following change to the title of my thesis.

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Life-cycle Assessment of a Low Energy Building Using BIM Tools

New title to be confirmed:
Life-cycle Assessment of a Low Energy/Carbon Building Using BIM Tools

Please note that changing the title of the final thesis does not constitute a rejection of the topic as defined by § 21, no. 2 of HTW's Examination Framework Regulations!

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International Master of Science in Construction and Real Estate Management
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Conceptual Formulation

Master Thesis for Ms Homa Javadi

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Life Cycle Assessment of a Low Energy/Carbon Building Using BIM Tools

Background

For more than 200 years, industrial civilization has ruled over cities and exerted negative impacts like global warming, climate changes, environmental pollutions, CO2 emissions, suburb spread and degradation of the ecological system. Overlooking required actions to improve the ecological processes and continuing using fossil fuels, unsustainable human activities will eventuate in enormous climate change and energy challenges (Mostafavi, 2010). Based on the definition of sustainable development, natural resources are not only the basic asset of today's generation but also belong to the future generation (Alessandria, 2016).

The construction industry consumes approximately half of the world yearly energy supply and accounts for roughly 40% of greenhouse gas (GHG) emissions. A building consumes energy in the form of embodied and operational energy throughout its life cycle. (Venkatraj and Dixit, 2021). This energy is mainly produced by fossil fuels (Gu, 2007). Environmental impact and the amount of CO2 emissions of a building can be assessed by Life Cycle Assessment (LCA). LCA is an analytical process that considers and interprets a product's or service's possible environmental implications over the course of its life cycle. This technique provides for the analysis of the stages (Extraction and Production, Use, and End-of-life) from the cradle to the grave, as well as the most significant connected consequences (Sierra et al., 2020).

Research Objectives

The general goal of this research is to analyze the Life Cycle Assessment (LCA) of a sample low energy/carbon building by using BIM applications. Being more specific, the following objectives are set:

O_1: To establish a procedural guideline to help practitioners in reducing buildings' environmental effects by introducing the concept of low energy/carbon building.

O_2: To analyze the LCA and CO2 emission of the sample low energy/carbon building (case study) via BIM tools and compare it with a conventional building.

O_3: To check the compatibility of theoretical studies with the practical experiment (evaluating the case study).

Research Questions

Based on the thesis objectives, the questions that arose are:
Q_1: Which design strategies and materials should be adopted to decrease energy demand and consequently CO2 emission and negative impacts of buildings on the environment?
Q_2: How to analyze a building 's LCA and carbon emissions in the use phase?
Q_3: What is the role of BIM tools in LCA?
Q_4: What are the benefits of LCA of a low energy/carbon building?

Research Methods

The research methodology is a mixed-method including qualitative and quantitative methods. The qualitative research method explores the ideas about low energy/carbon buildings and energy efficiency methods through a comprehensive literature review and study of earlier research. The specified goals at this phase are to figure out techniques of maximizing energy efficiency and minimizing carbon emission to have a better LC.

The quantitative research method focuses on the evaluation of the collected data from the theoretical part of the thesis by analyzing LCA of a sample low energy/carbon building and a conventional building. The applicability of research objectives and research questions will be evaluated in this stage. Therefore, the specified goals at this phase are to assess the building's LCA through the integration of Building Information Modelling (BIM), and to discuss the result of the evaluation from environmental views. Finally, research contributions and benefits will be presented.

Resources

Library website of the Metropolia University: https://metropolia.finna.fi/
Google Scholar: https://scholar.google.com/schhp?hl=en&as_sdt=0,5
Web of Science: https://login.webofknowledge.com/
Elsevier Website: https://www.elsevier.com/
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Abstract

For more than 200 years, industrial civilisation has dominated over cities and caused devastating environmental impacts, including climate change, environmental pollutions, CO2 and greenhouse gas emissions (GHG), global warming, and many more. The construction industry accounts for almost half of CO_2 and GHG emissions worldwide. Life cycle assessment (LCA) as a solution is an evaluation technique assessing a building's environmental impact and carbon emission from raw material extraction to disposal phase. A building’s potential environmental implications, energy demand, and carbon emissions are tracked and monitored by LCA from the early design phase to the end of the building’s service life. Accordingly, this thesis is aimed to minimize adverse impacts of residential buildings on the environment by introducing the concept of a low energy/carbon building, figure outing the factors affecting the quality of the building’s life cycle, and analyzing the LCA of the building via integrating the BIM tools. Therefore, seminal literature discussed LCA, energy and carbon relevant parameters in a residential building to reach this goal.

Furthermore, a chapter was devoted to BIM to emphasise the importance of the latest technology in easement and accuracy of data transfer for evaluating the LCA of a building. As the thesis case study, a sample residential model in Revit software located in Finland, Helsinki, is selected. The case study is treated from two different scenarios for LCA; the first scenario assumes the model as a low energy/carbon building (stud-frame), and the second scenario considers the case study as a Conventional building (concrete frame). The research methodology consists of qualitative and quantitative approaches. Data collection is carried out via seminal literature review, BIM tools, Revit and One Click LCA software. Data evaluation of LCA for two scenarios is done by One Click LCA platform, and comparison was carried out to differentiate the result of LCA between the two scenarios. Consequently, the summary of findings is presented as outcomes of the investigation. Last but not least, the conclusion summarizes the thesis and its scientific results, and for improvement of the research for further studies, some recommendations are proposed.

Keywords: Life Cycle Assessment (LCA), Low energy/carbon building, BIM, Revit, One Click LCA

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List of Abbreviations

AP	Acidification Potential
BIM	Building Information Technology
BPA	Building Performance Analysis
BREEAM	Building Research Establishment Environmental Assessment Method
CCS	Carbon Capture and Storage
CFC	Concrete Framework Construction
DHW	Domestic Hot Water
EIO-LCA	Economic Input-Output Life Cycle Assessment
EP	Eutrophication Potential
EPD	Environmental Product Declaration
GDP	Gross Domestic Product
GHG	Green House Gas
GWI	Global Warming Impacts
GWP	Global Warming Potential
HVAC	Heating Ventilation and Air Conditioning
LC	Life Cyle
LCA	Life Cycle Assessment
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
MJ	Megajoule
ODP	Ozone Depletion Potential
PCM	Phase Change Materials
P-LCA	Process-based Life Cycle Assessment
SFC	Steel Framework Construction
WFC	Wood Framework Construction

Chapter 1

1. INTRODUCTION

1.1 Background of the study

For more than 200 years, industrial civilization has ruled over cities and exerted negative impacts like global warming, climate changes, environmental pollutions, CO_2 emissions, suburb spread and degradation of the ecological system. By overlooking required actions to improve the ecological processes and continue using fossil fuels, unsustainable human activities will result in enormous climate change and energy challenges (Mostafavi, 2010). Based on the definition of sustainable development, natural resources are the essential asset of today's generation and belong to the future generation (Alessandria, 2016).

The construction industry consumes approximately half of the world yearly energy supply and accounts for roughly 40% of greenhouse gas (GHG) emissions. A building consumes energy in the form of embodied and operational energy throughout its life cycle. (Venkatraj and Dixit, 2021). This energy is mainly produced by fossil fuels (Gu, 2007). Environmental impact and the amount of CO_2 emissions of a building can be assessed by Life Cycle Assessment (LCA). LCA is an analytical process that considers and interprets a product's or service's possible environmental implications throughout its life cycle. This technique provides for the analysis of the stages (Extraction and Production, Use, and End-of-life) from the cradle to the grave and the most significant connected consequences (Sierra et al., 2020).

1.2 Statement of the Problem

Residential buildings have a considerable share of energy usage and, consequently, CO_2 emissions. Simultaneously, natural resources are vulnerable to destruction and deterioration, raising questions over their long-term use and maintenance worldwide. The fact that energy resources will end one day and the consequences of the destruction of the natural environment will impact human life. Although perceptions of sustainability in design and construction are different, it is mutually agreed that architecture plays a key role in preserving natural resources to continue for the future generation. Likewise, using renewable energy resources serves sustainability goals and creates clean energy, reducing CO_2 emissions. At the same time, modern construction techniques prevent environmental pollution by applying low energy/carbon materials.

Therefore, due to the limited fossil resources and the destructive effects on the environment, designing and constructing buildings with minimal energy consumption and carbon emissions and independent of fossil fuels is an essential matter.

1.3 Thesis Objectives

The purpose of this research is to decrease the adverse impacts of residential buildings on the environment. This goal will be achieved by introducing a low energy/carbon building concept and getting acquainted with the design principles with minimum energy consumption and fewer carbon emissions through a systematic review of the relevant literature. Therefore, designers and construction engineers will be aware of the strategies used in existing projects from the very beginning of the design phase to the end. The sample case study in this research is assessed by computer simulation programs Revit software and BIM tools. Calculations and results will show that a significant percentage of the energy required by the building can be provided by renewable sources and how the building can efficiently consume lower energy, creating lower CO2 emissions and consequently having a better life cycle.

The general goal of this research is to analyse the Life Cycle Assessment (LCA) of a sample low energy/carbon building by using BIM applications. More specifically, the following objectives are set:

O_1: To establish a procedural guideline to help practitioners reduce buildings' environmental effects by introducing the concept of low energy/carbon building.

O_2: To analyze the LCA and CO_2 emission of the sample low energy/carbon building (case study) via BIM tools and compare it with a conventional building.

O_3: To check the compatibility of theoretical studies with the practical experiment (evaluating the case study).

1.4 Research Questions

Based on the thesis objectives, the questions that arose are:

Q1: Which design strategies and materials should be adopted to decrease energy demand and consequently CO_2 emission and negative impacts of buildings on the environment?

Q2: How to analyze buildings‘ LCA and carbon emissions in the use phase?

Q3: What is the role of BIM tools in LCA?

Q4: What are the benefits of LCA of a low energy/carbon building?

1.5 Limitations of the thesis

- Regarding Life Cycle Assessment, the traditional LCA methodology lacks a temporal component and has been identified as a significant flaw. Dynamic LCA is a form of LCA that integrates elements of temporal modifications that influence the effects and analysis of the evaluated scheme. It has only been around for a decade. The term "dynamics" refers to how a system evolves as a result of different forces. To measure the GWIs of buildings over time, some researchers have used a complex LCA approach. These studies took into account various dynamic variables, including environmental, cultural, technological, and social variables (shu et al., 2021). However, this research evaluates the LCA from the *environmental impact* of the building.
- User behaviour has a significant effect on the energy consumption and consequently carbon emission of the building. Therefore, the *users' behaviour* in this study can be mentioned as a research limitation.
- Economic aspects of implementing a low energy/carbon building compared to a Conventional building is another research limitation. This study is not considering the financial and cost of construction of a low energy/carbon building.

1.6 Significance of the thesis

This study will help to understand the concept of a low energy/carbon building in the design stage by investigating through a systematic literature review. The study will represent the theoretical overview of a low energy/carbon building and make a building energy efficient that consumes less energy and consequently produces less CO_2. With the aid of BIM tools, the building's Life Cycle and CO_2 emissions will be assessed and monitored. Therefore, a low energy/carbon building sample will be analyzed by BIM software and gets a low energy/carbon building certificate, meaning less negative environmental impacts. Hence, the results fill the gap between the theory and implementation of technology in building construction.

Aside from decreasing devastating environmental effects, executing LCA has many business advantages. It can be used to assess the environmental effects of prospective construction sites, enter property sales events, tournaments, refurbishments, or community planning, do a LCA of an infrastructure project, or earn points in green building certification systems for Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM).

1.7 Thesis methodology

The research methodology is a mixed-method including qualitative and quantitative methods. The qualitative research method explores low energy/carbon buildings and energy efficiency methods through a comprehensive literature review and study of earlier research. The specified goals at this phase are to figure out techniques of maximizing energy efficiency and minimizing carbon emission to have a better LC.

The quantitative research method focuses on evaluating the collected data from the theoretical part of the thesis by analyzing the LCA of a sample low energy/carbon building and a conventional building. The applicability of research objectives and research questions will be evaluated in this stage. Therefore, the specified goals at this phase are to assess the building's LCA by integrating Building Information Modelling (BIM) and discussing the result of the evaluation from environmental views. Finally, research contributions and benefits will be presented (Fig. 1).

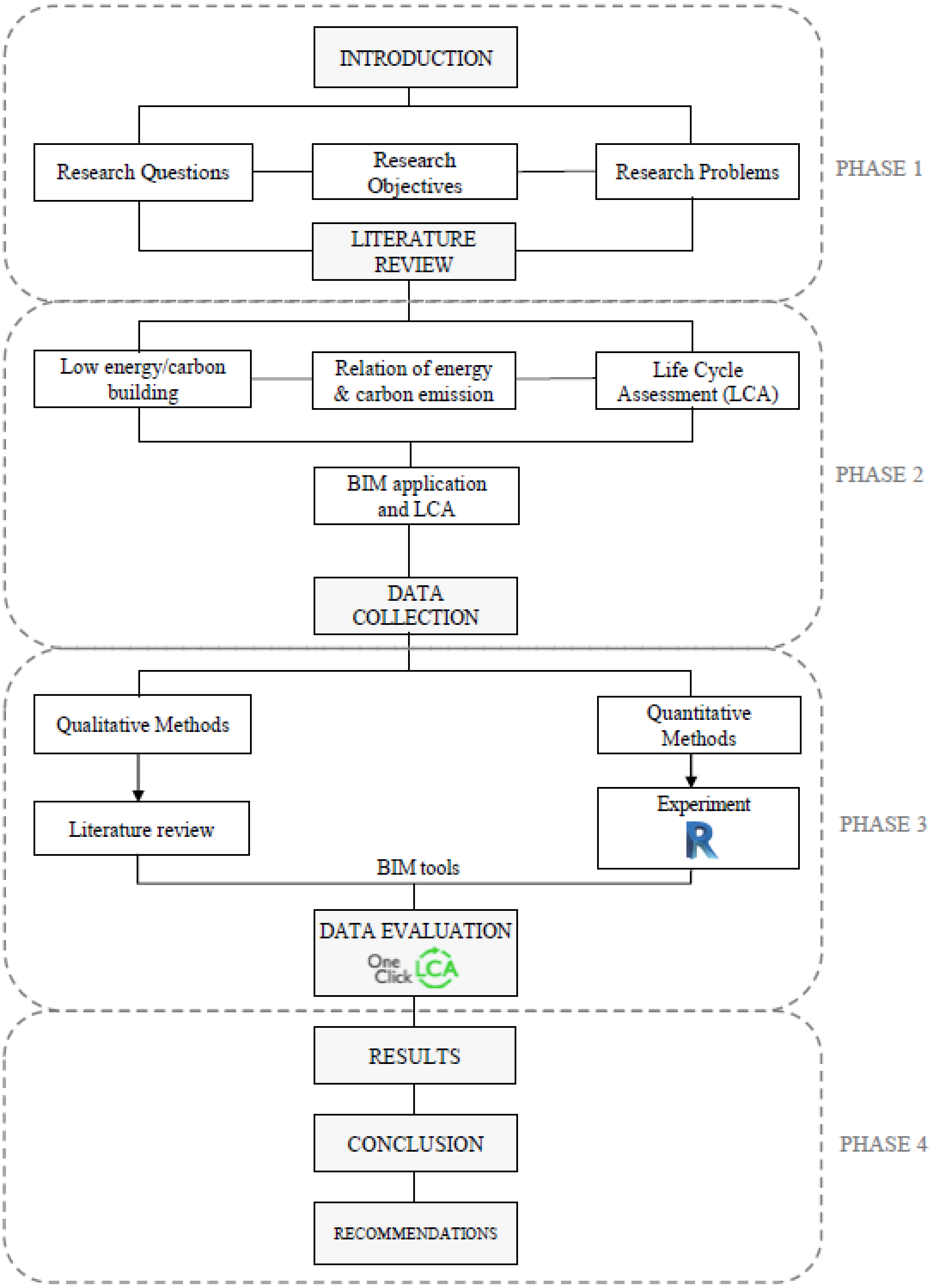


Figure 1. Thesis Methodology by author.

1.8 Thesis Structure

This thesis is organized into five chapters. The first chapter described the thesis background, problem, objectives, questions, limitations, and the significance of the thesis and methodology. Chapter two explains information about the concept of Life Cycle Assessment (LCA), construction law of low energy/carbon buildings in Finland, and the relation of energy and carbon in LCA in the base of theoretical literature. Then, the importance of Building Information Technology (BIM) and its application in the construction industry and Life Cycle Assessment (LCA) will be highlighted in chapter three. Chapter 4 explains research methodology and data collection methods. Moreover, chapter four evaluates the LCA of a sample model in two different scenarios. Chapter five, conclusion, underlines accentuates on findings, the contribution of the thesis, and further recommendations (Fig. 2).

Chapter One: Introduction

- Thesis Background
- Thesis Problem
- Thesis objectives and questions
- Thesis limitations and significance
- Thesis Methodology

Chapter Two: LCA & Concept of low energy/carbon building

- Life Cycle Assessment (LCA)
- Energy & CO_2 concerns
- Energy efficient buildings and energy relevant parameters
- Building technology

Chapter Three: Concept of Building Information Technology (BIM)

- BIM definition
- Relation between BIM and construction industry
- BIM application in LCA
- Introducing BIM software

Chapter Four: Case Study; Evaluation of a low energy building via BIM tools

- Porpuse of case study
- Reserach Methodology
- LCA of the case study via BIM tools
- Findings

Chapter Five: Conclusion

- Conclusion
- Recommendations and furthur study

Figure 2. Thesis structure by author.

2. LCA AND LOW ENERGY/CARBON BUILDINGS

2.1 Buildings' Life Cycle; An Idea

Buildings may be subjected to a whole-life cycle assessment, which can be used for new construction and renovation projects. The evaluation will be carried out in tandem with estimations of the building's energy efficiency. The technique isn't particularly well adapted to assessing infrastructure projects (Kuittinen, 2019).

Manufactured products, including buildings, structures, and infrastructure, have the longest lifespans. Since the transition from nomadic to settled communities, they have characterized human society. The evolution of human civilisation can be seen in buildings from former eras that have survived offer an archive of economic, physical, and cultural capital. Every structure must have the ability to withstand the elements. This topic is addressed in almost every building theory. In the first century BC, Vitruvius established three crucial features of buildings: "utilitas" (utility), "venustas" (beauty), and "firmitas" (firmness). Buildings, especially prominent buildings, are generally created across multiple generations. Buildings were constantly maintained and remodelled, and the rare materials from ancient buildings were recycled and reused when new ones were built. As a result, there was no awareness in this setting of a building's life cycle in the meaning of an end. Buildings, which have a long lifespan, will go through ongoing changes (usage, refurbishment, conversion) and are designed, constructed, and used by a large number of people. In theory, there are four stages to a life cycle; material production, building construction, usage/renewal, and demolition and disposal. Each phase of a building’s life cycle is made up of several separate process stages (Birgisdottir and Rasmussen, 2016):

- Strategy
- Project managemetn planning
- Implementation

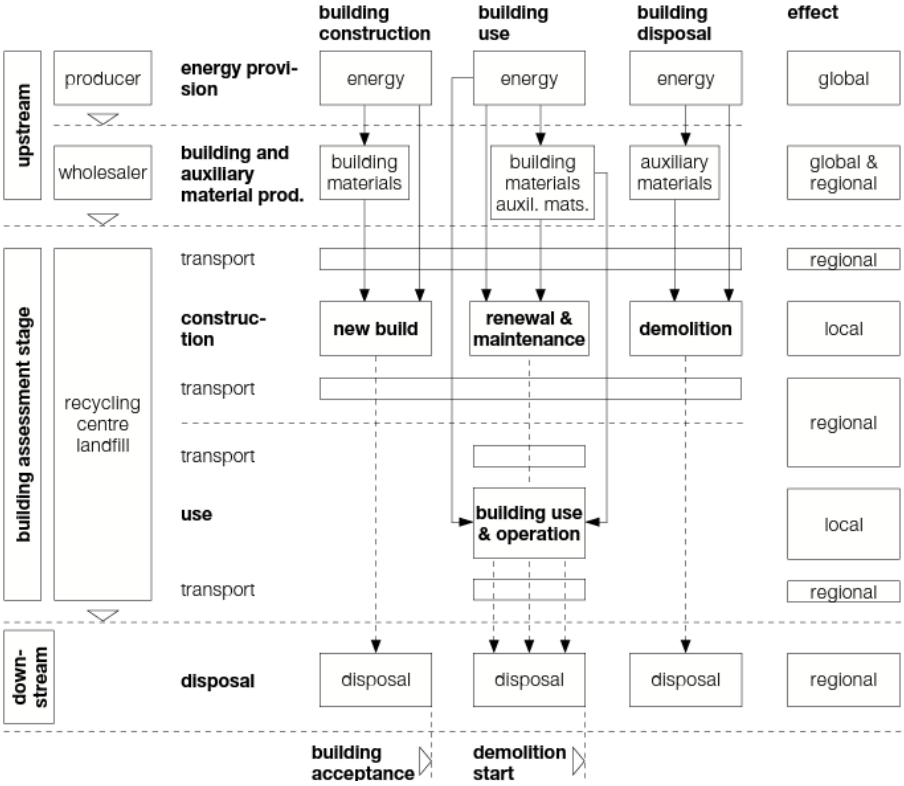


Figure 3. The life-cycle phase is based on the time and usage phase's cycles (Birgisdottir and Rasmussen, 2016, p.12).

Each phase generates energy flows and material due to resource extraction from the environment, generation and supply of energy, transportation, assembly on-site, removal, and consumption (Fig. 4). There are also information and financial flows in addition to the energy and material flows (Birgisdottir and Rasmussen, 2016).

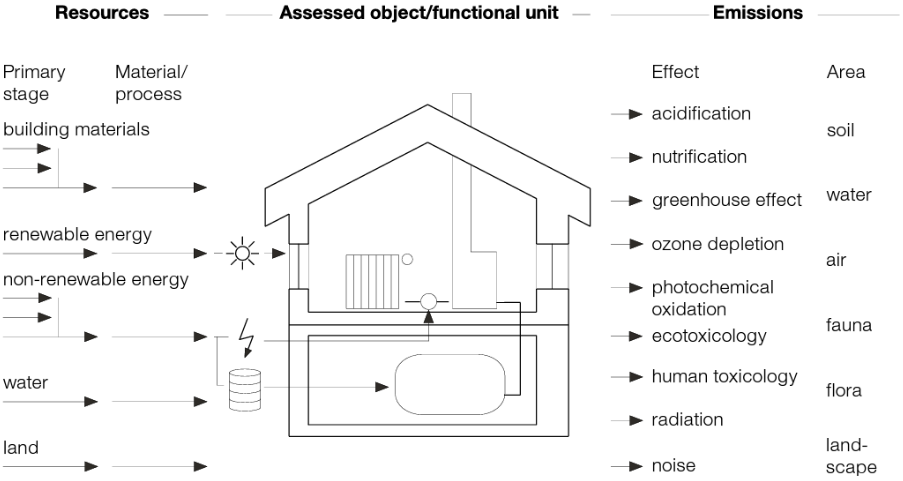


Figure 4. Energy flow and material of a building during its life cycle (Birgisdottir and Rasmussen, 2016, p.12).

2.2 Life Cycle Assessment

In 2017, a roadmap to low-carbon construction was published by the Finnish Ministry of Environment. According to the Finnish Ministry of Environment, the LCA of buildings will be monitored and need to be included in building’s permits by 2025. The technique is based on the Level method of the European Commission and European Standards and requires environmental expertise in creating a reliable platform and database that covers the development of new legislation and policies (Kuittinen, 2019).

Life Cycle Assessment (LCA) is a scientific technique for calculating the environmental effects of a product, facility, or operation, including its carbon footprint. It is possible to quantify a building's LCA and determine how it can impact the environment during its life cycle (Sierra et al., 2020). According to a comprehensive LCA of this building, the function and importance of all Life Cycle phases and subsystems must be carefully considered when discussing energy-saving and sustainability outputs of low energy/carbon buildings. Furthermore, the implementation of a life cycle strategy is more important the lower the activation energy. A comprehensive LCA includes a Life Cycle perspective that takes the following stages into account (Vilcekova et al., 2013):

- Material production's impact
    - Supply of raw materials
    - Transportation
    - Products manufacturing
    - From cradle to gate, including all the processes
- Building construction process
    - Transporting to the site of the building
    - Construction and installation of the building
- Use phase
    - Energy losses
    - Maintenace
    - Repair and replacement

  - Refurbishment
- End-of-life
  - Demolition and disposal
  - Recycling
  - Transport

Embodied energy contributed to a significant portion of all energy consumption in low energy/carbon homes, accounting for 40% of overall energy usage over a 50-year lifespan. Recycling will recover approximately 37–42% of the embodied energy (Vilcekova et al., 2013). Figure 5 represents the stages of a building’s life cycle from stage A1 to C and the related correspondent modules according to European standard EN 15978:201 (Kuittinen, 2019).

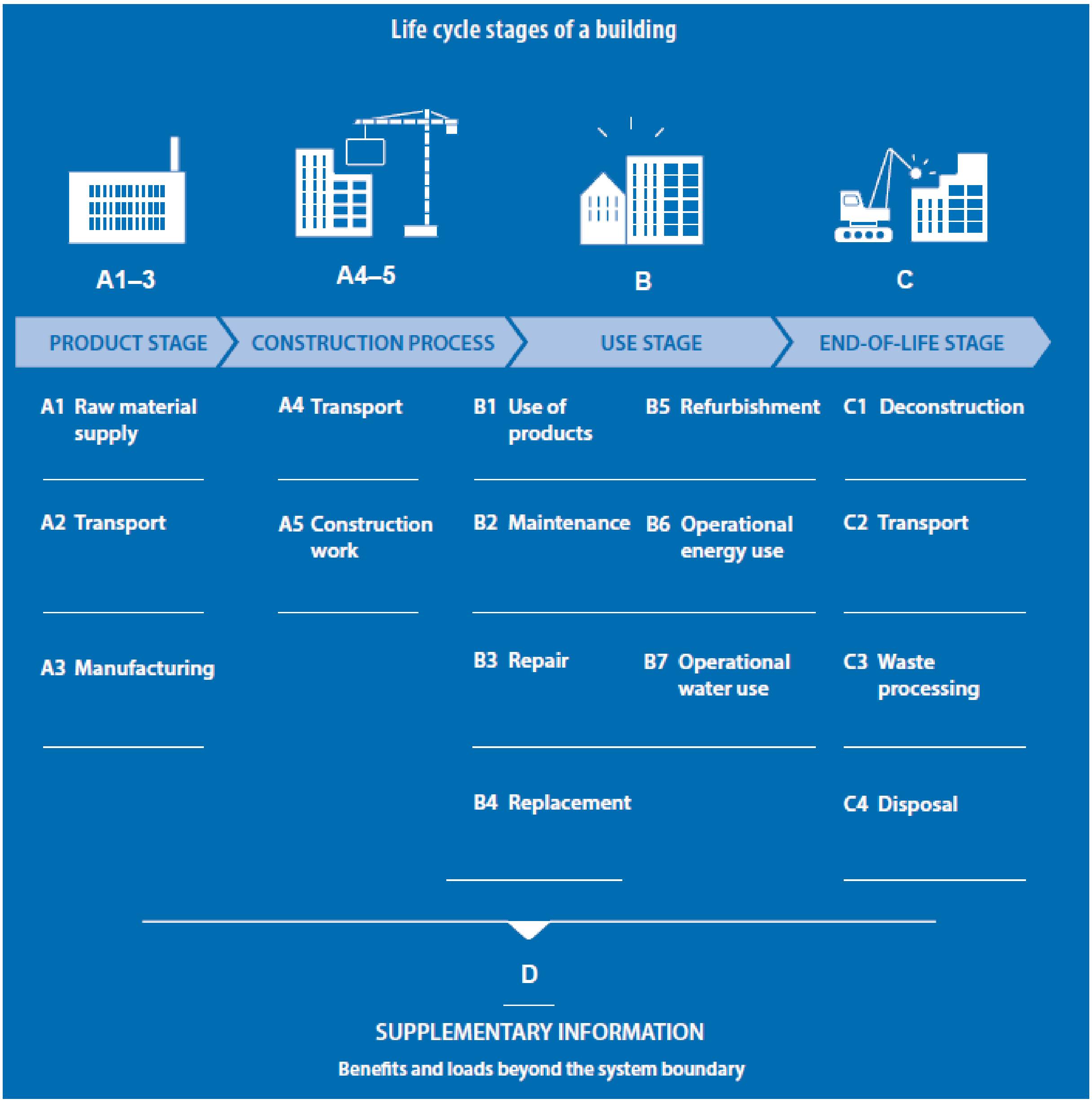


Figure 5. A building's life cycle stages (Kuittinen, 2019, p. 16).

