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Simultaneous CO_2 and Cost Estimation for Construction Projects in Finland

Master's Thesis

Master's In Construction and Real Estate Management

from

Mikko Henrik Hassinen

Date:

Berlin, 22.6.2023

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Acknowledgements

Thank you, Paula and Tuomas, for your help in steering this thesis in the right direction.

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

date 06.06. 2022

Conceptual Formulation
Master Thesis for Mr. Mikko Henrik Hassinen
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Topic:
Simultaneous CO2 and Cost Estimation for Construction Projects in Finland

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Background

Construction and operation of buildings generates around 30% of all greenhouse gas emissions in Finland.[1] The effect of material choices have on these emissions varies between 30-80%.[2] The Government of Finland and the Ministry of the Environment have decreed that all new construction projects should have their carbon dioxide (CO2) footprint from both construction and operational phases estimated, controlled, and reduced by legislation by the mid 2020's. In time, the CO2 footprint estimate will become a prerequisite to obtaining a building permit.[3] Some European countries such as France and the Netherlands have already adopted legislation obligating the estimation of CO2 emissions.[4]

For this reason, development of tools for the estimation of carbon emissions for the initial construction and the life cycle of the building is mandatory. For determining the initial carbon footprint, the estimator needs a vast database of different building materials, activities, and emissions related to them. The Ministry of the Environment has published a free database containing some of the most common building materials and their emissions (co2data.fi).[5]

The estimation of the carbon footprint of construction projects is commonly done separately from the actual design or even project planning, such as quantity take-off and cost estimation. This lack of connection can hinder the comparison of the ecological and economic viability of different design choices.[6]

The master's thesis corresponding this conceptual formulation is commissioned by the company Tocoman Oy, which provides its clients with, among other things, quantity take-off and cost estimation software. The client base has expressed desire to incorporate CO2 footprint estimation into Tocoman Estimation software so that they could perform the viability analyses simultaneously with the cost and quantity estimation. The feasibility of this simultaneous quantity take-off, cost estimation and CO2 footprint estimation is what the master's thesis paper will try to assess.

Research Questions

Is it feasible to perform carbon footprint estimation simultaneously with quantity and cost estimation?

Issues that may affect the feasibility and that can be considered in detail in the study include: The timing of the analysis in relation to building permit applications, project scale and level of detail of the planning when performing quantity and cost estimation, especially when considering alternative design choices.

How could Building Element-Activity-Resource -based estimation recipes be enhanced to withhold carbon emission data as well?

Things to be considered include whether to provide estimators with a pre-made library of recipes or let them develop their own libraries and to which level of the recipes the data should be tied to: Elements, activities, or resources? Source of the emission data is also an important topic to consider.

How does the presented method of CO2 footprint estimation compare to other methods?

There are many aspects to consider, such as useability, speed, accuracy, and reliability.

Methodology

The methodology of this study includes the following steps:

1. Literature review of the current situation regarding the legislation, pilot projects and tools available.
2. Interviews with stakeholders, clients, and officials. Interview questions will relate to the desired outcome of the CO2 estimation and its uses. Both civil servants of the ministry and the users should be interviewed to establish a clear goal for the estimation tool.
3. Creating a prototype estimator using Excel. This prototype may later be developed into a new piece of software or integrated into the existing estimation tool.
4. Comparison of competing CO2 footprint estimation methods: Assessment of accuracy, speed, and efficiency. Comparison done using a small project, such as a single-family house.

Timetable

- Literature review and interviews 1.4.-1.7.2022
- Interviews 2.5.2022-3.8.2022
- Prototype 1.6.-1.9.2022
- Learning other tools 1.4.2022-1.9.2022
- Comparison of Prototype and other tools (1-3 tools) 1.8.2022-1.11.2023
- Assessment of findings 1.11.-1.2.2023
- Finalisation of thesis 2.1.-1.3.2023
- Submittal of thesis 1.4.2023

Resources

- Excel
- Tocoman Laskenta (the estimation software)
- Oneclick LCA (competing software)
- Co2data.fi (the CO2 estimator of the Ministry of the Environment)
- Word

References

[1] Kangas Hanna-Liisa, Sankelo Paula, Kautto Petrus, Ruokamo Enni, Lazarevic David, Mattinen-Yuryev Maija, Turunen Topi, Nissinen Ari. (2019). *Taloudellisten kannusteiden käyttö vähähiilisen rakentamisen ohjauksessa TALO-hankkeen loppuraportti.*. Ympäristöministeriö.

[2] Ympäristöministeriö. (2021.) *Rakennuksen vähähiilisyyden arviointimenetelmä 2021*. Ympäristöministeriö.

[3] Suomen Hallitus. (Date not available). *Luonnos hallituksen esityksestä rakentamislaiksi eduskunnalle*. Available at https://api.hankeikkuna.fi/asiakirjat/6df1d533-c70e-4f34-81f9-b7e932433d84/9aeaf76a-9e66-4d53-8cf9-d0f15f39929c/LIITE_20220411123124.PDF [Accessed 27.5.2022]

[4] Ympäristöministeriö. (2017). *Vähähiilisen rakentamisen tiekartta*. Available at https://ym.fi/vahahiilisen-rakentamisen-tiekartta [Accessed 27.5.2022.]

[5] Ympäristöministeriö. (Date not available). *Rakentamisen päästötietokanta*. Available at https://co2data.fi/ [Accessed 27.5.2022]

[6] Bionova Oy. (2017). *Tiekartta rakennuksen elinkaaren hiilijalanjäljen huomioimiseksi rakentamisen ohjauksessa*. Bionova Oy.

Abstract

The aim of the thesis was to perform a feasibility study on whether quantity, cost and carbon footprint estimation could be performed simultaneously to possibly start developing a new software for that purpose. This was to address the legislative changes happening in Finland that obligate new building permit applicants to submit a climate declaration that assesses the environmental impacts of the project along with the building permit application.

The study consisted of a thorough overview of the legislation and relevant decrees, as well as contemporary tools already available for carbon assessment and in the market by different public and private vendors. Once the framework and processes were clarified, a prototype tool was developed to establish whether the information required by the climate declaration could be added to existing quantity and cost estimation processes. The tested tools and prototype were assessed to find out their strengths and weaknesses.

In the end, it is safe to say that performing carbon assessment simultaneously with quantity and cost estimation could be potentially feasible in some projects and delivery methods where the planning and cost estimation is done to a relatively accurate degree before the building permit application. The manufacturing and updating of the carbon assessment would be more organised, reliable, and faster. Issues that affect the proposed method of simultaneous estimation, such as low level of detail and poor planning, are issues that affect other carbon assessment methods as well.

Contents

Appendices

Appendix 1. The carbon estimate done using the tool of the Ministry of the Environment.

Appendix 2. Final report of the estimate using OneClickLCA.

Appendix 3. Prototype of the simultaneous carbon and cost estimation tool.

Appendix 4. Building element estimate of the case project.

Appendix 5. Activity list estimate of the case project.

Appendix 6. Resource list of the case project.

Appendix 7. Full version of Table 4.

Appendix 8. The test reports on the Ministry's tool and OneClickLCA.

Appendix 9. Results of the comparison of different tools tested.

Most of these appendices are Excel-tables or tools. Due to the nature of the appendices, they could not be attached to the PDF version of this thesis. Thus, the appendices can be downloaded as a ZIP-file using the link below. The same ZIP-file was included in the e-mail submission of this thesis to Mr. Stoll from HTW Berlin, Dr. Naukkarinen from Metropolia, and Mr. Palolahti from Tocoman Oy.

https://drive.google.com/file/d/1EvXxZfP01zMcQZpV8HbtZeAkjORR1d7N/view?usp=sharing

Table of Figures

List of Tabulations

List of Abbreviations

BIM	Building Information Modelling
GWP	Global Warming Potential
LOD	Level of Detail
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
API	Application Programming Interfaces
BoQ	Bill of Quantities

1. Introduction

1.1 Background and Rationale

The Government of Finland has decreed that Finland should be carbon neutral in 2035. This requires a reduction of 5.3 megatons of emissions by 2030 and an additional 2 megatons of emissions by 2035. To achieve these results, Finland needs emission reductions in agriculture, industry, traffic, construction, and other sources. (Finnish Government, 2021) Out of all the greenhouse gases in Finland, the construction and operation of buildings generates around 30%. (Kangas, 2019). For construction emissions, the material choices during design phase can affect these emissions in the magnitude of 30%-80% (Ministry of the Environment, 2019b).

Currently, there is no legislation concerning the carbon footprint of construction projects or its estimation in Finland. Most sustainability analyses are done voluntarily using tools available in the market, such as LEED or BREEAM. To address this, the Government of Finland, and the Ministry of the Environment (FI: Ympäristöministeriö) established a roadmap in 2017 to steer the construction industry into low-carbon mode of business operation as part of a larger legislative update concerning construction law that comes into force in 2025. (Ministry of the Environment, 2021).

According to this roadmap to achieve low-carbon construction the Ministry of the Environment will start to regulate the carbon footprint of construction projects by requiring a **“climate declaration”** to be submitted along with a building permit application by 2025. This climate declaration will contain a full assessment of the climate impacts of the building and its operation, including a carbon footprint estimate. (Kuittinen, 2021). In addition to a carbon footprint, a carbon handprint must also be calculated. A carbon footprint details the emissions released by the construction and the operation of the building, while a carbon handprint details the net positive effects on the environment by means of carbon capturing. The positive effects on the environment can be accrued by using recycled or reused materials, use of renewable energy, and carbon capture caused by carbonisation of concrete. These emission reductions considered in the handprint estimate are analysed and presented separately from the footprint in the climate declaration and are not deducted from the footprint estimate at any point. (Ministry of the Environment, 2021)

The Ministry of the Environment has developed its own method for calculating the carbon footprint and handprint of a building for the entirety of its life cycle, starting from manufacturing and transportation of materials to construction, operation, maintenance, and demolition of the building (Ministry of the Environment, 2019b). This method is based on the Level(s)-framework for sustainable buildings developed by the European Commission, which aims to harmonise sustainability analyses on the European level (European Commission, 2022a). The method for carbon assessment was developed in cooperation with the Swedish government to ensure the harmonisation of assessment methods nationally, but also in the larger framework of Nordic cooperation (Finnish Government, 2021b). The method is detailed in the decree of the Ministry of the Environment which was under evaluation during the writing of this thesis, with the newest version of the decree published in September 2022 (Ministry of the Environment, 2022b).

In addition to the assessment method, data is required. To assist in the estimation of the carbon footprint of a project the Ministry of the Environment has developed in collaboration with their Swedish counterparts a database of the most common building materials and their emissions, www.co2data.fi. The information for the database was collected through collaboration with product manufacturers, research organisations and consultants. The co2data.fi database is updated regularly. (Finnish Government, 2021b).

The aim of this thesis was to find out whether the carbon footprint assessment method could be feasibly integrated into the existing quantity and cost estimation processes of a construction project in the Finnish environment. The objective and research questions are discussed in more detail in the following chapter 1.2. and the processes of cost and quantity estimation later in chapter 4.2.

1.2 Objective and Research Questions

This Master’s Thesis was commissioned by the software company Tocoman Oy. The company supplies its clients with various tools suitable for construction projects. Tools include software for quantity take-off and cost estimation, scheduling and building information modelling use. Tocoman Oy is a subsidiary of Admicom Oy which also provides its clients with software for managing the economics of construction, such as invoicing, payrolls, and cost control management tools. (Admicom Oy, 2022)

The client base of Tocoman Oy has expressed desire to be able to perform quantity and cost analyses simultaneously with carbon footprint estimation. The feasibility of performing such simultaneous quantity take-off, cost estimation and CO_2 footprint estimation is what this study assessed.

Research questions that the thesis addressed were as follows:

Is it feasible to perform carbon footprint estimation simultaneously with quantity and cost estimation?

Issues that may affect the feasibility and that will be considered in detail in the study include: The timing of the analysis in relation to building permit applications, project scale and level of detail of the planning when performing quantity and cost estimation, especially when considering alternative design choices. Legislative and methodological issues may also arise in terms of presentation of the estimation.

How could Building Element-Activity-Resource -based estimation recipes be enhanced to withhold carbon emission data as well?

The recipes mentioned are pre-made, but modifiable estimation templates that usually cover a single building element. More on them in chapter 4.2. Things to be considered include whether to provide estimators with a pre-made library of recipes or let them develop their own libraries and to which level of the recipes the emissions data should be tied to: Elements, activities, or resources? Sources and utilisation of the sources of emission data is also an important topic to consider.

How does the presented method of CO_2 footprint estimation compare to other methods?

The comparison will be made considering aspects such as useability, speed, accuracy, and reliability.

2. Methodology

First, a thorough literature review of the current situation in terms of legislation and regulation was performed. The aim of the legislature and regulation review was to clearly establish the goals and requirements of the Government of Finland and the Ministry of the Environment for the estimation of carbon footprint. Necessary interviews with the ministry officials and clients were also planned to be performed at this stage, although they were only used for clarification purposes as nearly all necessary information was ultimately obtained through legislation and decrees.

Second, a review of the tools currently available was performed. There are many tools for sustainability analyses on the market, but this study focused on the database provided by the ministry of the Environment, www.co2data.fi, along with an Excel-based tool built upon that database, and a private software solution OneClickLCA. The Level(s) framework by the European Commission was also looked at, along with “a material list tool” associated with the framework. A small model of a single-family house was used as a case example, with the quantities and works estimated using the Tocoman Estimation software. The process of quantity and cost estimation is also discussed before going into the analysis of the tools.

Once the literature review was finalised and the goals and constraints for carbon footprint estimation are established, a prototype version that could work for the Tocoman Estimation software was made using Excel.

Finally, the prototype was benchmarked against the other tools available in terms of useability, speed, accuracy, and reliability using the experience gained during the testing phase.

2.1. Limitations of Study

The research did not develop a working tool but was done to determine if the development of such a tool is at all feasible or whether another way of CO_2 footprint estimation is more viable. As the carbon handprint of the project is not technically connected to the footprint estimate nor is it deductible from the footprint estimate, the handprint calculation was at left out of the scope of this research study. It is nevertheless discussed in various part of the study as the topics go hand in hand throughout the climate declaration process and the presentation of both results is similar. A similar study ought to be performed on the carbon handprint estimate to establish whether the same results could apply as to the footprint estimation.

3. Background

3.1. Construction Law 2025 and Relevant Decrees

This chapter discusses the legislation and decrees relevant to the study. There are currently two draft decrees by the Ministry of the Environment specific to the climate declaration required for the building permit, as well as one planned but not yet published decree by the Council of State (FI: Valtioneuvosto). The decrees are both part of a larger legislative update of the construction law in Finland, which covers many aspects of the industry, such as land use laws, regulation, digitalisation, and environmental concerns. (Finnish Government, 2021b).

3.1.1. Construction law of 2025

These decrees are a direct consequence of the revision of the construction law by the government of Finland. The previous construction law dates to year 1999. Although the construction law of 1999 had received multiple updates and revisions throughout the years the law had become relatively complex. Moreover, integrating the provisions of the law to regulations and directives coming from the European Union concerning energy efficiency, climate change and product suitability was deemed to require new, streamlined, legislation.

The new construction law also withholds provisions about the digitalisation of the construction industry. A building information model (BIM) will be required as part of the building permit application. (Finnish Government, 2022) The models will be used to create a nation-wide digital system of the built environment, which will contain information on the building stock of the nation and zoning. The system is currently under development, and it should be ready for use by 2024 when the onboarding begins. The onboarding process will take the rest of the decade. This development of the national building stock system is done under the RYHTI-project. (Ministry of the Environment, 2022c). The requirements for the building information models that are to be delivered to Building Control for the permit application are under development, with the focus being in updating the Common BIM Requirements 2012 (COBIM2012) documentation into COBIM2020. This documentation details the objects that need to be modelled by the various designers that are taking part in the project at hand. (KIRA-Innohub Ry, 2021). According to the new construction law the model must contain at minimum information on the location of the real estate and its dimensions. The rest will be settled with a decree by the Ministry of the Environment later. (Finnish Government, 2022).

The latest version of the law was given by the government of Finland to the parliament to be discussed on 15.09.2022 and was passed during the writing of this thesis on 24.2.2023. The proposed law underwent multiple reviews and analyses, including statements from the various committees such as the committees of the environmental, economic, and constitutional affairs as well as private stakeholders. The law will come to force on 1.1.2025. The provisions of the law and related draft decrees relevant to this study along with their relations are shown below in Figure 1. (Council of State, 2023)

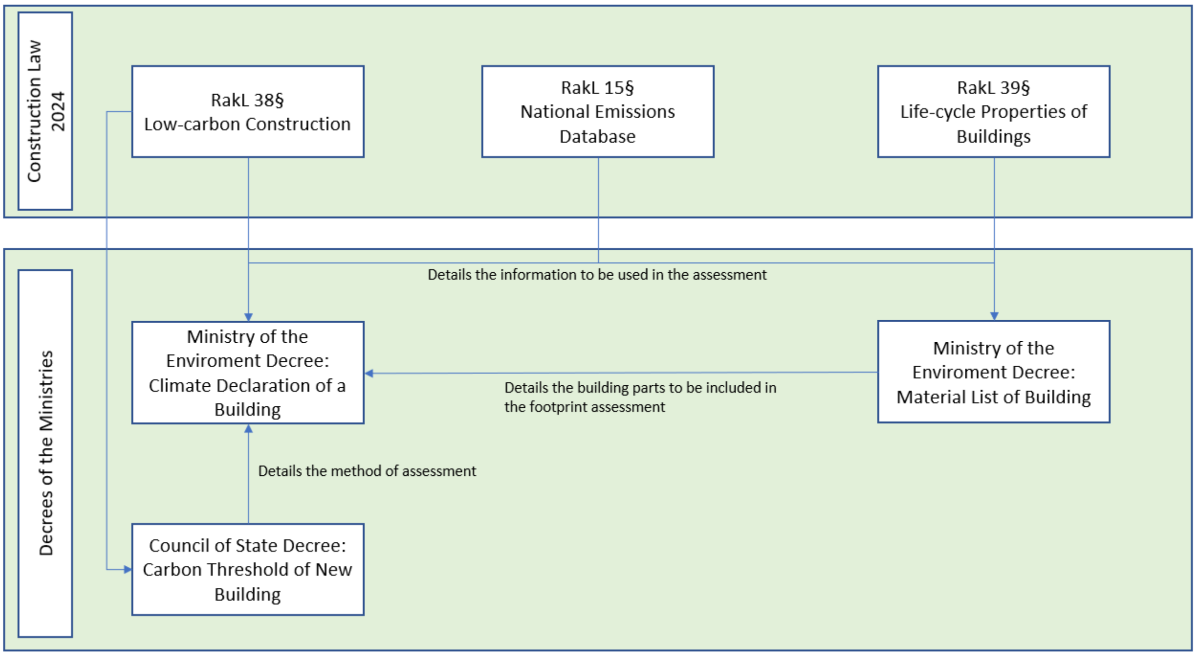

Figure 1. A map of the provisions of the construction law and the decrees related to the climate declaration. [1]

The decrees shown above in Figure 1. are discussed in the following chapters 3.1.2., 3.1.3. and 3.1.4. The scope of their applicability will be discussed in chapter 3.2.

3.1.2. Decree on Climate Declaration

The first of the two published drafted decrees is *the Decree on the Climate Declaration of a Building by the Ministry of the Environment (FI: Ympäristöministeriön asetus rakennuksen ilmastoselvityksestä).* This decree details the method and information

[1] (Kuittinen, 2022)

sources to be used in the assessment of the effects on the climate by the construction project for a life span of 50 years. (Ministry of the Environment, 2022b) The decree states that the party responsible for the climate declaration are the designers, be they lead architectural designers, structural designers, or special designers (i.e., HVAC, MEP, Fire) and that the climate declaration must be submitted to the Building Control officials (FI: Rakennusvalvonta) before the building permit application. Furthermore, when changes happen to material choices between the building permit application phase and operational phase, the climate declaration must be resubmitted. The manager on the site is responsible for keeping tabs on changes to materials between design and handover so that the climate declaration can be redone after construction. All data must be either in a building information model (BIM) or in other "machine readable" format. (Kuittinen, 2021)

3.1.3. Decree on Material List

The second decree, *"The Decree on the Material List of the Building"* or in Finnish *"Ympäristöministeriön asetus rakennuksen materiaaliselosteesta",* details that the designers of the building must produce and save a list of materials of the project to assist in the production of the climate declaration. The material list must contain a list of building elements, a list of building materials contained in the elements, and a list of materials by origin, i.e., whether the materials are new, recycled, reused renewable or non-renewable or hazardous. (Ministry of the Environment, 2022a)

3.1.4. Decree on Thresholds

The final decree, planned by the Council of the State later in the future, will establish thresholds for the results of the climate declaration and the carbon emissions within the climate declaration (Finnish Government, 2022). Possible target values are discussed later in chapter 3.9.

In other Nordic countries, similar legislation has been implemented or is in the process of being developed. Sweden has required a climate declaration since 2022 with thresholds coming to force in 2027. Norway has made carbon footprint calculation mandatory for all construction in 2022 while it has been mandatory in public projects for even longer. Denmark will implement thresholds in 2023, while Iceland and Finland are still in the process of legislative updates. (Koskela, 2022).

3.2. Scope of Legislation

In the previous chapters the legislative framework was discussed. This chapter details the building types that are affected by the new legislation and will be required to submit a climate declaration along with a building permit application.

According to the Ministry of the Environment and the memorandum concerning the climate declaration, the declaration should be made for buildings that require an energy declaration according to the Ministry's older decree 1010/2017 *"Decree on the energy efficiency of a building"* (Kuittinen, 2021). The covered buildings range from small residential buildings to offices, public and healthcare buildings. Excluded are buildings such as those less than 50 m^2 in area, bomb shelters, and religious buildings. The full list of inclusions and exclusions is shown below in Table 1. (Kuittinen, 2021).

Table 1. The building types requiring a climate declaration are shown on the left in the green field.[2]

Climate declaration required for building permit	**Climate declaration not required for building permit**
110 Small houses	Temporary buildings
111 Semi-detached houses	Buildings less than 50 m2
112 Row houses	Protected buildings (heritage)
12 Apartment buildings	211 Summer homes (not usable the whole year)
3 Business premises	512 Professional machinery maintenance buildings
4 Office buildings	514 Vehicle shelters
5 Traffic buildings (excluding weather shelters and maintenance buildings)	52 Information and communication technology buildings
6 Healthcare buildings	73 Religious buildings
7 Buildings for events / gatherings	9 Industry and mining
8 Educational buildings	10 Energy related buildings
12 Warehouses (Excluding unheated)	11 Infrastructure buildings
13 Emergency response buildings	1210 Unheated warehouses
Large-scale renovations with energy efficiency improvements required by law	1215 Rudimentary warehouse shelters
	1311 Bomb shelters
	14 Agricultural buildings and animal shelters
	19 Other buildings
	Separate construct not connected to buildings

[2] (Kuittinen, 2021)

The numbers in front of the buildings correspond to the use class types of the buildings. Currently, there are 15 types of use classes with various sub-classes. The use classes are provided by Statistics Finland, which operates under the Ministry of Finance. (Mäkelä, 2018).