There is a question in theoretical sciences: Does a building’s carbon footprint be considered the building’s life cycle assessment? The answer is No! Life cycle assessment of a building is more comprehensive than information about carbon footprint. Carbon footprint analyses how much CO_2 is released from a specific process to the atmosphere. Nonetheless, a life cycle assessment not only includes this but also contains other impact categories. These categories include (Bionova, 2021b):

- **Global warming potential (GWP)**

GWP describes increased concentrations of the atmosphere’s GHG induce changes in regional, local, or global temperatures at the surface. Emission of GHG has been linked to two other effect categories, smog and acidification, named "carbon footprint."

- **Acidification potential (AP)**

AP defines the acidifying impact of environmental contaminants. Carbon dioxide, for example, dissolves quickly in water, increasing acidity and contributing to global occurrences like ocean acidification.

- **Eutrophication potential (EP)**

EP characterizes the impact of mineral nutrients on water or soil. It enables certain species to destroy the ecosystem and put other species’ existence at risk, occasionally resulting in population die-offs.

- **Ozone depletion potential (ODP)**

ODP represents the impacts of atmosphere’ substances that degrade the layer of ozone. ODP is the prevention and absorption of harmful UV radiation to reach the surface of the Earth.

- **Ozone formation of the lower atmosphere**

This factor distinguishes the impacts of atmosphere’ substances in producing photochemical smog, named summer smog.

As mentioned, Global Warming Impacts (GWIs) can be assessed through the LCA method. Traditional assessment studies, on the other hand, usually a static metric is used, and possible temporal variations throughout a building's long lifespan are not considered, as seen below (Shu et al., 2021):

- In a traditional LCA, the elementary flows from multiple unit processes are generally added to produce a single aggregate value.

- The global warming potential (GWP) has been widely used in LCA studies. This indicator is seen in a sliding time window that spans many decades of pollution. As a result, the measurement date selected and the period covered by appraisal results can differ.

- The GWI's importance varies with time and is influenced by a variety of external factors. In most standard LCA studies, however, this temporal difference is ignored.

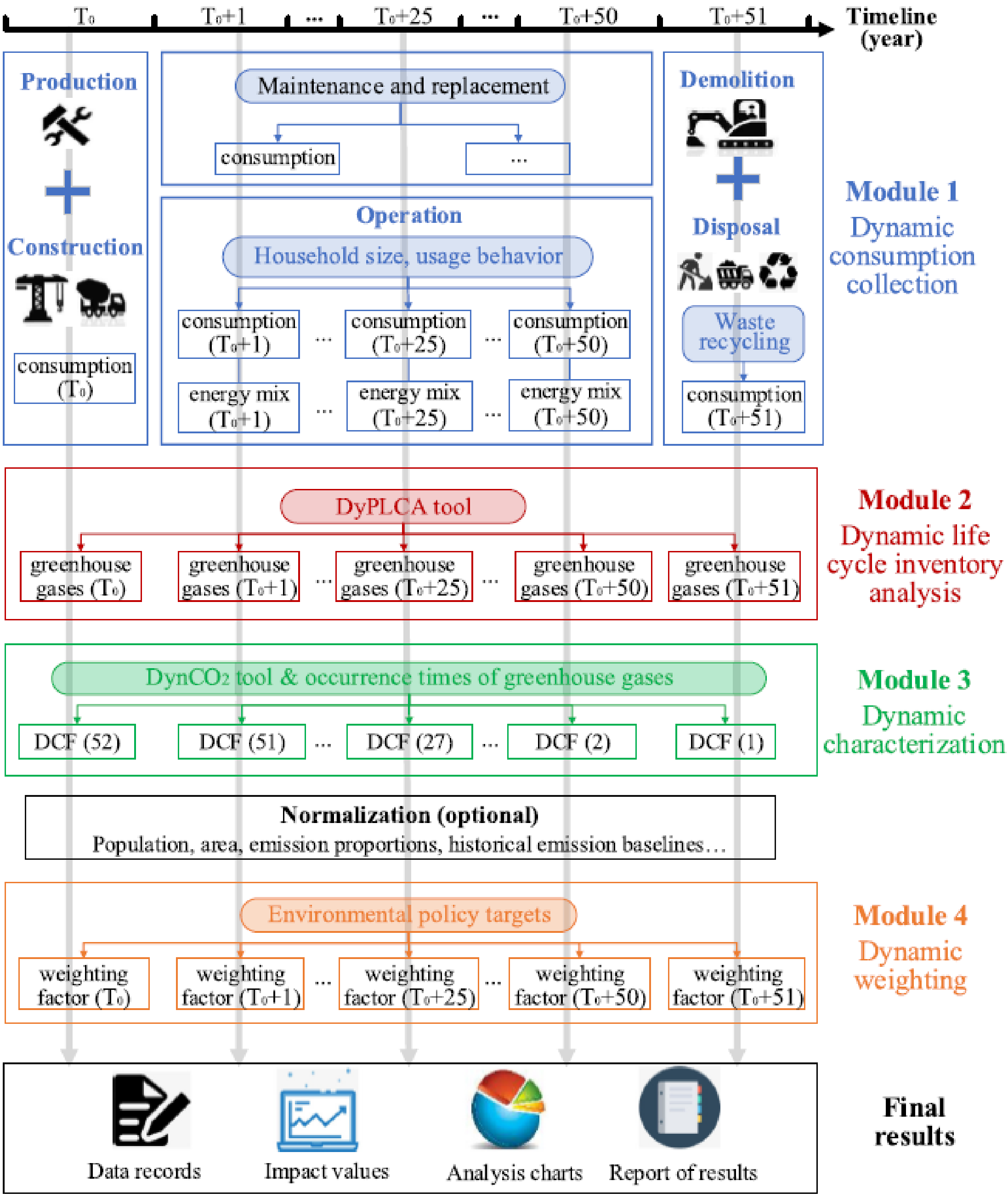


Figure 6. DGWI assessment model based on various dynamic variables in LCA (Shu et al., 2021, p. 3).

Statistical materials, on-site measurement, modelling techniques, questionnaire surveys, and other approaches are often used in traditional LCA studies to gather static consumption data. Five dynamic variables and their results were considered in this study to generate complex consumption results using static methods and data. The complex variables and their impacts on consumption in each life cycle period are summarized in Figure 7 (Shu et al., 2021).

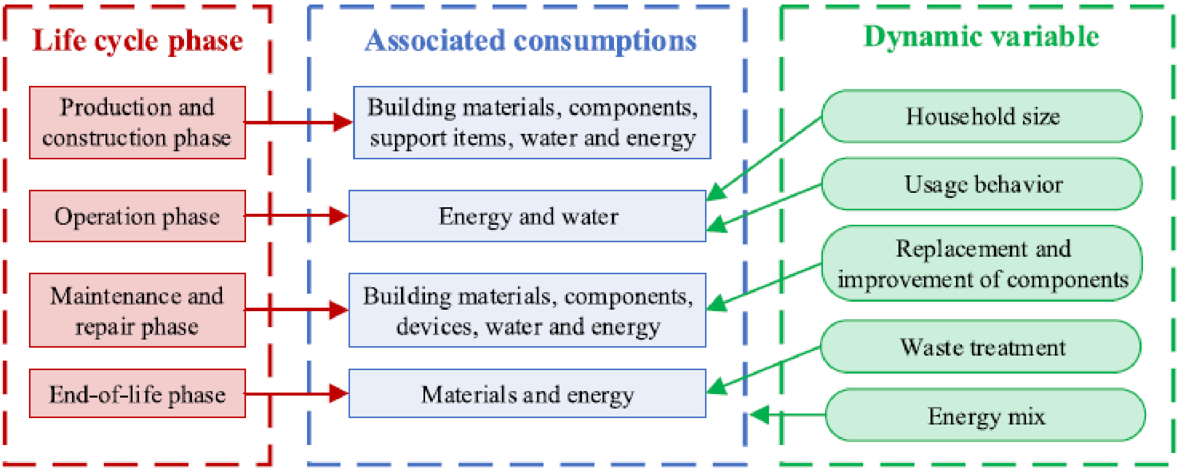


Figure 7. Life cycle consumption according to dynamic variables (Shu et al., 2021, p. 4).

Aside from lowering environmental effects, executing a building LCA has many business advantages. It can be used to assess the environmental effects of prospective construction sites, enter property sales events, tournaments, refurbishments, or community planning, do a Life Cycle Assessment of an infrastructure project, or earn points in green building certification systems for LEED and BREEAM.

Use Stage life cycle and emissions vs whole life cycle and emissions

The usage of fossil fuels in the energy generation process has an enormous impact on the building life cycle GWP. Because of the emissions from energy production, the energy spent in the usage stage of a structure and the energy used in material manufacturing are typically the significant sources of GHG emissions during a building's life cycle (Oy, 2017). The application of renewable energy systems in energy production and building energy efficiency is projected to rise as a result of international environmental accords. The use of renewable energy and a reduction in home energy usage is rising trends in the EU, according to the European Environment Agency EEA (Toroskainen, 2019). Building operational emissions is becoming less important over the life cycle due to a lowering trend in energy production emissions and an improvement in building energy efficiency. When the emissions arising from energy generation decrease, the percentage of embodied emissions increases (Oy, 2017).

2.4. Role of Carbon Footprint in Buildings' Life Cycle

According to research, employing timber construction instead of concrete saves a lot in terms of carbon emissions (68 %) and embodied energy (43%). Many research are done on the building's carbon emissions. There are stages in which carbon emissions are highly considered; as following (Luo and Lu, 2020):

- **Manufacturing stage of building materials**

In this phase, studies were carried on various construction materials. For instance, Buchanan and Levine (1999) research examined the CO_2 emission of wood as one of the construction materials. The research represented that wooden buildings and structures require lower CO_2 emissions and process energy. This sturdy wood has been compared to other construction materials like aluminium, brick, concrete, and steel. Kunic (2017), in another study, analyzed thermal insulation of various materials through a quantitative comparison. The result proved that artificial materials reduce carbon footprints desirably in a long turn.

- **Building carbon emissions calculation techniques**

Luo (2016) proposed the Chinese process-LCA approach, which assessed 44 elements impacting a building's carbon footprint from the perspectives of planning and design and mechanical and electrical systems. By incorporating actual energy usage data into the most recent IO accounting, Dixit and Singh (2018) created a methodology for the calcualtion of IO-based hybrid-based embodied energy calculation. Zhang and Wang (2016) presented a hybrid method that incorporates both process-based life cycle assessment (P-LCA) and economic input-output life cycle assessment (EIO-LCA) benefits.

- **Carbon emissions from various types of structures**

According to Yu et al. (2011), buildings with a bambo structure use less energy and produces less carbon dioxide to satisfy the exact practical requirements as a standard brick–concrete building. In a study done by Gong et al. (2012), the energy consumption of concrete framework construction (CFC) is nearly identical to that of steel framework construction (SFC) during the life cycle, and both are around 30% greater than that of wood framework structure (WFC).

- **The estimate of a building's carbon emissions at various phases of its life cycle**

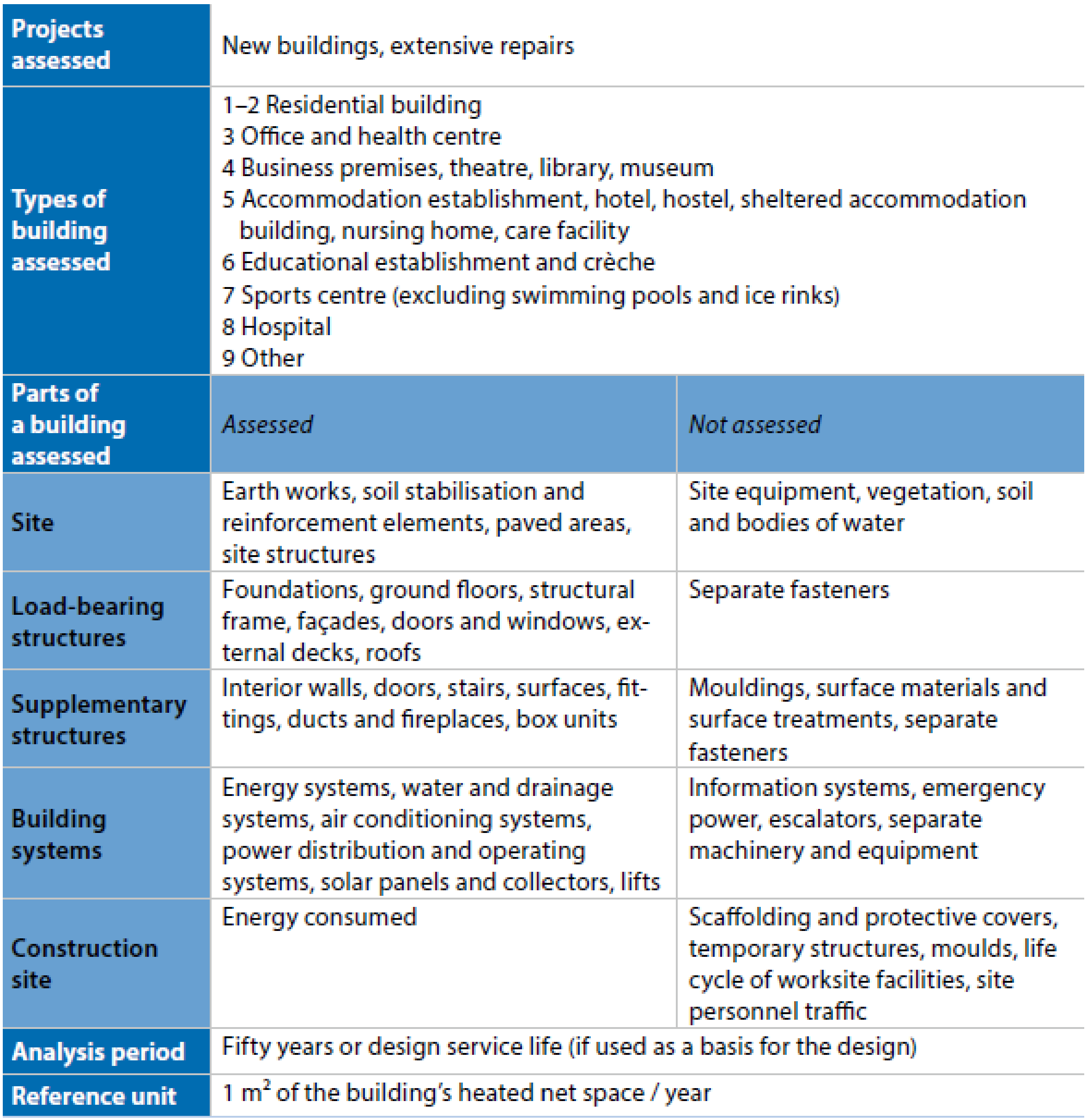
Sandanayake et al. (2018) examined energy consumption and GHG emissions during the construction of timber and concrete buildings; the study's findings revealed that using timber can minimize transportation and embodied emissions while constructing the building.

- **Strategies for lowering carbon emissions from buildings**

According to Huisingh et al. (2015), social metabolism must be dramatically shifted toward low carbon economies and plan and time the implementation of appropriate climate policy involvements like different carbon trading/taxation systems. According to Rogers' (2015) research, the net operating GHG emissions of a household can be cut by 80% compared to 1990 levels by employing a mix of micro generating equipment to meet their heat and power needs.

According to the Finnish Ministry of Environment, when evaluating the carbon footprint of a building in the early stage of design, some parts of the project are essential to be included in the analysis and some not. These are listed in Table 1 (Kuittinen,2019).

Table 1. Assessed part of building for carbon footprint analysis, (Kuittinen, 2019, p. 20).



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	

2.5. Role of Energy in Building Life Cycle

Recently, buildings' heating energy demands are decreasing; thus, power consumption and generation are becoming more critical. While the user can affect power consumption through the efficiency of the building's plant and equipment, energy generation is in the hands of the grid operator and his producing plant. It is necessary to include future changes in the composition of fuel mixtures and the impact of these changes on emissions in scenarios for the usage phase of buildings, in addition to current electricity generation. Because of the enhanced efficiency of new power plants, transferring the projected changes in fuel mix to the picture for CO_2 emission will only result in a 10% reduction in CO_2 emissions by 2030. As a result, equipment efficiency and power output are extremely important. (Birgisdottir and Rasmussen, 2016).

Energy-saving and carbon control are gaining attention worldwide (Li, Zhang, and Li, 2021). For more than 40 years, the earth has suffered from environmental issues. Climate change is one of the most serious of these issues (Gonel and Akinci, 2018). Scientists agree that human activities in the previous century induced contemporary climate change and other major environmental problems. How to distribute the pressures of decreasing GHG emissions in different countries is one of the most challenging and dynamic issues in international climate change negotiations (Yi et al., 2011).

Concerns over irreversible climate change have prompted policymakers to develop climate policies to reduce atmospheric emissions of greenhouse gas (GHG). For instance, China has assured to decrease CO_2 emissions by around 40%-45% by 2020 compared to 2005 (Yi et al., 2011). In order to reduce GHG emissions, significant R&D programs are ongoing around the world, including (Fan, Hong and Jin, 2019):

- Converting to low-carbon fossil fuels, including natural gas, biofuels, or hydrogen
- Decarbonization of flue gases or fuels, followed by carbon sequestration, for example, Carbon Capture and Storage (CCS)
- Increase in the use of green and renewable energy sources such as bioenergy, wind, and solar.

The energy performance Council and European Parliament's directive of buildings (Directive 2010/31/EU) established the formal background to achieve energy efficiency development in buildings in EU countries. The directive took effect in 2010 and was a rewrite of the previous EU Directive on Energy Performance of Buildings EPBD, which was issued in 2002 (Parliament and UNION, 2010). Additional changes were introduced in 2018 (2018/844/EU). The EU Commission has been encouraging the construction of low energy/carbon buildings and the application of energy-saving technology, such as solar and renewable energy. Because of Directive 2010/31/EU, efforts to minimize energy demand in buildings have resulted in a noticeable increase in buildings' thermal comfort as well as a decrease in environmental pollution. As a result of the official EU regulatory initiative to introduce low energy/carbon usage regulations in the design and use of buildings, the definition of energy efficiency in buildings has evolved from a concept of following general standards of energy-saving and decreasing their environmental footprint to a legal necessity and national obligation (Fig. 8) (Chwieduk and Chwieduk, 2020 & Kuittinen, 2019).

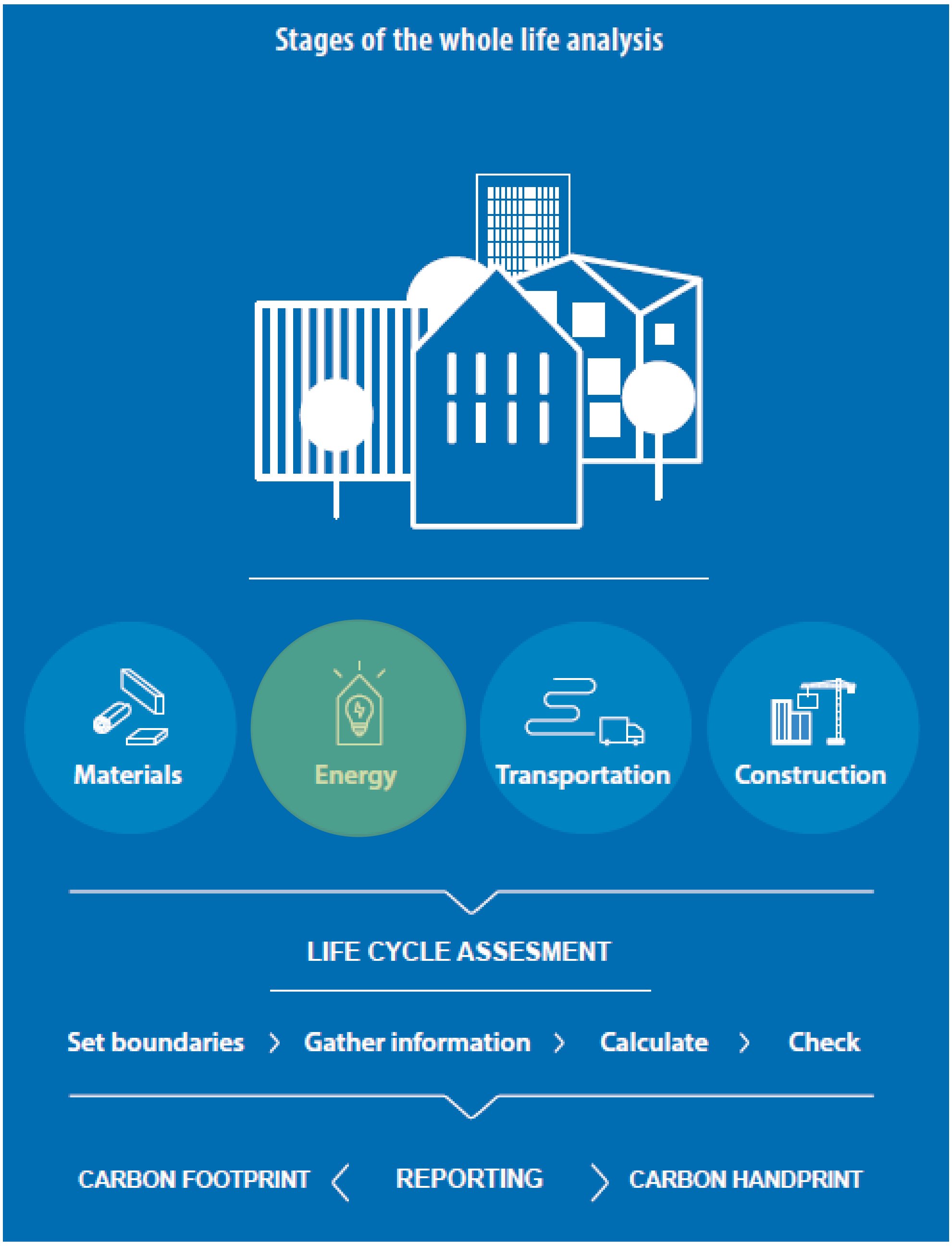


Figure 8. Energy as one of the main aspects affecting efficiency of a building's life cycle (Kuittinen, 2019, p. 17).[MOU1]

Energy consumption by residential sectors

Buildings consume a significant amount of energy all over the world. In 2008, the European Union placed the requirement of reducing energy demand while also improving energy efficiency (Ratajczak, Amanowicz, and Szczechowiak, 2020). Moreover, buildings are widely acknowledged as significant contributors to CO_2 emissions and the effects of global warming (GWI). Building and development accounted for 36-39% of global energy and construction expenditures CO_2 emissions from industrial processes in 2018 (Global ABC, 2019; Skandalos and Karamanis, 2021). Energy consumption in cities is projected to rise by 2.1% each year between 2012 and 2040 (Jain et al., 2020). China has the world's largest construction sector, with approximately 2 billion tons of CO_2 emitted annually from the construction industry (CABEE, 2020).

The definition of energy culture is used to provide the most systematic method for assessing household energy use and energy-saving habits. This definition refers to a broad approach that considers topics such as principles, family habits, learning technology, and daily life practices, in addition to economic considerations (Aune et al., 2016).

According to the energy culture context, a realistic view of household energy use must regard it as part of a more extensive network of daily life activities and infrastructures, including economic considerations. Energy is a derived market rather than a regular product. In other words, electricity is consumed due to other things, including the use of related technology like cooking, washing, working, or driving a vehicle. As a result, a household's energy use is influenced by its energy culture and the socio-material assemblage of the house and its objects and practices (Strengers, Nicholls and Maller, 2016).

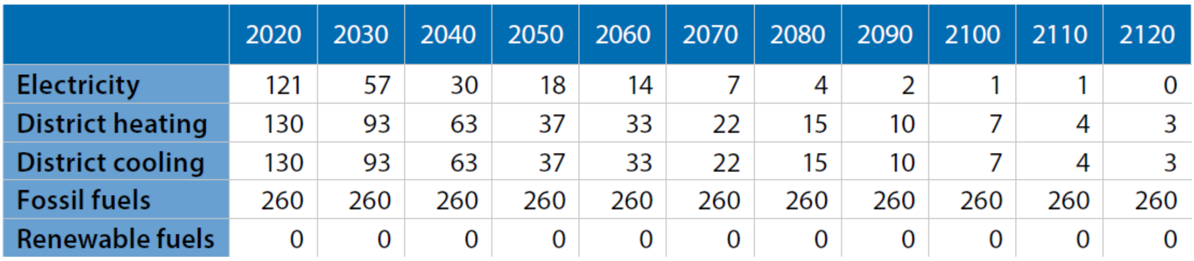
In many developing economies, existing buildings are among the major energy users and emitters of greenhouse gases (GHG). Furthermore, the use of existing buildings poses a number of environmental issues, including water and air pollution and CO_2 emissions. Without a doubt, lowering GHG emissions necessitates a reduction of energy usage during the operation phase, applying high-energy and low-impact building materials in construction (Dadzie, Runeson and Ding, 2019).

2.6. Relation of Energy Demand and Carbon Emission

Multiplying the estimated consumption of the supplied energy of a building to the emission coefficient for various types of energy equals energy’s carbon footprint. Therefore, concerning the Decree on the energy performance of new buildings, it specifies the projected energy consumption of the building. Assess the consumption of supplied energy using the calculation technique provided in the Decree if no energy report has been generated for the building in compliance with the Decree. The following table provided by the Finnish Ministry of

Environment represents different forms of energy and their emission coefficient from 2020 till 2120 (Kuittinen, 2019).

Table 2. Emission coefficient of energy types (Kuittinen, 2019, p. 48).



	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

Building energy management is the main issue in the field of sustainable design (Machar, 2013). According to estimates, nearly 90% of the buildings needed by 2050 have already been constructed and occupied. The rise in current housing stock has had an adverse effect on energy demand, resulting in a negative impact on the climate (Dadzie et al., 2019).

While a few studies have looked into the details of household energy use and CO_2 emissions, little consideration has been devoted to understanding the complex interrelationships between the various variables involved. The majority of energy demand calculations are available online, but most architects and tenants are unaware. It needs to be noted that an energy system of a building requires a consumption energy system (lighting, Domestic Hot Water (DHW), HVAC) as well as generating energy system (solar PV system), without discounting the importance of energy conservation and passive strategies and in lowering consumption of energy and carbon emissions (El Sayary and Omar, 2021).

The demand for energy supply is reduced in modern generation's buildings. A passive house, low energy/carbon/carbon building, a relatively zero-energy building are the examples of having high energy performance and a large share of energy production from renewable energy sources (Džiugaitė-Tumėnienė, Jankauskas, and Motuzienė, 2012). A low energy/carbon building addresses environmental issues and energy crises to use the least amount of energy to operate (Li and Wang, 2020; Sartori and Hestnes, 2007). Some examples of low energy/carbon design could be (Khalid, Mahmood, and Ahmed, 2012):

- Roof insulation and heavy wall to increase the resistance of the building envelope against heat flow
- Using high reflectance material for outer surfaces of walls and roof in order to decrease the absorption of solar radiation

- Using double/triple glazed transmittance windows that ensure less radiation and heat transmission
- Making the building envelop airtightly

Venckus et al. (2010), in another study, associate the concept of low energy/carbon buildings with passive houses with the following requirements:

- The External buildings' envelop must be well thermally insulated.
  - U-value of floors, roofs, and walls is better not to exceed 0.15 W/m^{2}K
  - U-value of windows is better not to exceed 0.8 W/m^{2}K
  - U-value of thermal bridges is better not to exceed 0.01 W/m2K
  - Overall yearly energy demand for heating the building must be less than than 15 kWh/m^2.
- The building's external envelope must be airtight.
  - 50 Pa is in the amount of indoor and outdoor air pressure, and the air exchange ratio must be less than 0.6 times per hour
  - In a low energy/carbon building, natural air change must be less than 0.04 times per hour.

2.7. Energy Relevant Parameters in Buildings' Life Cycle

While the design phase of every building, it is best to do LC[MOU2]A evaluation. At this point, there is sufficient detail on the building's energy requirements and the materials (Kuittinen, 2019). Considering the life cycle of a building in the usage phase, buildings' energy loss and energy demand become important. Therefore, the amount of used electricity and energy in the building dramatically affects assessing the building’s life cycle. There are four major components of energy efficiency, namely design, building envelope, HVAC, and lighting (Anderson, 2016).

2.7.1. Design

It is critical to assess a building's efficiency in terms of energy and carbon emission during the design period to ensure that it consumes the least amount of energy and has the best possible performance before it is constructed, as any modifications made later would incur a high expense and waste of resources (Zhong et al., 2019).

Based on global pressures for improving conditions related to energy scarcity, it has been agreed that high energy production should be prioritized in the construction industry, followed by gradual changes (Berardi, 2018). In order to optimize the construction performance of low energy buildings, Polly et al. (2016) classified design principles into four categories: building strength, renewable thermal energy, solar potential, and load management. Several interrelated sub-principles in each group can be used to achieve maximum efficiency (Figure 9).

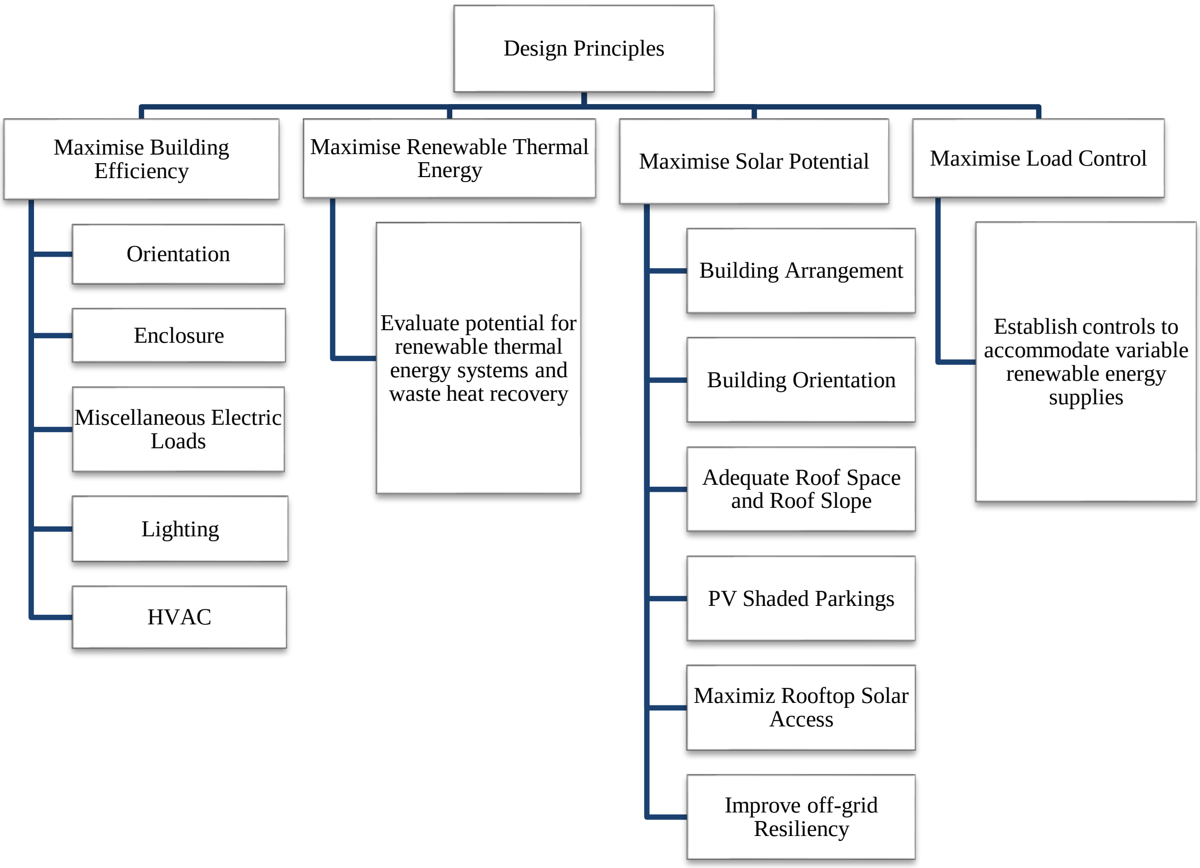


Figure 9. Design principals of low energy/carbon buildings (Adopted from Polly et al. 2016, pp. 5-7).

Jin et al. summarize the design principles of a low energy/carbon building into[MOU3] the three phases of conceptual, preliminary, and detailed design. In this study, the classification is also based on building performance analysis (BPA) (Jin et al., 2019):

Conceptual Design

Descriptions of internal environmental factors should be planned during the conceptual design stage. BPA demands that design goals, preferred rooms, relationships between spaces, room sizes, and the site relationships be identified at this time. Several variables, such as natural ventilation, daylight harvesting and thermal mass, can influence a building's energy consumption. The building orientation, form and scale of a building, and building topology are important considerations when reducing energy usage (Abanda and Byers, 2016).

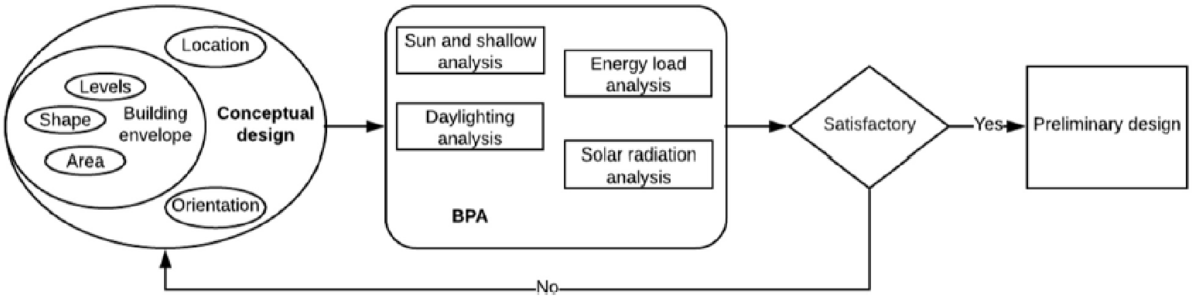


Figure 10. The conceptual design phase of low energy/carbon building (Jin et al., 2019, p.2).

Preliminary Design

Floor plan studies and 3D models are used to create the preliminary concept. At this point, building architecture should be linked to a more precise BPA. In order to measure building efficiency at the preliminary stage, it is essential to consider a detailed collection of building records. Topological, geometric, and semantic data are all included at this point (Schlueter and Thesseling, 2009).

Building architecture, building envelope, building orientation, geometry, and shape, building fabrics, and passive strategies like shade, solar gain, and natural ventilation strategies are all factors that influence building energy consumption. Building performance simulation may help with design optimization by recognizing and weighing the crucial impact variables. Decisions made during the early design phase is responsible for considerable impact on the energy efficiency of a house.

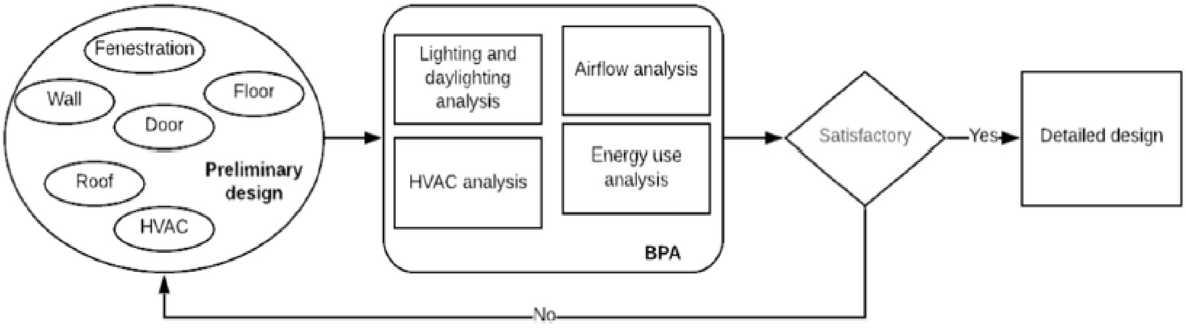


Figure 11. The preliminary design phase of low energy/carbon building (Jin et al., 2019, p.3).

Detailed Design

Finalizing the dimensions of the spaces and rooms, designing the layout, choosing materials, specifying the systems, and agreeing on the door and window styles and positions was all part of the comprehensive design process. A comprehensive systematic sustainability appraisal should be conducted. A carbon/energy declaration at the design level is needed. The details provided at this point should be sufficient to generate shop drawings and construction records. More precise scale, quantity, position, form, and orientation can be used for geometry descriptions of the building elements. Alphanumeric properties can be used to describe the building elements' physical characteristics.

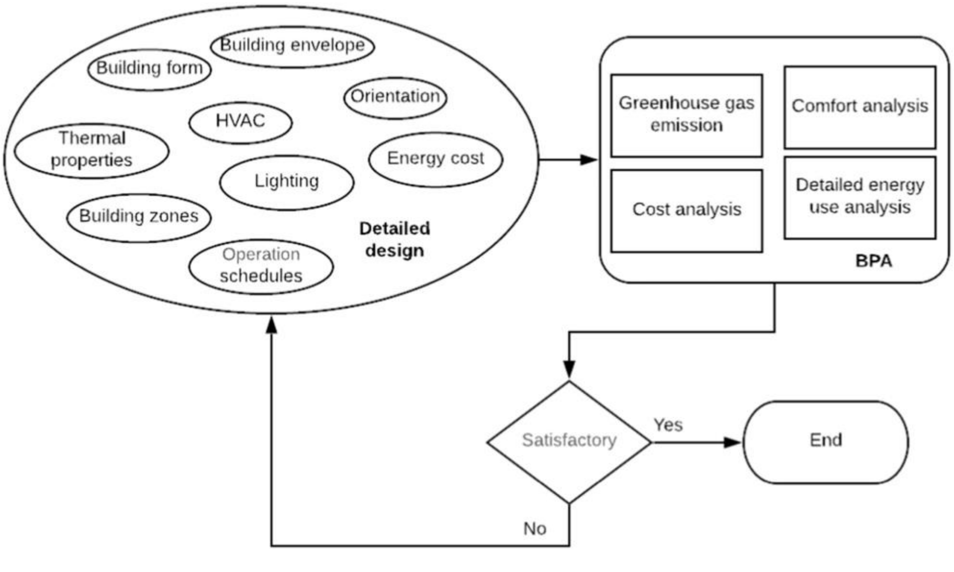


Figure 12. Detailed design phase of low energy/carbon building, (Jin et al., 2019, p.3)

2.7.2. Building envelope; heat gain and loss[MOU4]es

thermodynamics first law explains that energy is contained in any system and mechanism and can neither be absorbed nor destroyed. Therefore, energy can only be converted (Moran et al., 2010). The concept of energy that flows inside the building needs to be described more. Definition of an environmental control mechanism for houses, like a heating system, can be believed to consider the thermodynamic principles of exergy and entropy. It is necessary to provide energy and mass in order to sustain safe indoor temperatures. It is assumed that heat transmission happens typically from the warmer area (inside) to the colder area (outside).

If the energy can be transformed, it can be reused (Schmidt, 2004). The continuous transfer of energy from a building's inside to the outside causes an increase in entropy flow through the envelope of the building (Shukuya, 1998). Exergy can be lost if the energy source's potential is reduced. A basic illustration can be used to demonstrate this: a combustion mechanism is used to heat water for cooking inside an enclosure. The water is heated to a high temperature of 60 °C using an exergy supply such as petrol, which delivers a temperature of 900 °C. The water will be heated with a small portion of the supplied heat; the remainder diffuses into the atmosphere. The original quantity of energy inside the enclosure remains constant, according to the thermodynamics first law. Therefore, the valuable part of the energy is another definition for the exergy. The majority of energy in a building is used to keep rooms at a safe temperature. Heating will account for up to 57% of a building's overall energy consumption (Schlueter and Thesseling, 2009).

Heating energy can be produced using both high-potential and low-potential sources of energy present in the atmosphere. Low-potential sources, such as ambient air, are almost limitless. Exergy derived from sources like fossil fuels can be minimized where the heating chain is built to maximize the use of a low potential supply, such as to drive a heat pump. Since the effect of a building structure, architecture, and technological structures on a building's exergy use, taking exergy into account gives the building planner greater versatility in selecting optimization steps. As a result, the word "energy conservation" must be redefined; exergy efficiency, not energy conservation, is critical for lowering CO_2 emissions (Schlueter and Thesseling, 2009).

In order to provide the residents with thermal comfort and quality, the indoor atmosphere is isolated and air tightened from the outdoor environment. The form of the envelope is directly proportional to the temperature conditions of the region. A rigid isolated non-engaging envelope can be used in the case of high or low temperature, for example. On the other hand, an inviting envelope would be used in a pleasant atmosphere where inhabitants can engage well with the outside (Anderson, 2016).

A building requires a certain amount of electricity to run in order to ensure customer convenience and accessibility. An energy balance must be established in order to determine the amount of energy required. The demand side is determined by adding up energy losses in the building envelope, such as cooling and transmitting heat losseses. The energy gains will compensate for these losses entirely or partially. Energy benefits may come from a variety of places. Internal energy gains from appliances and consumers and solar gains from openings reduce the amount of heating energy required. Ventilation, lighting, and the installation of building structures all require additional energy input. After subtracting gains from overall losses, the total energy demand that must be met is calculated (Schlueter and Thesseling, 2009).

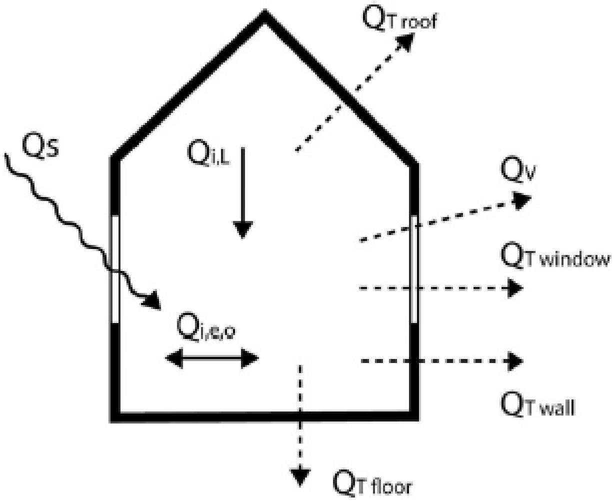


Figure 13. Implemented energy model, (Schlueter and Thesseling, 2009, p. 3).

Envelop haet losses[MOU5]

The geometry of walls, floors, windows, and roofs and the basic u-values of window and wall elements can be taken from the building model and can be calculated according to the following formula. The location of the building determines the indoor (θi) and outdoor (θe) temperatures in order to design the heating systems. The sum of the heat losseses of all envelope surfaces is the overall transmitting heat losses. Heat bridges are not taken into account. The temperature similarity factor $F_{X,i}$ allows components facing varying environmental conditions to be calculated using the same design temperature differential. According to the regulations, this factor is adjusted to 1.0 for roofs and external walls and to 0.6 for floors facing the ground and walls, according to the regulations (Schlueter and Thesseling, 2009).

$$\Phi_T = \sum(F_{x,i} * U_i * A_i *) * (\theta_i - \theta_e) \quad [W]$$

2.7.2.1. Ventilation heat losseses

A simplified formula captures the ventilation heat losseses. The overall volume V is yielded

The overall volume V is yielded from the building model and then multiplied by the air exchange rate n_d (Schlueter and Thesseling, 2009).

$$\Phi_V = (0.34 * n_d * V) * (\theta_i - \theta_e) \quad [W]$$

2.7.2.2. Solar heat gain

Building's location and Openings' orientation are the factors affecting the maximum solar radiation gain. Dependent on the presence of opening surfaces $A_{w,i}$, the solar radiation that heats the interior of the building is measured for each window. The windows' g-value defines the solar radiation's input energy which passes through a special glass. Possible shading by surrounding buildings (F_S), shading devices (F_C), window framing (F_F), and non-orthogonal solar radiation (F_W), are the four correction variables (Schlueter and Thesseling, 2009).

$$\Phi_S = \sum\left(I_{s,j} {}^* A_{w,i} {}^* g_{L,i} {}^* F_{F,i} {}^* F_{W,i} {}^* F_{C,i} {}^* F_{S,i}\right) \quad [W]$$

2.7.2.3. Internal heat gain

Human-caused internal heat gains are retained as a static parameter in the room's occupancy parameter no_o. in this process, $\Phi''_{i,o}$ stands for per person's heat gain. It is multiplied by the number of people who live in the building. $\Phi''_{i,e}$ stands for electrical appliances' specific heat gains for all rooms. Building different types can be captured by the following static values (Schlueter and Thesseling, 2009):

$$\Phi_{i,e} = \Phi''_{i,e} * A_n \quad [W]$$

$$\Phi_{i,o} = \Phi''_{i,o} * no_o \quad [W]$$

Specific lighting power

According to Swiss regulation SIA 380/4, E_{vm} stands for necessary illumination, which defines specific lighting power for each room. Type and light efficiency η_V of the artificial lighting are determining the calculation of specific lighting power. This calculation contains some factors, including usage and gains factor ρ_v, lamp efficiency η_{Lo}, room characteristics η_R such as room geometry and reflectivity. These factors are set to standard values dependent on the type of artificial lighting following the regulations (Schlueter and Thesseling, 2009).

$$p_{\mathrm{Li}} = \frac{(E_{\mathrm{vm}} * p_{\mathrm{v}})}{(\eta_{\mathrm{V}} * \eta_{\mathrm{Lo}} * \eta_{\mathrm{R}})} \quad [\mathrm{W/m^2}]$$

The required lighting power, therefore, as a result, is:

$$\Phi_{i,L} = p_{Li} * A_n \quad [\mathrm{W}]$$

Summary heat demand

In order to create heating energy balance, the overall heat flows of the building, including heat losseses and gains, must be summed up (Schlueter and Thesseling, 2009).

$$\text{heat demand} = \text{sum of heat losses} - \textit{sum of heat gains}$$
$$\Phi_{\mathrm{h=}}(\Phi_{\mathrm{T}} + \Phi_{\mathrm{V}}) - (\Phi_{\mathrm{s}} + \Phi_{\mathrm{i,o}} + \Phi_{\mathrm{i,e}} + \Phi_{\mathrm{i,L}}) \quad [\mathrm{W}].$$

Approaches in summers and winters

In recent years, the issue of building energy conservation and certification has been at the centre of a strong science and technological discussion. The amount of energy required is determined by an extensive range of architectural criteria, each of which has a different impact on winter and summer loads (Bertoldi and Atanasiu, 2006). The environment has a significant impact on the design of low energy/carbon buildings. Wide windows facing the south side are favoured in colder climates. When the sun is low and inclined in the northern hemisphere in the winter, this approach makes for the most efficient use of solar energy for heating the building. Over the summer, cold night air can be used to cool the house's thermal mass and can keep the house cool during the day while storing heat; this strategy can be used in any climate (Khalid et al., 2012).

The European Directive 2002/91/EC specifies that member states must develop methodologies for buildings certification and energy assessment. These methodologies aim to propose steps to reduce energy waste by increasing energy efficiency. The majority of the newly proposed energy labelling methodologies are only applicable during the winter; only a few experiences are still valid during the summer (Asdrubali et al., 2008).

The percentile ratio selected is 99% in winter and 1% in summer, requiring heating and summer conditions requiring cooling. The Maximum Load Curve for the winter months is known as the building load curve on the coldest day of the month. On the other hand, the Minimum Load Curve is known as the building load curve on the hottest day of the month. The Medium Load Curve is derived from both as arithmetic media, and it is this curve is used to calculate energy demand (Rey, Velasco, and Varela, 2007).

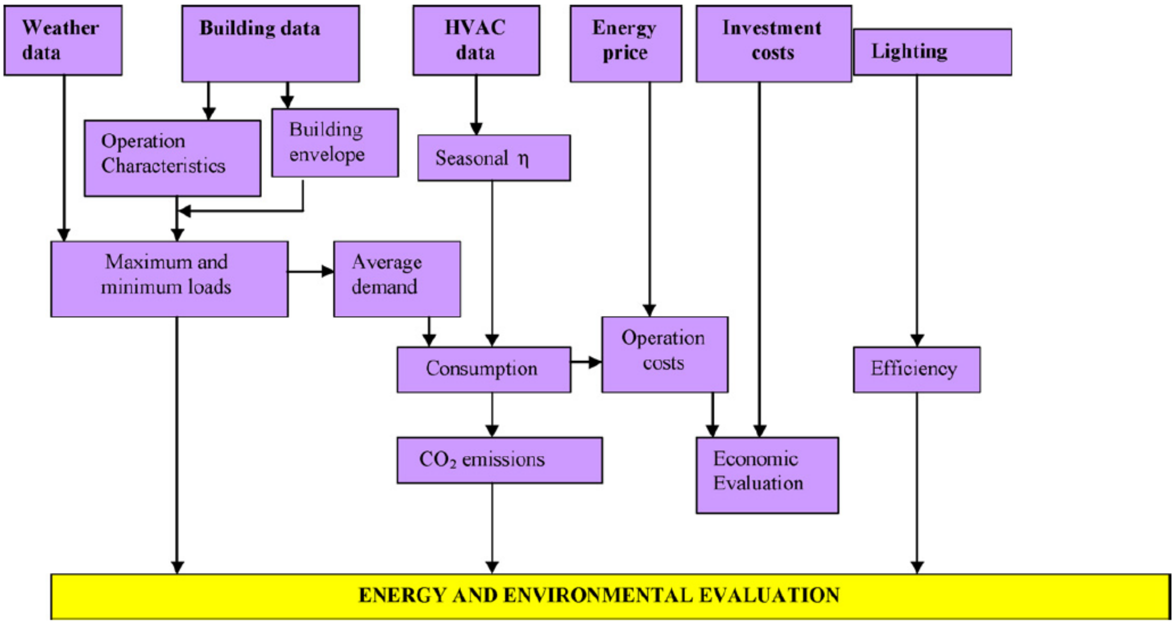


Figure 14. Building Energy Analysis according to seasons and weather (Rey et al., 2007, p. 3)

In the summer seasons, it is vital to pay attention to the possibility of overheating in low energy/carbon buildings with a higher ratio of heat gains. The thermal and optical properties of windows are fundamental in this regard. The shading of windows, which has several choices for controlling shading components of windows, is one way to prevent overheating in the summer. Automatic shading blinds, which are mobile and installed outside of windows, can be regulated based on solar irradiation level; this approach can also control thermal comfort during hot seasons (Geletka and Sedláková, 2013). Summer nights necessitate heat losseses to dissipate excess heat obtained during the day due to high solar irradiation and to maintain the necessary indoor air temperature (Chwieduk and Chwieduk, 2020).

In another research done by Khalid, et al. in 2012 in Karachi, the total energy demand of a low energy/carbon and Conventional building base on seasonal consumption were analyzed. The following graph represents the differences in energy consumption between these two models. It is shown that if a traditional building in Karachi is replaced with a low energy/carbon building, considering seasonal energy consumption, the energy demand for cooling can be reduced by 53.4%. This energy reduction is accomplished solely by the use of low energy conservation methods.

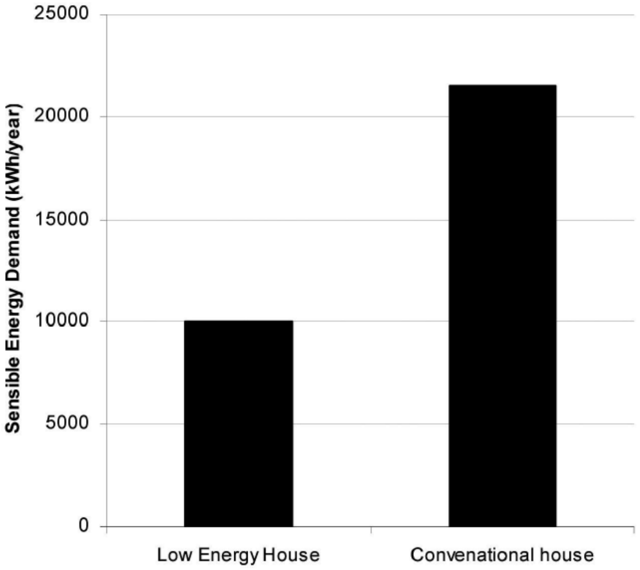


Figure 15. Total energy consumption between a low energy/carbon and conventional building (Khalid et al., 2012, p. 7).

2.7.3. Building energy technology

Since space heating accounts for 78% of EU15 household supplied energy usage, supporting low energy buildings will result in substantial reductions in energy demand (Audenaert, Cleyn, and Vankerckhove, 2008). In general, speaking about low energy buildings mean having less CO_2 and carbon emissions. Technology as a tool enables humans to change the functions and how such functions enhance other services to make them more valuable (Dadzie, Runeson, and Ding, 2020). Mean to a purpose is another definition for technology stated by Arthur in 2009. Generally, technology can be divided into two categories: the first one serves the environment and named sustainable technology, and others perform otherwise. Sustainable technologies aim to reduce energy consumption while they are helping the improvement of environmental performance, such as lowering carbon emissions. Therefore, it has no negative impact on the environment (Weaver et al., 2000).

Energy demand reduction of a low energy/carbon building can be achieved through passive and active energy technologies. A passive energy technology consists of better performance of windows, increased insulation, reduction of losses in air infiltration and recovering the heat in ventilation air. On the other hand, heat pumps combined with heat sources (water/ground/air), solar photovoltaic panels, solar thermal collectors, and biomass boilers are examples of active technologies (Džiugaitė-Tumėnienė et al., 2012).

Photovoltaic panels

The history of solar cells dates back to 170 years ago. Each step from theory to real practice has had a significant influence on this development. PV power generation system is divided into two forms; independent PV power generation and grid-connected PV power generation. The first form includes controller, PV array, AC load, inverter, and battery. The second form consists of a PV array, inverter, and controller (Fu, Shen, and Yin, 2012).

HVAC

The outside environment has an impact on the mechanical system's and HVAC's efficiency. In particular, in some climates, the HVAC system is unnecessary. In developing countries, it is estimated that the HVAC machine consumes 20% of total energy consumption (Anderson, 2016).

Lighting

Using high-efficiency lighting systems like LED lights or compact fluorescent lamps. The advantage of these lamps is to save energy by lighting the house and reducing the air-conditioning load (Khalid et al., 2012). Artificial lighting accounts for 30% of total electricity consumption. Artificial lighting in low energy/carbon buildings has a significant impact on the HVAC system and the thermal load of the building by emitting heat. Depending on the season, the induced heat can be beneficial (winter) or disadvantageous (summer). By then, the amount of daylight available, the amount of heat emitted to be reduced from 50% to 80% by artificial lighting (Anderson, 2016).

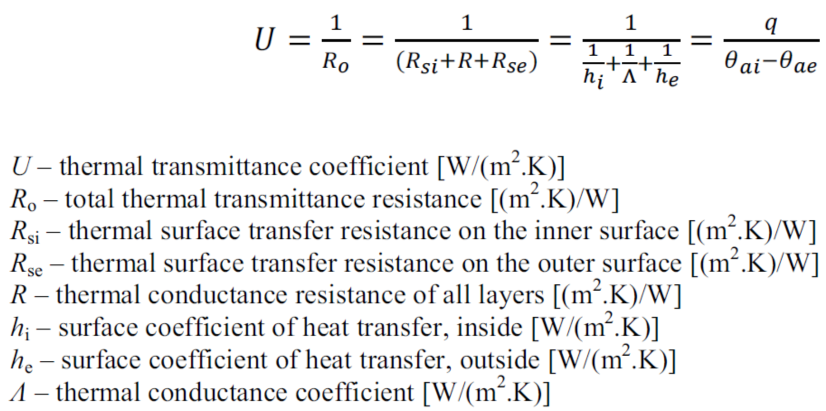
Dadzie et al. (2020) has summarized a list of passive and active energy methods and technologies:

- Direct Current (DC) induction
- Thermally high efficient insulated windows with low emittance
- Solar Photovoltaic (PV) panels
- Efficient LED lighting
- Heat pumps (water/ground/air source)
- Phase Change Materials (PCM) enhanced opaque for building envelope
- Improvement of the building airtightness
- Insulated walls and roof
- Solar PV shading
- Using lightweight concretes
- Double glazed façade
- Air and duct sealing
- Applying Trombe wall
- Green roof technology
- Floor heating
- High efficient HVAC system

2.7.4. Thermal insulation of the wooden structure

Built energy requirements have been significantly reduced in recent years as a result of adopted legislation, owing primarily to well-designed building envelopes and systems (i.e., construction type, buildings' shape, construction materials, thermal insulation). Buildings' thermal quality has recently received attention, emphasising the use of dense thermal insulation with low conductivity. Besides, for windows, the focus is low heat transmission or heat losses as well as low coefficients heat transfer (U-values) (Chwieduk and Chwieduk, 2020).