In the following chapter 3.3., the Level(s) framework upon which the methods portrayed in the decrees of the Ministry of the Environment are based upon is discussed before going deeper into the specifics of the decrees.

3.3. Level(s) Framework for Sustainable Buildings

As stated in the introductory chapter 1.1. of this thesis, the climate declaration assessment method developed by the Ministry of the Environment is based on the Level(s) system developed by the European Commission (Ministry of the Environment, 2019b). This chapter briefly goes over the characteristics of the framework, while chapter 4.5 discusses a tool provided by the European Commission.

Level(s) is a framework for the assessment and monitoring of sustainability performance of buildings. It is a free-to-use, open-source tool that helps measure the impacts of construction and building use and disposal. It considers the carbon footprint of construction materials and building operation, while also considering the wider scope of water use, healthy and comfortable building environment, and climate change impacts. (Publications Office of the European Union, 2022)

The Level(s) framework is not a certification scheme like LEED or BREEAM, but it does tie into them to give a common language between certification schemes and bring greater consistency between the schemes. These schemes are already aligning themselves with the indicators and methods of the Level(s) framework. (Publications Office of the European Union, 2022)

The Level(s) framework consists of six macro-objectives with sixteen indicators divided between them. These indicators guide the design and construction of buildings and are shown on the following page in Figure 2.

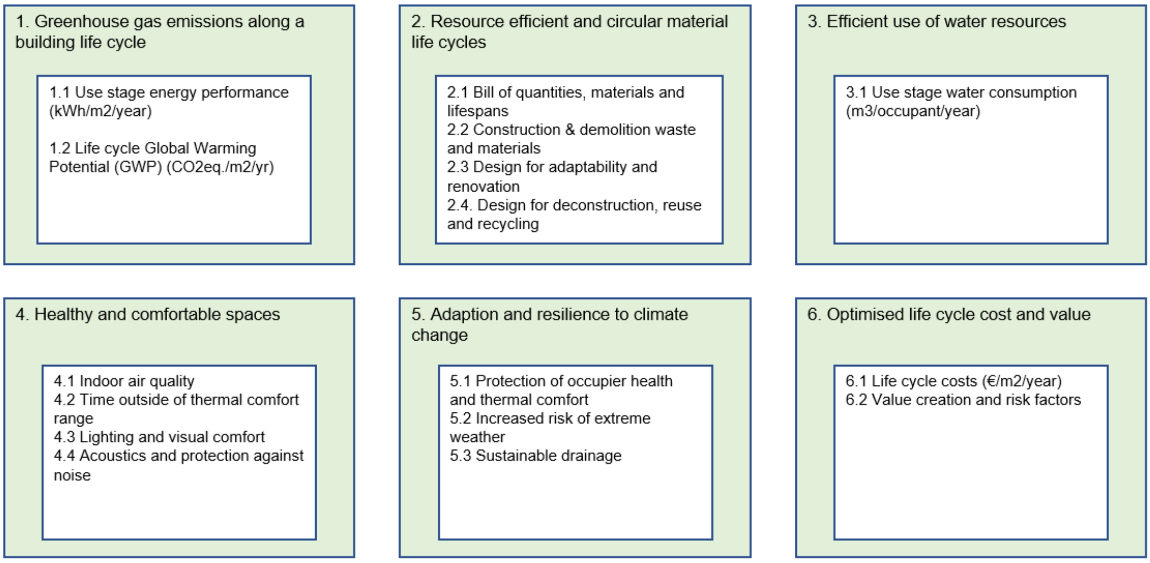

Figure 2. The six macro-objectives of the Level(s) framework and their indicators.[3]

The macro-objectives most relevant to this research are objectives 1 and 2, and thus are discussed in more detail. According to the guidelines on Level(s), the indicators shown in Figure 2 can be applied in any stage of the project, be it during the early conceptual design where the Level(s) framework can be used to set objectives, or during the detailed design and construction phase where the designs can be quantitatively assessed. Level(s) can also be used during building operation, where the energy use and performance of the building can be monitored to generate data. This data can be used to improve future projects and their design. (European Commission c, 2022c)

As previously stated, for the scope of this research the design phase, and macro-objectives one and two are most relevant and are discussed briefly below:

The first macro-objective, **1. Greenhouse gas emissions along a building life cycle**, is aimed at reducing the whole life carbon output of the building. This macro-objective is divided into two indicators. The first indicator estimates the use stage energy performance in kilowatt hours per square meters annually (kWh/m^2/year). The second indicator estimates the Global Warming Potential (GWP) in CO_2 equivalent per square meter annually (kgCO_2e/m^2/year).

The second macro-objective is **2. Resource efficient and circular material life cycles.** The aim of this macro-objective is to reduce the material use to minimise the

[3] (European Commission, 2022a)

carbon footprint. This is done by optimising materials used during construction by producing an accurate bill of quantities (indicator 2.1) and minimising both construction and demolition waste (indicator 2.2) by considering the life cycles of individual building elements and their replacement cycles, along with the ease of replacement and deconstruction (indicators 2.3 and 2.4). (European Commission, 2022a)

The generation of a bill of quantities in indicator 2.1 helps in assessing the other indicators as well, especially the life cycle global warming potential (Indicator 1.2), construction and demolition waste and materials (indicator 2.2) and life cycle cost analysis (indicator 6.1). The bill of quantities allows for easier cost estimation, assignment of life cycles to individual materials and enables the production of a Bill of Materials compatible with reporting requirements on construction and demolition waste. (European Commission, 2022b)

To help produce a bill of quantities, the European commission has created an Excel-based tool for designers, engineers, and other professionals. This tool is discussed later in this thesis in chapter 4.5. The tool does not calculate the carbon footprint of the materials but enables the user to find out which portion of the building is of which material and how much of that material is coming from sustainable sources. It also has functions to allow for the cost estimation of the materials. (European Commission c, 2022c)

3.4. Construction Project Phasing

In the previous chapters the legislative framework was discussed in terms of climate declaration. This chapter describes the phases of a construction project according to the guidelines given by the construction industry consortium RTS (FI: Rakennustietosäätiö) to establish how the level of detail of designs changes throughout the project. The designs such as floor plans are to be used for both the quantity and cost estimation processes as well as in the climate declaration process and thus the level of detail of the plans may influence the feasibility of these processes and the reliability of the end results. The project phases are also affected by chosen project deliver method, as discussed in chapter 3.4.3.

According to the guidelines by RTS, there are seven phases in a construction project of a building. These phases are shown in Figure 3. The building permit is obtained during the general planning and implementation planning phases and is highlighted in the Figure 3. (Rakennustieto Oy, 2016)

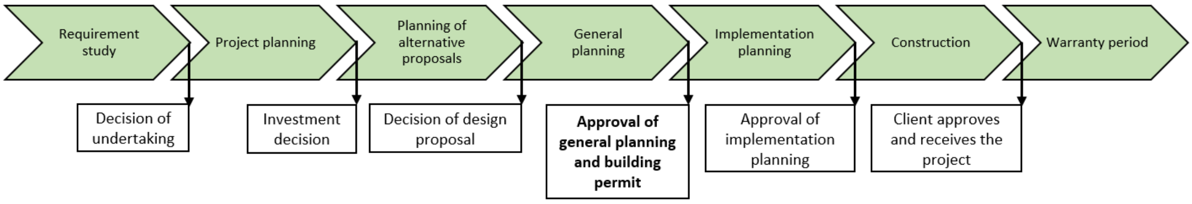

Figure 3. The phases of a building construction project according to RT 10-11224 guideline. The building permit is obtained between the transition from general planning to implementation planning phase.[4]

3.4.1. Influence on Level of Detail of Plans

The project phases are also described in the previously mentioned building information modelling guidelines, Common BIM Requirements (COBIM2012, FI: YTV2012). These guidelines set the level of detail recommended for the plans and building information models in each planning phase. In the scope of this study, the level of detail of the general planning phase was important to know to assess whether the quantity and cost estimation process described later in this thesis can be used properly. There are three levels of detail (LOD) in COBIM2012, listed below. These levels are generalised for the whole building and there exists additional specific instructions for each building part in COBIM2012. (Rakennustieto Oy, 2012)

Level 1: Used for collaboration between designers. Model contains information regarding location and geometry, with building parts named descriptively.

Level 2: Use cases include preliminary energy analyses, building element-based quantity take-off. Location and geometry modelled according to relevant specifications, building parts named correctly and modelled in such a way that quantities and units can be extracted from the model.

Level 3: Used for scheduling and procurement. In addition to the information mentioned in the previous levels, the modelled elements must contain information relevant to procurement such as specifications for windows and doors in terms of noise cancellation or fire safety. (Rakennustieto Oy, 2012)

COBIM2012 states that during the general planning phase the level of detail is one, with exceptions to some building parts where the level is two. The “building component model”, i.e., the model that contains building parts is in this phase still less accurate

[4] (Rakennustieto Oy, 2016)

than in the upcoming implementation phase. In this phase, for example, the walls and slabs must be separable with different objects representing exterior and interior and load-bearing and non-load-bearing walls. Windows and doors must specify their basic qualities such as fireproofing and mechanisms, with the omission of specific types. Surfaces can be omitted from spatial information. Even in the later implementation planning phase where accuracy increased, the level of detail is still usually one or two, as the third level where specific products are chosen can be difficult to attain with the tendering and procurement still unfinished. (Rakennustieto Oy, 2012)

3.4.2. Influence on Cost Estimation

Cost estimation is performed in all phases of the project with the accuracy increasing gradually as the designs become more accurate. In the early phases of the project the costs are estimated by benchmarking the costs to other similar projects. This can be performed by the developer or client of the soon-to-be-chosen general contractor, for example. Later, costs can be estimated by space allocation plans and using benchmarked costs assigned to each space. Only starting from the general planning phase are building elements considered and only during implementation planning can those building elements be considered in relation to the costs of the different methods of construction. (Rakennustieto Oy, 2016). According to Mr. Jiri Hietanen, a BIM expert whose views will be discussed later in chapter 4.8, this is the phase where an experienced builder can do their best to find the most suitable production methods to the designs and save some costs (Hietanen, 2022). The guidelines by RTS state that even in this late phase the changes can extend to the type of frame used, i.e., whether the frame is cast-in-place or assembled from elements. Another example given is the decision to either do the painting with a roller or by spraying the paint. Procurement and chosen sub-contractors can also influence the final method used in the project. The cost estimate of the general planning phase is converted into a budget and the quantities are converted into suitable procurement units to help the site manager manage and oversee the cost accumulation. Once the project is completed, the costs accumulated are compared to the costs estimated and lessons learned taken forward to the next project. (Rakennustieto Oy, 2016)

3.4.3. Influence of Delivery Methods

There are various delivery methods of construction projects that influence the level of detail of plans but also the responsibilities of different stakeholders in the project. In addition, the onboarding time of stakeholders performing the different methods of cost estimation differs between delivery methods. The phases at which the stakeholders enter the project also differ from one delivery method to another. The party responsible for starting the project, the "client", has the most influence on the project when they themselves are responsible for all designs after which they tender the entire building to a general contractor who builds according to plan. This is called a design-bid-build method. When the client lets the general contractor do most of the planning according to the goals and objectives stated by the client, the method is called design-build. There are also delivery methods like the project management method and collaborative method where the responsibilities and power over the project is shared differently. The differences are shown in Table 2 on the following page. (Rakennustieto Oy, 2016).

The onboarding time of the party doing the element-activity-resource based cost estimation described later in chapter 4.2., usually the general contractor, varies between the different delivery methods (Rakennustieto Oy, 2016). The lack of need for a certain level of accuracy in the cost estimation before a contractor responsible for the actual construction is chosen may affect the cost estimate and thus the feasibility of a simultaneous cost and carbon estimate, or at least its reliability.

Table 2. Different project delivery methods and their influence on the design responsibilities and level of design when making the general contract.[5]

	Delivery method	Plans included in the contract between client and general contractor	Responsibility for planning	Chooses the sub-contractors	More information
Design and build methods	Design and build	Project plan or alternative project designs	General contractor (GC)	General contractor (GC)	The GC is given a level of quality and some specifications as to the use and requirements of the building, but the GC handles the design according to a style that fits their production methods.
Design and build methods	Technical solutions contract	Alternative project designs or general plans	Responsibility shifted to the party in charge of the design and installation.	General contractor (GC)	A piece of a larger project is given to a contractor to both design and build. The GC could handle the majority of construction, but sub-contract the design of MEP systems and their installation to a more specialised party.
Design and build methods	All-in-Contract	General or implementation plans	Client	General contractor (GC)	The client has the responsibility over the designs that the GC implements. The client only has a contract with a GC who handles the rest of the contracts and sub-contracts on the site.
Design-bid-build methods	Split contract	General or implementation plans	Client	General contractor (GC)	The client has the responsibility over the designs but makes separate contracts with specialised contractors, for example with a GC and MEP contractos.
Project management methods	Project management contract	Project-specific decision	Client or shifted to GC	Client	Design contracts can be handled either by client or GC. Procurement contracts, implementation planning and steering of designs are handled by GC. There can be project specific variance in these responsibilities and tasks.
Project management methods	Project management as a service	Project plan or alternative project designs	Client	Client	A consultant is hired as the "GC" and they handle all the tendering and procurement. The contracts on the site are made with the client as the other party, not the consultant.
Project management methods	Project manager as a developer	General or implementation plans	Client	Client	A larger project is completed in parts consisting of separate contracts and sub-projects. The responsibilities of a GC are shared between individual contracts and contractors.
Collaborative models	Partnership contract	Project-specific decision	Shared responsibility	Decided together	No standardised method has yet been established. The responsibilities, gains and losses are shared between parties to encourage collaboration.
Collaborative models	Alliance model	Project plan	Shared responsibility	Decided together	Responsibilities, tasks, losses and gains are spread evenly to all stakeholders. Many contractors are onboarded earlier than in other delivery methods. Suitable for massive projects and projects with an abundance of risk to be shared.
Lifespan model	Public-Private-Partnership	Alternative project designs	General contractor (GC)	General contractor (GC)	Usually a contract between a public client and a private contractor. There are two contracts between the same parties: One for the construction and one for the services provided after construction such as maintenance and hospitality services. Length of the latter contract can be decades.

As can be seen from Table 2 column “more information”, the delivery methods influence the level of detail of plans during contract negotiations and thus may

[5] (Rakennustieto Oy, 2016)

influence the feasibility of the simultaneous quantity, cost and carbon footprint estimation process investigated by this study (Rakennustieto Oy, 2016).

3.5. Climate Declaration

This chapter discusses the climate declaration that is to be delivered to the Finnish Building Control along with the building permit: the formulas for estimating the carbon footprint in chapter 3.5.1., as well as the presentation of the material list in chapter 3.5.2. and the presentation of the climate declaration in 3.5.3. Finally, in chapter 3.5.4., the thesis discusses the parameters that must be fulfilled to ensure that the climate declaration can be considered reliable.

3.5.1. Formula for Climate Declaration and Phases of Building Life Cycle

According to the decree drafts published by the Ministry of the Environment to support the new construction legislature, the climate effects of a building's life cycle must be calculated using the following formula below. The formula covers all relevant phases of the building life cycle. Some phases or sources of emissions are intentionally left out while others are included. The reasoning for these inclusions and exclusions is given in Table 3 that also details the phases of construction and the life cycle of the building while splitting these phases into even smaller modules than in the formula below. The phases start from phase A1 (material extraction) and go until C4 (disposal). There is also a "phase D", that considers emissions outside the system boundaries of the building, mainly the carbon handprint by means of renewable energy, for example. Some modules will be able to be calculated using table values and some using more accurate calculations. (Kuittinen, 2021).

$$
\begin{gathered}
Cfootprint = \\
GWPmanufacturing + GWPreplacements + GWPwaste\ processing \\
+ GWPwaste\ disposal + GWPtransports + GWPconstruction\ site \\
+ GWPenergy\ consumption
\end{gathered}
$$

The acronym, GWP, refers to *global warming potential*, which compares the emissions generated by the product or activity to the effect of comparable amount of carbon dioxide in a span of a hundred years. Some greenhouse gases are more potent and damaging to the environment than others, so the carbon dioxide works as a benchmark to compare the other gases. The emissions are quantified as $kgCO_2e$, known as kilograms of CO_2 equivalent. The formula covers all processes generating greenhouse gases and processes that may contain or remove greenhouse gases from the atmosphere, such as mining and planting of trees for timber, respectively. (Kuittinen, 2021)

Next, the study briefly covers the various phases of a product life cycle and ties them to the modules of a life cycle of a building presented in Table 3.

$GWPmanufacturing$ covers all organic and fossil fuel related emissions from the manufacturing of base material, transport to further processing and finally the manufacturing of the product that will be installed on site. Looking at Table 3, this would correspond to phases A1-A3. (Kuittinen, 2021)

$GWPreplacements$ covers all emissions related to the replacement of building elements during the operation of the building and correspond to phase B4 in Table 3. Different building parts have different life spans, which can be relatively easily assessed (Kuittinen, 2021).

$GWPwaste\ processing$ covers all emissions generated by waste processing from site operations (A5), product replacements (B4), and demolition (C3).

$GWPwaste\ disposal$ l covers all emissions generated by the disposal of non-processable waste (C4) generated by site operations (A5), product replacements (B4), and demolition (C3).

$GWPtransports$ covers the emissions generated by transportation of products to the site (A4), transportations of replacements and waste generated by replacements (B4), and transportation of waste generated by demolishing operations.

$GWPconstruction\ site$ covers the emissions generated by site operations during initial construction (A5), replacement operations (B4) and demolishing operations (C1).

$GWPenergy\ consumption$ covers the emissions generated by the operation of the building (B6). (Kuittinen, 2021)

According to the decree by the ministry of the environment, in the assessment of the carbon footprint, those processes that have an existing method of standardised CO_2 footprint estimation should be calculated. Sources can include the national emissions database (www.co2data.fi), along with product information made along the guidelines of European standards EN 15643, EN 15978 and specifically EN 15804. (Kuittinen,

2021) The use of these sources is discussed later in the study in chapters 3.6, 3.7. and 3.8.

Table 3. Modules of building life cycle to be included in the CO2 footprint assessment. Grey phases are excluded. The phases in blue can be estimated using table values provided by the Ministry of the Environment.[6]

Phase of Life Cycle		Inclusion	Argument for inclusion/exclusion
Pre-Use	A1-3 Raw material extraction and processing. Transport to the manufacturer. Manufacturing.	Included	Impact of products is significant and easily assessed during design phase.
	A4 Transport to the building site	Included	Impact of product transportation is not that significant, but relatively easy to assess. Reduction of transportation has additional benefits to society.
	A5 Site Operations	Included	There are actions being taken to reduce the CO2 footprint of site operations. Quantifying these is essential in making the effects of reductions visible.
During Building Use	B1 Product Use	Excluded	Minimal impact, mainly HVAC cooling fluid leaks could be included.
	B2 Maintenance	Excluded	Relatively small impact. Design phase has little to no control over products and machinery used in building maintenance.
	B3 Repair	Excluded	Sudden breakdowns of materials or machinery is difficult to forecast reliably.
	B4 Product replacement	Included	Wear and tear of individual products is relatively easy to quantify. By assessing the carbon footprint of products replacements, the regulation can steer the builders away from products with low initial carbon footprint but short life cycle.
	B5 Refurbishment	Not included ir	In large renovations, significant changes are made to the building. These are difficult to forecast when during the initial design phase. Large-scale renovation projects will be required to assess the environmental impact separately during the planning of the renovation.
	B6 Operational energy use	Included	Energy use is one of the most important factors affecting the CO2 footprint of the building.
	B7 Operational water use	Excluded	Water use is not a significant factor in the CO2 footprint of the building, and the assessment is time-consuming. The heating of water for use is taken into account in section B6 Energy use.
	B8 User activities	Excluded	User impact would require project specific assessments, which would be difficult to confirm.
Post-use	C1 Demolition	Included	The quantity of materials is adequately known during design phase. Inclusion of post-use phases would assists in the assessment of design
	C2 Transportation to waste processing	Included	
	C3 Waste processing	Included	
	C4 Disposal	Included	
Post-use	D Benefits and loads beyond the system boundary (carbon handprint)	Included	Included in the assessment methodologies of other Nordic countries. Benefits for the circular economy and climate are to be done according to specific ISO and EN standards.

[6] (Kuittinen, 2021)

As stated in the beginning of this chapter, some of the modules shown in Table 3 can be calculated using table values provided by the Ministry of the Environment. These modules are shown in blue colour in Table 3. The calculation is discussed later in chapter 4.0 and its sub-chapters where the tools available are tested. (Ministry of the Environment, 2021)

3.5.2. Presentation of the Material List

The building elements included or excluded in the material list and climate declaration are shown in Table 4 on the following page and in more detail in Appendix 7. The division of the building elements in the decree is made according to the Building2000 (FI: Talo2000) classification system.

The party responsible for the material list should separate the building according to a few parameters: Into the site and the actual building, as well as into site elements, building elements, internal space elements and service elements. Construction happing outside the building is designated to “site”, while everything inside the building envelope is designated to “building.” According to the draft of the ministry, foundations are part of “site”, but ground floor slabs are part of the “building.”

Parts left out are usually packaging of products or building parts that are difficult to quantify or those that have minimal impact on the footprint of the building, such as IT systems, building automation systems and signs. Up to 5% of materials that should be included in the material list and climate declaration can be excluded. This is done to ease the calculation as some parts can be more difficult to assess than others and follows the same principle as the EN 15804 standard for life-cycle assessment of building parts. (Kuittinen, 2021).

Table 4. The Building2000 classification system contains all relevant building parts and systems to be included in the climate declaration. A more detailed set of inclusions and exclusions can be found in Appendix 7.[7]

	Building elements included in the assessment, based on Building2000-classification system		
	Building	**Building Site**	**Not included in the assessment**
Site Elements	-	Ground Elements Soil Stabilisation and reinforcement elements Pavements Green areas Site structures	Clearings, digs and canals Site equipment Packaging Demolishing of old buildings of structures Vegetation, soil and water systems
Building Elements	Ground floor slabs Frame Facade, doors and windows External decks Roof structures	Foundations	Separate nails, screws, glues, sealants, seams, and other adhesives not included in the products. Smoke extraction structures Product packaging
Internal Space Elements	Internal dividers Space surfaces Internal fixtures Other internal space elements Box units (e.g. bathroom modules)		Balustrades and railings Internal signage Maintenance platforms and catwalks Other special internal space elements (infills) Separate nails, screws, glues, sealants, seams and other adhesives not included in the products. Battens, fiddles, edge strips Product packaging
Service Elements	Heating system, main elements Water and sewage system, main elements Air-conditioning system, main elements Cooling system, main elements Sprinkler system, main elements Electrical system, main elements Elevators and escalators	Service elements outside the building servicing the site rather than the building, e.g. lighting and external shed electrical systems.	IT-systems Building automation systems Back-up systems Separate machines and devices Product packaging

All in all, the building elements, the materials, and the origins of the materials in the building parts must be listed. The materials must be divided by type like below:

1. Concrete, masonry, mineral-, ceramic-, and natural stone materials.
2. Wood and natural fibres
3. Glass
4. Plastics and rubber
5. Bitumen materials and mixtures
6. Metals
7. Insulation
8. Gypsum
9. Machines and equipment
10. Other materials
11. Soil and mineral aggregates

[7] (Kuittinen, 2021)

The material origins must be divided in the following manner:

1. Renewable material (renewal within 100 years)
2. Non-renewable material
3. Recycled material
4. Reused products
5. Hazardous products

(Kuittinen, 2022).

The Ministry of the Environment has given an example of the material listing with a window as an example. This example is shown in Table 5. Some materials can fit more than one category and must be declared in all relevant categories. This can be the case for example where a certain portion of metal alloy is made by smelting recycled metal parts from and another portion is sourced from virgin ore. The decree covering the material list acknowledges that in the early phases of project development the final material choices for example for windows can be unpredictable due to unfinished designs and procurement processes. In such a case a generic value from for example the www.co2data.fi database should be used and updated when the final product is known. (Kuittinen, 2022).

Table 5. Presentation of the classification of materials of a window by material type and origin.[8]

Origins of Materials, Example of a Window		
This example window is estimated to weigh 15 kg, consisting of 10 kg of glass, 3,5 kg of wood, 1 kg of metal and 0,5 kg of synthetic rubber. The materials would be divided in the following manner. Materials fitting more than one category must be declared in all relevant categories, as is the case of metal material in this example.	Weight	Explanation
Renewable materials	3,5 kg	Wooden materials.
Non-renewable materials	11,5 kg	10 kg of glass, 1 kg of metal, 0,5 kg of synthetic rubber.
Recycled materials	0,3 kg	In the example 30% of metals are recycled.
Reused materials	0 kg	The product would not contain any reused materials.
Hazardous materials	< 0,1 kg	The product would not contain any significant amounts of hazardous materials.

In summary, the material list must contain the following information:

1. Unique building ID (FI: Rakennustunnus)
2. Class of intended use of building (residential, office, etc.)
3. Heated net area
4. List of building elements
5. List of materials within building elements (gypsum, wood, etc.)
6. List of materials classified by origin (reused, new, hazardous, etc.)
7. Intended operational life span of the building.
8. Date of the material list as well as the signature and education of the person responsible. (Ministry of the Environment, 2022a).

3.5.3. Presentation of the Carbon Calculation

The draft decree on climate declaration by the Ministry of the Environment states that the sustainability analysis of the climate declaration must be split into two parts:

- The carbon footprint of the building.
- The carbon footprint of the building site.

[8] (Kuittinen, 2022)

In addition, the sustainability analysis climate declaration must be divided into 3 phases:

- The construction phase.
- The operational phase.
- The demolition/disposal phase.

In its final form, the climate declaration should look like in Tables 6 and 7. The climate declaration must detail the carbon footprint as well as handprint from the building construction, operation, and disposal phases. Both the results of the footprint and the handprint calculations are shown here to give the reader a clearer picture of the deliverables to the Building Control, despite this thesis focusing on the footprint calculation. The CO_2 equivalents must be given both in per square meter values as well as total values. (Ministry of the Environment, 2021).

Table 6. The presentation of the carbon footprint for the climate declaration.[9]

	Carbon footprint	
	Building	**Building Site**
A1-A3 Raw material extraction and product manufacturing	kgCO2e/m2/a	kgCO2e/m2/a
A4 Transport	kgCO2e/m2/a	kgCO2e/m2/a
A5 Site operations	kgCO2e/m2/a	kgCO2e/m2/a
B4 Product replacement	kgCO2e/m2/a	kgCO2e/m2/a
B6 Operational energy use	kgCO2e/m2/a	kgCO2e/m2/a
C1 Demolition	kgCO2e/m2/a	kgCO2e/m2/a
C2 Transportation to waste processing	kgCO2e/m2/a	kgCO2e/m2/a
C3 Waste processing	kgCO2e/m2/a	kgCO2e/m2/a
C4 Disposal	kgCO2e/m2/a	kgCO2e/m2/a
Total carbon footprint	**kgCO2e/m2/a**	**kgCO2e/m2/a**
	kgCO2e total	**kgCO2e total**
m2 = total sum of heated floor area calculated from the interior surfaces of the exterior walls a = length of assessment period in years		

[9] (Ministry of the Environment, 2022b)

Table 7. The presentation of the carbon handprint calculation for the climate declaration. [10]

	Carbon Handprint	
	Building	**Building Site**
D1 Reuse and recycling	kgCO2e/m2/a	kgCO2e/m2/a
D2 Use as energy	kgCO2e/m2/a	kgCO2e/m2/a
D3 Excess renewable energy	kgCO2e/m2/a	kgCO2e/m2/a
D4 Product carbon containment	kgCO2e/m2/a	kgCO2e/m2/a
D5 Carbonisation	kgCO2e/m2/a	kgCO2e/m2/a
D6 Planted trees	kgCO2e/m2/a	kgCO2e/m2/a
Total carbon footprint	**kgCO2e/m2/a**	**kgCO2e/m2/a**
	kgCO2e total	**kgCO2e total**
m2 = total sum of heated floor area calculated from the interior surfaces of the exterior walls a = length of assessment period in years		

In addition to the emissions information shown in Tables 6 and 7, the climate declaration must contain the following information:

1. Unique building ID (FI: Rakennustunnus)
2. Class or classes of intended use of building (residential, office, etc.)
3. Heated net area and site area
4. Results of the carbon assessment, both the total and a separated value for each intended building use
5. Intended number of users of the building
6. Estimate of purchased energy used by the building.
7. Duration(s) of used lifespans for the separate assessments
8. Intended operational lifespan of the building.
9. Main structural material
10. Software or tools used in the assessment.
11. Date of the climate declaration as well as the signature and education of the person responsible. (Ministry of the Environment, 2022b)

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[10] (Ministry of the Environment, 2022b)

3.5.4. Reliability of the Climate Declaration

According to the guidebook on making the climate declaration drafted by the Ministry of the Environment, the climate declaration is deemed reliable when:

- The building is built according to building code.
- The carbon estimate is done according to the decree(s) of the Ministry of the Environment.
- Quantity information is deemed adequate, when the quantities contain the building parts listed in in the decree on climate declaration. This corresponds to Appendix 7 of which a short version was shown in Table 4 in chapter 3.5.2.
- In relation to the building service systems, accurate quantity information can be replaced with table values from the national emissions database.
- The sources used are either the national emissions database or environmental product declarations based on the EN 15804+A2 standard. This also applies to the quality of the information. (Ministry of the Environment, 2021). The older EN 15804+A1 is also acceptable until 2024 (Ministry of the Environment, 2022b).

The EN 15804+A2 standard lays out the basis for the exclusion of data when assessing environmental data. The estimator can leave out emission sources when their amount of total mass of the produced unit is less than 1% or when their energy consumption is less than 1% of total consumption. As previously mentioned, a maximum of 5% per assessed module (A-D) can be neglected. Larger gaps in information must be supplemented with generic information or a conservative estimate if no other source of data is available. (Suomen Standardoimisliitto, 2019).

3.6. Priority and Sources of Emissions Data

According to a guide to climate declaration published by the Ministry of the Environment, the climate declaration must be established using reliable sources, of which the order of preference is given by the Ministry of the Environment. The source of emissions has an impact on which data source should be used primarily. The two primary sources for emissions data are environmental product declarations (EPDs) and the national CO2 database (www.co2data.fi). More on EPDs later in chapter 3.7 and the national CO_2 database in chapter 3.8. Peer-reviewed studies or other emissions databases can be used as tertiary sources. This chapter discusses the preferred sources for emission data as stated by the Ministry of the Environment per building life cycle phase. (Ministry of the Environment, 2021)

3.6.1. For the Building Permit

For construction materials (modules A1-A3), the primary source of emissions data should be the environmental product declaration (EPD) of the chosen product. If no product is chosen at the time, generic data from the national CO_2 database should be used. If no information is found in those two sources, the information can either come from another commonly used emissions database, or a peer-reviewed study that is applicable to Finnish conditions and is under ten years old. (Ministry of the Environment, 2021)

For transport emissions (A4), a table value given by the national emissions database should be used. Nevertheless, if desired, more accurate distances and fuel consumption and emissions from factory to site can also be used. (Ministry of the Environment, 2021). The table value is 27 kg CO_2e/m^2 (net area of building), of which a screenshot is shown of the CO_2 database in Figure 4.

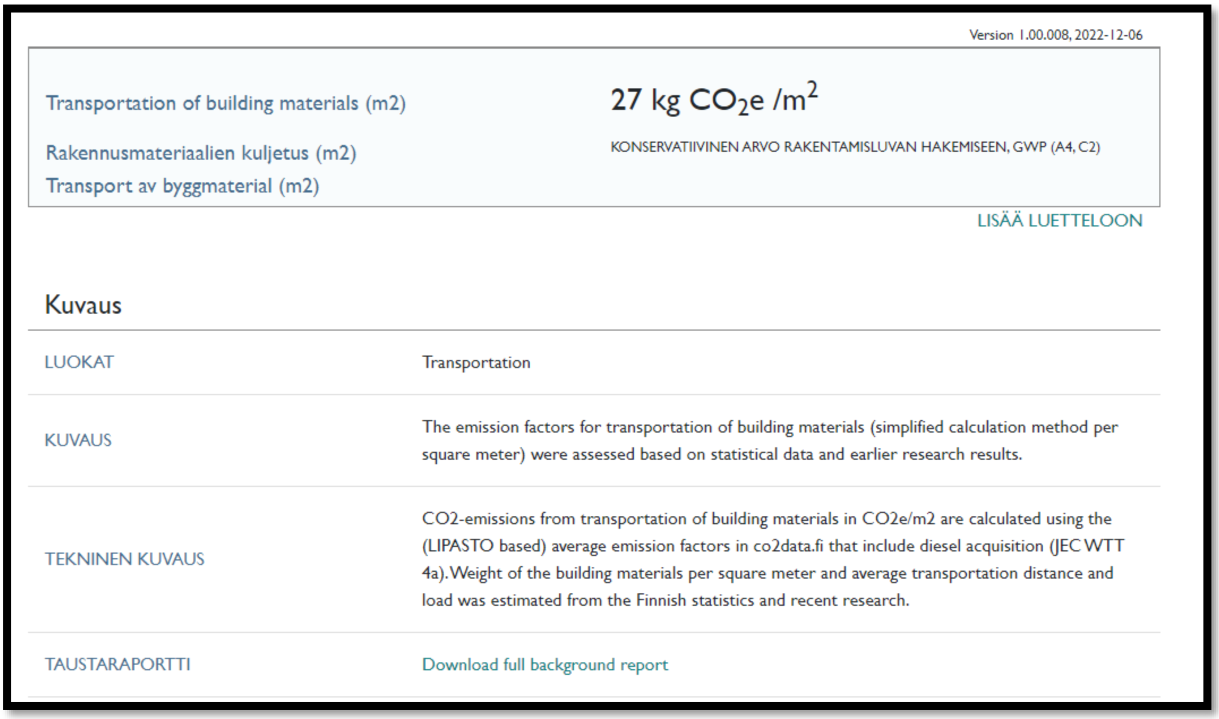

Figure 4. The table value for transports is shown on the co2data.fi database.[11]

The national emissions database also provides a description of the value and a full background report to explain how the researchers came up with such a number. (Finnish Environmental Insititute, 2022)

For site energy use (A5), the national database contains table values for the construction processes of different building types and their preceding earthworks and stabilisation. These table values can be used to estimate the climate effects of the site operations. If desired, the actual energy consumption of the site can also be calculated, just like in the case of transports. The data for different buildings does not consider earthworks or stabilisation, so the total of the site and building emissions is a sum for the building type emissions and the earthworks plus stabilisation if the latter is necessary. (Ministry of the Environment, 2021)

The table values for different kinds of works are shown in Table 8, with the values taken form the national www.co2data.fi database.

[11] (Finnish Environmental Insitute, 2023)

Table 8. The table values for different construction operations. The construction operations exclude earthworks and stabilisation, and they should be added in the total if necessary.[12]

Type	Table value	Unit
Construction: Office building	78	kg CO2e/m2 (net)
Construction: Residential building	46	kg CO2e/m2 (net)
Construction: School or kindergarten	60	kg CO2e/m2 (net)
Earthwork	7	kg CO2e/m2 (gross)
Stabilisation	0,04	kg CO2e/ unit of stabiliser

For the buildings, the emissions are calculated based on net area, whereas for the earthworks and stabilisation the gross area is used (Finnish Environmental Insitute, 2023).

3.6.2. For the Finished Building

For determining energy consumption of the finished building, an energy declaration should primarily be used. And example of an energy declaration showcasing the consumption of a building is shown below in Figure 5. (Ministry of the Environment, 2021)

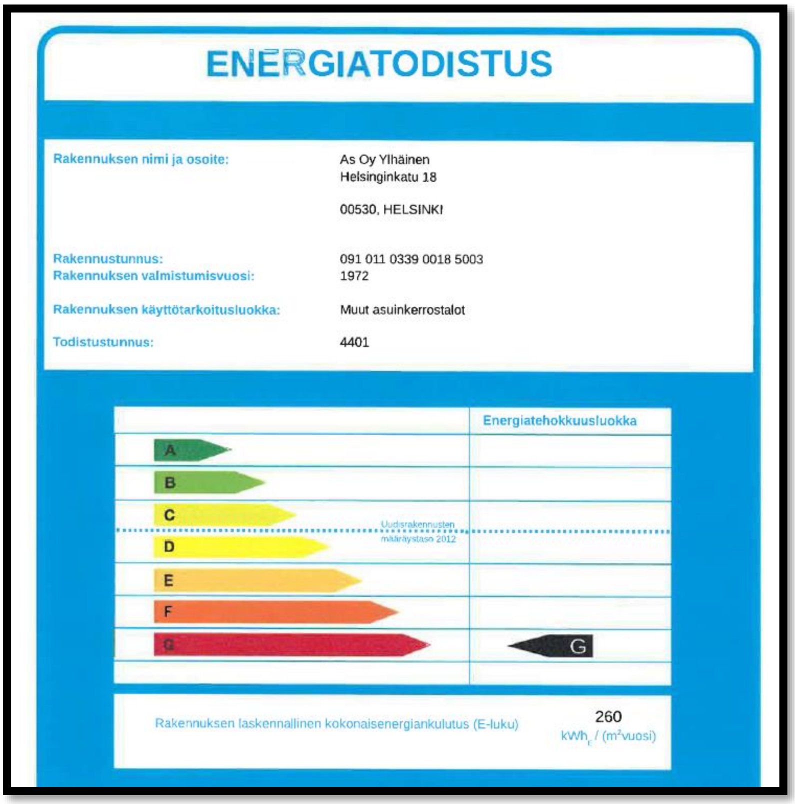

Figure 5. An energy declaration of a building built in 1973. On the bottom right one can see the energy consumption in kilowatt hours per square meter per annum.[13]

[12] (Finnish Environmental Insitute, 2023)
[13] (Harju, 2015)

The consumption of energy by the building is shown as kilowatt hours per square meter on the bottom right of the energy declaration. The emissions are then calculated by multiplying the energy consumption with the net floor area of the building and a multiplier given by the National Emissions Database that depends on the fuel source used. If the building is missing an energy declaration, a similar method akin to the energy declaration process should be used to establish energy consumption. (Ministry of the Environment, 2021)

3.7. Environmental Product Declarations

In the previous chapter this study briefly introduced the order of priority of emissions data sources for different life cycle sources of emissions of the building: The product manufacturing, transports, site operations and building operation. This chapter discusses the main source of data, i.e., the Environmental Product Declarations (EPDs). In the following chapter 3.8. the study introduces the National Emissions Database that can be used if no EPD is available, or no product is yet chosen and thus generic data is preferred for emissions calculations.

According to the EN 15804+A2 standard, which lays out the core rules for construction products in terms of sustainability, an Environmental Product Declaration (EPD):

> *"…provides quantified environmental information for a construction product or service on a harmonized and scientific basis. It also provides information on health-related emissions to indoor air, soil, and water during the use stage of the building"* (Suomen Standardoimisliitto, 2019).

The standard itself is intended to provide rules and framework for harmonious EPD generation. This is achieved by defining the indicators that need to be declared and the way they must be presented, as well as describing the stages of product life cycle to be considered. The standard also lays out the conditions upon which separate construction products can be compared based on the EPD information. The standard applies to not only construction products but also services. (Suomen Standardoimisliitto, 2019).

Environmental Product Declarations can usually be found on the website of the manufacturer of the product. Anyone can generate their own EPD, but there are companies that provide EPD generation as a service and in addition verify the EPD via a third party. Two examples of such service providers are the company OneClickLCA Oy and Rakennusteollisuus (RT), the consortium of the construction industry. As an example of the verification system, the industry consortium RT accredits its third-party verifiers for three years at a time. Currently, RT has 5 accredited EPD verifiers in Finland, of whom two come from the company Bionova Oy (which is known as of 2021 as OneClickLCA), one from Granlund Consulting Oy, another from Nordic Offset Oy and the last one from the Finnish Environmental Insititute (SYKE). The goal of the third-party verification process is to ensure that the EPD is made in accordance with the EN 15804+A2 standard. (Rakennusteollisuus, 2023).

3.7.1. Storage of Environmental Product Declarations

The organisations creating EPDs have or are in the process of creating EPD databases to enhance the accessibility and useability of the EPD files. The previously mentioned OneClickLCA generates EPDs for their clients but also maintain a large library of EPD data, useable within their browser-based software for life cycle analyses and carbon footprint and handprint estimates. This software will be discussed later in chapter 4.7. (OneClickLCA, 2023)

The industry consortium RT meanwhile is in the process of uploading all their product information along with their EPD files to a digital platform called ECO Portal by the company ECO Platform (Seppänen, 2022). ECO Portal is an ongoing project to create a database network where anyone can access and add EPD information using a common digital format and a standardised set of rules for data exchange and use. ECO Portal already has more than 5000 entries. There is no master data base, but a connection of smaller individual databases, be they public or private. The network of databases will be accessible via Application Programming Interfaces (APIs) so that other software can access the EPD information in a machine-readable format.

3.7.2. Content of Environmental Product Declarations

The EN15804+A2 states that a construction product or service EPD must declare the data on modules A1-A3 and C1-C4 covering the product stage and the end-of-life stages of the product. In addition, an EPD must cover the module D that covers the life cycle stage in a life cycle analysis known as the “reuse, recovery and recycling potential” of a product. There can be exemptions to the modules covered, but only if the product fulfils the following three requirements: It must not contain biogenic carbon (stored carbon e.g., wood products), and in the end of life of the product it must be unidentifiable and inseparable from another product. EPDs allowed exemption from

C1-4 and D must provide information on where to find information on the end of life for these modules. The standard provides an example of cement, which is exempt from these latter modules, whereas the EPDs covering products made partly from cement, i.e., concrete and mortar must cover these modules. There are additional optional modules that can be included in the EPDs, but at minimum the product EPD will cover “cradle to gate” data covering modules A1-A3, if the modules C1-4 can be excluded due to the nature of the product. (Suomen Standardoimisliitto, 2019)

Two examples of construction product EPDs are shown below in Figures 6 and 7 to further demonstrate the content and variety of the EPDs. Below are the cover pages of an EPD covering a 12.5 mm gypsum board by the company Saint-Gobain Finland Oy and an EPD covering several paints by Tikkurila Oy. (Dalborg, 2019).