The expression "U-value" refers to a building element's heat transfer coefficient. The U-value is a measurement of a building's insulation efficiency with the unit of W/ (m^{2}K). U-value or thermal transmittance coefficient describes the amount of thermal energy per m2, in 1° K ambient temperature and at a constant difference, passing through a structural element from the outdoor environment to the indoor and vice versa. U-value consists of characteristics of thermal transfer (h_i and h_e) on ist surfaces. U-value is the inverse of gross thermal transmittance resistance R_o of a material. The sum of the structure's thermal surface transfer resistances plus thermal conductance resistances is so-called R_o. The U-value formula is shown in the following equation (Juras, Staffenova, and Durica, 2017):



$$U = \frac{1}{R_o} = \frac{1}{(R_{si}+R+R_{se})} = \frac{1}{\frac{1}{h_i}+\frac{1}{\Lambda}+\frac{1}{he}} = \frac{q}{\theta_{ai}-\theta_{ae}}$$

U – thermal transmittance coefficient [W/(m^2.K)]
R_o – total thermal transmittance resistance [(m^2.K)/W]
R_{si} – thermal surface transfer resistance on the inner surface [(m^2.K)/W]
R_{se} – thermal surface transfer resistance on the outer surface [(m^2.K)/W]
R – thermal conductance resistance of all layers [(m^2.K)/W]
h_i – surface coefficient of heat transfer, inside [W/(m^2.K)]
h_e – surface coefficient of heat transfer, outside [W/(m^2.K)]
Λ – thermal conductance coefficient [W/(m^2.K)]

Figure 16. U-value formula and the explanation (Juras et al., 2017, p. 3).

PAROC® provides stone wool insulation materials and environmentally friendly, energy-efficient, and fire-safe technologies for new and revamped homes, marine and offshore HVAC, and other industrial applications. There is an 80-year legacy of stone wool manufacturing know-how behind such things, as well as specialized insulation experience and creativity (Paroc, 2021).

Windows

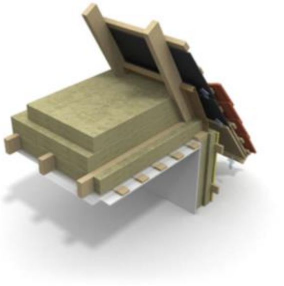
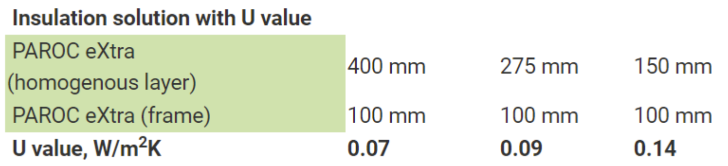
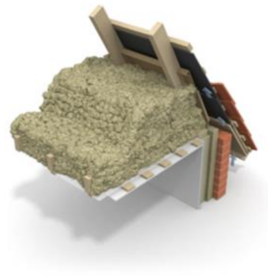
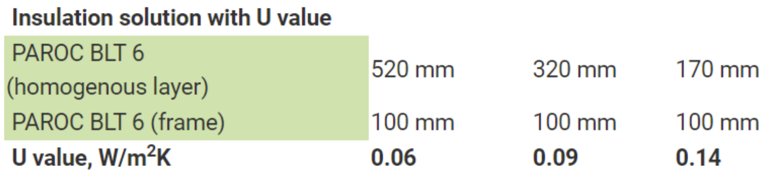
Technologically speaking, windows have had a significant improvement through the centuries from material and construction perspectives. Windows are considered as transparent parts of the building envelope, and their function is more than isolating and protecting the building's indoor climate. Therefore, the first function of the windows is to insulate the space from solar radiation. Air ventilation is another crucial function of the windows. Besides, windows are one of the elements in the building that providing contact with the outdoor environment. With a focus on lowering thermal conductivity, it is important to use thermally insulated material with a low U-value for both glazing and frames. The glazings can be double, triple, heat modules, gas filling, and low emissivity surface. Windows' frames can be made of different materials such as wood, thermo-model plastics, aluminium and so on (Juras et al., 2017).

Pitched Roofs

Pitched roofs are always the most common form of a roof in residential structures. Insulating a pitched roofed structure at the joist level (cold attic) is the cheapest way to insulate a roof. Mineral wool insulation installed inside and on top of the joists is one of the most cost-effective ways to achieve this. Except for the eaves, where there is a reasonable limit to the depth and thickness of insulation that can be added, loft insulation provides an extraordinarily high degree of energy efficiency using this approach (Paroc, 2021).

Paroc pitched roof systems have a safe and healthy living environment. Our insulation is long-lasting, lightweight, and available in various ways, making it simple to mount securely in timber frame structures. The material's porosity provides superb sound absorption, although its non-combustibility provides the highest possible fire protection.

Overall, there are two types of pitched roofs, Roof trusses, cold attic and Roof trusses, warm attic. Cold attics are divided into slabs, with blowing wool, and with slabs and blowing wool. The details of each are presented as following.

<table>
<tr>
<td>With slabs</td>
<td></td>
<td>
<table>
<tr><th colspan="4">Insulation solution with U value</th></tr>
<tr><td>PAROC eXtra (homogenous layer)</td><td>400 mm</td><td>275 mm</td><td>150 mm</td></tr>
<tr><td>PAROC eXtra (frame)</td><td>100 mm</td><td>100 mm</td><td>100 mm</td></tr>
<tr><td>**U value, W/m^{2}K**</td><td>**0.07**</td><td>**0.09**</td><td>**0.14**</td></tr>
</table>
</td>
</tr>
<tr>
<td>With blowing wool</td>
<td></td>
<td>
<table>
<tr><th colspan="4">Insulation solution with U value</th></tr>
<tr><td>PAROC BLT 6 (homogenous layer)</td><td>520 mm</td><td>320 mm</td><td>170 mm</td></tr>
<tr><td>PAROC BLT 6 (frame)</td><td>100 mm</td><td>100 mm</td><td>100 mm</td></tr>
<tr><td>**U value, W/m^{2}K**</td><td>**0.06**</td><td>**0.09**</td><td>**0.14**</td></tr>
</table>
</td>
</tr>
</table>

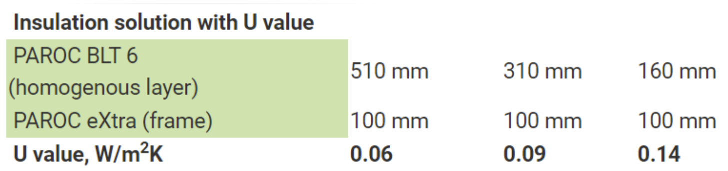
<table>
<tr>
<td>With slabs and blowing wool</td>
<td></td>
<td>
<table>
<tr><th>Insulation solution with U value</th><th></th><th></th><th></th></tr>
<tr><td>PAROC BLT 6
(homogenous layer)</td><td>510 mm</td><td>310 mm</td><td>160 mm</td></tr>
<tr><td>PAROC eXtra (frame)</td><td>100 mm</td><td>100 mm</td><td>100 mm</td></tr>
<tr><td>**U value, W/m^{2}K**</td><td>**0.06**</td><td>**0.09**</td><td>**0.14**</td></tr>
</table>
</td>
</tr>
</table>

Figure 17. Categories of Roof trusses cold attic (Paroc, 2021).

In both new and refurbished residential and non-residential structures, the insulation of a pitched roof at rafter level (warm attic) allows for the most efficient use of roof space. Even if the attic is not intended for immediate use, it is a surprisingly easy and inexpensive job to turn an unused, cold room at the top of the house into a warm, cosy living space later.

A construction permit is sometimes required when adding new rooms to a cold attic. The height of the available area determines the insulation thickness. Be sure there is enough ventilation when preparing the insulation solution. Try insulating the attic floor as well to improve sound insulation. When installing the insulation, make sure it is airtight to avoid cold bridges and condensation. The roof ceilings of modern low energy/carbon houses can be insulated to a depth of around 450 mm.

Figure 18. Pitched roof, Roof trusses warm attic (Paroc, 2021).

Floors

Floors that are ventilated or suspended are very energy efficient. The designer may choose the thickness of insulation in a ventilated room under the floor. A well-ventilated floor solution quickly eliminates capillary moisture from the ground. The air vents under the floor must not get clogged. The floor joists will be subjected to constant airflow if the natural ventilation system is efficient, which will dry the foundation and avoid condensation. To prevent potential mould growth in the soil, it is also essential to clean all organic content under-ventilated floors.

To minimize the amount of moisture beneath the earth, cover it with plastic foil or insulation. In both directions, insulate the base. Frost insulation can be installed in the earth outside the building to prevent the whole frame from freezing. The design of ventilated floors is somewhat similar to that of walls.

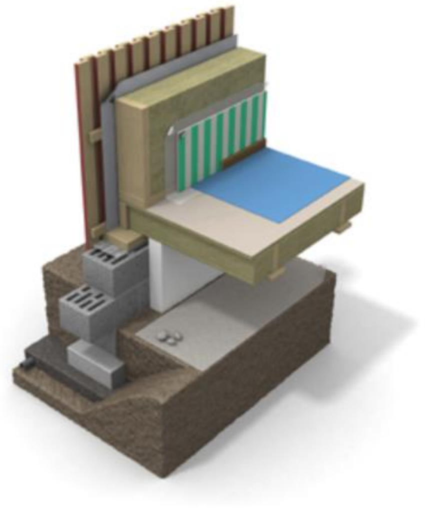
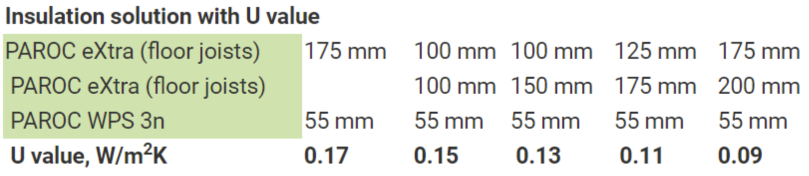


Figure 19. Ventilated Timber Floors (Paroc, 2021).



Insulation solution with U value

PAROC eXtra (floor joists)	175 mm	100 mm	100 mm	125 mm	175 mm
PAROC eXtra (floor joists)		100 mm	150 mm	175 mm	200 mm
PAROC WPS 3n	55 mm	55 mm	55 mm	55 mm	55 mm
U value, W/m^{2}K	**0.17**	**0.15**	**0.13**	**0.11**	**0.09**

Figure 20. Insulation solution with U-value (Paroc, 2021).

Exterior walls

The Nordic Wall is basically a timber wall structure. In comparison to other timber structures, a Nordic Wall has the desired U-value with a thinner construction. A ventilation space behind the wood cladding ensures adequate ventilation. As a result, using wind resistance insulation as an additional continuous thermal insulation coating on top of the studs is recommended. The continuous coat decreases moisture and cold bridges on the timber studs. The tape must be used to tighten the seams of wind resistance slabs (PAROC XST 020 or PAROC XST 021).

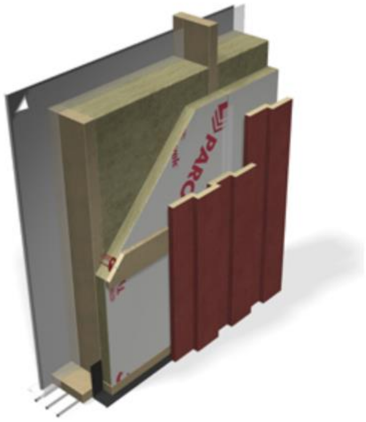
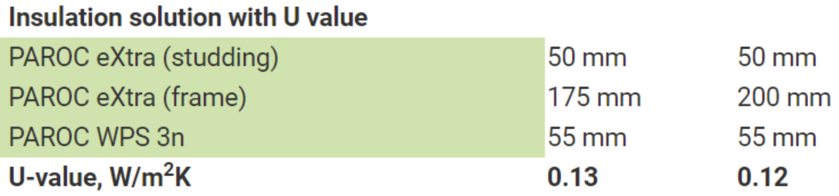


Figure 2.5. Nordic wall with cladding (Paroc, 2021).



Insulation solution with U value		
PAROC eXtra (studding)	50 mm	50 mm
PAROC eXtra (frame)	175 mm	200 mm
PAROC WPS 3n	55 mm	55 mm
U-value, W/m^{2}K	**0.13**	**0.12**

Figure 2.6. U-values of a Nordic wall with cladding (Paroc, 2021).

Only the necessary components of layered wall construction are used in this simple ventilated timber wall. Insulation is installed to the timber frame, and plasterboard is used with covered seams to provide wind cover. Depending on the orientation of the timber cladding, the ventilation gap is generally made using 22x100mm horizontally laid timber.

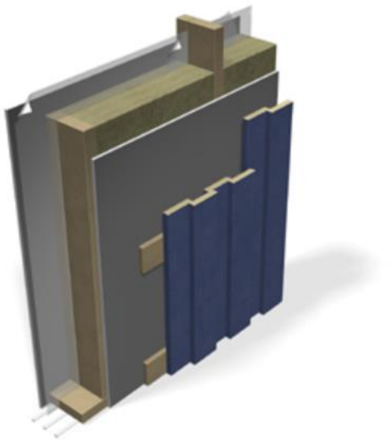
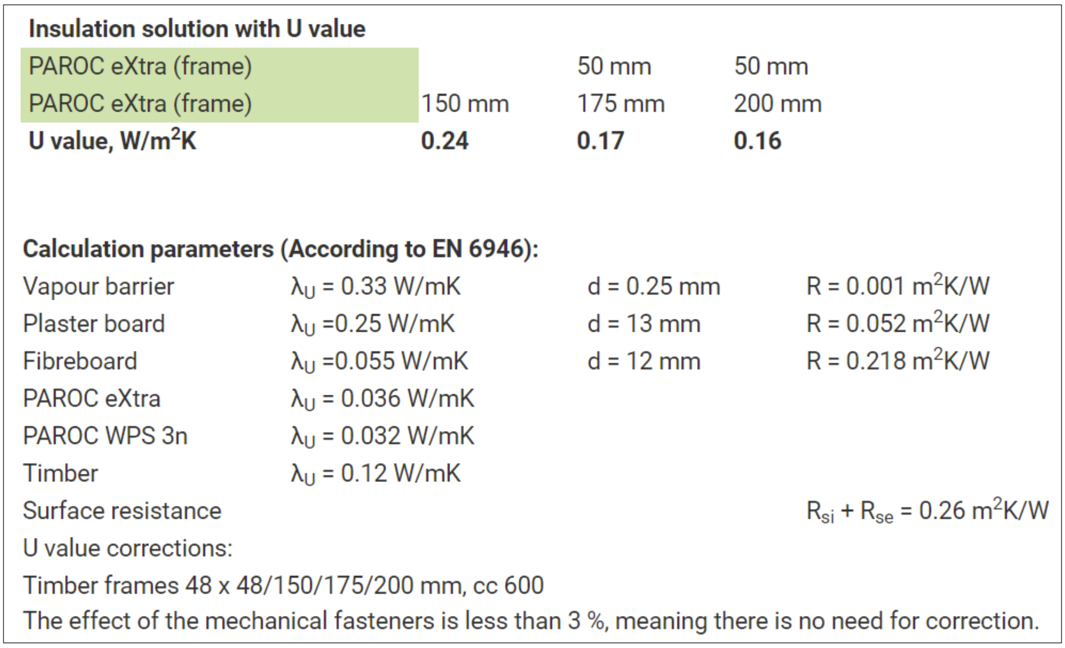


Figure 21. Frame with Timber Cladding or Brick façade (Paroc, 2021).



Insulation solution with U value

PAROC eXtra (frame)		50 mm	50 mm
PAROC eXtra (frame)	150 mm	175 mm	200 mm
U value, W/m^{2}K	**0.24**	**0.17**	**0.16**

Calculation parameters (According to EN 6946):

Vapour barrier	λ_U = 0.33 W/mK	d = 0.25 mm	R = 0.001 m^{2}K/W
Plaster board	λ_U =0.25 W/mK	d = 13 mm	R = 0.052 m^{2}K/W
Fibreboard	λ_U =0.055 W/mK	d = 12 mm	R = 0.218 m^{2}K/W
PAROC eXtra	λ_U = 0.036 W/mK		
PAROC WPS 3n	λ_U = 0.032 W/mK		
Timber	λ_U = 0.12 W/mK		
Surface resistance			$R_{si} + R_{se}$ = 0.26 m^{2}K/W

U value corrections:

Timber frames 48 x 48/150/175/200 mm, cc 600

The effect of the mechanical fasteners is less than 3 %, meaning there is no need for correction.

Figure 22. Insulation solution with U value and Calculation parameters (According to EN 6946) (Paroc, 2021).

Ground

The foundation of a building is the structure's lowest and most important supporting sheet. It is also the part of the structure, which is the most difficult to alter after it has been built. Therefore, it is critical to plan and insulate it correctly from the start. Frost heave is a significant consideration while constructing foundations. Frost heave destroys foundations and the entire frame of a house. Frost heave and other issues can be avoided with proper insulation. Stone wool prevents frost heave and moisture issues, lowers heating costs, and makes below-grade rooms more comfortable. The following drawing represents one example of an insulated foundation. The most popular cellar wall and foundation insulation solution for buildings can be found in the section below.

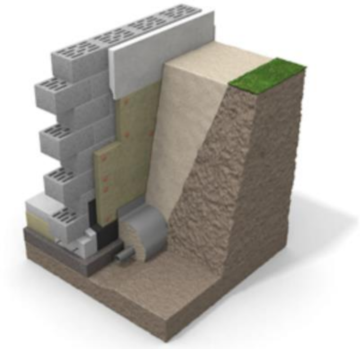


Figure 23. Cellar Walls (Paroc, 2021).

External cellar wall insulation made of stone wool can be an ideal alternative for thermal insulation and drainage. The stone wool's open structure helps the structure to dry outwards. This approach is suitable for both new construction and reconstruction of problematic walls.

Ceilings

Ceilings act as ideal locations for sound-absorbing fabrics as well as fire and thermal insulation. The soft and absorbent stone wool slabs and lamellas are protected from mechanical damage and have optimal acoustic efficiency because they are mounted high. It improves the structure's fire protection and energy conservation while also creating a pleasant sound atmosphere.

3. BIM APPLICATION IN LOW ENERGY/CARBON BUILDINGS

3.1. BIM and Construction Industry

About a third of all construction energy demand and the greenhouse gas emissions correlated with its production is responsible for global warming. It has been noted that conserving energy is more straightforward than producing it, and hence the need to ensure building energy conservation is now well recognized. To reduce global demand for electricity and emissions, it is also essential to make buildings more energy-efficient and sustainable. Measures are taken to reduce the heat load, cooling, vertical transport, and hot water energy usage in buildings to achieve energy conservation. Energy modelling methods are commonly used in the building design process to predict the energy needed to ensure the comfort of the indoor atmosphere while meeting the desired energy efficiency (El Sayary and Omar, 2021).

Access to all details describing a structure, such as its shape, materialization, and technological structures, is required to understand building functionality during the early design stages. In the 1970s, the concept of "semantic data models" was developed, linking both abstract and physical data to meet the building's requirements. This definition was modified for generic "building description" in the construction industry, later renamed "building product models". The expression "making knowledge templates" has been widely used since 2002. Building knowledge models allow for the storage of multi-disciplinary data in a single virtual image of a building. Since it can hold various types of material, a building information model is a "richer library" than a collection of sketches. (Schlueter and Thesseling, 2009).

Construction projects are getting more complicated to handle, and more construction workers are becoming acquainted with Building Information Technology (BIM) as technology advances. The construction industry has shifted its focus dramatically to the idea of BIM as a result of this. BIM is the most often used abbreviation for a modern approach to structural planning, renovation, and upkeep (Abanda and Byers, 2016). Via multi-dimensional digital modelling solutions, BIM provides a "simulation" of digital architectural models to visualise and analyse science cooperation (Bonenberg and Wei, 2015). The convergence of architecture and building energy modelling techniques has recently transformed how the two groups of professionals collaborate. In the design process, BIM is a new technique that is recently applied.

BIM outperforms conventional computer-aided programming in terms of accuracy and interoperability (Marzouk and Abdelaty, 2014).

3.2. BIM Application in LCA

Due to a lack of information technology applications on building sites, data flow during the project life cycle becomes complicated. In order to improve the effectiveness of construction projects over their life cycle and through various construction business processes, the implementation of information systems in the construction sector has become a significant concern (Masood, Kharal, and Nasir, 2014).

While a few studies have looked into the details of household energy use and CO_2 emissions, little consideration has been devoted to understanding the complex interrelationships between the various variables involved. The majority of energy demand calculations are available online, but most architects and tenants are unaware. It needs to be noted that an energy system of a building requires a consumption energy system (lighting, Domestic Hot Water (DHW), HVAC) as well as a generation energy system (solar PV system), without discounting the importance of energy conservation and passive strategies and in lowering consumption of energy (El Sayary and Omar, 2021)

3.2.1. Revit

Civil engineers, architects, and construction professionals utilize Revit ® software to generate exact 2D and 3D designs. Solids, surfaces, and mesh objects are used to create and manipulate 2D geometry and 3D models. Compare drawings, count, add blocks, create timetables, and more may all be automated. Customize the experience with different applications and APIs.

Revit is a BIM software that creates BIM-based models. It is a program for creating virtual models and project drawings. Revit is a BIM-based program that engineers, architects, designers, and contractors use to generate a unified model, including real-life data. Virtual modelling can be attained via Revit software before it is constructed on-site. More importantly, Revit tools support BIM, which means it creates intelligent models that store important data. As a result, it avoids the rework, detects clashes and collisions before construction of the model, minimizes the costs, minimizes delays and so on (Somani, 2019).

3.2.2. One Click LCA

Design optimization plays the most significant role in carbon reduction potential and is the most cost-effective. In One Click LCA, the purpose is to provide tools and solutions that allow all actors in the building sector to quickly and easily analyze environmental consequences. That implies more efficient eco-design, greener structures, and a brighter future for all. Life Cycle Assessment, Life Cycle Costing, developing low-carbon and more circular projects and getting green building certifications are made more accessible with One Click LCA project-level tools. Building materials and other details can be manually entered, or data may be imported from Revit, energy models (gbXML), Excel, IESVE, IFC, and other programs. To receive a comprehensive view of the facility's Life Cycle impacts, enter building areas, water consumption, energy consumption, emissions, construction site operations, and removals.

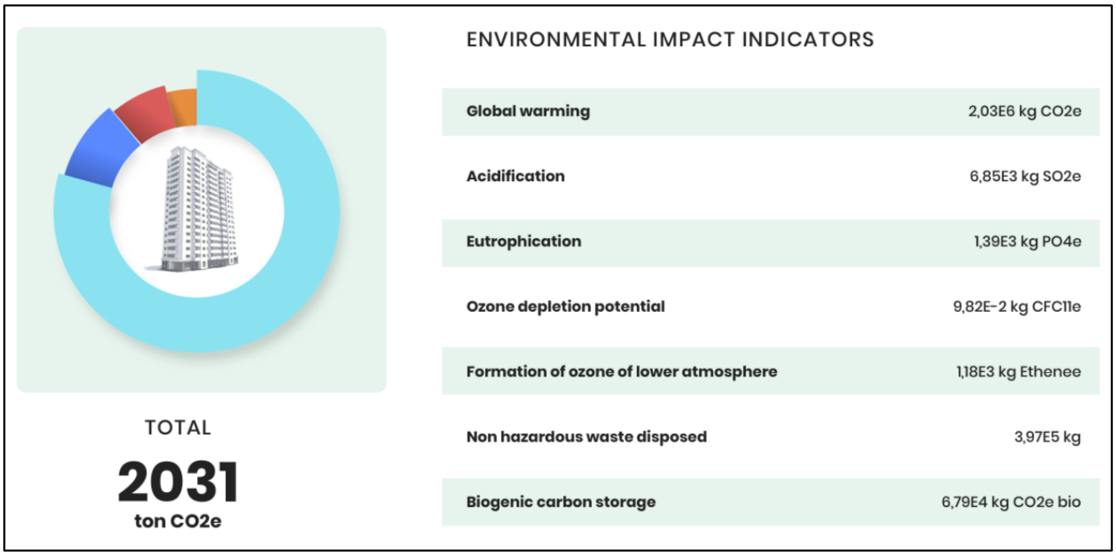
Figure 24. Coordination of One Click LCA with other BIM tools (Bionova, 2021 a).

LCA is a method for calculating the environmental impacts throughout its entire life cycle from raw material to end-of-life. The goal of a Life Cycle Assessment is to assess overall environmental performance while avoiding burden shifting. When the critical environmental effects are identified, this allows for better environmental performance. A complete LCA considers a wide range of environmental factors. LCA is carried out according to ISO 14044 and ISO 14040 standards, besides a complementary country-specific standard like EN 15804 (Bionova, 2021 a).

In Once Click LCA, the term carbon footprint refers to the greenhouse gases (GHG) released as a result of an organization or service operations. The carbon footprint is a measuring and management technique used to identify emission sources and cost-cutting possibilities. The results of carbon footprint analysis can be used in operative and strategic planning, personal management, marketing and environmental communication, and procurement. Carbon footprint may also be used as a measure of value chain efficiency. It follows the LCA standards as well as complementary country-specific standards like PAS 2080, NS 3720 etc. (Bionova, 2021 c).

Considering the building's LCA, One Click LCA is responsible for:

- Creating a complete image of carbon and other indicators that have a negative impact (Fig. 25).
- Focusing on the most critical part of the building's structure in terms of carbon emission (Fig. 26)
- Analysing the most contributing materials (Fig. 27).



TOTAL

2031

ton CO2e

ENVIRONMENTAL IMPACT INDICATORS

Global warming	2,03E6 kg CO2e
Acidification	6,85E3 kg SO2e
Eutrophication	1,39E3 kg PO4e
Ozone depletion potential	9,82E-2 kg CFC11e
Formation of ozone of lower atmosphere	1,18E3 kg Ethenee
Non hazardous waste disposed	3,97E5 kg
Biogenic carbon storage	6,79E4 kg CO2e bio

Figure 25. environmental impact indicators (Bionova, 2021 b).

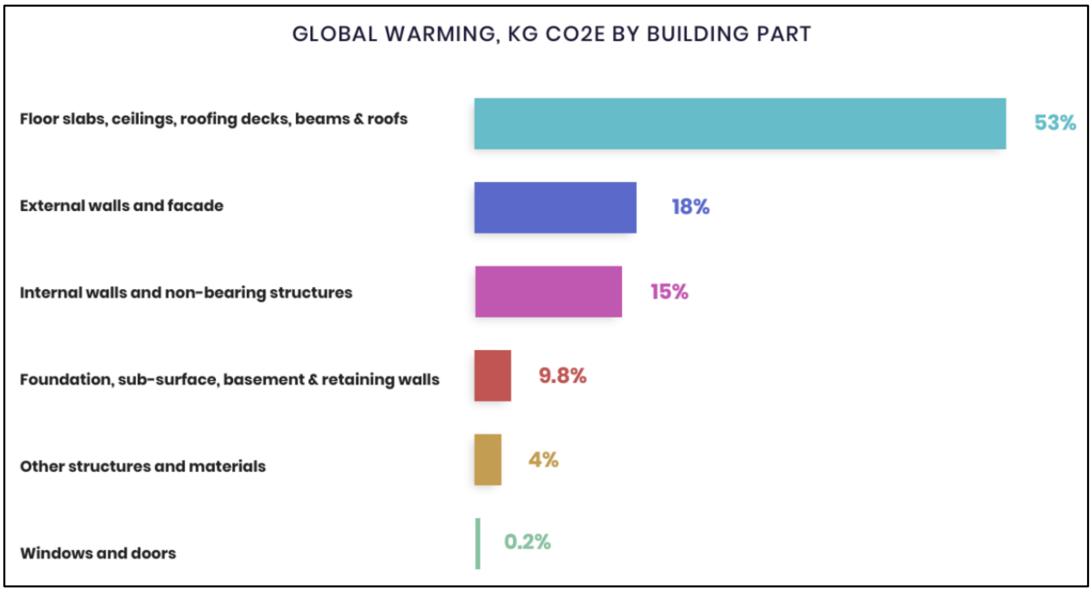
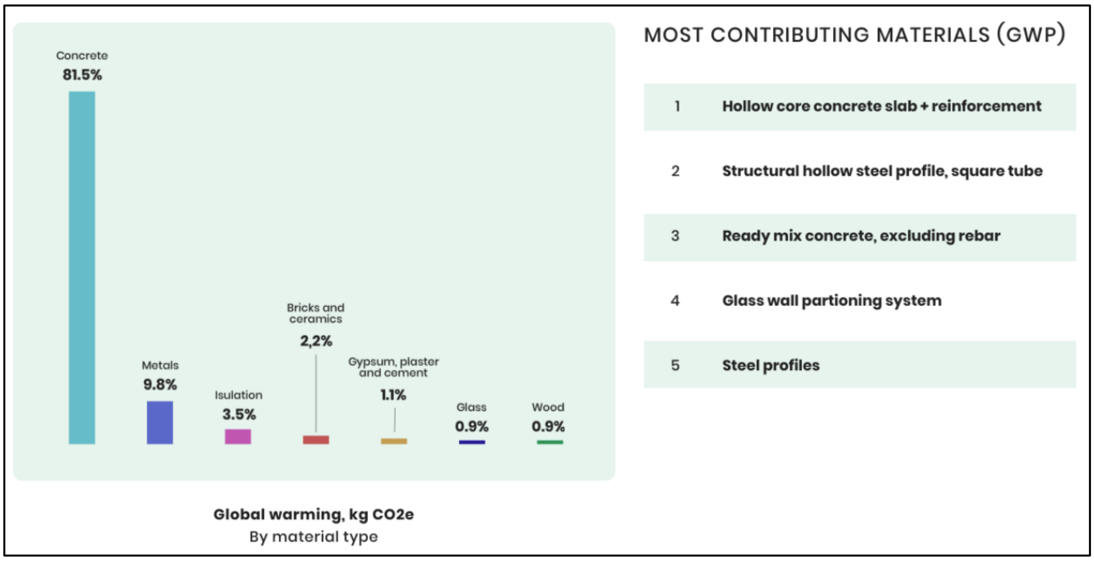


Figure 26. Amount of CO_2 (kg) by building part (Bionova, 2021 b).