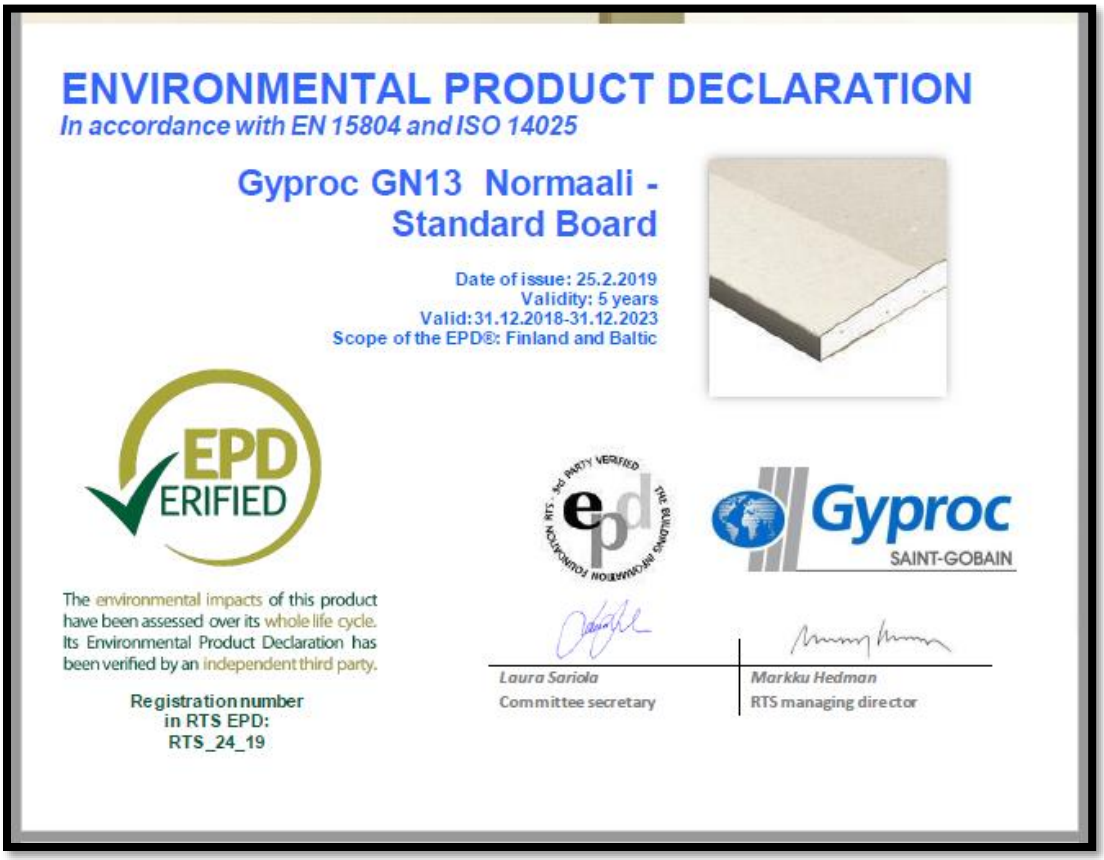

Figure 6. Cover page of the EPD of 12.5 mm thick gypsum board by the company Gyproc Saint-Gobain.[14]

[14] (Dalborg, 2019)

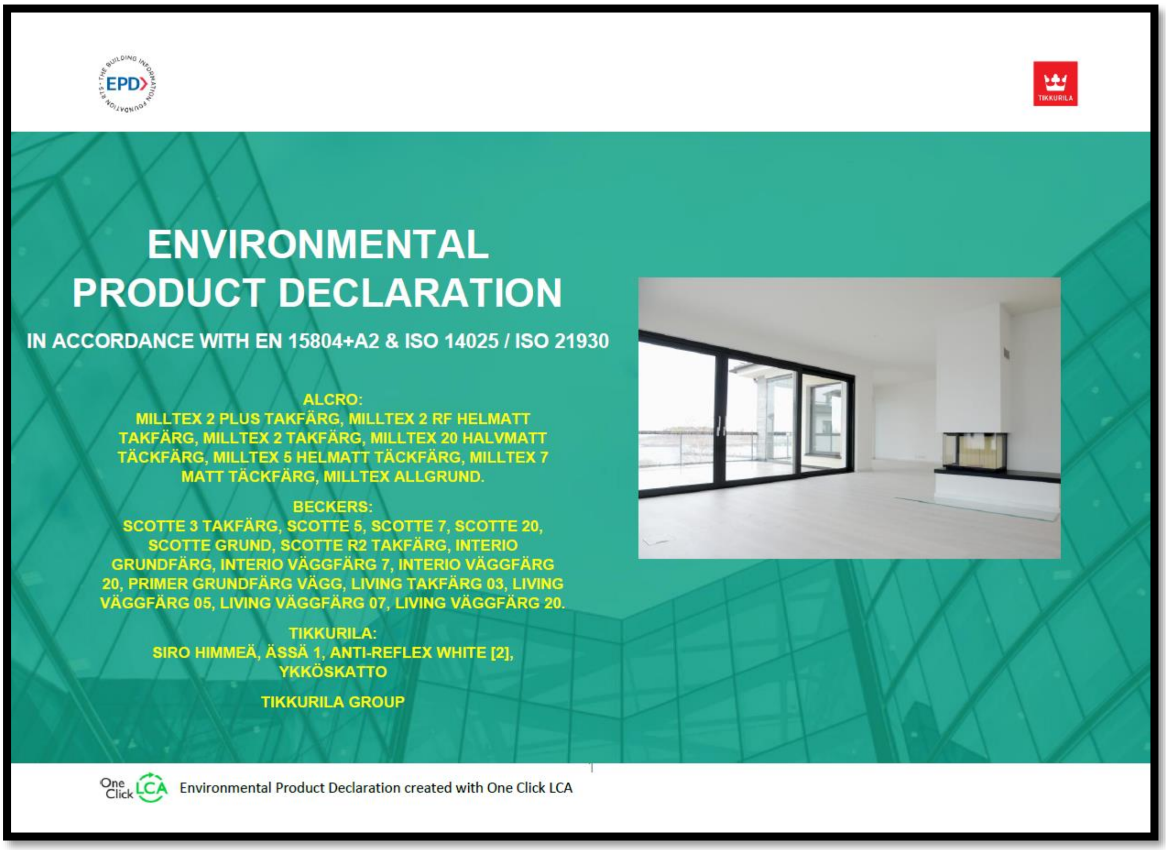

Figure 7. Cover page of the EPD of multiple Tikkurila paints.[15]

After the cover page, the EPD lists general information on the product in more detail. The information on the Saint-Gobain gypsum board for some of these details are given in parentheses as examples:

- Manufacturer (Saint-Gobain)
- Programme used for the creation of the EPD (The Building Information Foundation RTS)
- Publisher of the EPD (The Building Information Foundation RTS)
- EPD Registration number (RTS_24_19)
- Product category rules (PCR) and scope of the EPD ("…in accordance with EN 15804:2012)
- Site of manufacture of the product (Address)
- Owner of the declaration (Saint-Gobain Finland Oy, Gyproc)
- Issue dates and validity (25.2.2019. Valid from 31.12.2018 to 31.12.2023.)
- Intended service life of product (50 years)

[15] (Prieto, 2021)

- Contact regarding the EPD
- Declared unit of product and its characteristics: (1 m^2 of installed board of 12.5 mm thickness. Weight 8.40 kg/m^2 and density of 672 kg/m^3)

After the general information, information on the products themselves is given:

- Use cases (Plasterboard used for lining walls, floors, and ceilings.)
- Description (Gypsum core, paper liner, smooth surface with tapered or square edges.)
- Raw materials used and their composition (70-75 % Natural gypsum, 12-25 % recycled gypsum, 1-3 % additives, 5-7 % paper.)
- Physical properties (EN classification, fire resistance, water vapor resistance and thermal conductivity)
- If the EPD covers more than one product, like in the case of the Tikkurila paints, the list of the products concerned, and their product names are given.

After the product information, the information on the life cycle assessment methods (LCA) performed on the product is given. The corresponding page of the gypsum board EPD in shown as an example in Figure 8.

- EPD type (Cradle-to-gate)
- Declared unit (1m^2 of installed board of 12.5mm thickness. Weight 8.40 kg/m^2)
- System boundaries (A1-A3, A4-A5, B1-B7, C1-C4, D)
- Reference service life (50 years)
- Geographical coverage (Finland and Baltic)
- Product CPC code (37530)

LCA calculation information

EPD TYPE DECLARED	Cradle to Gate with options Product-specific (one product, one manufacturing site)
DECLARED UNIT	1 m² of installed board of 12.5mm of thickness and 8.40 kg/m² of weight
SYSTEM BOUNDARIES	Cradle to Gate with options: stages A1 – 3, A4 – A5, B1 – 7, C1 – 4 and D
REFERENCE SERVICE LIFE (RSL)	50 years By default, it corresponds to Standards building design life and value is included in Appendix III of Saint-Gobain Environmental Product Declaration Methodological Guide for Construction Products.
CUT-OFF RULES	Life Cycle Inventory data for a minimum of 99% of total inflows to the upstream and core module shall be included
ALLOCATIONS	Production data. Recycling, energy and waste data have been calculated on a mass basis
GEOGRAPHICAL COVERAGE AND TIME PERIOD	Scope includes: Finland and Baltic Data included is collected from one production site in Kirkkonummi, Finland, Saint-Gobain Finland Oy, Gyproc Data collected for the year 2018. Cradle to grave study. Background data: Ecoinvent (from 2015 to 2016) and GaBi (from 2013 to 2016)
PRODUCT CPC CODE	37530 Articles of plaster or of composition based on plaster

According to EN 15804, EPDs of construction products may not be comparable if they do not comply with this standard.
According to ISO 21930, EPDs might not be comparable if they are from different programmes.

Figure 8. The information on the LCA calculation of the gypsum board EPD.[16]

Beyond the short list of technical properties and boundaries, the life cycle assessment of each module is further delved into. The meaning of all the modules is explained and the values used to gain results. For example, in the A4 Transport module, the estimated distance and delivery method are stated. Finally, the EPD report shows the results of the assessment. The examples of the result pages are shown on the following pages for both the gypsum board and the paints in Figures 9 and 10. The modules A1 to A3 are the ones concerning the carbon footprint of a building relevant to this thesis and the climate declaration and are highlighted on the results in yellow. (Dalborg, 2019).

[16] (Dalborg, 2019)

[17]

ENVIRONMENTAL IMPACTS

Parameters	Product stage	Construction process stage		Use stage							End-of-life stage				D Reuse, recovery, recycling
	A1 / A2 / A3	A4 Transport	A5 Installation	B1 Use	B2 Maintenance	B3 Repair	B4 Replacement	B5 Refurbishment	B6 Operational energy use	B7 Operational water use	C1 Deconstruction / demolition	C2 Transport	C3 Waste processing	C4 Disposal	
Global Warming Potential (GWP 100) - *kg CO_2 equiv/FU*	2,1E+00	2,8E-01	1,1E-01	0	0	0	0	0	0	0	4,0E-02	3,3E-02	0	1,2E-01	1,9E-02
	The global warming potential of a gas refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1. GWP only accounts for greenhouse gases (GWPGHG) as outlined in EN 15804 and do not include biogenic CO².														
Ozone Depletion (ODP) *kg CFC 11 equiv/FU*	1,1E-07	3,3E-14	2,7E-09	0	0	0	0	0	0	0	1,1E-14	1,2E-14	0	1,2E-13	1,4E-13
	Destruction of the stratospheric ozone layer which shields the earth from ultraviolet radiation harmful to life. This destruction of ozone is caused by the breakdown of certain chlorine and/or bromine containing compounds (chlorofluorocarbons or halons), which break down when they reach the stratosphere and then catalytically destroy ozone molecules.														
Acidification potential (AP) *kg SO_2 equiv/FU*	8,9E-03	2,6E-03	4,8E-04	0	0	0	0	0	0	0	1,4E-04	3,6E-04	0	7,4E-04	1,1E-04
	Acid depositions have negative impacts on natural ecosystems and the man-made environment incl. buildings. The main sources for emissions of acidifying substances are agriculture and fossil fuel combustion used for electricity production, heating and transport.														
Eutrophication potential (EP) *kg $(PO_4)^{3-}$ equiv/FU*	3,8E-03	3,9E-04	1,3E-04	0	0	0	0	0	0	0	8,2E-06	5,1E-05	0	1,0E-04	2,8E-05
	Excessive enrichment of waters and continental surfaces with nutrients, and the associated adverse biological effects.														
Photochemical ozone creation (POPC) *kg Ethylene equiv/FU*	3,8E-04	1,2E-04	4,4E-05	0	0	0	0	0	0	0	9,2E-06	1,8E-05	0	6,1E-05	2,2E-05
	Chemical reactions brought about by the light energy of the sun. The reaction of nitrogen oxides with hydrocarbons in the presence of sunlight to form ozone is an example of a photochemical reaction.														
Abiotic depletion potential for non-fossil ressources (ADP-elements) - *kg Sb equiv/FU*	4,2E-06	4,3E-09	2,0E-06	0	0	0	0	0	0	0	1,1E-09	1,3E-09	0	4,3E-08	1,2E-08
Abiotic depletion potential for fossil ressources (ADP-fossil fuels) - *MJ/FU*	3,4E+01	3,9E+00	1,5E+00	0	0	0	0	0	0	0	5,0E-01	4,4E-01	0	1,6E+00	2,8E-01
	Consumption of non-renewable resources, thereby lowering their availability for future generations.														

10

Figure 9. The environmental impacts page of the Gyproc 12.5 mm gypsum board, with the global warming potential of modules A1-A3 highlighted in the top left corner. [15]

[17] (Dalborg, 2019)

[18]

EPD

ENVIRONMENTAL IMPACT DATA

Note: additional environmental impact data may be presented in annexes.

CORE ENVIRONMENTAL IMPACT INDICATORS – EN 15804+A2, PEF

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
GWP – total	kg CO2e	1,53E0	8,59E-2	2,18E-1	1,84E0	6,05E-2	8,48E-2	MND	MND	MND	MND	MND	MND	MND	5,23E-7	4,68E-3	0E0	1,09E-1	-1E-2
GWP – fossil	kg CO2e	1,52E0	8,58E-2	2,15E-1	1,82E0	6,1E-2	9,43E-2	MND	MND	MND	MND	MND	MND	MND	5,74E-8	4,68E-3	0E0	1,09E-1	-4,57E-4
GWP – biogenic	kg CO2e	1,08E-2	4,64E-5	-3,44E-3	7,44E-3	3,25E-5	-9,48E-3	MND	MND	MND	MND	MND	MND	MND	7,57E-8	2,12E-6	0E0	6,15E-5	-9,54E-3
GWP – LULUC	kg CO2e	8,14E-4	3,04E-5	6,18E-3	7,02E-3	2,16E-5	1,11E-6	MND	MND	MND	MND	MND	MND	MND	3,9E-7	1,72E-6	0E0	3,66E-6	-4,55E-6
Ozone depletion pot.	kg CFC11e	1,32E-7	1,93E-8	5,92E-9	1,57E-7	1,39E-8	4,86E-10	MND	MND	MND	MND	MND	MND	MND	4,24E-15	1,03E-9	0E0	2,3E-9	-1,24E-10
Acidification potential	mol H+e	3,1E-2	4,12E-4	8,33E-4	3,23E-2	2,49E-4	2,48E-5	MND	MND	MND	MND	MND	MND	MND	2,45E-10	1,96E-5	0E0	6,51E-5	-1,5E-5
EP-freshwater[2)]	kg Pe	2,2E-4	7,76E-7	6,26E-6	2,27E-4	5,1E-7	4,47E-8	MND	MND	MND	MND	MND	MND	MND	1,6E-12	4,67E-8	0E0	1,36E-7	-2,32E-7
EP-marine	kg Ne	1,73E-3	1,18E-4	1,48E-4	1,99E-3	7,41E-5	1,04E-5	MND	MND	MND	MND	MND	MND	MND	6,61E-11	5,68E-6	0E0	2,23E-5	-4,76E-6
EP-terrestrial	mol Ne	1,64E-2	1,31E-3	1,66E-3	1,94E-2	8,18E-4	1,07E-4	MND	MND	MND	MND	MND	MND	MND	7,52E-10	6,28E-5	0E0	2,45E-4	-7,36E-5
POCP ("smog")	kg NMVOCe	6,38E-3	4,02E-4	6,58E-4	7,44E-3	2,5E-4	3,23E-5	MND	MND	MND	MND	MND	MND	MND	2,37E-10	1,96E-5	0E0	8,8E-5	-1,38E-5
ADP-minerals & metals	kg Sbe	2,35E-5	1,94E-6	2,36E-6	2,78E-5	1,65E-6	5,9E-8	MND	MND	MND	MND	MND	MND	MND	5,48E-13	1,14E-7	0E0	8,13E-8	-6,27E-9
ADP-fossil resources	MJ	2,68E1	1,3E0	4,53E0	3,26E1	9,2E-1	3,75E-2	MND	MND	MND	MND	MND	MND	MND	5,01E-7	6,99E-2	0E0	1,75E-1	-5,4E-3
Water use[1)]	m3e depr.	1,73E0	4,94E-3	1,35E-1	1,87E0	2,96E-3	4,61E-4	MND	MND	MND	MND	MND	MND	MND	2,57E-7	2,89E-4	0E0	7,73E-3	-7,21E-5

1) GWP = Global Warming Potential; EP = Eutrophication potential; POCP = Photochemical ozone formation; ADP = Abiotic depletion potential. 2) EN 15804+A2 disclaimer for Abiotic depletion and Water use and optional indicators except Particulate matter and Ionizing radiation, human health. The results of these environmental impact indicators shall be used with care as the uncertainties on these results are high or as there is limited experienced with the indicator. 3) Required characterisation method and data are in kg P-eq. Multiply by 3,07 to get PO4e.

ADDITIONAL (OPTIONAL) ENVIRONMENTAL IMPACT INDICATORS – EN 15804+A2, PEF

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Particulate matter	Incidence	1,08E-7	6,71E-9	9,27E-9	1,24E-7	4,25E-9	4,65E-10	MND	MND	MND	MND	MND	MND	MND	4,68E-15	3,56E-10	0E0	1,22E-9	-1,93E-10
Ionizing radiation[3)]	kBq U235e	5,46E-2	5,55E-3	3,84E-3	6,4E-2	4,02E-3	1,47E-4	MND	MND	MND	MND	MND	MND	MND	2,46E-9	2,91E-4	0E0	6,87E-4	-2,16E-5
Ecotoxicity (freshwater)	CTUe	3,44E1	1,05E0	3,63E0	3,9E1	7,1E-1	1,04E-1	MND	MND	MND	MND	MND	MND	MND	8,1E-7	5,97E-2	0E0	1,47E-1	-1,28E-1
Human toxicity, cancer	CTUh	3,85E-9	2,85E-11	6,96E-10	4,58E-9	2,06E-11	1,54E-11	MND	MND	MND	MND	MND	MND	MND	1,28E-16	1,55E-12	0E0	4,29E-11	-3,36E-12
Human tox. non-cancer	CTUh	4,02E-8	1,16E-9	4,54E-9	4,59E-8	8,03E-10	2,09E-10	MND	MND	MND	MND	MND	MND	MND	1,33E-15	6,32E-11	0E0	2,26E-10	-6,6E-11
SQP	-	4,06E0	1,51E0	1,91E-1	5,76E0	7,66E-1	4,51E-2	MND	MND	MND	MND	MND	MND	MND	-1,29E-7	7,68E-2	0E0	6,17E-1	-2,84E-3

13

Alcro: Milltex 2 Plus Takfärg, Milltex 2 RF Helmatt Takfärg, Milltex 2 Takfärg, Milltex 20 Halvmatt Täckfärg, Milltex 5 Helmatt Täckfärg, Milltex 7 Matt Täckfärg, Milltex Allgrund. Beckers: Scotte 3 Takfärg, Scotte 5, Scotte 7, Scotte 20, Scotte Grund, Scotte R2 Takfärg, Interio Grundfärg, Interio Väggfärg 7, Interio Väggfärg 20, Primer Grundfärg Vägg, Living Takfärg 03, Living Väggfärg 05, Living Väggfärg 07, Living Väggfärg 20. Tikkurila: Siro Himmeä, Ässä 1, Anti-reflex white [2], Ykköskatto

Environmental Product Declaration created with One Click LCA

Figure 10. The environmental impacts page of the various paints covered by the Tikkurila EPD. The global warming potential of modules A1-A3 is highlighted in yellow on the top of the page. [16]

[18] (Prieto, 2021)

3.7.3. Criticism of EN15804

There has been some criticism on whether the EN15804 standard adequately works for buildings. Some of the criticism about to be detailed has already been addressed by the updating of the EN15804 standard by the European Committee for Standardization (CEN). Some of the updates exist to align the EPDs with another EU standard for the Product Environmental Footprint (PEF) while the ECO Platform initiative mentioned earlier in this study is also connected to the updating and harmonisation of the EPD generation and storage. (Gaasbeek, 2019).

Ph.D. researcher Sahar Mirzaie stated that when considering EPDs and construction, the results of the EPD are not weighted in any way, thus leaving the interpretation of the results to the reader. When comparing two different products, Mirzaie states that there is more than just the global warming potential to be considered. An example is given when comparing two different insulation materials: Not only in the GWP important, but also the insulative properties and the life span of the product. Some issues that have already been addressed by the update of the standard were lack of water and human health related indicators, lack of consideration of recyclability of the product and the scope of the EPD that was previously a kind of pick-and-choose approach. Nowadays, all EPDs must consider the modules A1-A3, C1-C4, and D, and only in very specific cases are they allowed to only consider product manufacturing. This is meant to help in making comparisons between products, though some of the criticism made by Mirzaie is still most likely valid in terms the other properties of the products. (Mirzaie, 2016).

3.8. National Emissions Database

The previous chapter discussed EPDs, which should be used as a primary source for emissions information. Nevertheless, if no product is chosen by the time of the first carbon assessment, generic data may be used. For this purpose, the Finnish Environmental Institute (FI: SYKE, Suomen Ympäristökeskus) has developed, in collaboration with Green Building Council Finland and their Swedish counterparts, a database of the environmental effects of common building materials used in Finland and the Nordics. The work was commissioned by the Ministry of the Environment. The Nordic collaboration was done to enable harmonisation of future environmental assessment methods throughout the region. Both the carbon footprint and handprint of various materials is accounted for in the database, as well as material efficiency and recyclability. The information is presented as generalised information, with no individual company or product information presented. The information is based on various sources, mainly environmental product declarations supplemented with generic data from for example VTT (Technical Research Centre of Finland) test reports. This database is meant to assist construction companies and designers in establishing the carbon estimate of construction projects. (Finnish Environmental Insititute, 2022).

Next, this thesis looks at the actual database and how it is organised and accessible. The database can be accessed on the site www.co2data.fi. The site is divided into building construction data and infrastructure construction data pages, shown below in Figure 11.

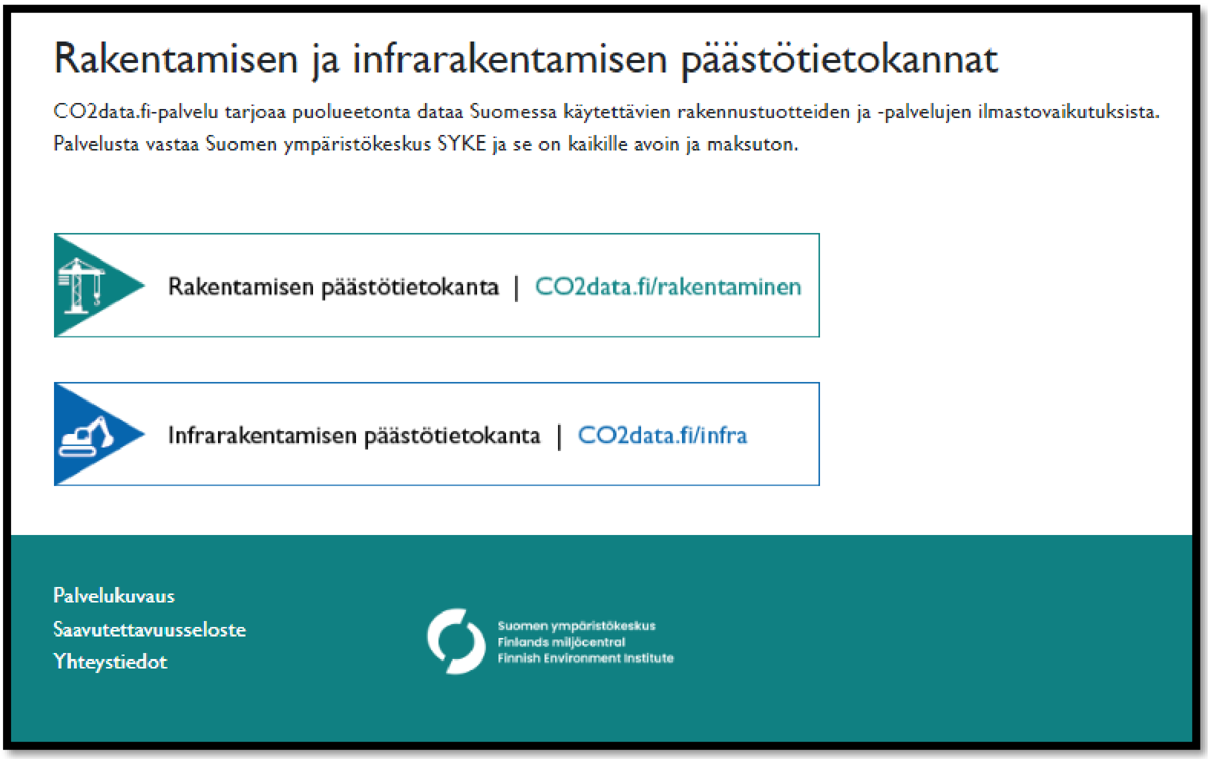

Figure 11. The main page of the national CO_2 database.[19]

The site requires no creation of an account and is completely free for anyone interested. By clicking the "Rakentamisen päästötietokanta", the user is taken to the construction emissions database of which a screenshot is shown in Figure 12.