MOST CONTRIBUTING MATERIALS (GWP)

1	Hollow core concrete slab + reinforcement
2	Structural hollow steel profile, square tube
3	Ready mix concrete, excluding rebar
4	Glass wall partioning system
5	Steel profiles

Figure 27. Indicating the most contributing material in terms of CO_2 emission (Bionova, 2021 b).

Furthermore, One Click LCA is more than a BIM software. It has a variety of benefits, including:

- Before start sketching, search for concepts with minimal embodied carbon.
- Calculate the cost of a building's life cycle automatically.
    - Calculate expenses at all phases of the life cycle. Compare and select the best environmentally friendly and cost-effective design. Earn certification credits by submitting life cycle cost results.
- More circular structures can be designed.

- Quantify and optimize the circularity of materials supplied and consumed, as well as the end-of-life circularity, can be tracked by using One Click LCA Building Circularity.
- LCA and carbon for infrastructure projects such as airports, highways, parks, pipelines, marine works, rail stations, etc. Consequently, One Click LCA enables the desired design and material choice with less expense and less time.

In the end, the building design can achieve the desired certificate, including impact indicators, life cycle stages, benchmarking, and so forth.

Figure 28. Some certificates, standards and schema that compile with One-Click-LCA (Bionova, 2021 b).

4. CASE STUDY

4.1. Information of Case Study

General Information

The case study is a sample two-story dwelling located in Helsinki, Finland. The building is a schematic design of a family house, which is popular in Finland. The house aims to be a low energy/carbon building, which means it follows the design parameters and materials that lead to low-energy consumption and less carbon emission.

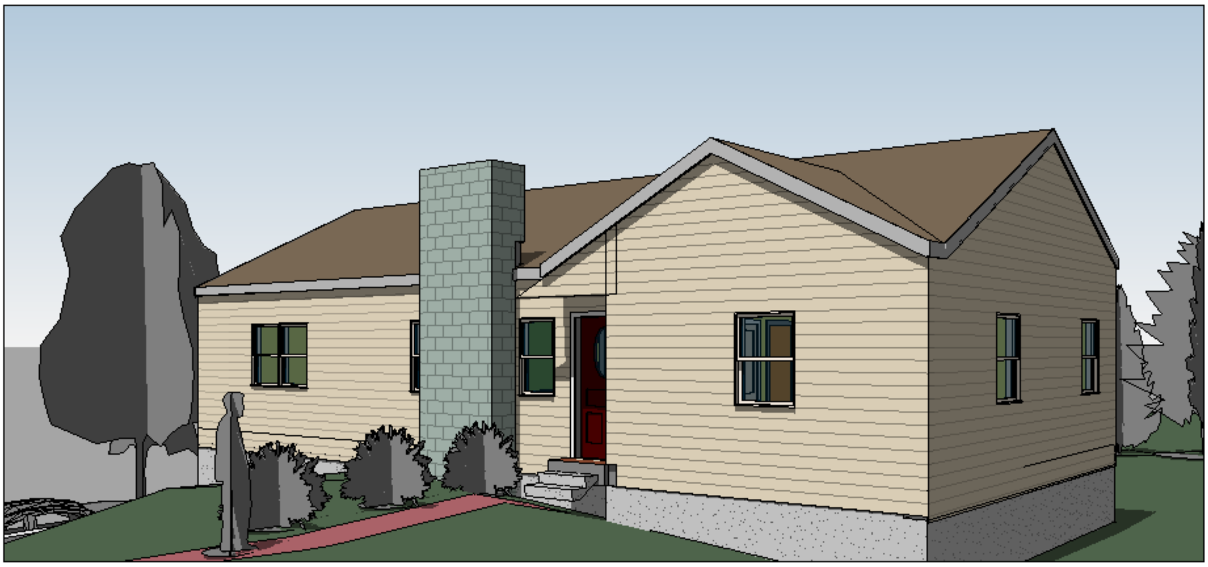


Figure 29. 3D view of the sample residential design by Revit Software

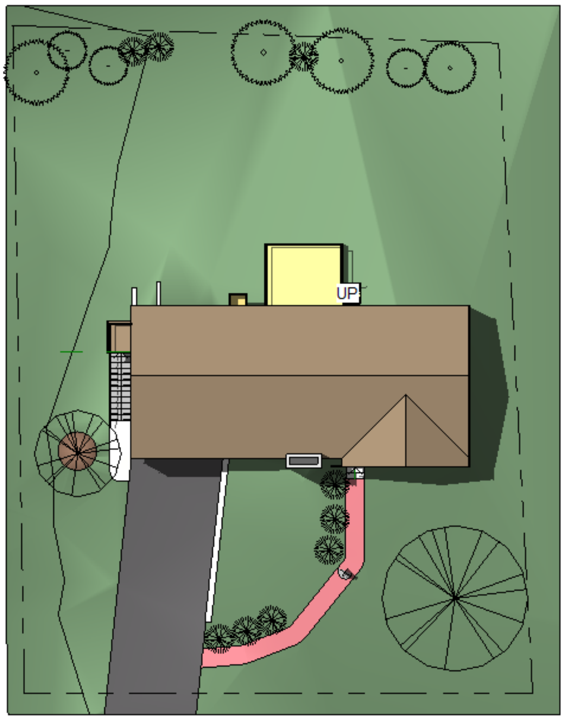


Figure 30. The sample's site plan by Revit Software.

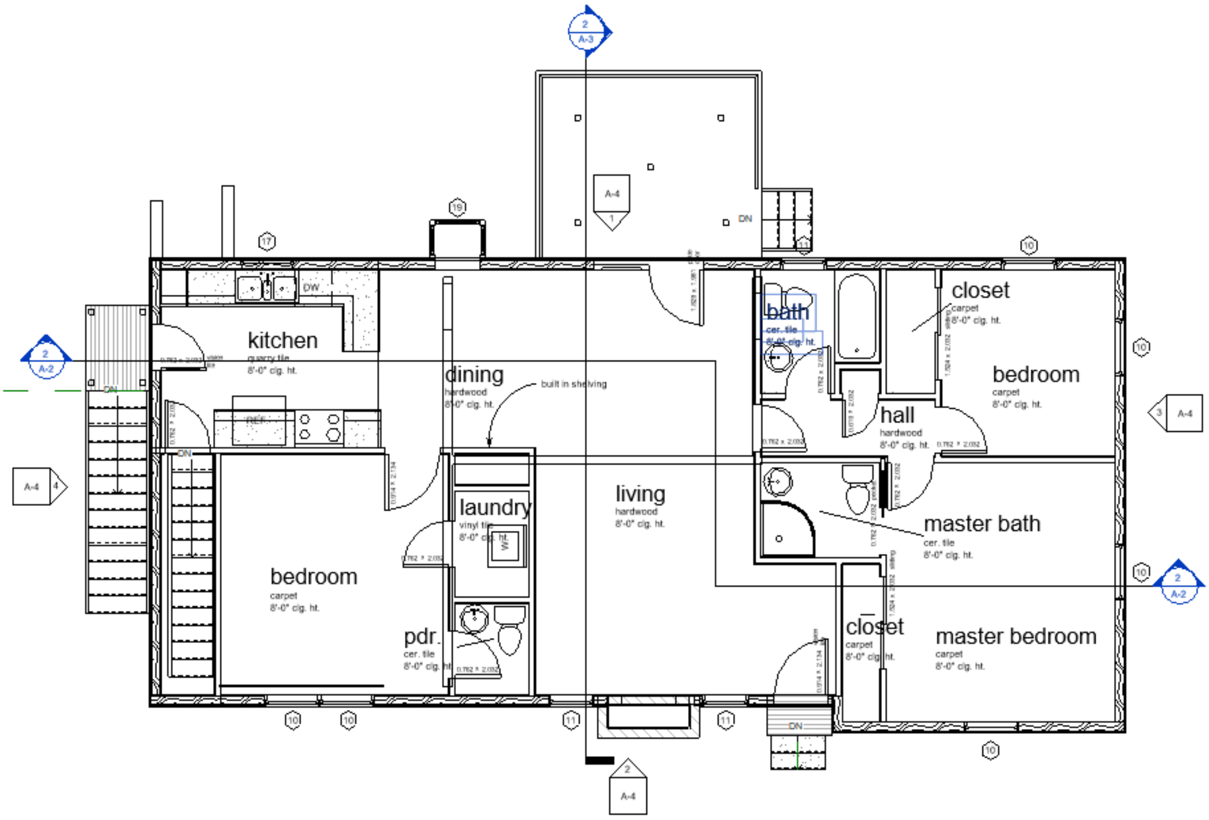


Figure 31. The sample’s ground floor plan by Revit Software.

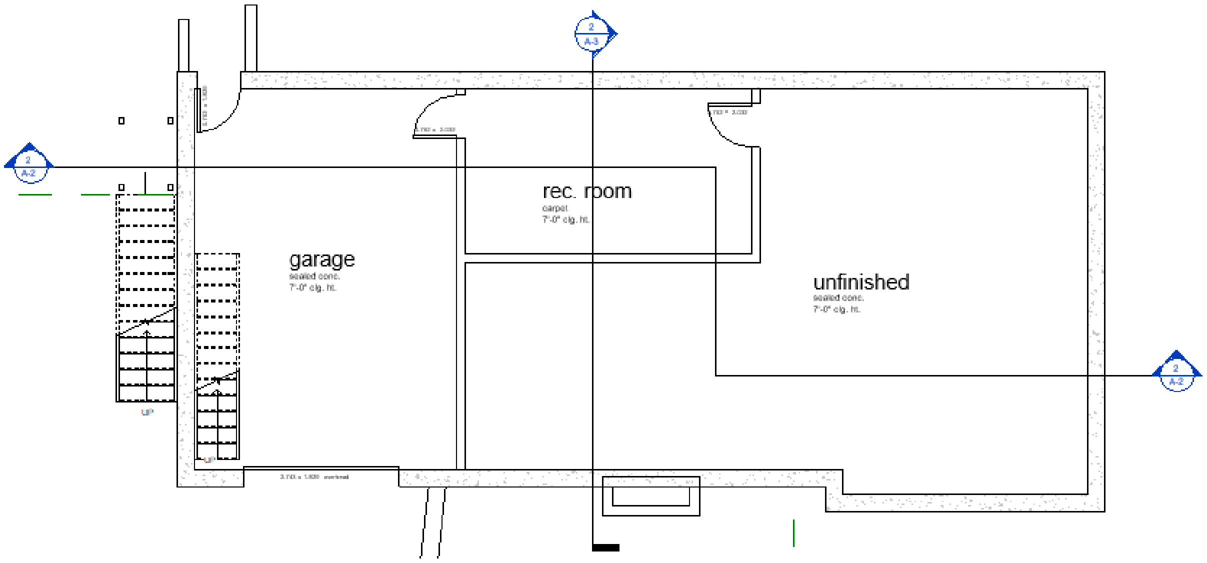


Figure 32. The sample's ground floor plan by Revit Software.

More specific architectural information about the case study is provided in Appendix A, p 79; however, Table 3 explains more general information about the building:

Table 3. Case study's general information

Item	Description
Project type	New construction
Building type	One-dwelling residential building
Reference region:	Finnish reference building (all types)
Construction year	2021
Assessment method	Life cycle assessment, EN 15978
Purpose of the LCA study	LCA, calculating climate emissions, building certification
Calculation period	60 years
Gross floor area	128 m^2
Gross internal floor area (GIFA)	128 m^2
Total number of floors	2
Number of above-ground floors	1
Number of underground heated floors	0
Number of unheated underground floors	1
Baseline scenario (original selection)	Small house - stud frame
Comparison scenario	Small house - concrete element
Height	6.0 m
Width	14 m
Depth	6.3 m
Internal floor height	2.7 m

Maximum column spacing distance	9.0 m
Load bearing internal walls	40 %
Number of staircases	1

Technical information

Based on the principles of sustainable architecture, the low energy/carbon building is the building energy concept. Therefore, while preparing the model to export from Revit, all considerations regarding to a low energy/carbon building are met. The technical structure, servicing type, and service life of the project, which the model provided, were also considered for the evaluation process. This information consists of:

- Building structure

The load-bearing structure of the building is primarily made up of a glued-profile timber skeleton and, to a lesser extent, a reinforced concrete frame. The floor is made out of a wooden grid (in the house's public sections) and partially concrete (in technical areas of the house). The roof is pitched, insulated, ventilated with protective waterproofing. The window frames are made of solid wood and are topped with triple-paned, thermally insulating glass. Partitions in the home are made of wood.

- Servicing type

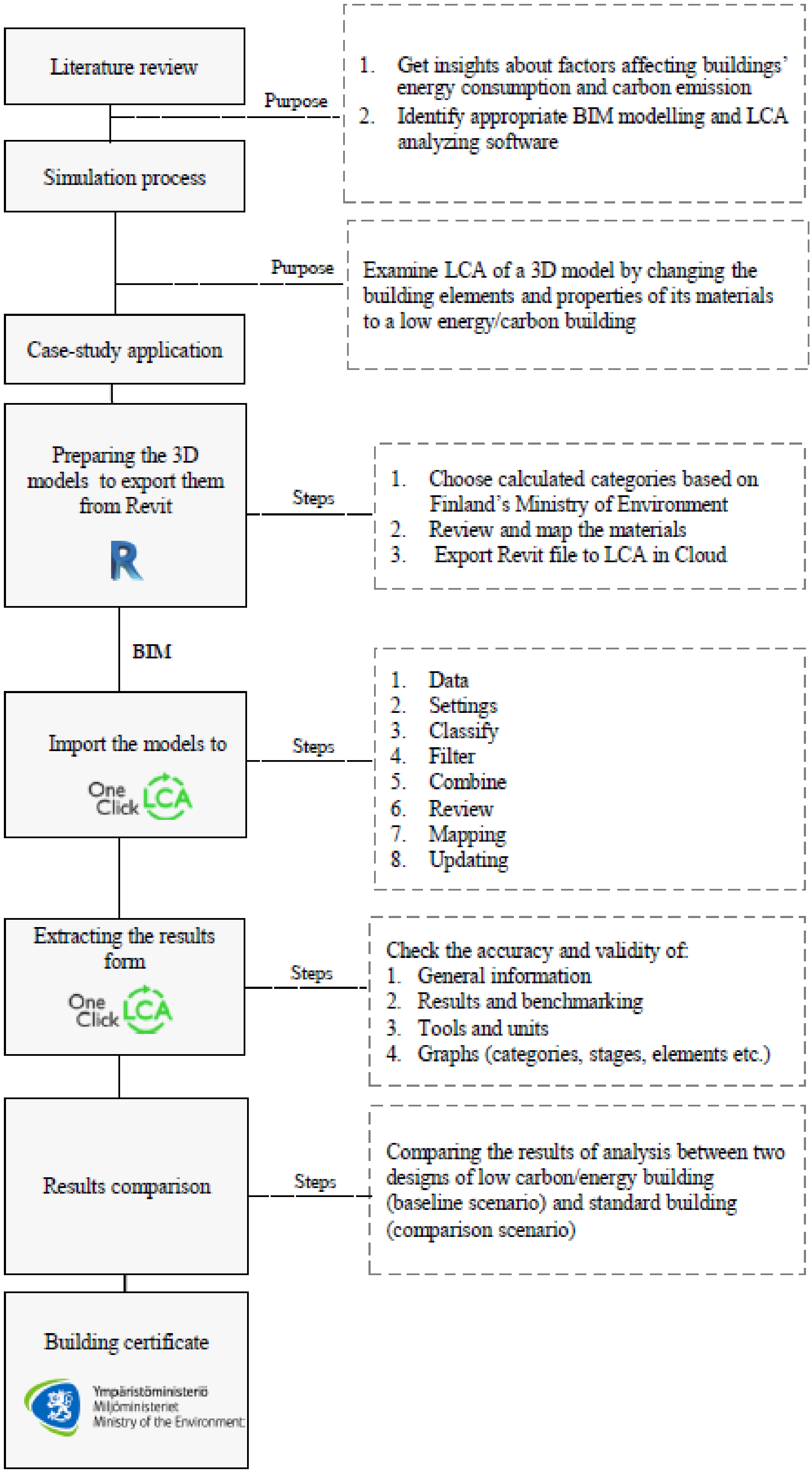
heating, ventilation, and hot water service system type are the systems centralized.

- Required service life: 60 years.

4.2. Research Methodology

The thesis research methodology is *qualitative* and *quantitative*. The qualitative part includes a systematic literature review and investigation of the previous studies. The quantitative method contains evaluating the life-cycle and carbon emission of a Revit 3D residential model. The study focuses on low energy and low carbon buildings; therefore, the sample was modified in terms of parameters and materials based on the information and criteria of low energy/carbon buildings described in the literature review chapters. In order to analyze the model, One Click LCA software as a BIM tool was applied. This experiment proves the reliability of collected qualitative and quantitative data by One Click LCA.

This study is set to examine the effectiveness of factors affecting a buildings energy demand and carbon emission. Thus, to compare the results, the case study was once evaluated considering all the parameters affecting the energy consumption and carbon emission and life cycle of the building named Baseline Scenario (low energy/carbon building). Furthermore, once without considering low energy/carbon building's parameter and criteria named Comparison Scenario (Conventional building). In the end, the results show the differences between the two scenarios. The following chart (Fig. 33) depicts the path of the thesis from literature review to case study evaluations and results.



1. Get insights about factors affecting buildings' energy consumption and carbon emission
2. Identify appropriate BIM modelling and LCA analyzing software

Examine LCA of a 3D model by changing the building elements and properties of its materials to a low energy/carbon building

1. Choose calculated categories based on Finland's Ministry of Environment
2. Review and map the materials
3. Export Revit file to LCA in Cloud

1. Data
2. Settings
3. Classify
4. Filter
5. Combine
6. Review
7. Mapping
8. Updating

Check the accuracy and validity of:
1. General information
2. Results and benchmarking
3. Tools and units
4. Graphs (categories, stages, elements etc.)

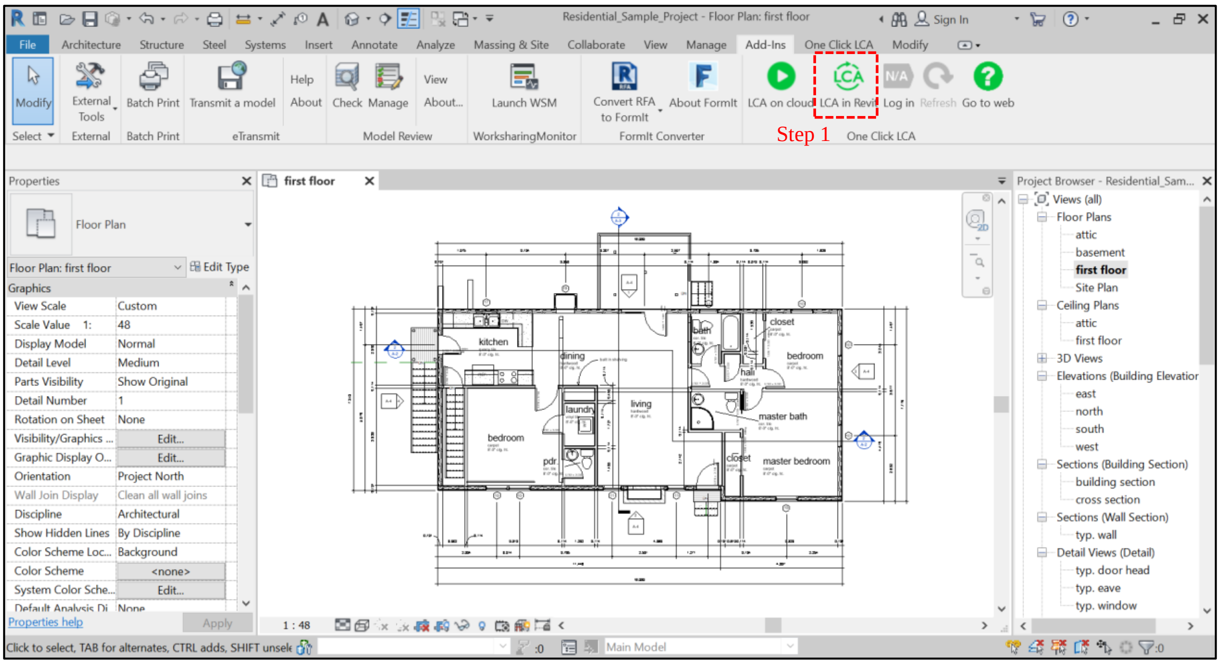
Comparing the results of analysis between two designs of low carbon/energy building (baseline scenario) and standard building (comparison scenario)

Figure 33. Research methodology and analysing the case study by the author.

4.3. Data Collection

4.3.1. Experiment Approach – Revit

As mentioned, the methodology of the thesis is to evaluate the case study's life cycle and carbon emission by a BIM tool named One Click LCA. Two approaches can do this step. Firstly, the building's materials and parameters can be extracted from the Revit file of the building to an Excel sheet and then manually imported to One Click LCA to evaluate the building's current design. Secondly, install the One Click LCA plugin in Revit Add-Ins named One Click in Revit (step 1) and automatically import the data to One Click LCA. The second approach is the thesis prefered methodology, as one of the thesis objectives is to apply BIM technology in data evaluation.

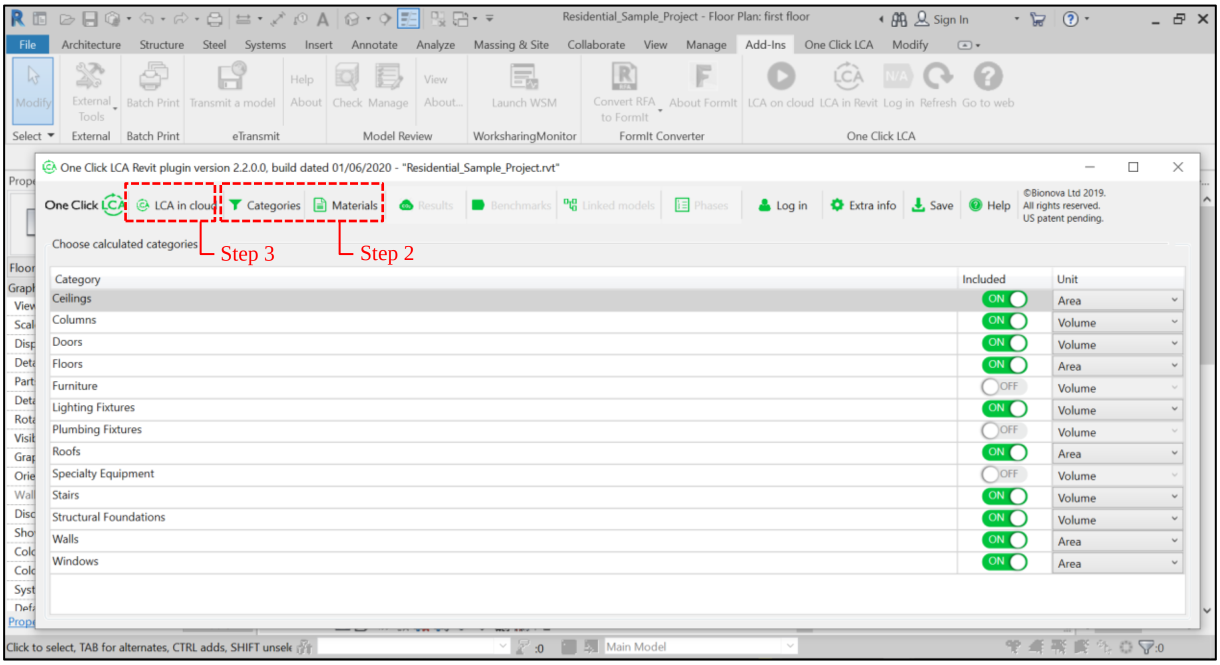


Graphics	
View Scale	Custom
Scale Value 1:	48
Display Model	Normal
Detail Level	Medium
Parts Visibility	Show Original
Detail Number	1
Rotation on Sheet	None
Visibility/Graphics ...	Edit...
Graphic Display O...	Edit...
Orientation	Project North
Wall Join Display	Clean all wall joins
Discipline	Architectural
Show Hidden Lines	By Discipline
Color Scheme Loc...	Background
Color Scheme	<none>
System Color Sche...	Edit...
Default Analysis Di	None

Figure 34. Step 1 to make the data ready to export from Revit to One Click LCA.

After pressing the LCA in Revit button, the plugin asks to choose desire categories and materials that need to be evaluated for LCA. Thus, parts of the building that are meant to be chosen and evaluated are selected from the list provided earlier in the literature review as a table "Assessed part of the building". According to Finland's Ministry of Environment, this table represents the parts of the building that needs to be included while assessing the building's life cycle. After reviewing, filtering and assigning the required categories and materials to be evaluated (step 2), the plugin allows the user to synchronize the data quickly from Revit to One

Click LCA by pressing LCA in the cloud button (step 3). The user can also add supplementary data, which is not included in the model, to the cloud easily.



One Click LCA Revit plugin version 2.2.0.0, build dated 01/06/2020 - "Residential_Sample_Project.rvt"

Step 3

Step 2

Choose calculated categories

Category	Included	Unit
Ceilings	ON	Area
Columns	ON	Volume
Doors	ON	Volume
Floors	ON	Area
Furniture	OFF	Volume
Lighting Fixtures	ON	Volume
Plumbing Fixtures	OFF	Volume
Roofs	ON	Area
Specialty Equipment	OFF	Volume
Stairs	ON	Volume
Structural Foundations	ON	Volume
Walls	ON	Area
Windows	ON	Area

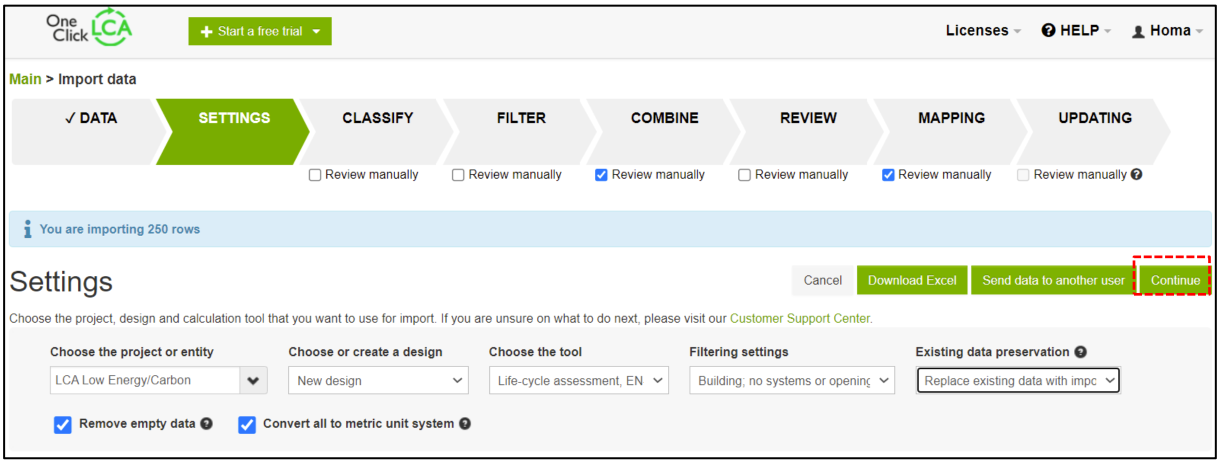
Figure 35. Steps 2 and 3 to make the data ready to export from Revit to One Click LCA.

4.3.2. Experiment Approach – One Click LCA

After the data are successfully imported to One Click LCA, six steps need to be taken to evaluate the building's life cycle and carbon emission. These steps are Setting, Classify, Filter, Combine, Review, Mapping, Updating, respectively.

Setting

After data, the first step that needs to be taken in the One Click LCA environment is Setting. The Setting is where the user chooses the *project name or entity*, *design type* (new design or already existing one), *calculation tool* (Life-cycle assessment, EN-15978 or Building carbon footprint), *filtering setting* (structure and envelop/LEED, building without building technology/BREEAM/HQE/YM, building without external areas or technology/NS3720/DGNB, building without external areas, all data, and infrastructure/all date), and *existing data preservation* (replace the existing data with imported data, add import to the existing data, and only update the quantities from the import). Figure 36 represents the setting step.