[19] (Finnish Environmental Insitute, 2023)

The main page of the building material database works in Finnish, Swedish and English. The site has data for products but also services and processes such as energy, transportation and construction and demolition processes. (Finnish Environmental Insitute, 2023).

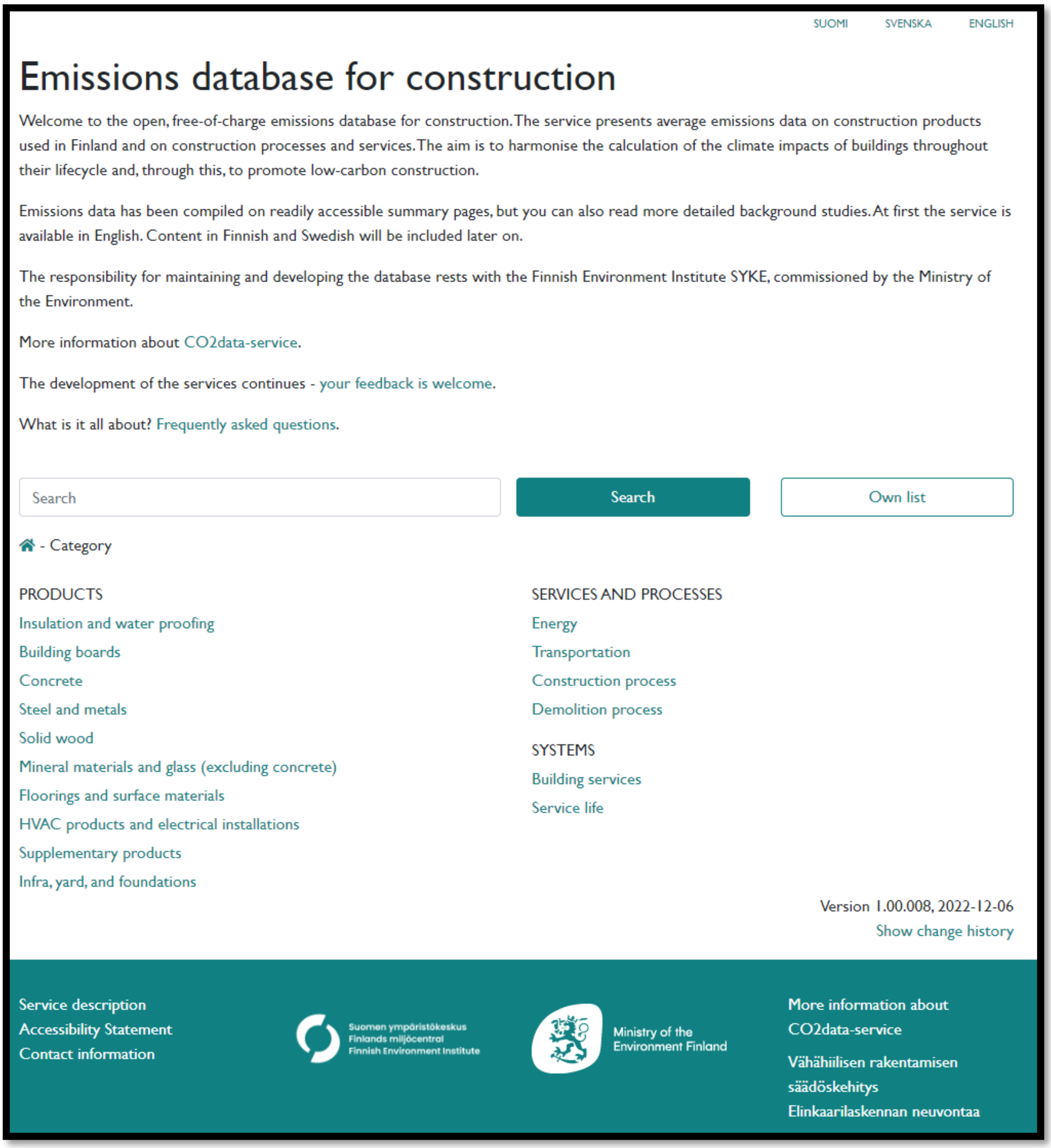

Figure 12. The main page for building construction emissions data of the co2data.fi website. [20]

The materials are sorted according to type. By clicking any blue link, the user is transferred to look at a more specific list of products in that category.

[20] (Finnish Environmental Insitute, 2023)

The data is presented as a fact sheet with the global warming potential of a product shown first for the modules A1-A3 required for the building permit climate declaration. An example of a search for gypsum board is shown in Figure 13. The emission value is in the unit of kg CO_2e / product kg. To help obtain this number, a conversion factor is given. In the case of gypsum board, the density (kg/m^3) of the board is given. By knowing the density, thickness of a single board, and the total number of square meters to be installed, the total weight of the materials used in construction can be calculated. The shares of renewable and recycled materials needed for the material list are also given.

Search | Search | Own list

- Category > Building boards > Gypsum plasterboard for interior use

Version 1.00.008, 2022-12-06

Gypsum plasterboard for interior use — **0.31 kg CO_2e /kg**

Kipsi-kartonkilevy sisäkäyttöön — CONSERVATIVE VALUE FOR BUILDING PERMIT CALCULATIONS, GWP (A1-A3)

ADD TO LIST

Environmental indicators

TYPICAL VALUE, GWP (A1-A3) Not for building permit calculations	0.26 kg CO_2e /kg	
CONSERVATIVE VALUE CONVERSION FACTOR	1.2	
CARBON HANDPRINT	D1 Re-use and material recycling D2 Energy recovery D4 Carbon storage effect D5 Carbonation	
WASTE FACTOR Loss at building site	1.05	
SHARE OF RENEWABLE MATERIALS (%)	-	
SHARE OF RECYCLED MATERIALS (%)	20 %	
SHARE (%) AND TYPE OF HARMFUL SUBSTANCES (SVHC)	<0.1 %	
END OF LIFE SCENARIO (%)	Reuse Recycled as secondary rawmaterial Energy recovery Final disposal Hazardous waste to be removed from use	0 % 15 % 0 % 85 % 0 %
CONVERSION FACTOR	Density, kg/m^3	670

Figure 13. The generic emissions and material information of gypsum board.[21]

[21] (Finnish Environmental Insitute, 2023)

Below material information, the environmental indicators and description of the product is given as well as its relation to the classification system (Talo2000). A full background report on the environmental assessment is also downloadable to ensure transparency. The information for the gypsum boards is shown in Figure 14.

General description

CATEGORIES	Building boards Mineral materials and glass (excluding concrete)
RELATED HARMONISED STANDARD(S)	EN 520 Gypsum plasterboards. Definitions, requirements and test methods
CLASSIFICATION / TALO 2000	261.1 kipsi-kartonkilevyt, Gypsum board panels
DESCRIPTION	As the market share of domestic manufacture of gypsum boards is high, and as the carbon footprint emissions values of the boards manufactured in Finland are rather on the same level, the emission and density values were calculated as average values on the basis of the Finnish EPDs for - normal/standard board - hard/enhanced strength/fire resistant/impact board and - wind shield/wind resistant board. Representative data for products purchased by the construction sector in Finland
TECHNICAL DESCRIPTION	Gypsum plasterboard is used indoors. It consists of two sheets of cardboard and a gypsum layer in between them. The raw materials for gypsum plasterboards are calcinated gypsum, cardboard and additives. The gypsum is either from mined gypsum, by-product gypsum, or recycled gypsum.
MARKET	Gypsum boards are manufactured in Finland by Gyproc Saint Gobain and Knauf Oy. Gyproc is the market leader responding for roughly two thirds of the market. Domestic manufacturers have a large market share. According to statistics, the imports of gypsum boards are low.
BACKGROUND REPORT	Download full background report
ID	7000000258

Version 1.00.008, 2022-12-06
Show change history

Figure 14. General description part of the gypsum board page in the national database.[22]

In addition to the data for emissions being accessible from the database on the website, there is a downloadable Excel-file that construction companies and designers can use to calculate the carbon emissions of their projects using the data of the co2data.fi database. The Excel-file is made so that the user must input the quantities of their building elements and the file does the rest of the calculations based on pre-set data in the Excel-file. The Excel data is based on the database data. The user can also replace the information of the database with their own data, but they must then

[22] (Finnish Environmental Insitute, 2023)

deliver a report that establishes the basis for the changes when submitting the climate declaration. The tool is completely free to download and use for anyone interested. The use of the tool is showcased later in this thesis in chapter 4.6. (Ministry of the Environment, 2019a)

3.9. Possible Desired Values for the CO_2 Assessment

The previous chapters discussed the sources for emissions data, as well as their use and readability. This chapter discusses the possible thresholds for the results of the climate declaration and carbon footprint. The Finnish government is not implementing a threshold for emissions in the early phases of climate declaration implementation. Nevertheless, there is a mention in the drafted decrees concerning the material lists and climate declaration that the government has thresholds planned to come in to force in the mid 2020's. These thresholds would be enacted by a decree by the Council of State. (Kuittinen, 2022).

To supplement this lack of thresholds, this study looks at a German study by (Braune, 2021) of 46 office buildings and four residential buildings that found out that the mean global warming potential (GWP) of the various buildings was 8.7 kg $CO_2e/m^2/a$, while the values ranged between -0.4 kg $CO_2e/m^2/a$ and 15.5 kg $CO_2e/m^2/a$. This study considered the following modules of life cycle analysis:

A1 Raw Material
A2 Transport
A3 Manufacturing
B4 Replacement
C3 Waste Processing
C4 Disposal
D Reuse, recovery, and recycling potential

A4 and **A5**, i.e., transport and site operations were not included in the emissions in the study.

When calculating emissions for the phases A1-A3 only, the mean value of emissions was found out to be 7.3 kg $CO_2e/m^2/a$, or 365 kg CO_2e/m^2. The life cycle of the buildings was estimated to be 50 years in this case. The study states that, as this was an average result of buildings already finished or under construction, the target value for future CO2 footprint emissions reductions should be around 3.7 kg $CO_2e/m^2/a$ or 185 kg CO_2/m^2 for the modules A1-A3 to reach 50% emissions cuts as recommended by climate scientists. (Braune, 2021).

4.0. Currently Available Tools for Climate Declaration

Chapter 3.0 and the sub-chapters therein discussed the legal framework, presentation, and data sourcing of the climate declaration. The following chapters delve into the tools currently available for carbon emissions calculations. There are multiple tools available for both compiling the materials list and climate declaration, both from the public and private sectors. For this thesis, three tools were chosen:

- The Level(s) Excel Tool for Material Bills,
- The National Emissions Database Tool from the Ministry of the Environment and the Environmental Institute of Finland,
- The private browser based OneClickLCA software by the company OneClickLCA.

First, a brief introduction on the utilised case project is given in chapter 4.1. The key concepts of cost estimation in the Finnish Building80 classification system are described in Chapter 4.2. and the process used on the case project to obtain the material quantities necessary for the emissions calculations in chapter 4.3. Chapters 4.5-4.7. discuss the tools and their testing. Finally, in chapter 4.8. the study lays out some of the criticism on the climate declaration and emissions calculation process before moving on to Chapter 5.0. to present a possible prototype for simultaneous quantity, cost, and carbon estimation.

4.1. Case Project

To obtain data and experience on the carbon footprint estimation process, a single-family house was chosen as a case study. The building was modelled and designed during the first year the authors master’s degree studies in Metropolia UAS. The size and scope of the building made producing the Bill of Quantities relatively quick, while still containing most of the building parts that a larger project would have, such as foundations, walls, windows, and a roof. The model of the building is shown in Figure 15.

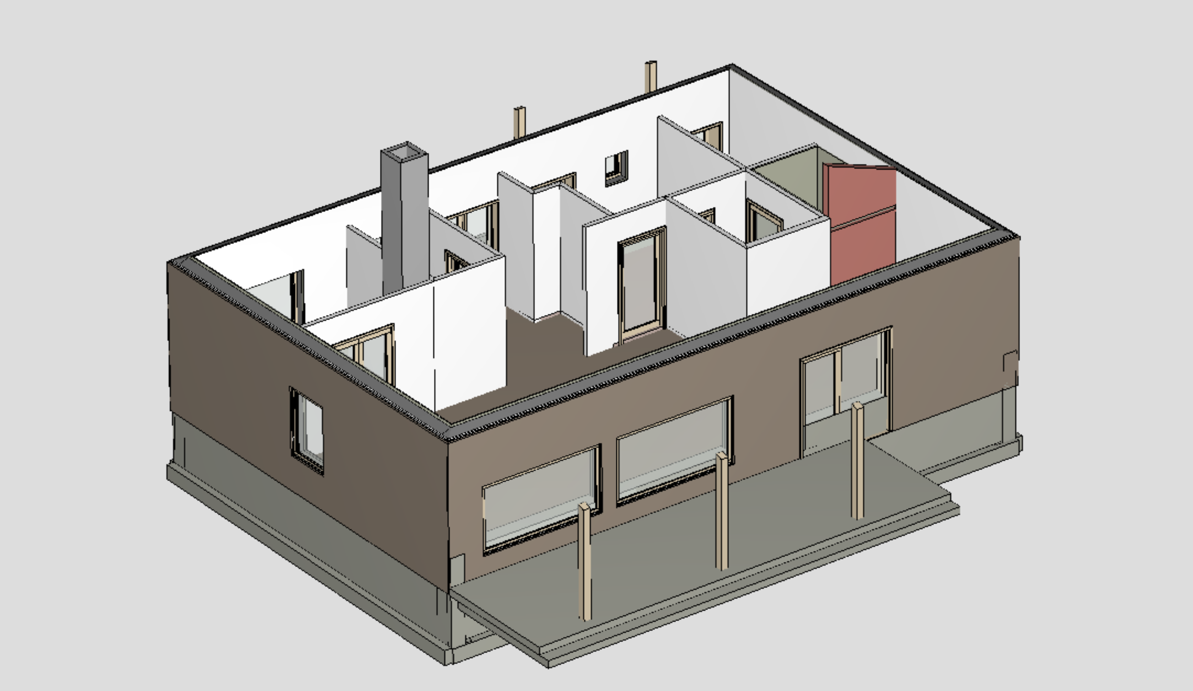

Figure 15. The house used in the CO_2 analysis. Roof and Space objects have been hidden to show the interior a little better. (Picture by the Author). This project, while imaginary, is of reasonable size and scope and contains all building elements relevant to the CO_2 assessment tool.

Some parts of the project, such as earthworks and building service systems, were not modelled, or designed, but were assumed to be generic for the scale of the building. The building information model of the project is shown above in Figure 15 shows the lack of interior detail and groundworks. The assumptions made during the quantity and cost estimation are stated later in the report. The next chapter describes the process of breaking down building elements into activities and resources to obtain the necessary material quantities needed for the carbon footprint assessment.

4.2. Cost Estimation Process

A quantity and cost estimate of the project was made using Tocoman Estimation software using the Building80 classification system, which is an older but very similar classification system as the previously introduced Building2000 system. The entire cost estimate can be found in Appendices 4, 5, and 6 and a part of it in Figure 18. The three appendices correspond to either building elements (App. 4.), activities (App. 5.), or resources (App. 6.) Those three concepts are explained below.

To obtain accurate quantities and costs, the Building80 classification system requires the user to single out the building elements, then break the elements down into activities and finally to calculate the consumption rate of resources such as manpower and materials per activity unit. An example of this breakdown in show in Figure 16. This breakdown is called a “recipe.” (Rakentajain Kustannus Oy, 1984).

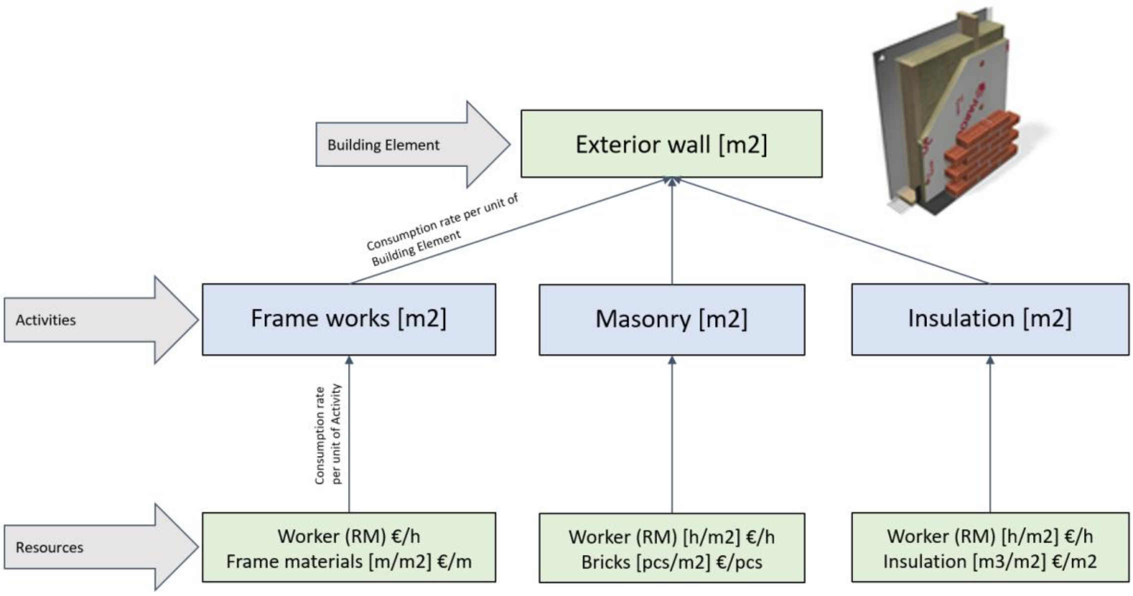

Figure 16. An example of a construction element estimation recipe for an exterior wall element. [23]

For purposes of easier control of the budget, the building elements and other relevant costs are allocated into main cost groups, under which there are groups for building elements and then activities. The idea is shown in Table 9. (Rakentajain Kustannus Oy, 1984)

[23] (Diagram by the Author)

Table 9. A partly opened up Building80 Classification system consists of main groups, building element groups and activities related to building elements. This is used to help in cost estimation but also cost control.[24]

Main groups	Building element groups	Activity groups
0. Preliminary costs		
1. Earthworks		
	11. Clearance and demolitions	
	12. Excavation	
	13. Mining	
	14. Base structures (Piles)	
	15. Underground drains	
	16. Fillings	
	17. Construction area	
	18. Outdoor equipment	
2. Foundations		
	21. Footings	
		2111. Footing formworks
		2121. Footing reinforcements
		2122. Footing concrete works
	22. Plinths	
		2211 Plinth formworks
		2221 plinth reinforcements
		2222 Plinth concrete work
	23. Load-bearing slabs	
3. Frame		
4. Complementary building elements		
5. Surfaces		
6. Furniture and equipment		
7. Building service systems		
8. Temporary construction works and costs		
9. Administrative costs		

These main groups and the construction element groups within assist the estimator in making sure that all building parts are taken into consideration, acting as a sort of a checklist. The numbering of the classification system also helps in reading the quantity or cost estimate, because the structure is standardised. When allocating resource costs, a following classification structure based on cost type is used:

1. Works
2. Materials
3. Sub-contracts
4. Rental equipment
5. Others

(Rakentajain Kustannus Oy, 1984)

[24] (Rakentajain Kustannus Oy, 1984)

Tocoman Estimation software provides a pre-made library of over 3000 commonly used recipes for building element estimation. These estimation recipes were used while estimating the quantities and costs of this building. A screenshot of the estimation software is shown on the next page is Figure 18 with some rows of the estimated single-family house visible. (Admicom Oy, 2022)

4.3. Estimate of Case Project

The estimation process was done using the previously presented methods of using estimation recipes and classifying them according to the Building80 classification system. The parts where assumptions had to be made are listed below, along with their explanations:

- Main group 0: Preliminary costs. Negligible emissions to consider.
- Main group 1: Excavations approximated by building area, but in addition an assumed 222 m^2 site area where some excavations and drainage works are supposedly done.
- Main group 5: Some surfaces were not modelled, assumed parquet flooring and gypsum board suspended ceilings.
- Main group 6: Equipment and furniture were not modelled. Included basic kitchen and bathroom equipment.
- Main group 7: Building service systems based purely on €/m^2 cost given by Tocoman Estimation software recipes.
- Main groups 8 and 9: Based on €/m^2 costs given by Tocoman Estimation software. Includes temporary scaffolding and machinery, as well as administrative costs from site management.

Main groups 0, 8 and 9 have little to no impact on the CO_2 assessment process, as their climate impacts can be assessed using table values provided by the Ministry of the Environment. The main groups 8 and 9 correspond to modules A4 and A5. (Ministry of the Environment, 2021).

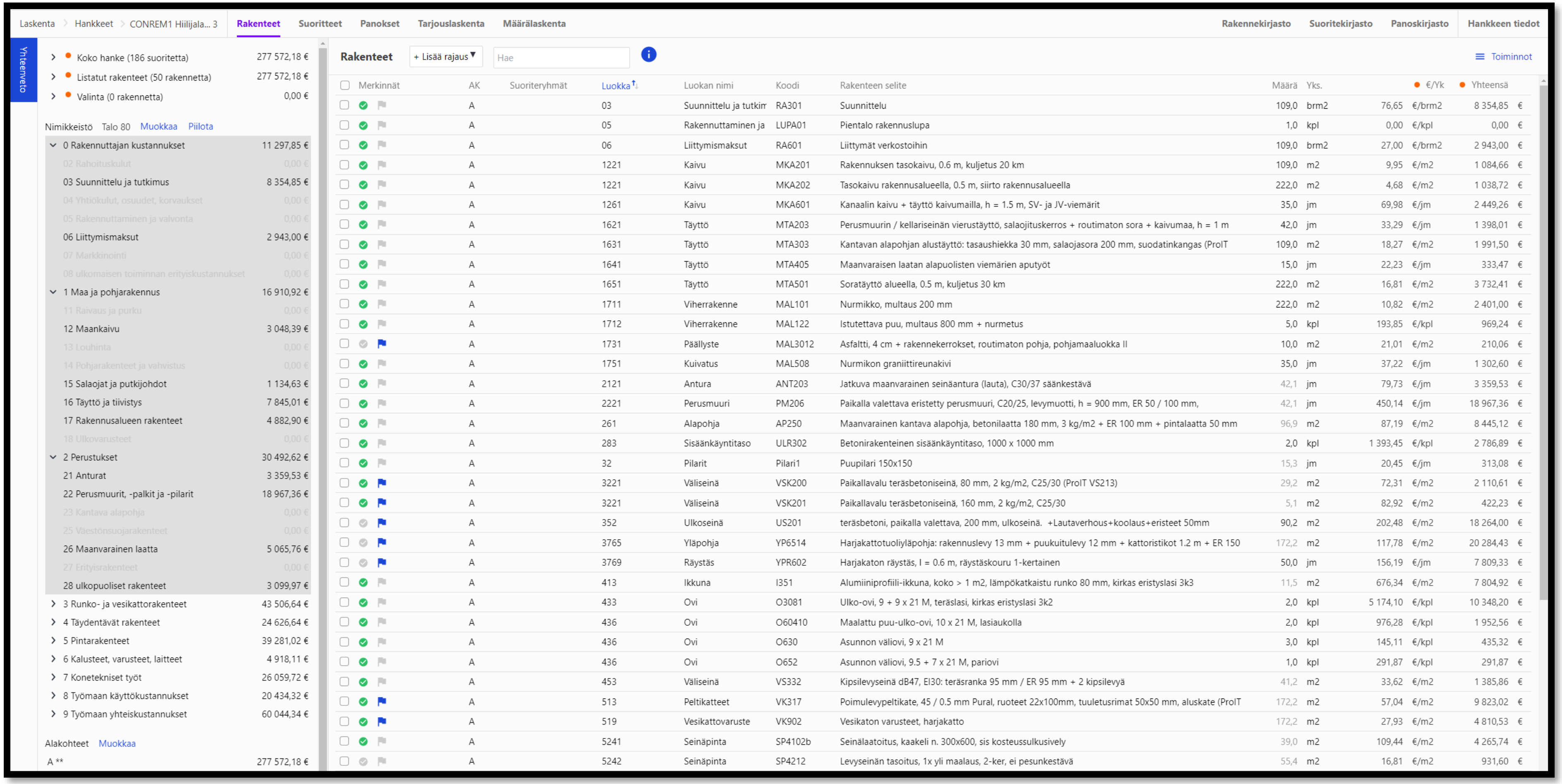

Figure 17. A screenshot from the Tocoman Estimation software, where the quantities and costs of the building were estimated. The rows shown are building element parts, that can consist of one or more activities that consist of one or more resources.[25]

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[25] (Admicom Oy, 2023)

4.5. Level(s) Excel Material Bill Tool

The Level(s) Excel Material Bill tool allows to produce a material list that contains the share of sustainable material sources, which is part of the tasks set by the decree on climate declaration. The tool developed by the European Commission to implement the Level(s) framework is readily available at Academy Europa website, where other materials such as guidelines, parameters and manuals can also be downloaded and viewed. (European Commission, 2022b). The tool can also be used to estimate the costs of the materials. Thus, the tool has four sheets: One used to input the quantities and two sheets to show the results of the inputs. The fourth sheet is used for quotations to compare different material choices by various suppliers and sub-contractors. The input sheet is shown in Figure 19. The input sheet needs the user to input the building elements using a three-tier classification system and their quantities, as well as a conversion factor to transform the lengths, areas, and units into kilograms. On the next page in Figure 20, the material origins part of the input sheet is also shown. The final product is a list of materials in kilograms, enabling their carbon footprint per kilogram to be estimated. (European Commission, 2022d).

	A	B	C	D	E	F	G	H	I	J	K
1											
2	Bill of quantities organised by the main building parts and elements *Fictive entries have been added below for illustration purposes, please delete any information in the green or yellow cells before starting*								Building floor area (m2)		2500
3–4	Tier 1 building element	Tier 2 building element	Tier 3 building element	Optional further description of the product/material being purchased	Bill of Quantities (number of units)	Unit	Conversion factor (kg/unit)	TOTAL (kg)	Cost I/unit	Cost I/kg	TOTAL cost I
5	Shell	Foundations_substructure	Piles	Reinforced concrete pile foundations with rebar at 130kg/m3	100	m3	2600	260000	150,0	0,1	15000
6	Shell	Foundations_substructure	Basements	Concrete basement floor (0.3 x 150m2) with rebar at 120kg/m3	55	m3	2400	132000	135,0	0,1	7425
7	Shell	Foundations_substructure	Basements	Ceramic tiled basement surface	150	m2	20	3000	15,0	0,8	2250
8	Shell	Foundations_substructure	Retaining walls	Reinforced concrete retaining walls with rebar at 120kg/m3	160	m3	2400	384000	120,0	0,1	19200
9	Shell	Loadbearing_structural_frame	Frame (beams, columns and slabs)	Reinforced concrete slabs and columns with rebar at 120kg/m3	900	m3	2400	2160000	125,0	0,1	112500
10	Shell	Loadbearing_structural_frame	Upper floors	Pretensioned hollow-core concrete slabs produced offsite (20m x 1.2m x 0.3m)	50	pieces	5600	280000	175,0	0,0	8750
11	Shell	Facades	External wall systems, cladding and shading devices	Full length glass curtain walling on an aluminium frame	3000	m2	22	66000	80,0	3,6	240000
12	Core	Fittings_and_furnishings	Floor coverings and finishes	Laminate flooring with foamed plastic underlay	2500	m2	7,5	18750	12,0	1,6	30000
13	Core							0		#DIV/0!	0
14	Core	Energy_system	Cooling plant and distribution					0		#DIV/0!	0
15								0		#DIV/0!	0
16	Shell	hgh						0		#DIV/0!	0
17	Shell	Foundations_substructure	Basements					0		#DIV/0!	0
18								0		#DIV/0!	0
19								0		#DIV/0!	0
20								0		#DIV/0!	0
21								0		#DIV/0!	0
22								0		#DIV/0!	0
23								0		#DIV/0!	0

Figure 18. The bill of quantities, materials, and lifespans calculator. The user inputs data into the green cells. Yellow cells can be filled with optional information. [26]

[26] (European Commission, 2022d)

	A	B	C	D	E	F	G	H	I	J	K
1											
2	**Bill of quantities organised by the main building parts and elements** *Fictive entries have been added below for illustration purposes, please delete any information in the green or yellow cells before starting*								Building floor area (m2)		2500
3–4	Tier 1 building element	Tier 2 building element	Tier 3 building element	Optional further description of the product/material being purchased	Bill of Quantities (number of units)	Unit	Conversion factor (kg/unit)	TOTAL (kg)	Cost €/unit	Cost €/kg	TOTAL cost €
5	Shell	Foundations_substructure	Piles	Reinforced concrete pile foundations with rebar at 130kg/m3	100	m3	2600	260000	150,0	0,1	15000
6	Shell	Foundations_substructure	Basements	Concrete basement floor (0.3 x 150m2) with rebar at 120kg/m3	55	m3	2400	132000	135,0	0,1	7425
7	Shell	Foundations_substructure	Basements	Ceramic tiled basement surface	150	m2	20	3000	15,0	0,8	2250
8	Shell	Foundations_substructure	Retaining walls	Reinforced concrete retaining walls with rebar at 120kg/m3	160	m3	2400	384000	120,0	0,1	19200
9	Shell	Loadbearing_structural_frame	Frame (beams, columns and slabs)	Reinforced concrete slabs and columns with rebar at 120kg/m3	900	m3	2400	2160000	125,0	0,1	112500
10	Shell	Loadbearing_structural_frame	Upper floors	Pretensioned hollow-core concrete slabs produced offsite (20m x 1.2m x 0.3m)	50	pieces	5600	280000	175,0	0,0	8750
11	Shell	Facades	External wall systems, cladding and shading devices	Full length glass curtain walling on an aluminium frame	3000	m2	22	66000	80,0	3,6	240000
12	Core	Fittings_and_furnishings	Floor coverings and finishes	Laminate flooring with foamed plastic underlay	2500	m2	7,5	18750	12,0	1,6	30000
13	Core							0		#DIV/0!	0
14	Core	Energy_system	Cooling plant and distribution					0		#DIV/0!	0
15								0		#DIV/0!	0
16	Shell	hgh						0		#DIV/0!	0
17	Shell	Foundations_substructure	Basements					0		#DIV/0!	0
18	Core	Fittings_and_furnishings	Ceilings	Alakatto	300	m2	15	4500	15,0	1,0	4500
19	Shell	Facades	External wall systems, cladding and shading devices		200	m2	10	2000		0,0	0
20								0		#DIV/0!	0
21								0		#DIV/0!	0
22								0		#DIV/0!	0
23								0		#DIV/0!	0
24								0		#DIV/0!	0
25								0		#DIV/0!	0
26								0		#DIV/0!	0
27								0		#DIV/0!	0
28								0		#DIV/0!	0
29								0		#DIV/0!	0
30								0		#DIV/0!	0
31								0		#DIV/0!	0
32								0		#DIV/0!	0
33								0		#DIV/0!	0

	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1															
2	**Bill of Materials by material type (% weight).** *Enter the approximate % split by material according to the options below (esp.important if intending to report on indicator 2.2, construction and demolition waste). Note: If using LCA software, the split of materials in the EPD or chosen LCI inventory may be adapted to the options below.*											Assumed building life (yrs)	60		
3–4	Concrete, brick, tile, ceramic etc.	Wood	Glass	Plastic	Bituminous mixtures	Metals	Insulation materials	Gypsum	Mixed	Electrical and Electronic Equipment	Total % (should be 100%)	Assumed lifetime of product/ material (years)	Normalised requirement factor over building lifetime	Normalised weight of materials needed over lifetime	Normalised cost of materials needed over lifetime
5	95,0%					5,0%					100,0%	75	0,8	260000	15000
6	95,0%					5,0%					100,0%	75	0,8	132000	7425
7	100,0%										100,0%	50	1,2	3600	2700
8	95,0%					5,0%					100,0%	75	0,8	384000	19200
9	95,0%					5,0%					100,0%	50	1,2	2592000	135000
10	80,0%					20,0%					100,0%	50	1,2	336000	10500
11			97,0%			3,0%					100,0%	30	2	132000	480000
12		95,0%		5,0%							100,0%	15	4	75000	120000
13											0,0%		0	0	0
14											0,0%		0	0	0
15											0,0%		0	0	0
16											0,0%		0	0	0
17											0,0%		0	0	0
18											0,0%		0	4500	4500
19											0,0%		0	2000	0
20											0,0%		0	0	0
21											0,0%		0	0	0
22											0,0%		0	0	0
23											0,0%		0	0	0
24											0,0%		0	0	0
25											0,0%		0	0	0
26											0,0%		0	0	0
27											0,0%		0	0	0
28											0,0%		0	0	0
29											0,0%		0	0	0
30											0,0%		0	0	0
31											0,0%		0	0	0
32											0,0%		0	0	0
33											0,0%		0	0	0

Figure 19. The full view of the Level(s) tool used to produce the material list. Green cells are mandatory, yellow optional and red cells are preset. The user can do material origins checks as well as a cost estimate for the materials with this tool. [27]

[27] (European Commission c, 2022c)

There are conversion tables for common building materials available online, like The Constructor magazine website. These can be used to convert the various units used in construction to kilograms. One example of such a website is linked below:

https://theconstructor.org/building/density-construction-materials/13531/

Most of these tables have the density of the material listed, so in the case of surface materials or timber, the areas or meters must be first converted into cubic meters (Anupoju, 2022). The National Emissions database (co2data.fi) also contains conversion factors for materials. (Finnish Environmental Insitute, 2023)

In the end, the user gets a listing of building materials by type, as well as a cost estimate for the material costs. The materials are also sorted according to the hazard levels designated to them. The building itself is divided into the first level of the three-tier classification system: The shell, core, and external parts. This conclusion is shown below for the construction phase of the project in Figure 21. A simplified estimate for construction waste is also given for the materials used, along with proportions of inert, non-hazardous, and hazardous waste generated by the building shown in Figure 22. (European Commission, 2022d)

Bill of Quantities/ Materials (for construction)							
Breakdown by material type			Building floor area (m²)	2500	Totals check (should =0)	-6,5	
			Breakdown by building aspect				
	Material total (t)	Material total (%)	Shell	Core	External	Total	Units
Combined total	3310,25	99,8%	3287	23,25	0	3310,25	tonnes
Concrete, brick, tile, natural stone, ceramic	3016,2	91,1%	99,3%	0,7%	0,0%	100,0%	mass %
Wood	17,8125	0,5%	405,125	34,5	0	439,625	000 €
Glass	64,02	1,9%	92,2%	7,8%	0,0%	100,0%	€ %
Plastic	0,9375	0,0%	Total cost €/m2		Total cost €/t		
Bituminous mixtures	0	0,0%	175,9		132,8		
Metals	204,78	6,2%					
Insulation materials	0	0,0%					
Gypsum	0	0,0%					
Mixed	0	0,0%					
Electrical and Electronic Equipment	0	0,0%					

Figure 20. An example of results for the material list for construction.[28]

[28] (European Commission, 2022d)

Simplified estimate for Construction Waste				
	Assumed wastage/ over-ordering rate	Assumed waste type	Assumed LoW code	Total CW (t)
Concrete, brick, tile, natural stone, ceramic	15,0%	Inert	17 01 01	452,43
Wood	20,0%	Non-haz	17 02 01	3,56
Glass	15,0%	Inert	17 02 02	9,60
Plastic	10,0%	Non-haz	17 02 03	0,09
Bituminous mixtures	5,0%	Non-haz	17 03 02	0,00
Metals	8,0%	Non-haz	17 04 07	16,38
Insulation materials	20,0%	Hazardous	17 06 05	0,00
Gypsum	22,5%	Non-haz	17 08 02	0,00
Mixed	10,0%	Non-haz	17 09 04	0,00
Electrical and Electronic Equipment	10,0%	Hazardous	16 02 XX or 20 01 XX	0,00
	Inert	**Non-haz**	**Hazardous**	**Total**
Tonnes	462,03	20,04	0,00	482,07
% split	95,8%	4,2%	0,0%	100,0%

Figure 21. The estimate for the construction waste.[29]

The lifetimes assumed for the products chosen have influence on the lifetime results of the building. These results are shown on another sheet of the file. An example of the results is shown in Figure 23. (European Commission, 2022d)

Bill of Quantities/ Materials (for lifetime)								
Breakdown by material type			**Building floor area (m²)**	**2500**	**Totals check (should =0)**	**-6,5**		
			Breakdown by building aspect					
	Material total (t)	**Material total (%)**	**Shell**	**Core**	**External**	**Total**	**Units**	
Combined total	**3921,1**	**99,8%**	**3841,6**	**79,5**	**0**	**3921,1**	**tonnes**	
Concrete, brick, tile, natural stone, ceramic	3472	88,5%	98,0%	2,0%	0,0%	**100,0%**	**mass %**	
Wood	0	0,0%	669,825	124,5	0	**794,325**	**000 €**	
Glass	71,25	1,8%	84,3%	15,7%	0,0%	**100,0%**	**€ %**	
Plastic	128,04	3,3%	**Total cost €/m2**		**Total cost €/t**			
Bituminous mixtures	3,75	0,1%	**317,7**		**202,6**			
Metals	0	0,0%						
Insulation materials	239,56	6,1%						
Gypsum	0	0,0%						
Mixed	0	0,0%						
Electrical and Electronic Equipment	0	0,0%						

Figure 22. Results for the lifetime assessment of the materials.[30]

[29] (European Commission, 2022d)
[30] (European Commission, 2022d)

4.6. Co2data.fi for Carbon Estimation Tool

The Ministry of the Environment has developed a tool with the Finnish Environmental Institute to help in the production of a climate declaration. The tool is based on and functions much like the Level(s) tool shown in the previous chapter, but with an added carbon footprint and handprint estimation tool. The cost estimation tools briefly discussed in the Level(s) chapter are missing from this tool. To enable carbon footprint and handprint estimation, pre-set table values for some module phases such as transport and site operations, and emissions data for materials is available inside the Excel file itself. The data used comes from the co2data.fi website database discussed earlier in this thesis.

There are eight sheets in the assessment tool Excel, all of which are described below:

Guide

This sheet (FI: Ohje) details how to use the Excel-file. In short, the user only must input information on the cells that are grey, whereas the rest of the information such as results of emissions estimation is shown in cells of the other colours. Most cells are locked, so the user has no ability to type in them.

Summary

The user starts on the summary page (FI: Yhteenveto). In the summary page, the user inputs the basic information regarding the building project, such as name, address and building type. In addition, technical information regarding frame type, area and estimated life cycle can be filled. Later, when the user has input all the necessary data to calculate the CO_2 footprint and handprint, the results are shown in this sheet. The summary page is shown after discussion on the other sheets in Figure 29 to show the results of the carbon estimate of the single-family house case project.

Material List

On this sheet, (FI: Materiaaliluettelo), shown in Figure 24, the user inputs the quantities of the materials to gain emissions data for modules A1-A3. This sheet is where most of the work is done.

Rakennusten hiilijalanjäljen arviointityökalu
Luonnos hiilijalanjäljen arvioinnin testausta varten 9.12.2019

Ympäristöministeriö
Miljöministeriet
Ministry of the Environment

Materiaaliluettelo

Syötä rakennuksen materiaalitiedot alla olevaan listaan esim. Määräluetteloon perustuen. Hiilijalanjäljen ja -kädenjäljen päästöt muodostuvat automaattisesti, kun määrät on syötetty. Lisää tarvittaessa rivejä kunkin otsakkeen alle 'Lisää rivi' -napilla. Jos tarkempi päästötieto jollekin tuotteelle tai materiaalille on olemassa, voit syöttää sen painamalla 'Korvaa taulukkoarvoja tarkemmilla tiedoille' -nappia.

Korvaa taulukkoarvoja tarkemmilla tiedoilla

Piilota tarkennettu laskenta

Green Building Council Finland

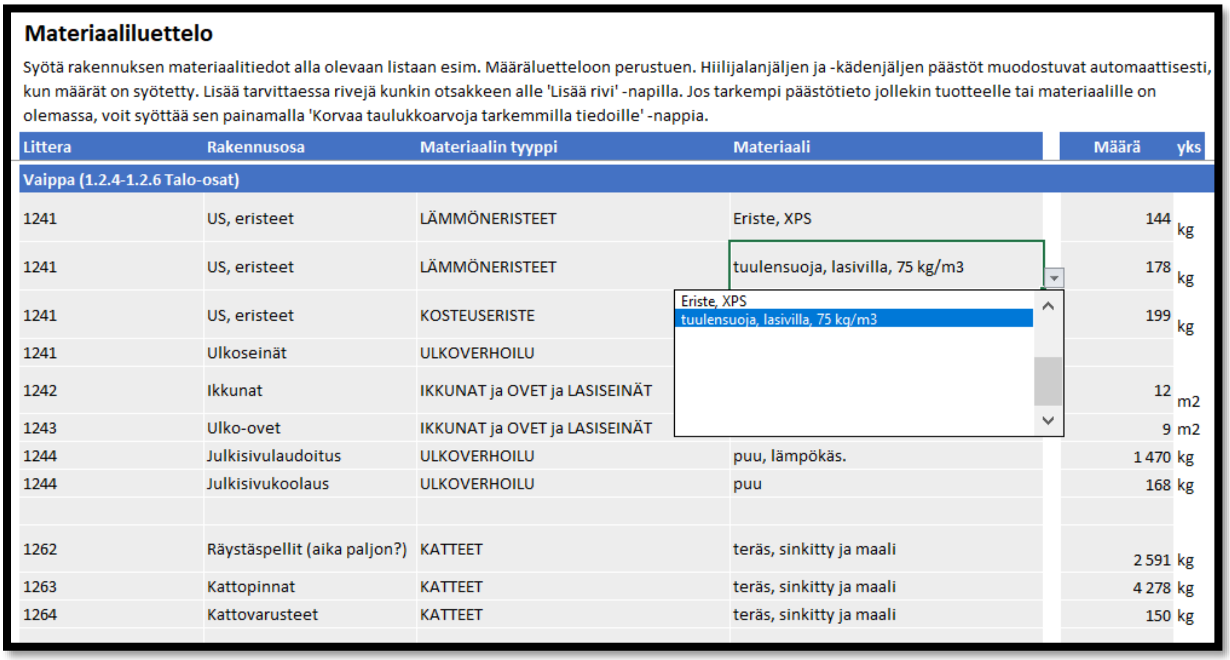
Littera	Rakennusosa	Materiaalin tyyppi	Materiaali	Määrä	yks	Hiilijalanjälki ($kgCO_2e$)	Hiilikädenjälki ($kgCO_2e$)	Hiilijalanjälki (Tarkennetut kertoimet kgCO2e/yksikkö)	Hiilikädenjälki (Tarkennetut kertoimet kgCO2e/yksikkö)	Vaihtoväli (a)	Vaihdot (kpl)	Hiilijalanjälki ($kgCO_2e$)
Tontti (1.1. Alueosat)												
1114	Täytöt	PIHA JA POHJARAKENTEET	Murske, 2/32	15 000	kg	88				Ei vaihdeta		
1221	Alapohja	PIHA JA POHJARAKENTEET	Kuitukangas	63	kg	143				Ei vaihdeta		
1116	Putkitäytöt	PIHA JA POHJARAKENTEET	Sora ja hiekka	48 000	kg	232				Ei vaihdeta		
	Laatan tasaus	PIHA JA POHJARAKENTEET	Sora ja hiekka	6 500	kg	31				Ei vaihdeta		
	Reunakivet!	PIHA JA POHJARAKENTEET	Noppakiveys	4 340	kg	451		0,10		Ei vaihdeta		
Total				Lisää rivi		946						
Kantavat rakenteet (1.2.1-1.2.3 Talo-osat)												
		PIHA JA POHJARAKENTEET	Betonianturа ja -perustus (sis raudoitteet)		kg					Ei vaihdeta		
		LAATAT	(massiivilaatta), betoni + teräkset		kg					Ei vaihdeta		
		PAIKALLAVALUBETONI JA RAUDOITTEET	Betoniteräs		kg					Ei vaihdeta		
		PAIKALLAVALUBETONI JA RAUDOITTEET	Valmisbetoni C35 (portland)		kg					Ei vaihdeta		
		SEINÄT JA SOKKELIT	Betonisokkeli		kg					Ei vaihdeta		
	Sokkeli + Laatta	PIHA JA POHJARAKENTEET	Routaeriste, EPS	480	kg	1 602				50		
Total				Lisää rivi		1 602						
Vaippa (1.2.4-1.2.6 Talo-osat)												
		LÄMMÖNERISTEET	Eriste, XPS		kg					Ei vaihdeta		
		LÄMMÖNERISTEET	tuulensuoja, lasivilla, 75 kg/m3		kg					Ei vaihdeta		
		KOSTEUSERISTE	Kosteussulku		kg					Ei vaihdeta		
		ULKOVERHOILU	tiililaatta		kg					50		
		IKKUNAT ja OVET ja LASISEINÄT	Ikkunat, Puu-alumiini-ikkuna, sisältää myös lasit		m2					50		
		IKKUNAT ja OVET ja LASISEINÄT	Ovi, ulko metalli		m2					50		
		IKKUNAT ja OVET ja LASISEINÄT	Ovi, sisä		m2					50		
		IKKUNAT ja OVET ja LASISEINÄT	Lasiverhoilu ja seinät		m2					50		
Total				Lisää rivi								
Kevyet rakenteet (1.3 Tila-osat)												
		SEINÄT JA SOKKELIT	Muurattu rak. kahi 85+laasti	61	kg	9				Ei vaihdeta		
		SEINÄT JA SOKKELIT										
Total				Lisää rivi		9						

Figure 23. The material list of the assessment tool. The user quantifies the masses of building elements in kilograms. Only the grey cells require inputs from the user, the green cells contain automatic calculations based on the co2data.fi database emission data. [31]

Nearly all material quantities, apart from windows and doors, must be input in kilograms to get the emission data. The building is divided much like the Level(s) material list, but with the separation of the building site from the building itself. There are five levels of material classification: Location, classification number, building element, material type and material. On the location level the headings are prefixed and consist of site, load-bearing elements, shell, core and building service systems. The user chooses under which heading the material they are inputting belongs to and moves on to the next row under the heading. Next, the user chooses the element type related to the material they are about to type information on and the matching classification number of the element, i.e., foundations, walls, façade, windows, doors etc. The classification number comes from Building2000 classification system shown previously in the material list chapter and Appendix 7. After typing the element type and classification number, the user chooses the material type from a drop-down menu. Material types range from concrete and rebar to insulation and doors, windows, and

[31] (Ministry of the Environment, 2019a)

glass walls. Finally, the user chooses the correct material for the material type from a drop-down menu. This selection process of a material shown in Figure 25 below.