☐ Review manually ☐ Review manually ☑ Review manually ☐ Review manually ☑ Review manually ☐ Review manually

You are importing 250 rows

Settings

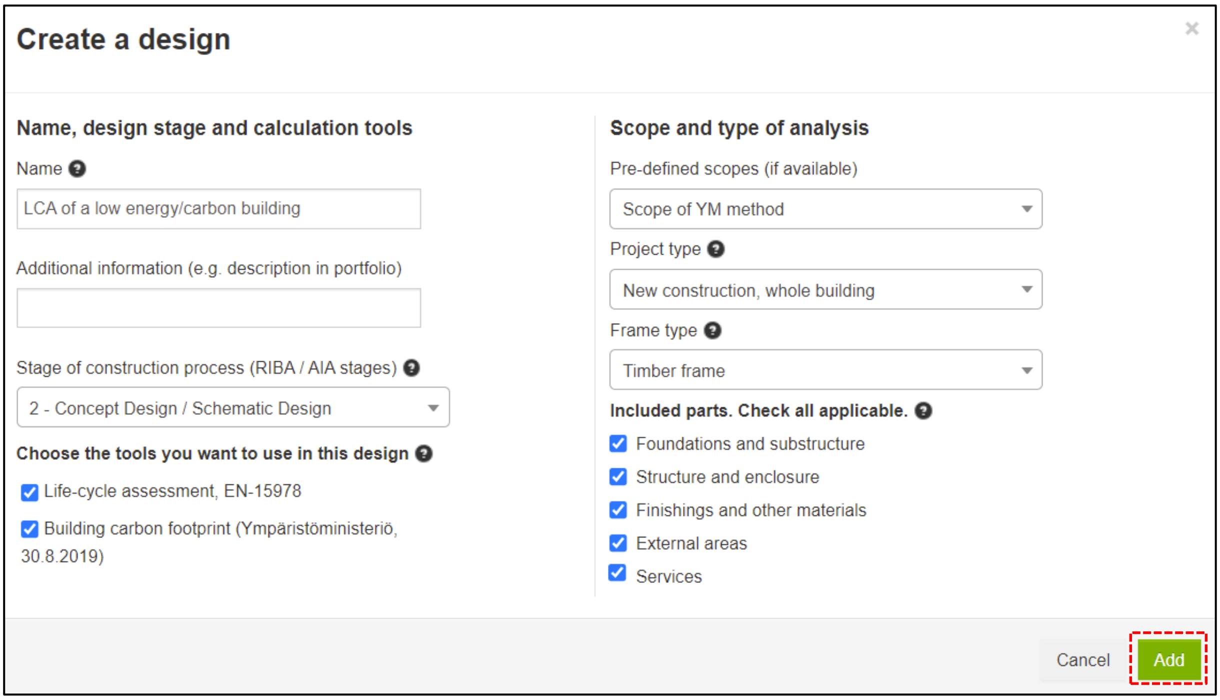
Choose the project, design and calculation tool that you want to use for import. If you are unsure on what to do next, please visit our Customer Support Center.

Choose the project or entity: LCA Low Energy/Carbon
Choose or create a design: New design
Choose the tool: Life-cycle assessment, EN
Filtering settings: Building; no systems or opening
Existing data preservation: Replace existing data with impc

☑ Remove empty data ☑ Convert all to metric unit system

Figure 36. Setting of the imported data from Revit to One Click LCA (One Click LCA ©, 2021).

After choosing an appropriate option in each part, then by clicking on Continue, the program will ask to add the design to the platform. In this step, before clicking on Add, based on Finland‘s Ministry of Environment criteria, all the critical parts of the building need to be marked for carbon footprint evaluation.



Create a design

Name, design stage and calculation tools

Name: LCA of a low energy/carbon building

Additional information (e.g. description in portfolio):

Stage of construction process (RIBA / AIA stages): 2 - Concept Design / Schematic Design

Choose the tools you want to use in this design

☑ Life-cycle assessment, EN-15978
☑ Building carbon footprint (Ympäristöministeriö, 30.8.2019)

Scope and type of analysis

Pre-defined scopes (if available): Scope of YM method

Project type: New construction, whole building

Frame type: Timber frame

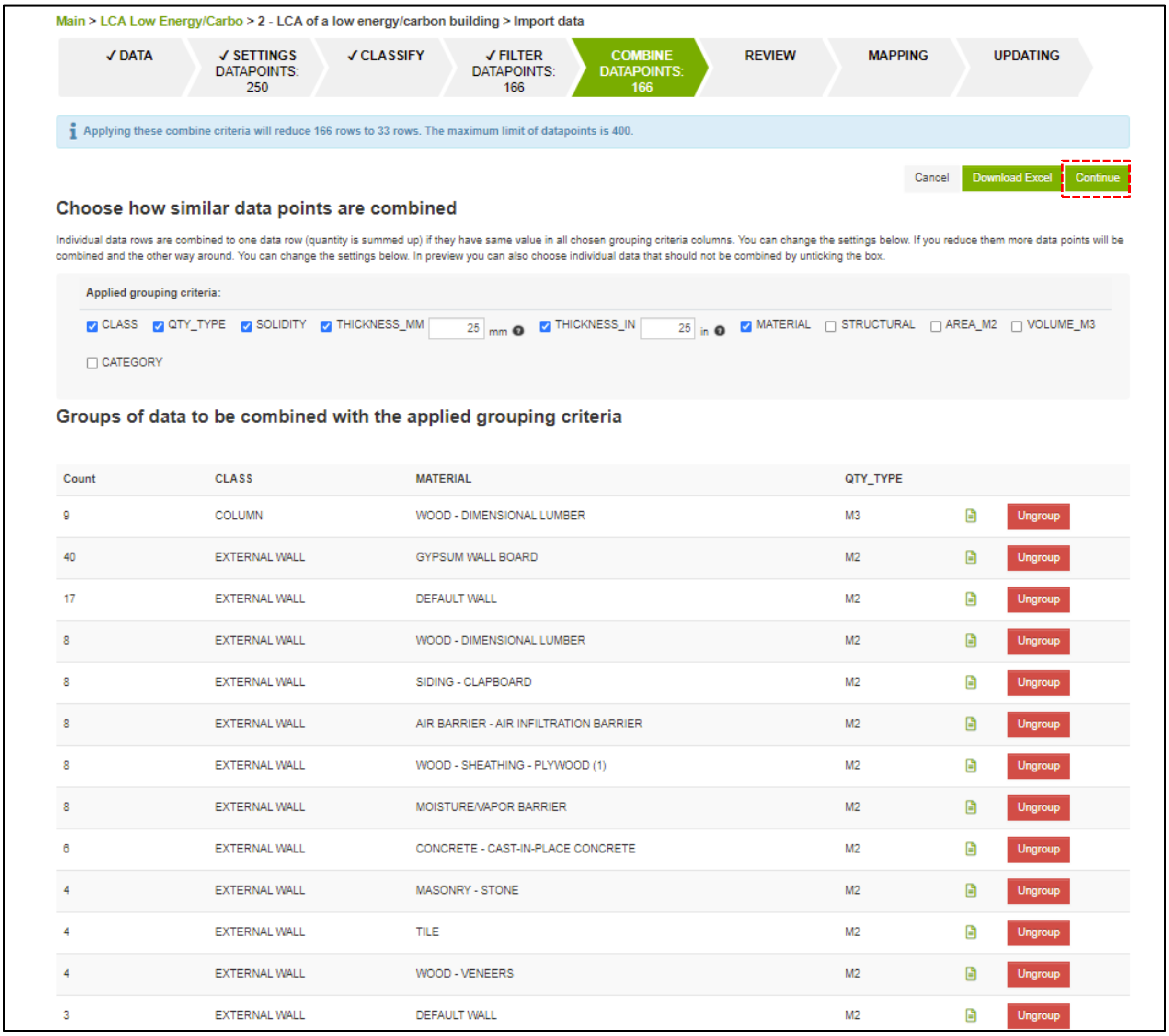
Included parts. Check all applicable.

☑ Foundations and substructure
☑ Structure and enclosure
☑ Finishings and other materials
☑ External areas
☑ Services

Figure 37. Create a design in One Click LCA (One Click LCA ©, 2021).

Combine

The software itself automatically did the two steps of Classify and Filter after choosing the suitable options in the previous step. Therefore, in the Combine step as pictured by Figure 38, it is asked if all of the grouping criterion columns have the same value, then the individual data rows will be merged into one. Besides, by unchecking certain boxes, the users inform the software not to combine specific data. Finally, the designer press Continue after checking all the required boxes to be checked.



Applying these combine criteria will reduce 166 rows to 33 rows. The maximum limit of datapoints is 400.

Choose how similar data points are combined

Individual data rows are combined to one data row (quantity is summed up) if they have same value in all chosen grouping criteria columns. You can change the settings below. If you reduce them more data points will be combined and the other way around. You can change the settings below. In preview you can also choose individual data that should not be combined by unticking the box.

Applied grouping criteria:

☑ CLASS ☑ QTY_TYPE ☑ SOLIDITY ☑ THICKNESS_MM 25 mm ☑ THICKNESS_IN 25 in ☑ MATERIAL ☐ STRUCTURAL ☐ AREA_M2 ☐ VOLUME_M3

☐ CATEGORY

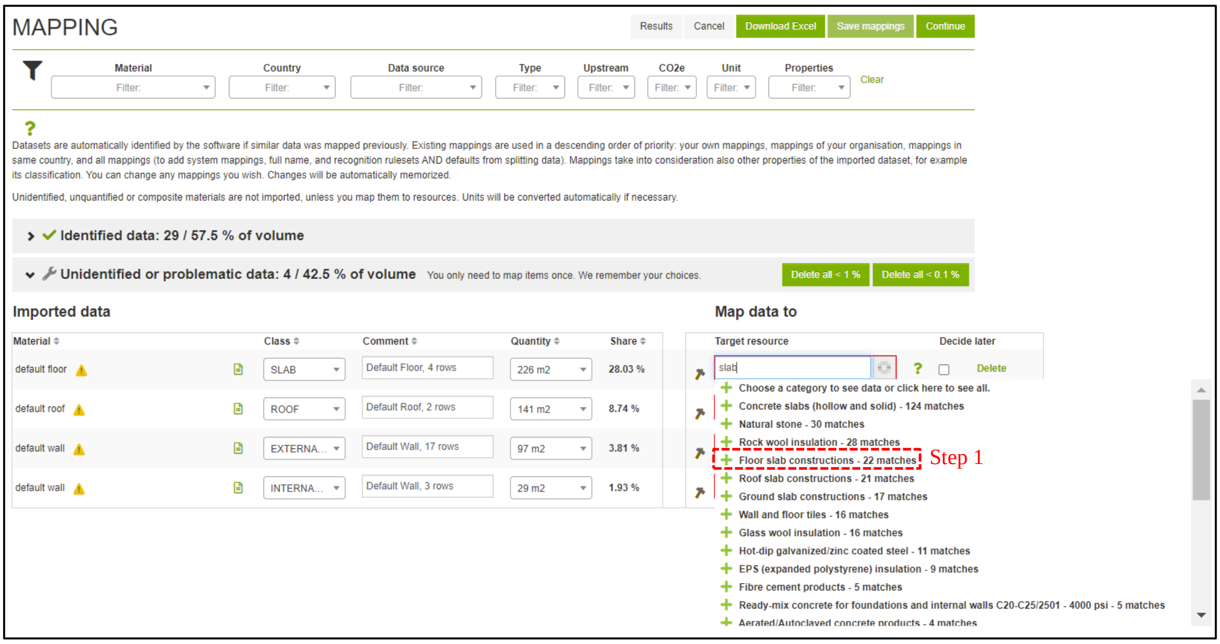
Groups of data to be combined with the applied grouping criteria

Count	CLASS	MATERIAL	QTY_TYPE		
9	COLUMN	WOOD - DIMENSIONAL LUMBER	M3	🗎	Ungroup
40	EXTERNAL WALL	GYPSUM WALL BOARD	M2	🗎	Ungroup
17	EXTERNAL WALL	DEFAULT WALL	M2	🗎	Ungroup
8	EXTERNAL WALL	WOOD - DIMENSIONAL LUMBER	M2	🗎	Ungroup
8	EXTERNAL WALL	SIDING - CLAPBOARD	M2	🗎	Ungroup
8	EXTERNAL WALL	AIR BARRIER - AIR INFILTRATION BARRIER	M2	🗎	Ungroup
8	EXTERNAL WALL	WOOD - SHEATHING - PLYWOOD (1)	M2	🗎	Ungroup
8	EXTERNAL WALL	MOISTURE/VAPOR BARRIER	M2	🗎	Ungroup
6	EXTERNAL WALL	CONCRETE - CAST-IN-PLACE CONCRETE	M2	🗎	Ungroup
4	EXTERNAL WALL	MASONRY - STONE	M2	🗎	Ungroup
4	EXTERNAL WALL	TILE	M2	🗎	Ungroup
4	EXTERNAL WALL	WOOD - VENEERS	M2	🗎	Ungroup
3	EXTERNAL WALL	DEFAULT WALL	M2	🗎	Ungroup

Figure 38. Combine the imported data from Revit to One Click LCA (One Click LCA ©, 2021).

Mapping

Mapping is one of the essential steps that require high accuracy. It provides the users with a variety of materials for construction elements listed in One Click LCA. The categories and their quantity are already extracted from the Revit file; therefore, the software asks about the target sources (step 1) such as the floor, roof, internal walls, external walls etc. (Fig. 39) and later on for the specific materials for them (step 2). The designer assigns the materials for each category based on the literature review and criteria of low energy/carbon buildings such as low U-value, thickness, timber structure, wooden stud frames, insulation, type of the building etc. More importantly, the designer needs to preferably choose the materials manufactured in the same country of the case study (Finland) to reduce embodied carbon produced by material production's impact, such as transportation. By completing all the rows and selections, the designer can move to the next step by pressing continue (Fig. 40).



Datasets are automatically identified by the software if similar data was mapped previously. Existing mappings are used in a descending order of priority: your own mappings, mappings of your organisation, mappings in same country, and all mappings (to add system mappings, full name, and recognition rulesets AND defaults from splitting data). Mappings take into consideration also other properties of the imported dataset, for example its classification. You can change any mappings you wish. Changes will be automatically memorized.

Unidentified, unquantified or composite materials are not imported, unless you map them to resources. Units will be converted automatically if necessary.

Identified data: 29 / 57.5 % of volume

Unidentified or problematic data: 4 / 42.5 % of volume You only need to map items once. We remember your choices.

Imported data

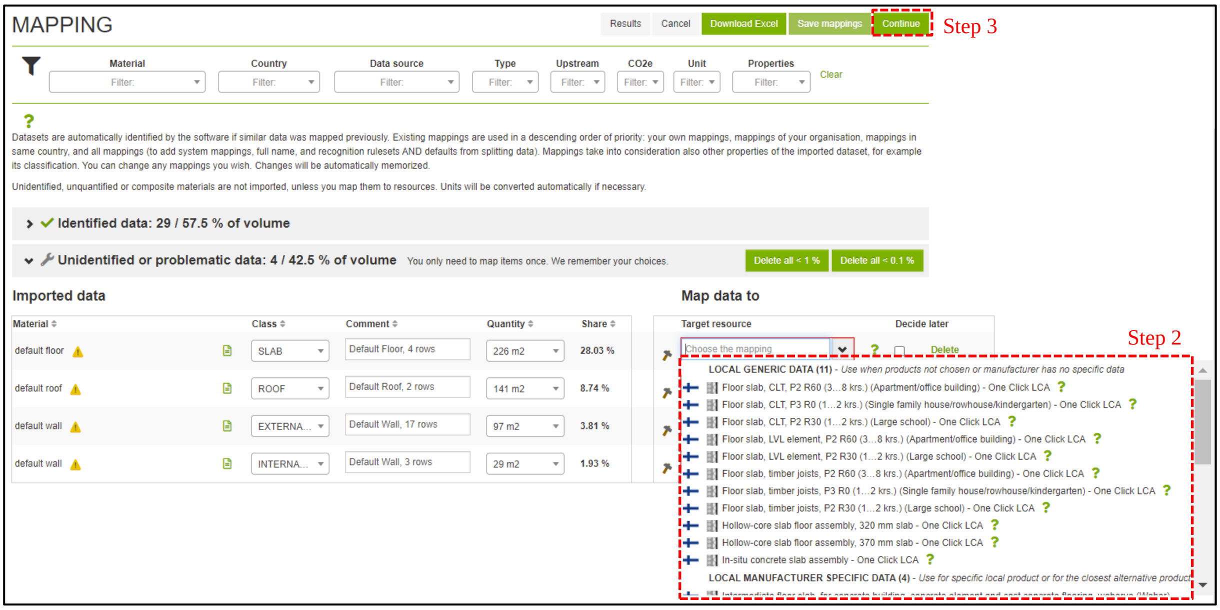
Material	Class	Comment	Quantity	Share
default floor	SLAB	Default Floor, 4 rows	226 m2	28.03 %
default roof	ROOF	Default Roof, 2 rows	141 m2	8.74 %
default wall	EXTERNA...	Default Wall, 17 rows	97 m2	3.81 %
default wall	INTERNA...	Default Wall, 3 rows	29 m2	1.93 %

Map data to

Target resource	Decide later
slab	☐ Delete

- Choose a category to see data or click here to see all.
- Concrete slabs (hollow and solid) - 124 matches
- Natural stone - 30 matches
- Rock wool insulation - 28 matches
- Floor slab constructions - 22 matches
- Roof slab constructions - 21 matches
- Ground slab constructions - 17 matches
- Wall and floor tiles - 16 matches
- Glass wool insulation - 16 matches
- Hot-dip galvanized/zinc coated steel - 11 matches
- EPS (expanded polystyrene) insulation - 9 matches
- Fibre cement products - 5 matches
- Ready-mix concrete for foundations and internal walls C20-C25/2501 - 4000 psi - 5 matches
- Aerated/Autoclaved concrete products - 4 matches

Figure 39. Step 1 in the Mapping phase; choosing the elements' category (One Click LCA ©, 2021).



Datasets are automatically identified by the software if similar data was mapped previously. Existing mappings are used in a descending order of priority: your own mappings, mappings of your organisation, mappings in same country, and all mappings (to add system mappings, full name, and recognition rulesets AND defaults from splitting data). Mappings take into consideration also other properties of the imported dataset, for example its classification. You can change any mappings you wish. Changes will be automatically memorized.

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default roof	ROOF	Default Roof, 2 rows	141 m2	8.74 %
default wall	EXTERNA...	Default Wall, 17 rows	97 m2	3.81 %
default wall	INTERNA...	Default Wall, 3 rows	29 m2	1.93 %

Map data to

Target resource	Decide later
Choose the mapping	☐ Delete

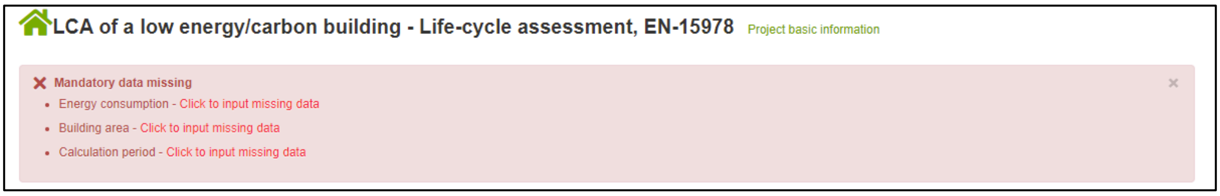
LOCAL GENERIC DATA (11) - *Use when products not chosen or manufacturer has no specific data*

- Floor slab, CLT, P2 R60 (3…8 krs.) (Apartment/office building) - One Click LCA
- Floor slab, CLT, P3 R0 (1…2 krs.) (Single family house/rowhouse/kindergarten) - One Click LCA
- Floor slab, CLT, P2 R30 (1…2 krs.) (Large school) - One Click LCA
- Floor slab, LVL element, P2 R60 (3…8 krs.) (Apartment/office building) - One Click LCA
- Floor slab, LVL element, P2 R30 (1…2 krs.) (Large school) - One Click LCA
- Floor slab, timber joists, P2 R60 (3…8 krs.) (Apartment/office building) - One Click LCA
- Floor slab, timber joists, P3 R0 (1…2 krs.) (Single family house/rowhouse/kindergarten) - One Click LCA
- Floor slab, timber joists, P2 R30 (1…2 krs.) (Large school) - One Click LCA
- Hollow-core slab floor assembly, 320 mm slab - One Click LCA
- Hollow-core slab floor assembly, 370 mm slab - One Click LCA
- In-situ concrete slab assembly - One Click LCA

LOCAL MANUFACTURER SPECIFIC DATA (4) - *Use for specific local product or for the closest alternative product*

Figure 40. Step 2 and 3 in the Mapping phase; selection the appropriate material for each building element and then continue (One Click LCA ©, 2021).

After Mapping, the software shows the mandatory missing data to be provided, such as the amount of energy consumption of the building, area of the building, and calculation period for life cycle assessment (Fig. 41).


LCA of a low energy/carbon building - Life-cycle assessment, EN-15978

Project basic information

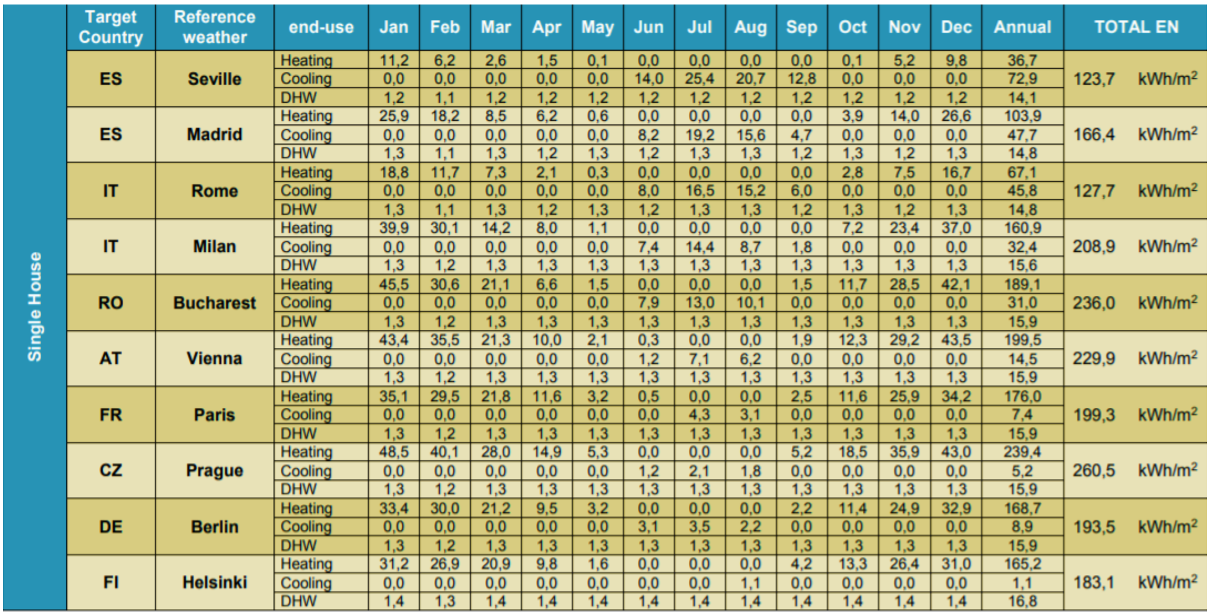
Mandatory data missing

- Energy consumption - Click to input missing data
- Building area - Click to input missing data
- Calculation period - Click to input missing data

Figure 41. Required missing data to evaluate the building's life cycle and carbon footprint (One Click LCA ©, 2021).

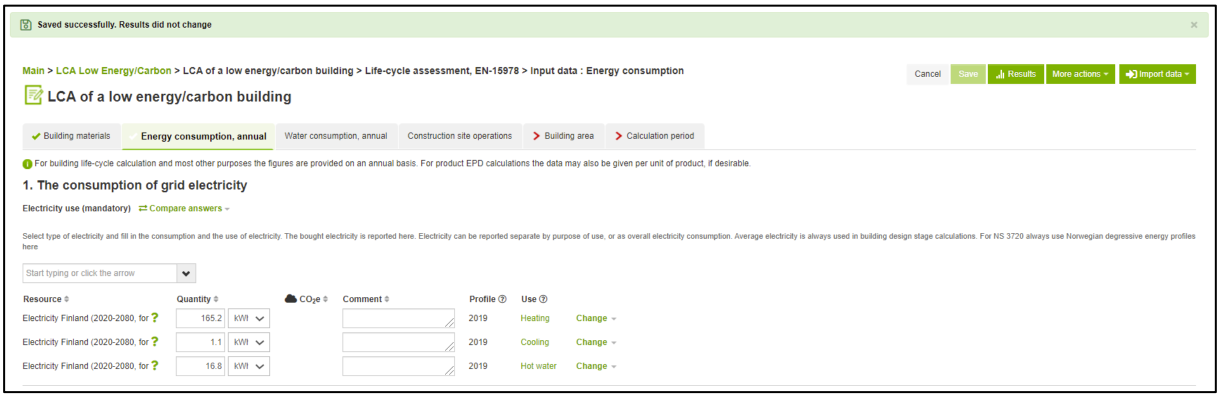
As mentioned in the literature review, the amount of supplied energy impacts the carbon emission of the building. Moreover, according to the Finnish Ministry of Environment, the amount of energy consumption for residential buildings can be converted to the amount of carbon emission by having the emission coefficient of the energy type. However, the other factor that needs to be considered is the amount of energy for heating, cooling, and domestic hot water (DHW). Table 4 demonstrates the amount of simulated energy for a single house in different countries, including Finland.

Table 4. The energy needed for Cooling, Heating and DHW in different target countries for a single house (Zangheri et al., 2014, p. 67).



	Target Country	Reference weather	end-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	TOTAL EN
Single House	**ES**	**Seville**	Heating	11,2	6,2	2,6	1,5	0,1	0,0	0,0	0,0	0,0	0,1	5,2	9,8	36,7	123,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	14,0	25,4	20,7	12,8	0,0	0,0	0,0	72,9	
			DHW	1,2	1,1	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	14,1	
	ES	**Madrid**	Heating	25,9	18,2	8,5	6,2	0,6	0,0	0,0	0,0	0,0	3,9	14,0	26,6	103,9	166,4 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,2	19,2	15,6	4,7	0,0	0,0	0,0	47,7	
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8	
	IT	**Rome**	Heating	18,8	11,7	7,3	2,1	0,3	0,0	0,0	0,0	0,0	2,8	7,5	16,7	67,1	127,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,0	16,5	15,2	6,0	0,0	0,0	0,0	45,8	
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8	
	IT	**Milan**	Heating	39,9	30,1	14,2	8,0	1,1	0,0	0,0	0,0	0,0	7,2	23,4	37,0	160,9	208,9 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,4	14,4	8,7	1,8	0,0	0,0	0,0	32,4	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,6	
	RO	**Bucharest**	Heating	45,5	30,6	21,1	6,6	1,5	0,0	0,0	0,0	1,5	11,7	28,5	42,1	189,1	236,0 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,9	13,0	10,1	0,0	0,0	0,0	0,0	31,0	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	AT	**Vienna**	Heating	43,4	35,5	21,3	10,0	2,1	0,3	0,0	0,0	1,9	12,3	29,2	43,5	199,5	229,9 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	7,1	6,2	0,0	0,0	0,0	0,0	14,5	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	FR	**Paris**	Heating	35,1	29,5	21,8	11,6	3,2	0,5	0,0	0,0	2,5	11,6	25,9	34,2	176,0	199,3 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	4,3	3,1	0,0	0,0	0,0	0,0	7,4	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	CZ	**Prague**	Heating	48,5	40,1	28,0	14,9	5,3	0,0	0,0	0,0	5,2	18,5	35,9	43,0	239,4	260,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	2,1	1,8	0,0	0,0	0,0	0,0	5,2	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	DE	**Berlin**	Heating	33,4	30,0	21,2	9,5	3,2	0,0	0,0	0,0	2,2	11,4	24,9	32,9	168,7	193,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	3,1	3,5	2,2	0,0	0,0	0,0	0,0	8,9	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	FI	**Helsinki**	Heating	31,2	26,9	20,9	9,8	1,6	0,0	0,0	0,0	4,2	13,3	26,4	31,0	165,2	183,1 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,1	0,0	0,0	0,0	0,0	1,1	
			DHW	1,4	1,3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	16,8	

Therefore, the amount of energy consumption was extracted from the table above and inserted into the software.



Saved successfully. Results did not change

Main > LCA Low Energy/Carbon > LCA of a low energy/carbon building > Life-cycle assessment, EN-15978 > Input data : Energy consumption

LCA of a low energy/carbon building

For building life-cycle calculation and most other purposes the figures are provided on an annual basis. For product EPD calculations the data may also be given per unit of product, if desirable.

1. The consumption of grid electricity

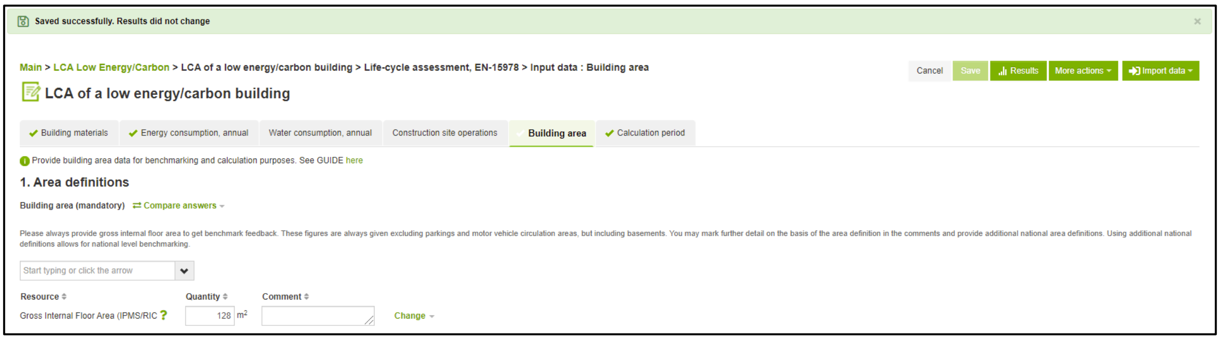
Electricity use (mandatory)

Select type of electricity and fill in the consumption and the use of electricity. The bought electricity is reported here. Electricity can be reported separate by purpose of use, or as overall electricity consumption. Average electricity is always used in building design stage calculations. For NS 3720 always use Norwegian degressive energy profiles here

Resource	Quantity		CO₂e	Comment	Profile	Use	
Electricity Finland (2020-2080, for	165.2	kWl			2019	Heating	Change
Electricity Finland (2020-2080, for	1.1	kWl			2019	Cooling	Change
Electricity Finland (2020-2080, for	16.8	kWl			2019	Hot water	Change

Figure 42. Table 4. Energy consumption of electricity grid (One Click LCA ©, 2021).

The other missing data is the building area. Then, according to general building information, the gross internal floor area of the sample building is 128 m^2.



Saved successfully. Results did not change

Main > LCA Low Energy/Carbon > LCA of a low energy/carbon building > Life-cycle assessment, EN-15978 > Input data : Building area

LCA of a low energy/carbon building

Provide building area data for benchmarking and calculation purposes. See GUIDE here

1. Area definitions

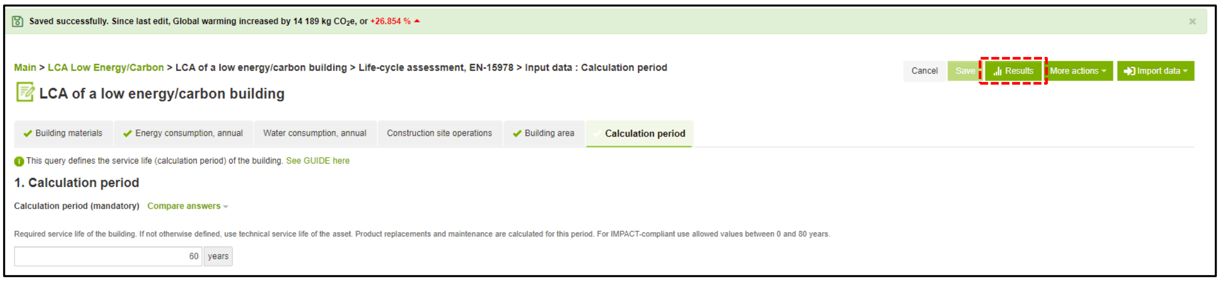
Building area (mandatory)

Please always provide gross internal floor area to get benchmark feedback. These figures are always given excluding parkings and motor vehicle circulation areas, but including basements. You may mark further detail on the basis of the area definition in the comments and provide additional national area definitions. Using additional national definitions allows for national level benchmarking.

Resource	Quantity	Comment	
Gross Internal Floor Area (IPMS/RIC	128 m^2		Change

Figure 43. Area definition of the sample building (One Click LCA ©, 2021).

The calculation period was the last missing data before data evaluation. For this purpose, the period of 60 years as a calculation period for the service life of the building was considered. After this step, by pressing on Results, the evaluation of the building's life cycle assessment and carbon footprint will be presented by the software.



Saved successfully. Since last edit, Global warming increased by 14 189 kg CO_2e, or +26.854 %

Main > LCA Low Energy/Carbon > LCA of a low energy/carbon building > Life-cycle assessment, EN-15978 > Input data : Calculation period

LCA of a low energy/carbon building

This query defines the service life (calculation period) of the building. See GUIDE here

1. Calculation period

Calculation period (mandatory)

Required service life of the building. If not otherwise defined, use technical service life of the asset. Product replacements and maintenance are calculated for this period. For IMPACT-compliant use allowed values between 0 and 80 years.

60 years

Figure 44. Calculation period for the building's service life (One Click LCA ©, 2021).

4.4. Data Evaluation – One Click LCA

As mentioned, life cycle analysis and carbon emission assessment of the case study is done via a BIM tool named One Click LCA Calculator. The program complies with the EN 15978 standard in each aspect. ITB has third-party validated One Click LCA for compliance with the following LCA standards: ISO 21929, EN 15978, ISO 21931–1, EN 15804, ISO 14040.

One Click LCA combines data from almost all EPD systems accessible across the world. The Environmental Product Declaration System (EPDS) is a global initiative for environmental declarations. Environmental Product Declarations (EPD) provide transparent, verifiable, and comparable information on a product's or service's life-cycle environmental effect. EPDs are thorough technical descriptions of building goods that conform with ISO 14025 and/or EN15804 requirements and are submitted into the One Click LCA database (kuittinen, 2019). Evaluation of the case study contributes to the following results:

- Overview of LCA principals
- Importance of calculating CO_2 emission and environmental impacts of the building
- Importance of a low energy/carbon building design

In order to emphasize the result of LCA and carbon emission of a low energy/carbon building, a comparison methodology was applied to compare the result of life cycle assessments and carbon emission between a low energy/carbon building (stud-frame) and a Conventional building (concrete-frame). For the Conventional building, non of the considerations of the Data Collection section, such as materials, building envelope, U-value, insulation types, energy consumption etc., was applied, and the building’s model was just imported from Revit to One Click LCA and treated as a standard building. The following sections will compare the results of both designs.

4.4.1. Life Cycle Assessment

- **System boundaries and Scope**

Before evaluation of the case studies, it is crucial to consider the scope of the analysis. Therefore, as mentioned in the literature review, the following table represents the stages in which the life cycle assessment of both buildings was included according to EN 15804.

Table 5. Life cycle assessment boundaries and scope (One Click LCA ©, 2021).

Product Stage			**Construction Process Stage**		**Use Stage**							**End-of-Life Stage**				**Benefits and loads beyond the system boundary**		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
x			x	x	x					x	x	x				x		

- **Analysis Material Scope**

One Click LCAanalyzed the building's life cycle according to the elements named in Tab. 6. These elements are based on the table of assessed part of the building provided by the Finnish Ministry of Environment in the literature review (Kuittinen, 2019).

Table 6. Life cycle assessment - material scope (One Click LCA ©, 2021).

Element	**Included**
SUPERSTRUCTURE	
Frame	Yes
Upper floors	Yes
Roof	Yes
Stairs	Yes
External Walls	Yes
Windows & External doors	Yes
Internal Walls and Partitions	Yes
Internal Doors	Yes
INTERNAL FINISHES	
Wall Finishes	Yes
Floor Finishes	Yes
Ceiling Finishes	Yes
BUILDING FITTINGS & FURNISHINGS	
Fixed fittings and equipment	Yes

SERVICES	
Sanitary Fittings	No
Services Equipment	Yes
Disposal Installations	Yes
Water Installations	Yes
Heat Source	Yes
Space Heating and Air Treatment	Yes
Ventilation Systems	Yes
Electrical Installations	Yes
Gas Installations	Yes
Lift Installations	No
Protective Installations, inc. internal CCTV	No
Communication Installations	No
Specialist Installations	No
EXTERNAL WORKS	
Site works	No
Drainage	No
External services	No

- **Life Cycle Impact Assessment**

the life cycle of both low energy/carbon and Conventional buildings were assessed according to seven impact categories. The description of these categories was mentioned in the literature review. One click LCA calculated the life cycle assessment of both buildings accordingly, and the results are summarized in Table 7 and Figure 45.

Table 7. Life cycle impact categories (One Click LCA ©, 2021).

Impact category	**Unit**	**Low energy/carbon building**	**Standard building**
Global warming potential (GWP)	kgCO$_2$ eq	67030	347377
Acidification potential (AP)	kgSO$_2$ eq	1052.91	1765.81
Eutrophication potential (EP)	kgPO$_4$-eq	52.33	138.41
Ozone depletion potential (ODP)	kgCFC$_{11}$eq	0.0085	0.01
Ozone formation of lower atmosphere (POCP)	kgC$_2$H$_4$eq	52.76	155.33
Total use of primary energy	MJ	1692645.98	5926462.59
Bio-CO2 storage Biogenic carbon storage	kgC$_2$bio	77140.38	45843.68

Figure 45. Comparison of all impact categories between the low energy/carbon building and the Conventional building (One Click LCA ©, 2021).

Illustrated in Fig. 45 and Table 7, the low energy/carbon building has a considerably lower percentage of impact in each impact category. Conventional building significantly produces more GHG, carbon footprint, and therefore cause more risk and damages for the ecosystem. By Considering the amount of total use of primary energy, the Conventional building has consumed almost 3.5 times more energy than a low energy/carbon building. Likewise, the Conventional building has nearly half bio-CO_2 storage than a low energy/carbon building, which means it contributes less to reduce the amount of CO_2 in the atmosphere. The more detailed results of the impact assessment are attached to Appendix C, p 86.

- **Life Cycle Assessment - Stages**

Depicted by Fig. 46, One Click LCA analysed the amount of CO_2 emission (kg) based on the quality of the input data from Revit and assigned materials in One Click LCA in different life cycle stages. These stages include A1-A3 (materials), A4 and A4-leg 2 (transportation), A5 (construction), B1-B5 (maintenance and replacement), B6 (energy), B7 (water), and C1-C4 (end of life).

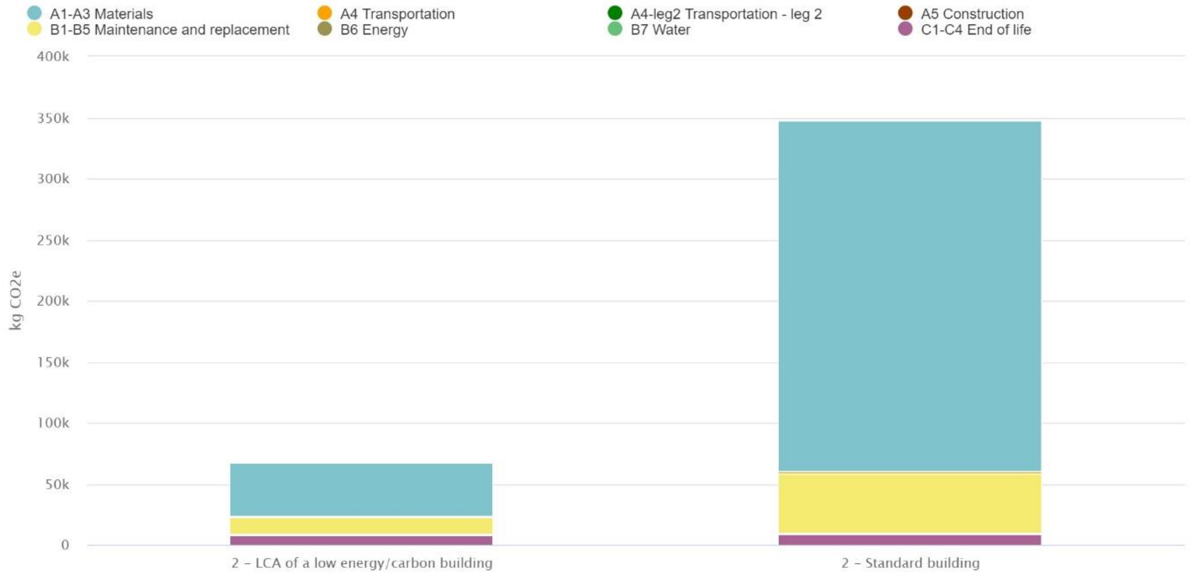


Figure 46. Comparison of life cycle stages between the low energy/carbon building and the Conventional building (One Click LCA ©, 2021).

As shown in the bar chart (Fig. 46), stage A1-A3 (materials) has the highest production CO2 in both buildings' life cycles. However, the CO_2 emission caused by the Conventional /standard building (370 k) is hugely more than a low energy/carbon building (70 k).

- **Life Cycle Assessment – Elements**

Building elements and construction materials are essential in energy loss, emitting CO2 and building a life cycle. These elements are classified into nine groups: external walls and facade, Foundation, horizontal elements (floor slabs, ceiling, beams, etc.), vertical elements (columns), windows and doors, internal walls, building system, and electricity use.

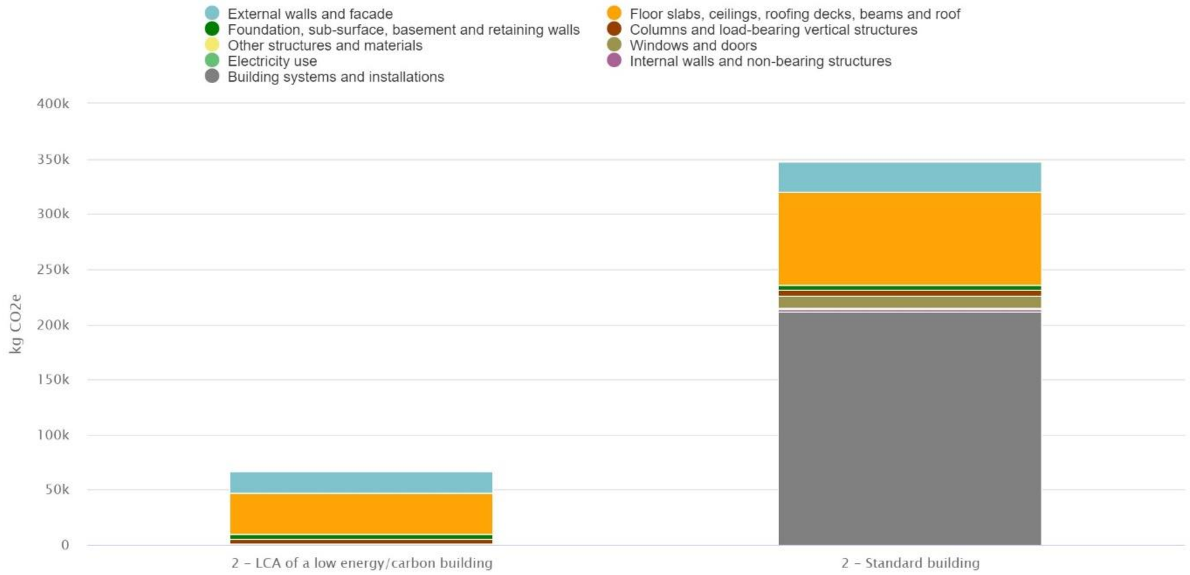


Figure 47. Comparison of Global warming, kg CO2e - Elements between the low energy/carbon building and the Conventional building (One Click LCA ©, 2021).

As evaluated by the One Click LCA tool (Fig. 47), the Conventional /standard building undoubtedly has a higher share in consuming energy, energy loss, emitting CO_2 in its life cycle period. Nevertheless, lower CO_2 emission and energy consumption are devoted to the low energy/carbon building. From all the construction materials, horizontal elements, including slabs, roof decks, ceilings, and beams, have a more significant portion of producing CO_2.

4.4.2. Building Carbon Footprint

As the evaluation of Conventional buildings and low energy/carbon building indicates, there is a massive difference between the amount of carbon emission and the life cycle of the two buildings.

- **Embodied carbon**

As mentioned in the literature review, Embodied carbon of a building depends on two main factors, first low-energy/carbon materials and second, the type of the building and construction methods. As Figures 48 and 49 represent, the embodied carbon of the low energy/carbon building stands as grade A, while the embodied carbon benchmark for the Conventional building stands as grade G.

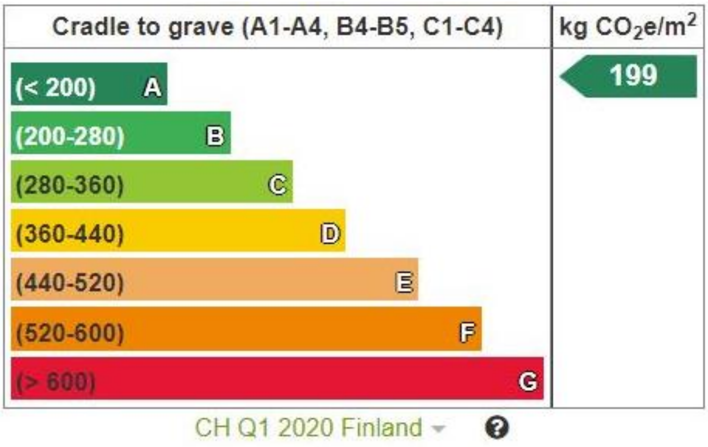


Figure 48. Embodied carbon benchmark of a low energy/carbon building (stud-frame), (One Click LCA ©, 2021).

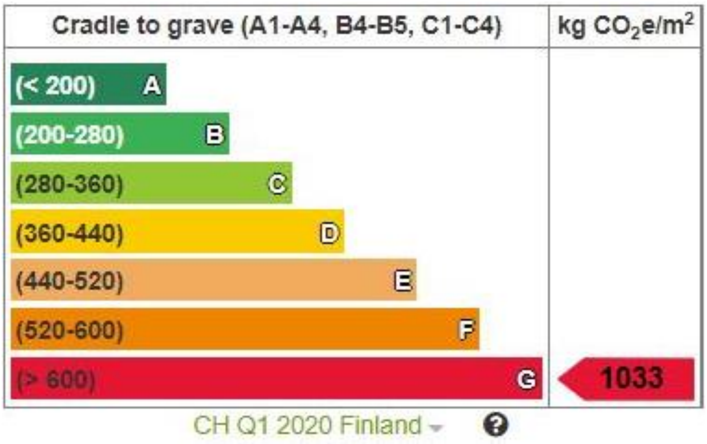


Figure 49. Embodied carbon benchmark of a Conventional building (concrete-frame) (One Click LCA ©, 2021).

It should be noted that the calculation period for both buildings was assumed as 60 years, and based on the quantity of materials, replacement of materials, transport of the materials, if the home country does not provide them, the carbon benchmark will differ.

- **Embodied Carbon by Life Cycle Stage**

As mentioned in Fig. 5 in the literature review (Kuittinen, 2019), the life cycle has four stages of A1-A3 (product stage), A4-A5 (construction process), B (use stage), and C (end-of-life stage). One Click LCA generates a pie chart for each building representing the distribution of embodied carbon in different life cycle stages. Figures 50 and 51 show the result of the analysis.

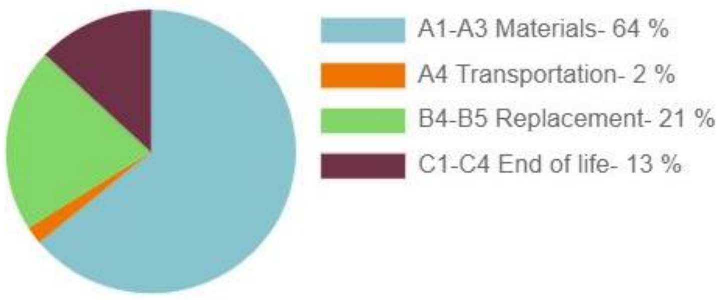


Figure 50. Embodied carbon by life cycle stages in a low energy/carbon building (stud-frame) (One Click LCA ©, 2021).

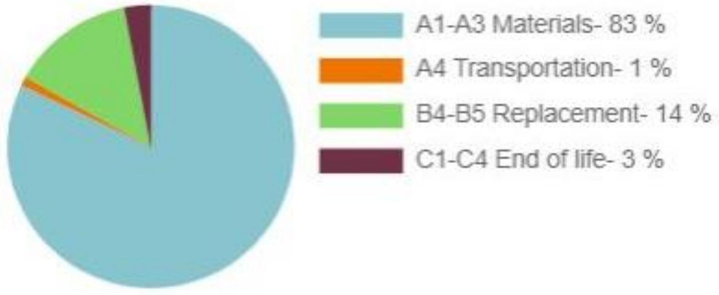


Figure 51. Embodied carbon by life cycle stages in a Conventional building (concrete-frame) (One Click LCA ©, 2021).

As can be seen clearly, stage A1-A3 (product stage) is the biggest and A4 (transportation) is the minor stage distributing embodied carbon in both buildings. However, as a comparison, the amount of embodied carbon in stage A1-A3 in the low energy/carbon building (64%) is significantly lower than the Conventional building (83%).

- **Embodied carbon by structure – Stage A1-A3**

The charts below represent the distribution of embodied carbon of both buildings in the stage of A1-A3 (product stage) and based on the structure and elements of the buildings.

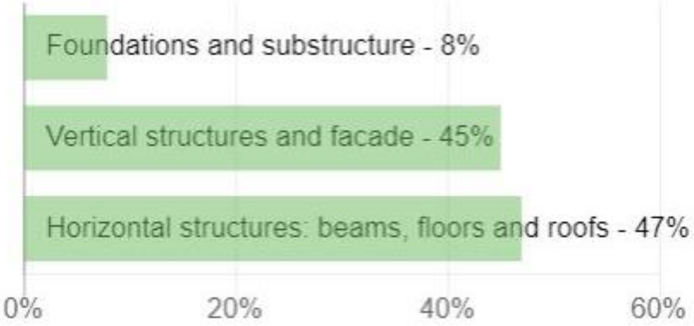


Figure 52. Embodied carbon by structure in a low energy/carbon building (stud-frame) (One Click LCA ©, 2021).

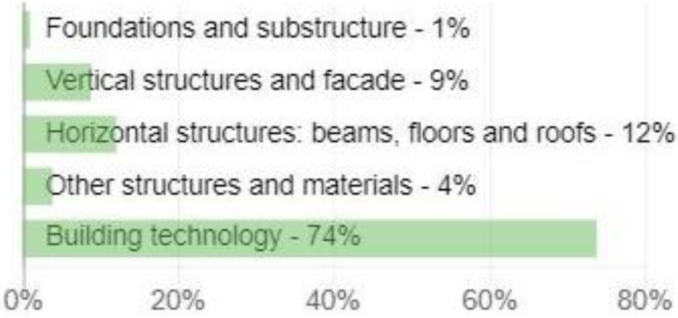


Figure 53. Embodied carbon by structure in a Conventional building (concrete-frame) (One Click LCA ©, 2021).

By comparing the two charts, the problematic part is the building technology for the conventional building (Fig. 53). It emphasizes the importance of the building's energy technology, such as improving the building airtightness, insulated walls and roof, heat pumps system etc., which were mentioned in the literature review. On the other hand, this issue is solved in a low energy/carbon building; therefore, the graph focuses on the structure and elements used in the product phase. As Fig. 52 shows, the highest amount of embodied carbon is devoted to horizontal structures such as beams, floors and roofs (47%). Vertical structure and facade stand as the second-largest distribution of embodied carbon by 45%, and finally, foundation and sub-structure represent the lowest percentage (8%) of embodied carbon distribution in stage A1-A3.

4.4.3. Economic Benefits

One Click LCA evaluated the social cost of carbon for both scenarios. The social cost of carbon is a calculation method of additional emission of CO2e such as human health and non-market impacts. In this method, each ton of CO_2 emission has a cost that helps decision-makers to evaluate if their designed particular actions to decrease are justified. In scenario number one, which is a low energy/carbon building, the social cost of carbon is 3,352 € per ton of CO_2 emission. This number, however, is 17.369 € per ton CO_2 for scenario number 2, which is a Conventional building.

In other words, if the Conventional building which has a higher cost, reduces the project design's emissions, for instance, by 1000 tons through applying new technology, energy reduction approaches, different construction materials and processes, therefore the investment money for the reduction of CO_2 emissions can be justified up to 17,367 €.

This evaluation helps a lot make any action of the project economic sense and understand how much money could be saved if, from the early stages of design, all aspects regarding lowering the energy consumption and carbon emission be taken into account.

4.5. Findings' Summary

The main finding of the thesis is that it proved the efficiency of a low energy/carbon building in LCA comparing to a conventional building. However, there are several other outcomes of the research and the case study evaluations, which are classified into the following items:

Importance of Design

It is critical to assess a building's efficiency in terms of energy and carbon emission during the design period to ensure that it consumes the least amount of energy and has the best possible performance before it is constructed, as any modifications made later would incur a high expense and waste of resources. From the case study analysis, it is clear that the design of the building makes a massive difference in buildings life cycle effectiveness and carbon benchmark, from benchmark A (199 kg CO_2e/m^2) for a low energy/carbon building to benchmark G (1033 kg CO_2e/m^2) for a Conventional building. The designer, therefore, has a key role in identifying the type of construction, area, service life, energy demand, and construction materials in the early stages.

Importance of Energy Demand

Energy has a direct relation with producing CO_2. Multiplying the estimated consumption of the supplied energy of a building to the emission coefficient for various types of energy equals energy’s carbon footprint. As specified in the literature review, a low energy/carbon building consumes 53.4% less energy than a conventional building. Thus, lowering the energy demand/consumption leads to the reduction of CO_2 emissions. Consequently, a building's energy management is another pivotal factor that needs to be met in the early design stages.

Importance of Construction Materials and Elements

The analysis results indicate that construction materials and energy demand significantly impact the buildings' life cycle. Therefore, the more the design materials and elements match with low energy/carbon building criteria, the less it causes CO_2 and carbon footprints. Besides, horizontal elements of a building (such as slabs) account for a significant portion of a building's embodied carbon and CO_2 emissions. By reducing net slab thickness by 10 cm, the building envelope height is decreased by the same amount, saving materials from slabs and walls and energy through reduced conductive loss. In concrete building (scenario two), one excellent practice can be employing new technology such as hollow core slabs and Bubbledeck. These modifications can minimize embodied impacts throughout the course of a building's life cycle.

Importance of Life Cycle Stages

Based on the investigation's result, the amount of CO_2 emission and embodied carbon was different in each life cycle stage for both buildings' life cycle. From all the stages, transportation (A4) has the least, and material production (A1-A3) has the highest portion in distributing embodied carbon.

Importance of BIM Tools

Undoubtedly, BIM technology has served enormously to yield the desired results for this research. As mentioned before, there is an option to insert the data from Revit to One Click LCA software by extracting an Excel sheet from all the materials and components of the project and importing them manually to the analysis platform. Thanks to technology and BIM tools, it could be difficult and complicated to synchronize the data from Revit software to One Click LCA platform.

Economic Benefits

Providing energy causes expenses, so why not make energy from a building rather than spend money on it to provide energy. Furthermore, constructing a low energy/carbon building will yield economic benefits in the future, as the building demands less energy and emits less CO_2. Analysis results of the case study also prove that the more project is precise in terms of energy and carbon emission factors, the less cost it will make in for the investor.

5. CONCLUSION

Life Cycle Assessment (LCA) is an evaluation system, which can be used for both new construction and existing projects. This evaluation could be carried out in tandem with estimations of the building's energy efficiency. In theory, there are four stages to a life cycle; material production, building construction, usage/renewal, demolition and disposal. Each phase of a building's life cycle is also made up of several separate process stages. Each phase generates energy flows and material as a result of resource extraction from the environment, generation and supply of energy, transportation, assembly on-site, removal, and consumption. Therefore, evaluation of a building's life cycle is a complicated process.

The aim of this thesis, as mentioned in chapter one, was to evaluate the LCA of a low energy/carbon building using BIM tools. In order to understand the effectiveness of a building's life cycle, the first step is to get acquainted with the design principles with minimum energy consumption and fewer carbon emissions through a systematic review of the relevant literature. This step was done in this research through chapter two. Chapter two represented the central theoretical database concerning building's life cycle assessment, the role of carbon footprint in LCA, the relation of energy and carbon emission in a low energy/carbon building, and last but not least, clarifying the energy-relevant parameters in buildings' LCA.