Materiaaliluettelo

Syötä rakennuksen materiaalitiedot alla olevaan listaan esim. Määräluetteloon perustuen. Hiilijalanjäljen ja -kädenjäljen päästöt muodostuvat automaattisesti, kun määrät on syötetty. Lisää tarvittaessa rivejä kunkin otsakkeen alle 'Lisää rivi' -napilla. Jos tarkempi päästötieto jollekin tuotteelle tai materiaalille on olemassa, voit syöttää sen painamalla 'Korvaa taulukkoarvoja tarkemmilla tiedoille' -nappia.

Littera	Rakennusosa	Materiaalin tyyppi	Materiaali	Määrä	yks
Vaippa (1.2.4-1.2.6 Talo-osat)					
1241	US, eristeet	LÄMMÖNERISTEET	Eriste, XPS	144	kg
1241	US, eristeet	LÄMMÖNERISTEET	tuulensuoja, lasivilla, 75 kg/m3	178	kg
1241	US, eristeet	KOSTEUSERISTE	Eriste, XPS tuulensuoja, lasivilla, 75 kg/m3	199	kg
1241	Ulkoseinät	ULKOVERHOILU			
1242	Ikkunat	IKKUNAT ja OVET ja LASISEINÄT		12	m2
1243	Ulko-ovet	IKKUNAT ja OVET ja LASISEINÄT		9	m2
1244	Julkisivulaudoitus	ULKOVERHOILU	puu, lämpökäs.	1 470	kg
1244	Julkisivukoolaus	ULKOVERHOILU	puu	168	kg
1262	Räystäspellit (aika paljon?)	KATTEET	teräs, sinkitty ja maali	2 591	kg
1263	Kattopinnat	KATTEET	teräs, sinkitty ja maali	4 278	kg
1264	Kattovarusteet	KATTEET	teräs, sinkitty ja maali	150	kg

Figure 24. The compilation of the material list using the three-layer system and drop-down menus in the estimation tool of the Ministry.[32]

These materials already have the emissions data attached to them, so the last thing for the user to do is to input the material quantity in kilograms to the correct cell in the quantity column, “Määrä” in Figure 25.

Manufacturing, Transport, Site operations

In this sheet (FI: Valmistus, kuljetus, työmaa) the tool uses table values from the national emissions database to establish the emissions from transport, and site operations (modules A4-A5) and adds them to the emissions generated from the data input on the material list sheet (modules A1-A3). It is possible to type in more site-specific information on the site emissions, but not mandatory. The climate declaration will require written reports attached to them to prove the site-specific information is valid. In Figure 26 the table values for manufacturing, transport and site operations are shown on the sheet. (Ministry of the Environment, 2019a)

[32] (Finnish Environmental Insitute, 2023)

Valmistus, kuljetus ja työmaa -vaiheiden päästöjen arviointi (A)

	Hiilijalanjälki	Hiilikädenjälki
	kg $CO_2e/m^2_{netto}/a$	kg $CO_2e/m^2_{netto}/a$
Ennen käyttöä syntyvät päästöt yhteensä	13,86	-2,12
Valmistus ja kuljetusvaihe (A1-4)	13,32	-2,12
Tontti	0,58	
Kantavat rakenteet	6,43	-0,81
Vaippa	4,90	-0,53
Kevyet rakenteet	0,89	-0,78
Talotekniikka	0,52	

Valmistusvaiheen päästöjen tulokset muodostuvat automaattisesti välilehdellä 'Materiaaliluettelo' annettujen arvojen perusteella.

Korvaa taulukkoarvot tarkemmilla tiedoilla

Työmaatoiminnot (A5)	0,55	

Työmaatoimintojen arvot perustuvat neliömetrikohtaiseen taulukkoarvoon.

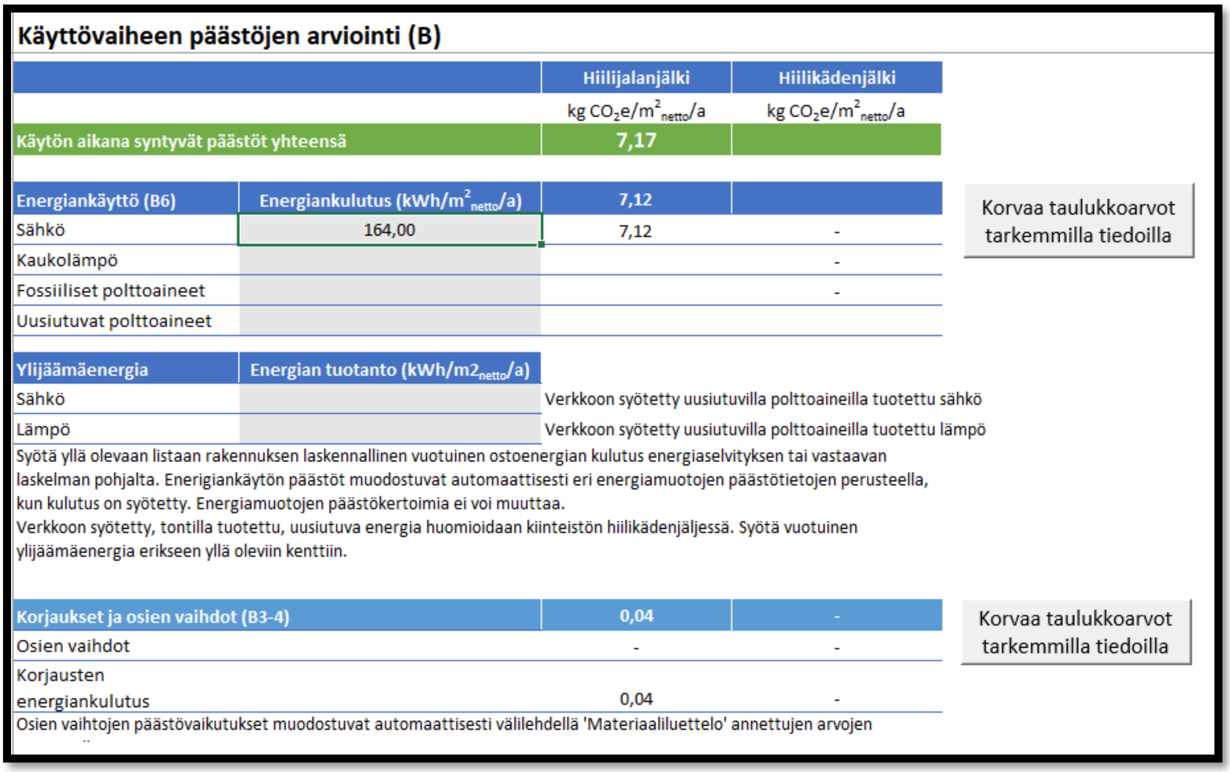
Korvaa taulukkoarvot tarkemmilla tiedoilla

Figure 25. The table values used for modules A4-A5. [33]

Building use emissions

In this sheet (FI: Käyttövaiheen päästöjen arviointi) the user estimates the energy consumption and excess production of energy by the building by production types for module B6. For example, solar power and fossil fuel are calculated separately. The energy consumption is typed in kilowatt hours per net square meter per annum, or kWh/net-m^2/a in short. Any energy production by the building systems, be it heat or electricity, can also be input for the carbon handprint calculation. As in the previous chapter, these table values for emissions can be replaced by more specific information, if the information is valid, and the relevant report is attached to the climate declaration submittal. Figure 27 shows this sheet. (Ministry of the Environment, 2019a)

[33] (Finnish Environmental Insitute, 2023)



Käyttövaiheen päästöjen arviointi (B)

		Hiilijalanjälki	Hiilikädenjälki
		kg $CO_2e/m^2_{netto}/a$	kg $CO_2e/m^2_{netto}/a$
Käytön aikana syntyvät päästöt yhteensä		7,17	
Energiankäyttö (B6)	Energiankulutus (kWh/m^2_{netto}/a)	7,12	
Sähkö	164,00	7,12	-
Kaukolämpö			-
Fossiiliset polttoaineet			-
Uusiutuvat polttoaineet			

Korvaa taulukkoarvot tarkemmilla tiedoilla

Ylijäämäenergia	Energian tuotanto (kWh/m2$_{netto}$/a)	
Sähkö		Verkkoon syötetty uusiutuvilla polttoaineilla tuotettu sähkö
Lämpö		Verkkoon syötetty uusiutuvilla polttoaineilla tuotettu lämpö

Syötä yllä olevaan listaan rakennuksen laskennallinen vuotuinen ostoenergian kulutus energiaselvityksen tai vastaavan laskelman pohjalta. Enerigiankäytön päästöt muodostuvat automaattisesti eri energiamuotojen päästötietojen perusteella, kun kulutus on syötetty. Energiamuotojen päästökertoimia ei voi muuttaa.
Verkkoon syötetty, tontilla tuotettu, uusiutuva energia huomioidaan kiinteistön hiilikädenjäljessä. Syötä vuotuinen ylijäämäenergia erikseen yllä oleviin kenttiin.

Korjaukset ja osien vaihdot (B3-4)	0,04	-
Osien vaihdot	-	-
Korjausten energiankulutus	0,04	-

Korvaa taulukkoarvot tarkemmilla tiedoilla

Osien vaihtojen päästövaikutukset muodostuvat automaattisesti välilehdellä 'Materiaaliluettelo' annettujen arvojen

Figure 26. The building use emissions calculator sheet. The building in this screenshot is using electricity for all purposes. [34]

End of life cycle

This sheet (FI: Elinkaaren loppu) uses table values from the national emissions database to establish a rough estimate of the end-of-life emissions from demolitions and waste management corresponding to modules C1-C4 in the climate declaration. Figure 28 shows this sheet. Some materials deteriorate faster than others, having a shorter lifespan. For example, the national emissions database assumes that most furniture and equipment must be replaced after 25 years, while concrete and other durable materials last at least twice as long. Because of this, some products are replaced once or even multiple times during the assessment period of fifty years. In many cases the lifespan of the product is longer than the assessment period of fifty years and thus is not considered at all. The table values adjust the emissions for these replacements and demolitions accordingly. (Ministry of the Environment, 2019a)

[34] (Finnish Environmental Insitute, 2023)

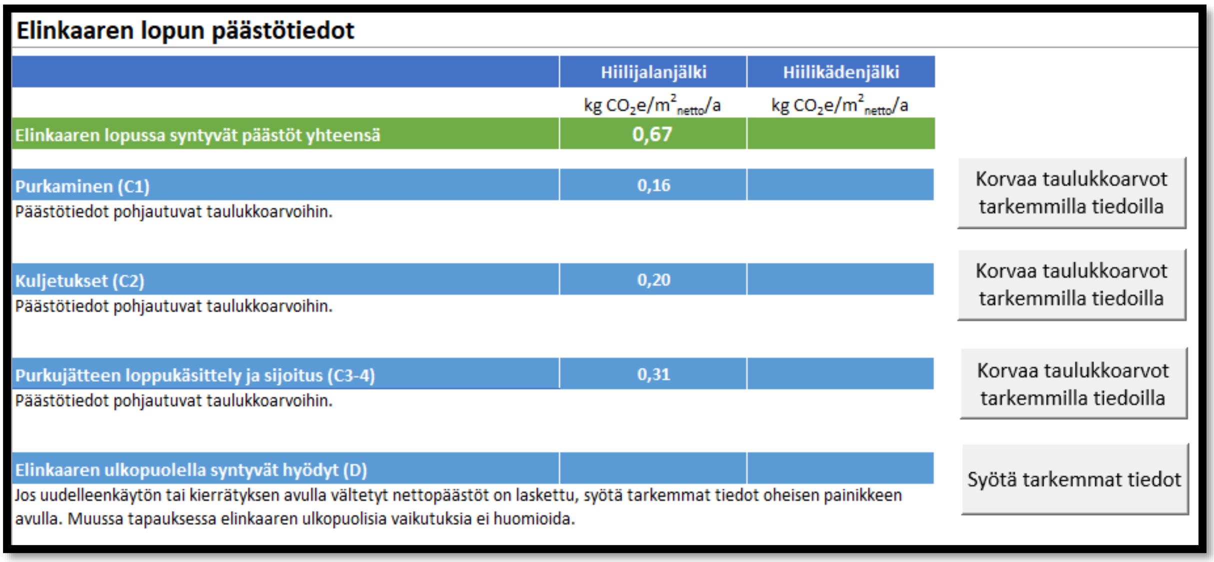


Figure 27. The end-of-life emissions. [35]

As is the case with other table values used in the sheets of this tool, the table values can be replaced with more accurate data on the distances and demolitions waste processing, if such information can be verified with additional reports. (Ministry of the Environment, 2019a)

Quality of information

If the user decides to use their own data on any materials instead of the national emissions database or if they replace table values of modules where they can be used, then this is the sheet (FI: Tietojen laatu) where they must assess and prove the reliability of the data. There are four aspects of reliability that must be assessed on a scale from one to three, with one being the least reliable and three being accurate. These four aspects are technological, geographical, temporal representativeness, and the uncertainty of data. The points are added together per aspect to give a score. If no data is used, then the score for that module and topic is zero. Sources must also be given. These aspects and short explanations to the scoring principles are shown in Table 10.

[35] (Ministry of the Environment, 2019a)

Table 10. The scoring table of external data used. [36]

Scoring of the data used				
	0	1	2	3
Technological representativeness	Not assessed	Information does not satisfactorily represent the technical properties of the product	Information partially represents the technical properties of the product	Information used reflects the technical properties of the product well
Geographical representativeness	Not assessed	Information used represents a completely different geographical area (Finland vs. Italy).	Information refers to a similard geographical context (Finland vs. Norway).	Information refers to specific geographical context.
Temporal representativeness	Not assessed	Time between the validation of the data and its use is longer than 6 years.	Time between the validation of data and use of data is between 2-4 years.	Time between the validation of data and use of data is less than 2 years.
Uncertainty	Not assessed	Information is either modeled or reflects the data of the product at hand. The reliability of data is assessed by an expert or producer qualitatively.	Information is either modeled or reflects the data of the product at hand. The reliability of data is deemed to be sufficiently reliable and is backed up by a quantified assessment of uncertainty.	Data used is project-specific and validated in a way that can be deemed exact and reliable. An Environmental Product Declaration (EPD) is one such source.

In summary, using new, localised, regionally representative EPDs as a reference seems to always be the best choice.

Material emissions data

On this sheet (FI: Materiaalien päästötiedot) is the raw data for the material emissions used by the other sheets in their calculations. The user does not have to change anything here. Both the carbon footprint and handprint, as well as the time between replacements of products are shown. (Ministry of the Environment, 2019a)

[36] (Ministry of the Environment, 2019a)

Summary After Calculations

The Figure 29 below shows the results of the carbon assessment of the case project on the previously introduced Summary sheet of the Excel tool. The entirety of the calculation is available in Appendix 1.

Rakennuskohteen tiedot	Kohteen nimi*	As Oy Esimerkki
	Rakennustunnus	1
	Osoite	Lemuntie 7
	Rakennustyyppi	Asuinrakennukset
Rakennuksen tekniset tiedot	Kerrosala [kem^2]	109
	Lämmitetty nettoala [m$^2_{netto}$]*	95
	Kerrosten lukumäärä	1
	Kellarikerrosten lukumäärä	
	Pääasiallinen runkomateriaali	Betoni
	Energialuokka	A
Laskennan tiedot	Laskenta-ajanjakso*	50
	Arvioinnin tekovaihe	Rakennuslupa
	Käytetty arviointitapa	Yksinkertaistettu
	Rakennuksen arvioitu käyttöönottovuosi*	2022
		*pakollinen tieto

Arvionnin tekijät	Arvioinnin laatija	Arvioinnin tarkastaja
Nimi	Henrik Hassinen	
Yritys	Tocoman Oy	
Koulutus	RI (AMK)	
Päivämäärä		

Elinkaariarvioinnin tulokset	Hiilijalanjälki	Hiilikädenjälki
	tn CO$_2$e	tn CO$_2$e
Elinkaaren aikana syntyvät kokonaispäästöt (A-D)	127	-10
	kg CO$_2$e/m$^2_{netto}$/a	kg CO$_2$e/m$^2_{netto}$/a
Vuotuiset päästöt lämmitettyä nettoalaa kohden (A-D)	26,66	-2,12
Valmistus, kuljetus ja työmaa (vaiheet A1-5)	18,82	-2,12
Tontti	0,58	
Kantavat rakenteet	7,00	-0,81
Vaippa	9,29	-0,53
Kevyet rakenteet	0,89	-0,78
Talotekniikka	0,52	
Käyttö (vaiheet B3-4, 6)	7,17	
Purkaminen (vaihe C)	0,67	
Elinkaaren ulkopuoliset vaikutukset (D)		

Figure 28. The summary page of the assessment tool.[37]

[37] (Ministry of the Environment, 2019a)

4.7. OneClickLCA Carbon Estimation Tool

The previous chapter gave an overview of a tool that is freely available to the public with no extra costs. This chapter looks at a private option, OneClickLCA, which is a carbon estimation tool by a Finnish company of the same name, formerly known as Bionova. The company also provides software various sustainability-related products such as planning phase carbon optimisation, life-cycle analyses and EPD generation, as well as consulting services. (OneClickLCA Oy, 2023).

The carbon footprint and handprint estimation tool itself was available for students for free for a 14-day trial, during which the carbon estimation of the single-family case project was performed with this tool. The previously introduced single-family house was used as a case project with the same quantities for materials. The tool was completely web-based, with no downloads required. The whole software was available www.oneclicklcaapp.com. (OneClickLCA Oy, 2023)

The frontpage of the project is shown below in Figure 30.

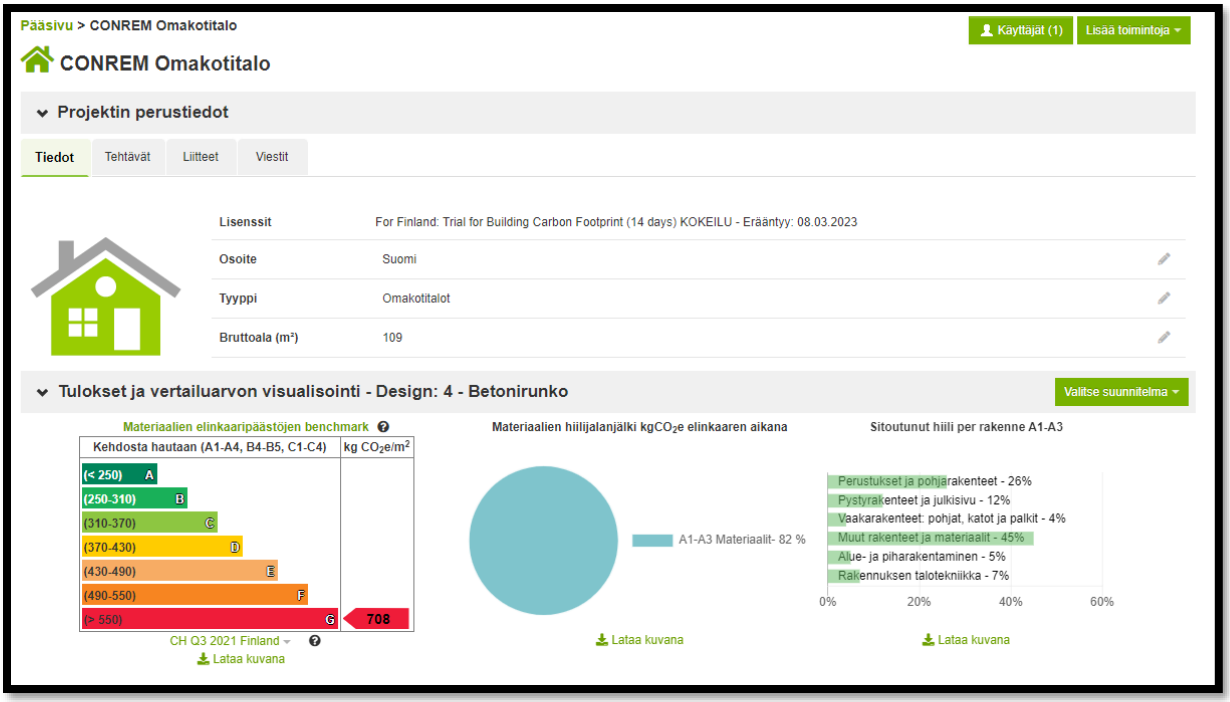


Figure 29. The front page of the carbon assessment project.[38]

First, the user creates a project in the application and fills the basic information on it, such as size, location, main material for the frame and the expected lifetime. The

[38] (OneClickLCA, 2023)

software assists the user in making the correct decisions for the basic information by asking for a specific use case and then giving out a license that lays out a framework for the task at hand. For this thesis, the license picked was called “For Finland: Trial for Building Carbon Footprint (14 days).” (OneClickLCA, 2023).

After the creation of the project, the software points out the modules that are missing information, such as the construction materials, site operations and energy use during building operation. By clicking on the text stating that material information is missing, the software leads the user to the material listing page, shown empty below in Figure 31. The structure in which way the building is assembled is slightly different from the tool given by the Ministry of the Environment. Here the locations are as follows: Foundations, vertical elements and shell, horizontal elements, other elements, site, and building service systems.