Construction projects are getting more complicated and difficult to handle, and more construction workers are becoming acquainted with Building Information Technology (BIM) as technology advances. BIM is a new technique that is recently applied and outperforms conventional computer-aided programming in terms of accuracy and interoperability. Thus, to figure out how the construction industry and design can get benefits from BIM tools, chapter three is devoted to the introduction of BIM how BIM can be applicable in LCA analysis of a low energy/carbon building. To do so, first, a brief history of computer-aided techniques was introduced, the application of BIM in LCA was explained. Revit and One Click LCA are two major tools associated with and supported by the BIM platform. The purpose of One Click LCA is to provide tools and solutions that allow all actors in the building sector to quickly and easily analyze environmental consequences. Life Cycle Assessment, Life Cycle Costing, developing low-carbon and more circular projects and getting green building certifications are all made more accessible with One Click LCA project-level tools.

As the thesis has targeted to apply the latest technology for analysing the LCA, the research employed using BIM tools as a bridge between theory and practice. In other words, by application of BIM tools like using Revit and One Click LCA, the research proved the reliability and effectiveness of BIM tools in LCA analysis. This objective was achieved through chapter four, which was meant to evaluate a sample design made by Revit software and analyze it from two different scenarios. Scenario number one was to treat the building as a low energy/carbon building with a stud frame, and scenario number two was to treat the building as a conventional building with a concrete structure. In order to analyze the scenarios, after connecting One Click LCA to Revit by installing the plugin, the model had to be prepared to export from Revit and import to One Click LCA; this step is called data collection.

Data preparation had two stages, first data had to be sorted and selected in Revit, and then this information was ready to be imported to One Click LCA through BIM linkage. After importing the data to One Click LCA, the software takes seven stages to prepare the data for LCA analysis; this step was done by experiment approach – One Click LCA. Life cycle assessment, building carbon footprint, and economic benefits of the assessment were presented after data evaluation. Data evaluation represented the analysis of the sample building and compared the results for both scenarios of a low energy/carbon and a Conventional building. Finally, the summary of findings was included at the end of chapter four.

The thesis has proposed four research questions to be answered through this investigation and analysis; the answers are:

Q_1: Which design strategies and materials should be adopted to decrease energy demand and consequently CO_2 emission and negative impacts of buildings on the environment?

In order to achieve a reduction in energy demand and CO_2 emission, which are the factors affecting a building’s LCA, two main parameters must be taken into account; *construction materials* and *the design*. Considering construction materials, their production, thermal insulation, transportation, energy losses, maintenance, repair and replacement, and recycling are the factors of importance. Likewise, considering the design of a building, load control, maximising building efficiency, building envelop, building technology, etc., must be considered.

Q2: How to analyze buildings‘ LCA and carbon emissions in the use phase?

LCA can be evaluated via BIM tools like One Click LCA. This software enables the designer to have measure and control the impact of carbon emissions from a building and/or an infrastructure not only in the use phase but also in three other phases such as the production of materials, transportation, and final disposal.

Q3: What is the role of BIM tools in LCA?

As experienced in this research, Building Information Modelling (BIM) facilitates the implementation of LCA. Moreover, by the application of BIM in the early stages of design, the decision-making process of the project will be empowered.

Q4: What are the benefits of LCA of a low energy/carbon building?

Life Cycle Assessment (LCA) of a low energy/carbon building and comparing it with a Conventional building yielded both environmental and financial benefits. Environmentally, evaluating a building’s life cycle makes the designer aware of the consequences of the design and how environmentally friendly is the design in terms of energy consumption, carbon footprint, and CO_2 emission. Economically, it calculates the amount of money the project can save by improving its standards. In the end, the building can also be certified as LEED and BREEAM, which means it achieved an environmental building permit.

Last but not least, this study attempted to highlight the value of low energy/carbon buildings as a method to fight climate change, maintain a sustainable atmosphere, reduce greenhouse emissions and fossil fuel reliance, and conserve natural resources for future generations.

5.1. Recommendation

Building Life Cycle Assessment (LCA) is a comprehensive evaluation. It includes different phases from raw material extraction to end of life and disposal. In this study, all the phases were equally treated; however, it is recommended if more focus is on the Use phase. Since in this phase, inhabitants' behaviour and lifestyle may impact energy consumption and carbon emission of the building.

Additionally, although the LCA of a building provides designers and decision-makers with environmental impact, it lacks the total budget required for the specific materials and elements it recommends. Therefore, it is recommended that next to each material shown in cross menue be selescted for each building element, the price is also indicated. This enables the designer to think about the project’s budget and cost overview at the same time.

One Click LCA is a BIM advance platform, which enables designers to control the project from the early phases environmentally. However, more focus is on Carbon footprint and CO_2 emissions. It is recommended to add more emphasis on the energy section of the software. For instance, if the model creates energy from PV panels or any green technology, it can also be mentioned as a source of energy and be included in evaluations. Besides, it is also recommended if One Click LCA may provide the designers with the required amount of energy demand based on the imported data from the other BIM application like Revit or Solibri.

One Click LCA is a semi-automated software, and material selection for each building element is made manually. Thus, for massive projects or infrastructures, it is recommended that the process of material selection be done automatically, or some best material suggestions approperiate for the project type to be poped up based on the project's location and amount of energy demand.

5.2. Future study

LCA is a broad methodology for compiling and evaluating outputs, inputs and possible environmental effects. It requires deep investigation into environmental factors, buildings materials and energy consumption issues. In this study, both scenarios of the case study were located in the same environment. However, as a further study, it can be evaluated if the location of case studies differs and how much the results will differentiate.

Furthermore, this project has linked the application of Revit software to One Click LCA by BIM tools. However, future research can be done by another BIM platform such as Tekla structure, Solibri, gbXML, IFC and any other software that One Click LCA supports.

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.

Berlin, 20 July 2021

Location, Date

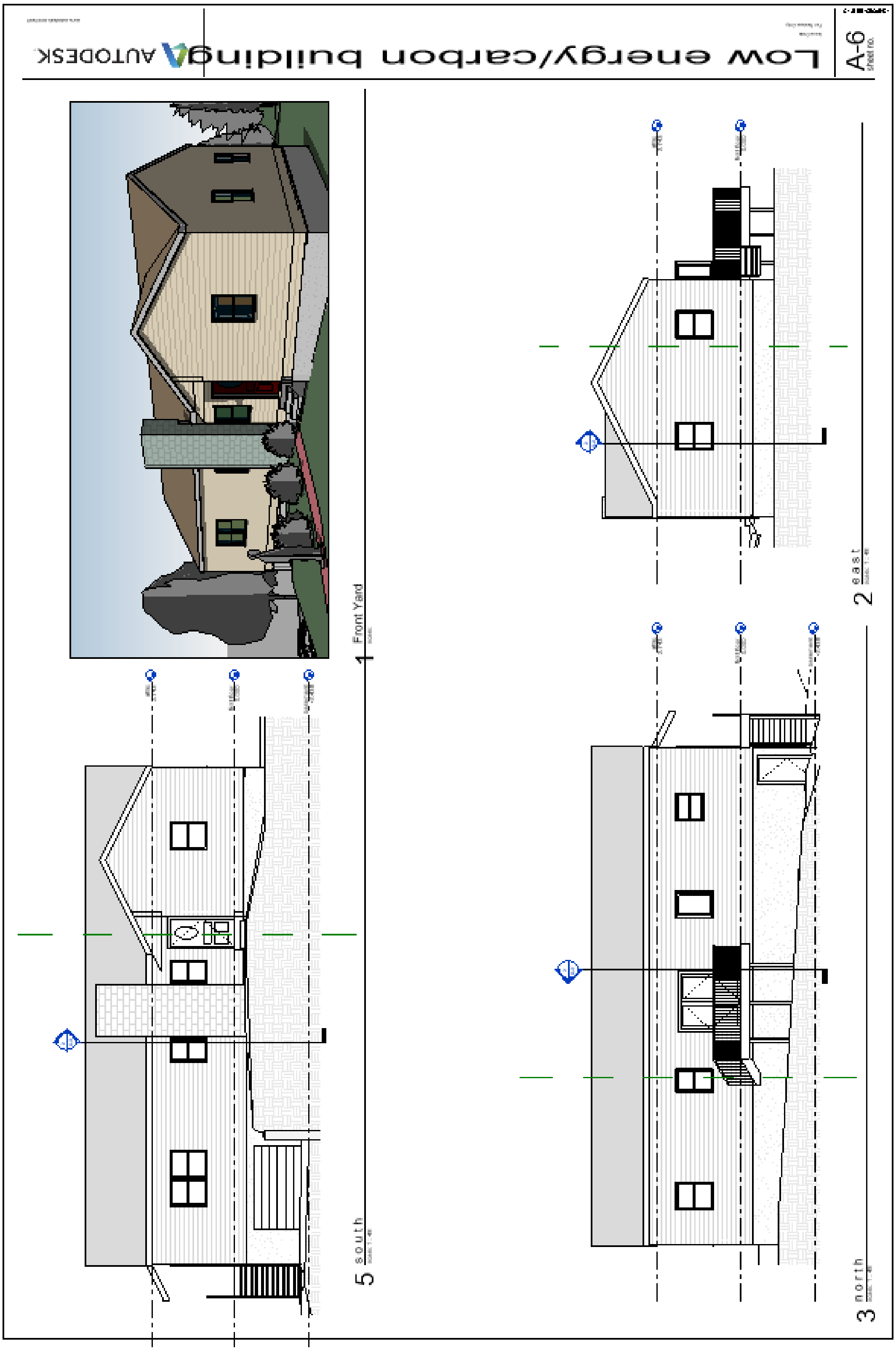
Homa Javadi

Signature of the student

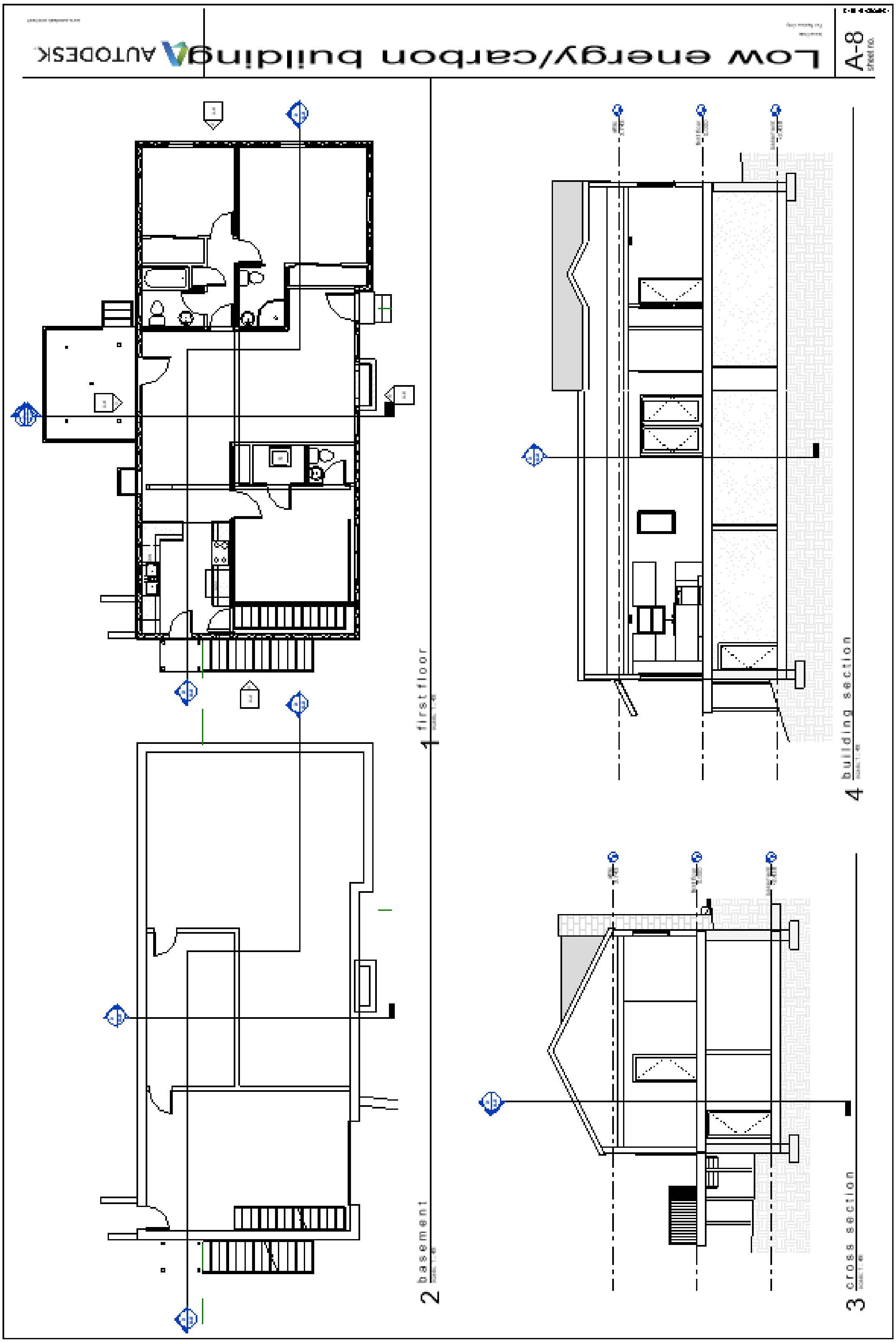
Appendices

Appendix A

3D view and elevations of the sample case study by Revit.

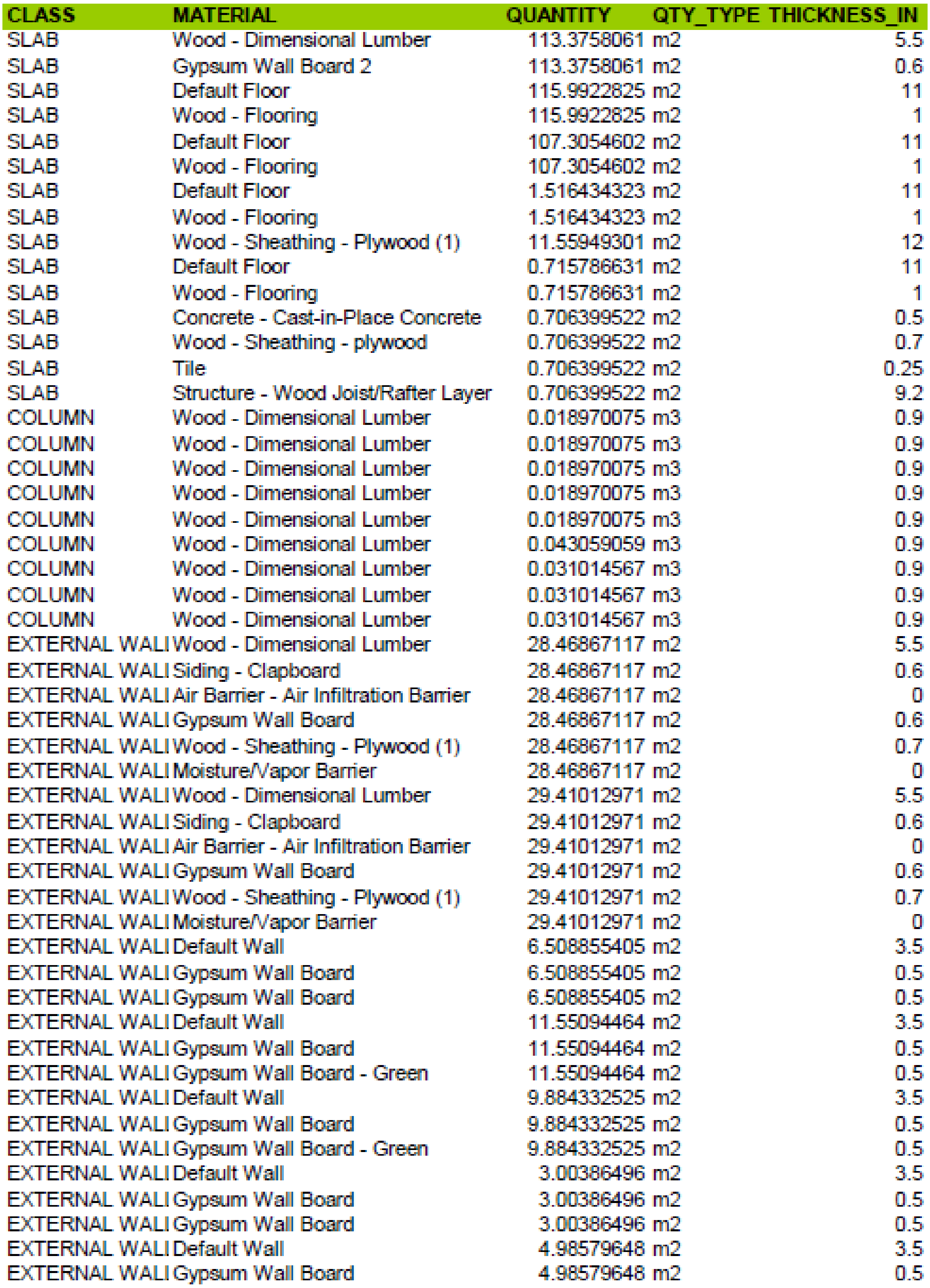


Plans and sections of the sample case study by Revit.


Low energy/carbon building
AUTODESK
A-8
sheet no.
1 first floor
2 basement
3 cross section
4 building section

Appendix B

List of the case study's sample building elements; imported from Revit to One Click CLA



CLASS	MATERIAL	QUANTITY	QTY_TYPE	THICKNESS_IN
SLAB	Wood - Dimensional Lumber	113.3758061	m2	5.5
SLAB	Gypsum Wall Board 2	113.3758061	m2	0.6
SLAB	Default Floor	115.9922825	m2	11
SLAB	Wood - Flooring	115.9922825	m2	1
SLAB	Default Floor	107.3054602	m2	11
SLAB	Wood - Flooring	107.3054602	m2	1
SLAB	Default Floor	1.516434323	m2	11
SLAB	Wood - Flooring	1.516434323	m2	1
SLAB	Wood - Sheathing - Plywood (1)	11.55949301	m2	12
SLAB	Default Floor	0.715786631	m2	11
SLAB	Wood - Flooring	0.715786631	m2	1
SLAB	Concrete - Cast-in-Place Concrete	0.706399522	m2	0.5
SLAB	Wood - Sheathing - plywood	0.706399522	m2	0.7
SLAB	Tile	0.706399522	m2	0.25
SLAB	Structure - Wood Joist/Rafter Layer	0.706399522	m2	9.2
COLUMN	Wood - Dimensional Lumber	0.018970075	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.018970075	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.018970075	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.018970075	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.018970075	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.043059059	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.031014567	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.031014567	m3	0.9
COLUMN	Wood - Dimensional Lumber	0.031014567	m3	0.9
EXTERNAL WALI	Wood - Dimensional Lumber	28.46867117	m2	5.5
EXTERNAL WALI	Siding - Clapboard	28.46867117	m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	28.46867117	m2	0
EXTERNAL WALI	Gypsum Wall Board	28.46867117	m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	28.46867117	m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	28.46867117	m2	0
EXTERNAL WALI	Wood - Dimensional Lumber	29.41012971	m2	5.5
EXTERNAL WALI	Siding - Clapboard	29.41012971	m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	29.41012971	m2	0
EXTERNAL WALI	Gypsum Wall Board	29.41012971	m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	29.41012971	m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	29.41012971	m2	0
EXTERNAL WALI	Default Wall	6.508855405	m2	3.5
EXTERNAL WALI	Gypsum Wall Board	6.508855405	m2	0.5
EXTERNAL WALI	Gypsum Wall Board	6.508855405	m2	0.5
EXTERNAL WALI	Default Wall	11.55094464	m2	3.5
EXTERNAL WALI	Gypsum Wall Board	11.55094464	m2	0.5
EXTERNAL WALI	Gypsum Wall Board - Green	11.55094464	m2	0.5
EXTERNAL WALI	Default Wall	9.884332525	m2	3.5
EXTERNAL WALI	Gypsum Wall Board	9.884332525	m2	0.5
EXTERNAL WALI	Gypsum Wall Board - Green	9.884332525	m2	0.5
EXTERNAL WALI	Default Wall	3.00386496	m2	3.5
EXTERNAL WALI	Gypsum Wall Board	3.00386496	m2	0.5
EXTERNAL WALI	Gypsum Wall Board	3.00386496	m2	0.5
EXTERNAL WALI	Default Wall	4.98579648	m2	3.5
EXTERNAL WALI	Gypsum Wall Board	4.98579648	m2	0.5

EXTERNAL WALI	Gypsum Wall Board	4.98579648 m2	0.5
EXTERNAL WALI	Default Wall	5.65934352 m2	2.9
EXTERNAL WALI	Gypsum Wall Board	5.65934352 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	5.65934352 m2	0.5
EXTERNAL WALI	Default Wall	4.61418432 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	4.61418432 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	4.61418432 m2	0.5
EXTERNAL WALI	Default Wall	12.91180213 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	12.9290064 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	12.9290064 m2	0.5
EXTERNAL WALI	Default Wall	4.86192576 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	4.86192576 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	4.86192576 m2	0.5
EXTERNAL WALI	Default Wall	5.223696685 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	5.223696685 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	5.223696685 m2	0.5
EXTERNAL WALI	Default Wall	4.93934496 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	4.93934496 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	4.93934496 m2	0.5
EXTERNAL WALI	Default Wall	4.93934496 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	4.93934496 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	4.93934496 m2	0.5
EXTERNAL WALI	Default Wall	2.80257504 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	2.80257504 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	2.80257504 m2	0.5
EXTERNAL WALI	Default Wall	9.605623405 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	9.605623405 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	9.605623405 m2	0.5
EXTERNAL WALI	Default Wall	3.00386496 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	3.00386496 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	3.00386496 m2	0.5
EXTERNAL WALI	Default Wall	1.8580608 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	1.8580608 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	1.8580608 m2	0.5
EXTERNAL WALI	Default Wall	0.9290304 m2	3.5
EXTERNAL WALI	Gypsum Wall Board	0.9290304 m2	0.5
EXTERNAL WALI	Gypsum Wall Board	0.9290304 m2	0.5
EXTERNAL WALI	Concrete - Cast-in-Place Concrete	20.07340457 m2	12
EXTERNAL WALI	Concrete - Cast-in-Place Concrete	26.35543116 m2	12
EXTERNAL WALI	Concrete - Cast-in-Place Concrete	18.56682803 m2	12
EXTERNAL WALI	Concrete - Cast-in-Place Concrete	41.82378732 m2	12
EXTERNAL WALI	Default Wall	12.76362144 m2	6
EXTERNAL WALI	Default Wall	11.08255848 m2	6
EXTERNAL WALI	Default Wall	4.67708742 m2	6
EXTERNAL WALI	Masonry - Stone	4.305088629 m2	6
EXTERNAL WALI	Tile	4.305088629 m2	1
EXTERNAL WALI	Masonry - Stone	9.43740048 m2	6
EXTERNAL WALI	Tile	9.43740048 m2	1
EXTERNAL WALI	Masonry - Stone	3.67860883 m2	6
EXTERNAL WALI	Tile	3.67860883 m2	1
EXTERNAL WALI	Wood - Dimensional Lumber	17.5181168 m2	5.5

EXTERNAL WALI	Siding - Clapboard	17.5181168 m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	17.5181168 m2	0
EXTERNAL WALI	Gypsum Wall Board	17.5181168 m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	17.5181168 m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	17.5181168 m2	0
EXTERNAL WALI	Masonry - Stone	9.712055466 m2	6
EXTERNAL WALI	Tile	9.712055466 m2	1
EXTERNAL WALI	Wood - Veneers	2.73789775 m2	23
EXTERNAL WALI	Wood - Veneers	1.2080621 m2	23
EXTERNAL WALI	Wood - Veneers	0.55886985 m2	23
EXTERNAL WALI	Wood - Veneers	1.0838688 m2	12
EXTERNAL WALI	Wood - Veneers	2.1241893 m2	12
EXTERNAL WALI	Wood - Veneers	1.0016109 m2	24
EXTERNAL WALI	Masonry - Concrete Masonry Units	24.08978928 m2	12
EXTERNAL WALI	Wood - Dimensional Lumber	4.569888848 m2	5.5
EXTERNAL WALI	Siding - Clapboard	4.569888848 m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	4.569888848 m2	0
EXTERNAL WALI	Gypsum Wall Board	4.569888848 m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	4.569888848 m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	4.569888848 m2	0
EXTERNAL WALI	Wood - Dimensional Lumber	18.4500542 m2	5.5
EXTERNAL WALI	Siding - Clapboard	18.4500542 m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	18.4500542 m2	0
EXTERNAL WALI	Gypsum Wall Board	18.4500542 m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	18.4500542 m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	18.4500542 m2	0
EXTERNAL WALI	Wood - Dimensional Lumber	2.149974073 m2	5.5
EXTERNAL WALI	Siding - Clapboard	2.149974073 m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	2.149974073 m2	0
EXTERNAL WALI	Gypsum Wall Board	2.149974073 m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	2.149974073 m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	2.149974073 m2	0
EXTERNAL WALI	Concrete - Cast-in-Place Concrete	11.8451376 m2	12
EXTERNAL WALI	Concrete - Cast-in-Place Concrete	1.204294809 m2	12
EXTERNAL WALI	Wood - Veneers	1.1967718 m2	23
EXTERNAL WALI	Masonry - Concrete Masonry Units	0.865021364 m2	8
EXTERNAL WALI	Masonry - Concrete Masonry Units	0.391047605 m2	8
EXTERNAL WALI	Wood - Dimensional Lumber	3.618933512 m2	5.5
EXTERNAL WALI	Siding - Clapboard	3.618933512 m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	3.618933512 m2	0
EXTERNAL WALI	Gypsum Wall Board	3.618933512 m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	3.618933512 m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	3.618933512 m2	0
EXTERNAL WALI	Wood - Dimensional Lumber	48.06024362 m2	5.5
EXTERNAL WALI	Siding - Clapboard	48.06024362 m2	0.6
EXTERNAL WALI	Air Barrier - Air Infiltration Barrier	48.06024362 m2	0
EXTERNAL WALI	Gypsum Wall Board	48.06024362 m2	0.6
EXTERNAL WALI	Wood - Sheathing - Plywood (1)	48.06024362 m2	0.7
EXTERNAL WALI	Moisture/Vapor Barrier	48.06024362 m2	0
EXTERNAL WALI	Wood - Veneers	0.677418 m2	12
ROOF	Default Roof	138.6132272 m2	5.5

ROOF	Roofing - Wood Shake	138.6132272 m2	0.6
ROOF	Default Roof	1.979998168 m2	5.5
ROOF	Roofing - Wood Shake	1.979998168 m2	0.6
FOUNDATION	Concrete - Cast-in-Place Concrete	2.209358984 m3	4.4
FOUNDATION	Concrete - Cast-in-Place Concrete	4.560782104 m3	4.4
FOUNDATION	Concrete - Cast-in-Place Concrete	2.105180564 m3	4.3
FOUNDATION	Concrete - Cast-in-Place Concrete	3.187415045 m3	4.4
FOUNDATION	Concrete - Cast-in-Place Concrete	0.248897261 m3	3.6
FOUNDATION	Concrete - Cast-in-Place Concrete	0.430707057 m3	3.5
FOUNDATION	Concrete - Cast-in-Place Concrete	0.298451742 m3	3.7
FOUNDATION	Concrete - Cast-in-Place Concrete	0.122356353 m3	3
FOUNDATION	Concrete - Cast-in-Place Concrete	1.11851544 m3	4.3
Stairs	Concrete - Cast-in-Place Concrete	0.074259759 m3	1.8
Stairs	Wood - Sheathing - plywood	0.07131853 m3	0.6

Appendix C

Detailed life cycle assessment result.

Section	Result category	Global warming kg	Acidification kg	Eutrophication kg	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
A1-A3	Construction Materials	42913.04	963.43	30.97	0.0041	41.66	1145672
A4	Transportation to site	1554.23	3.67	0.78	0.00028	0.19	29544.44
A4	Transportation to site	1554.23	3.67	0.78	0.00028	0.19	29544.44
A4-leg2	Transportation to site - leg 2						
A5	Construction/installation process						
B1-B5	Maintenance and material replacement	13736.62	68.5	15.33	0.0039	9.76	481356.4
B6	Energy use	452.26	0	0	0	0	0
B7	Water use						
C1-C4	End of life	8373.87	17.31	5.26	0.00033	1.15	36072.98
C1-C4	Deconstruction	8373.87	17.31	5.26	0.00033	1.15	36072.98
D	External impacts (not included in totals)	-37887.97	-50.5	-10.38	-0.00016	-5.93	-642447
A5m-benefit	Construction site - material use - benefit						
A5-benefit	Construction site - material wastage - benefit	-5228.71	-5.96	-1.03	-5.6E-06	-0.65	-91549
D	Installed Materials - benefit	-32659.26	-44.54	-9.34	-0.00015	-5.28	-550898
D2	Exported energy (not included in totals)						

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