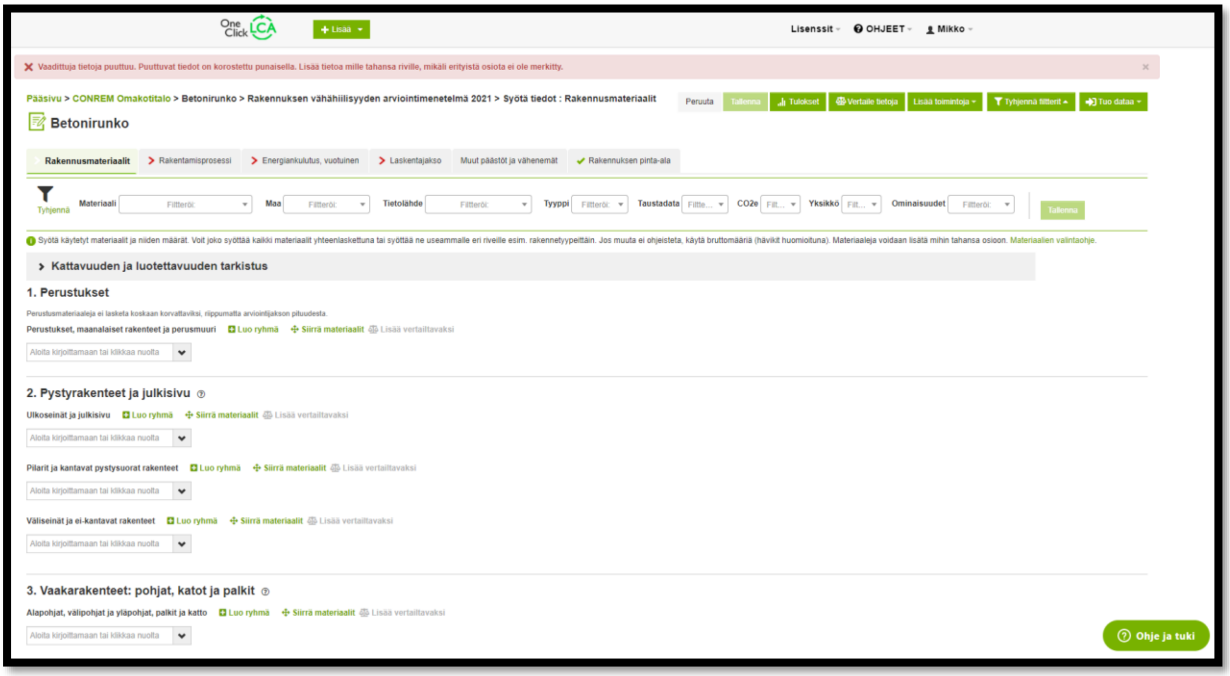


Figure 30. The starting view of the material list compilation page. The headings that are used to sort out the materials are already visible with drop-down menus used for searching the materials also visible. [39]

The user can start listing individual materials under the headings, but it is also possible to group them together. The listing begins by activating the drop-down menus visible in Figure 31. Using the search tool in the drop-down menu the user can type and search for suitable data to use. The data can come from various sources, both from national databases like the co2data.fi and product specific environmental product

[39] (OneClickLCA, 2023)

declarations. As OneClickLCA also helps manufacturers create EPDs, they have access to a large database to them. The search tool being used for concrete is shown in Figure 32.

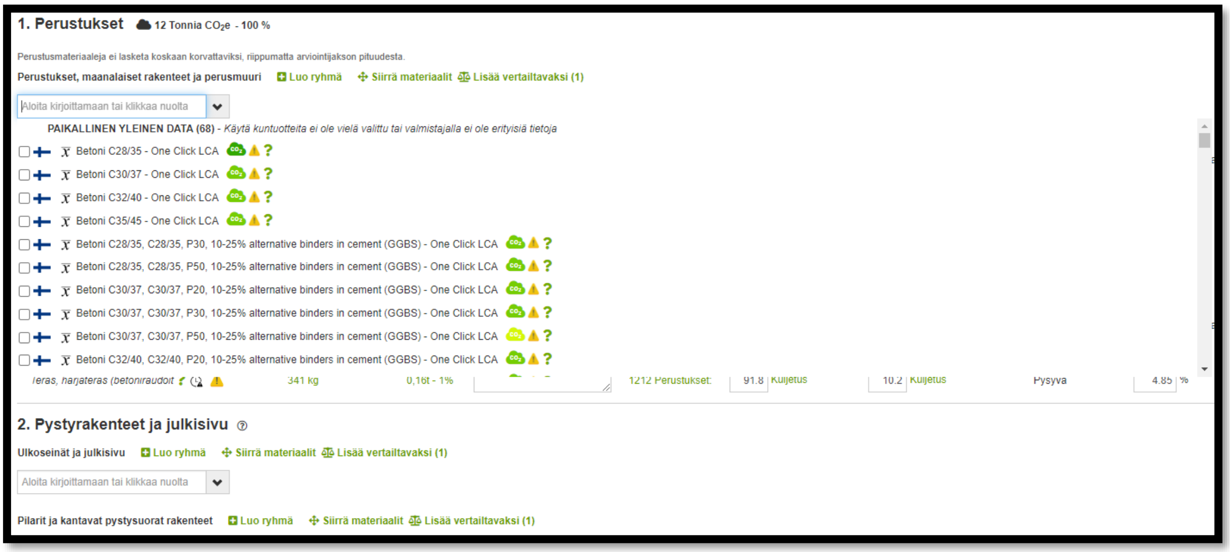


Figure 31. A search for concrete produced these results when compiling the material list. (OneClickLCA, 2023)

Some of the EPDs used were made using the earlier E15804:A1 standard, in which case the software gave an alert message stating that the EPD might not be suitable for use. The quantity of emissions data in this tool is vastly greater than in the tool provided by the ministry. In addition, there is an in-built conversion factor, so that the user can input the quantity usually direct from the bill of quantities without having to convert the quantities into kilograms. In the bill of quantities made for the case project, many quantities are in other units than kilograms. In Figure 33 two groups of materials under the heading “Foundations” are shown. These groups represent the plinths and footings of the case project.

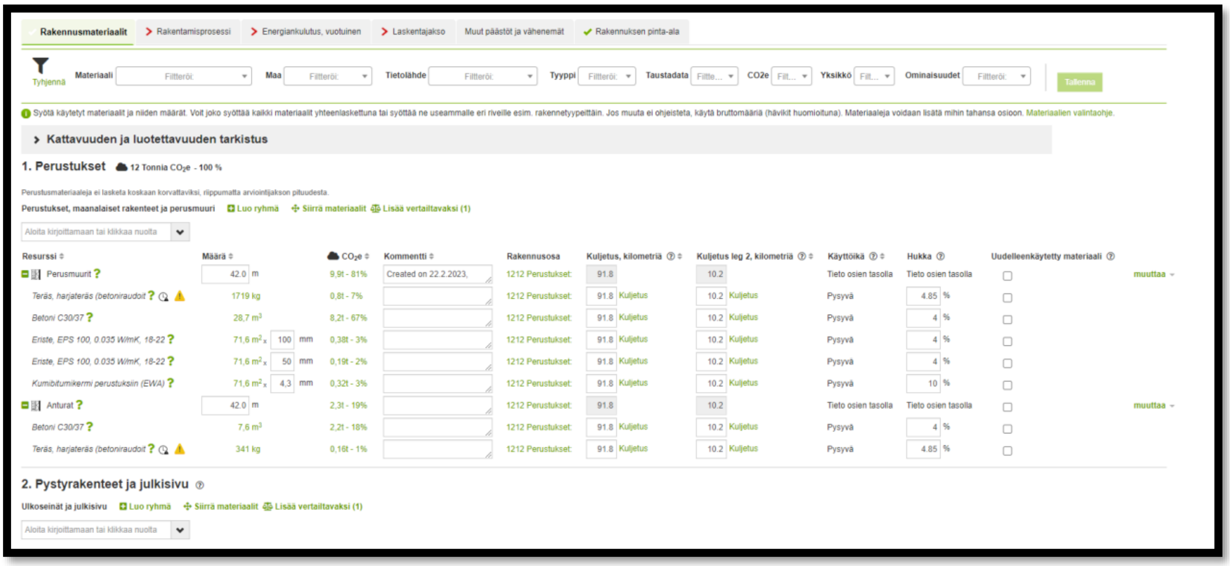


Figure 32. Materials of the single-family house foundations. [40]

There was an issue when trying to find the materials for waterproofing and tiling of the bathrooms. For some reason there was a pre-made “recipe” for the levelling, waterproofing, and tiling of the bathroom walls, but no such recipe could be found for flooring. This discrepancy is shown below in Figure 34. The impact of such discrepancy might be small enough for it not to matter according to the EN15803:A2 and the decree of the Ministry of the Environment concerning the climate declaration.

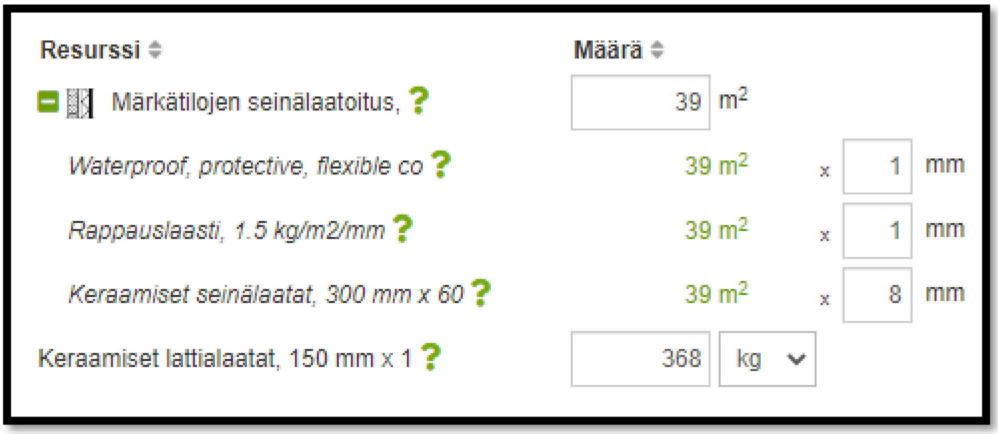


Figure 33. Discrepancy between bathroom wall tiling works and floor tiling works.[41]

A more major concern of note were the emissions of sand and gravel used in the estimation. The total quantity of sand and gravel in the project was 440 910 kg and the same emissions data source (co2data.fi) was used both in the tool made by the

[40] (OneClickLCA, 2023)
[41] (OneClickLCA, 2023)

Ministry and in OneClickLCA. For some reason, the emissions differed by a large margin, with OneClickLCA coming up with 7.1 tons of CO_2e and the tool of the Ministry coming up with 2.1 tons CO_2e. Some table values were also slightly different between the tools, for example the site operations module (A5). Nevertheless, the total amount of CO_2e emissions of both calculations were relatively close, considering the small differences in available data between the tools. Both estimation results can be found as appendices 1 and 2 and the notes made during the testing in Appendix 8. For the purposes of this study, the results of the estimations are less important than the process with which they are achieved, thus this study did not compare the results in too much detail. Both estimates made with the tool of the Ministry and OneClickLCA can be found in the Appendices 1 and 2, respectively, and the test reports in Appendix 8.

4.8. Criticism on Carbon Declaration Process

The previous chapters have discussed the legal and technical frame works of the climate declaration process, as well as possible tools that can be used to produce a climate declaration. This chapter focuses on criticism on these processes.

Jiri Hietanen, the CEO of the company DataCubist that specialises in BIM enrichment from design to production, writes in his blog that the carbon estimation should be based on the quantity take-off done for the cost estimation, and not on the designed building information model itself (Hietanen, 2022).

Hietanen first makes a difference between the design of the result (the modelling) and the design of the production (the cost estimation). The first issue comes from the level of detail in the building information model made by the designers. In the cost estimation phase, the model usually has only some of the building materials modelled, such as the walls without the surfaces. Some of the missing information will be supplemented in the cost estimation process by assumptions to make way for the production phase, even though the design is not fully finished. Hietanen states that an experienced cost estimator can predict the materials required that are not modelled, such as the moulds for formworks, and the gutters for roofs. Hietanen states that while the quantities generated for the cost estimation are based on the measurements made on the building information model, some of these quantities may never be modelled or will at least be missing in the beginning of the production phase. Consumption rates of materials can also be more easily assessed in the cost estimation phase, according to Hietanen. He gives an example where the hollow-core slab has been modelled as a solid slab and thus the quantity take-off from the model would give far too much concrete in the material list if done automatically. A skilled cost estimator would also be able to tell that the general waste of gypsum boards is around 10% and that concrete moulds can usually be used five times before being discarded. (Hietanen, 2022).

Hietanen closes his argument by stating that the cause of the emissions is equal to the cause of the costs of the project and that the quantity take-off done for the cost estimation is the most accurate prediction of the upcoming project and that the carbon estimate should be based on that. Additionally, he makes the point that while it is relatively easy to make mistakes when using BIM generated quantities due to lack of assumptions and level of detail, to perceive these errors can be more difficult whereas a mistake in cost estimation will almost always be noticed, along with the possible mistake in carbon estimation. (Hietanen, 2022).

5.0 Simultaneous Cost Estimation and Carbon Footprint Estimation Prototype

After the review of the tools available for carbon estimation, the roadmap of this study detailed the conceptualisation of a tool that could perform carbon estimation simultaneously with the quantity and cost estimation process. As previously described in chapter 4.2., the Building80 estimation process divides the building into main groups, building element groups and finally activities and resources. The resources in cost group two correspond to materials in the carbon estimation tool and thus represent the most logical level on which to do carbon estimation. The classification systems and digitalized estimation processes are structured in such a way that resources connected to many different building elements, such as concrete or gypsum boards, can have their quantities traced back to the corresponding building elements, such as floors, beams, or walls. An example of this is shown in Figure 35, where a resource used in the case building is selected in the Tocoman Estimation application and in the bottom of the screen the relevant activities are shown. Those activities can then be traced to the relevant building elements as well. (Admicom Oy, 2022)

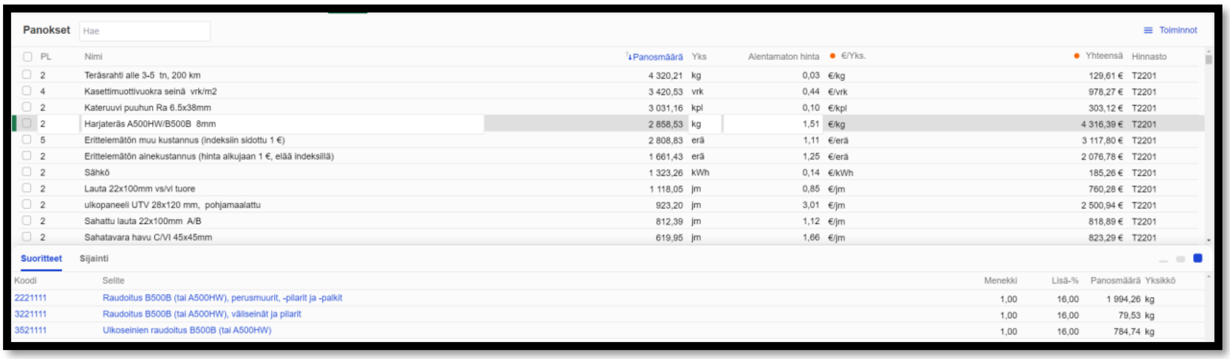


Figure 34. Selection of a rebar-resource. In blue the user can see the activities in which the resource is used. In this case rebar is used in plinths, partition walls and exterior walls.[42]

As discussed by Mr. Hietanen in the previous chapter, the cost estimator, when skilled, has the best knowledge on which type of materials will finally be installed in the building and from which manufacturers the materials come from. This could have a positive impact on the speed and accuracy with which the climate declaration is made in the early phases of the project but also would have a clear positive impact on the climate declaration made once the construction project is finished, as the Bill of Quantities and the differences between preliminary plans and as-built plans can be checked row-by-row and element-by-element. Like Mr. Hietanen stated in chapter 4.8. and as shown in the chapter 3.4.1. of this study discussing the modelling requirements in each phase of a construction project, the material list generated from an IFC model can be lacking in surfaces and may not contain all activities and consequently resources related to the building parts.

A logical step would be to connect the resources directly into corresponding EPDs or to generic information provided by for example the National Emissions database. This could be done by integrating the EPD databases or a platform connecting multiple EPD databases together into a possible cost estimation software, such as the EcoPlatform discussed in chapter 3.7.1. A draft of such an integration and flow of information required by the two applications is shown on the following page in Figure 36. A draft of a user interface (UI) of such a solution is also shown in Appendix 3, showcasing how the resources could be supplemented with additional information and how the user could possibly look for suitable EPDs or generic data to their resources. This could at first possibly be done using a drop-down menu or a search bar connected to the database(s), with which the user can look for matches.

[42] (Admicom Oy, 2023)

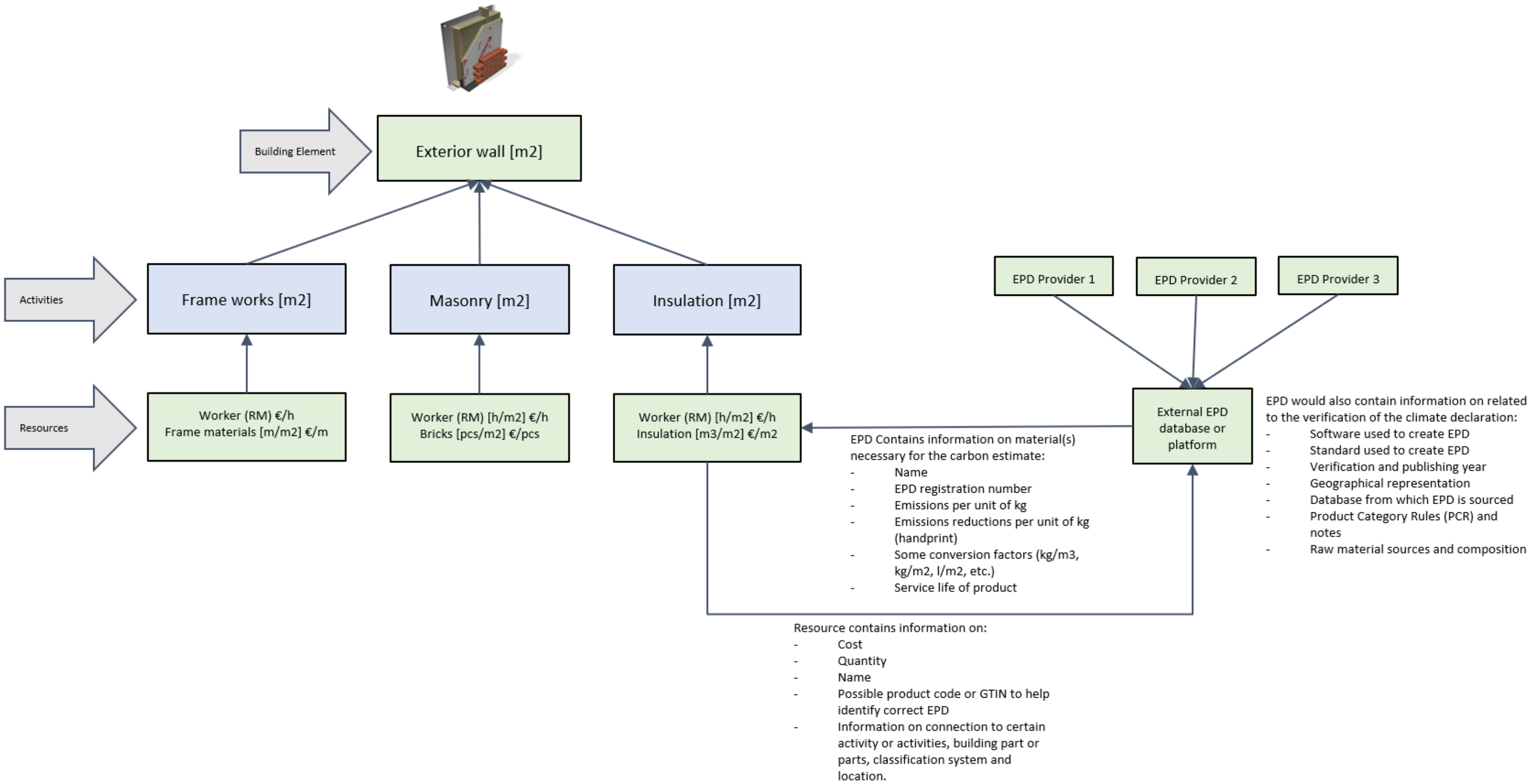


Figure 35. A draft of what information would come from the quantity and cost estimation, and what information would be needed from the EPD or external emissions database to fulfil the requirements of the law and decrees. [43]

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[43] (Diagram by the Author.)

6.0 Comparison of Different Tools

After the testing of the different tools and the development of a prototype tool, the different characteristics of the tools were assessed in terms of useability, speed, accuracy, and reliability. The Level(s) material list tool was excluded from this assessment, as it does not estimate the emissions of the project. All tools have their strengths and weaknesses, but the easiest way to compare the tools was deemed to separate the positive aspects of each viewpoint from the negatives. The full assessment is in Table 11 and as Appendix 9 for easier readability, but below is a short analysis of the four aspects considered.

In terms of useability, the contemporary tools offer a relatively simple way to perform the carbon assessment, although separate from other similar tasks such as quantity and cost estimation, which the prototype suggests being combined. Performing only one task at a time is usually simpler in any performance.

For speed, the separation of tasks can either be considered a faster or a slower way of doing things, as sub-contracting the carbon assessment could free the designers to focus on design. However, same applies if the cost estimator would be the one performing the assessment. The prototype also would add the benefit on using pre-made estimation recipes with pre-integrated EPD information, thus enabling carbon assessment to be done during the cost estimation with little extra input from the estimator after a few estimates. Naturally, at first, new recipes would need to be connected to EPDs, but the idea is for the connection to remain from one estimate to another.

In terms of accuracy, the level of detail in the building information models and plans affect all three tools, although the updating of the prototype method could be significantly easier due to its connection to the budget and thus procurement processes. As contracts are made and products chosen, the update can be done with less hassle than with a separate material listing.

The reliability of the three tools and methods is based on the sources of information used and the level of detail of planning, thus making the three comparable in this aspect.

Table 11. Comparison of useability, speed, accuracy, and reliability of the tools tested.[44]

	Tool of the Ministry of the Environment	OneClickLCA	Prototype
Useability Pros	Does not require cost estimation expertise.	Does not require cost estimation expertise.	In collaborative delivery methods can be done by the party producing and updating the cost estimate, resulting in one less contract in the project.
	Existing templates for proper climate declaration reduce the time it takes to form the document for the building control services.	Existing templates for proper climate declaration reduce the time it takes to form the document for the building control services.	Connection to resources used in cost estimation and later in procurement, allowing for more streamlined flow of information throughout the project.
		Possibility to import material list from IFC into the estimation tool.	Possibility to import material list from IFC into the estimation tool, which can then be supplemented by the cost estimator.
		Material quantities can be input in multitude of units, reducing the number of manual unit conversions and speeding up the process.	Could work well when design and cost estimation are done by the same company, allowing for faster comparison of alternatives both in terms of costs and emissions.
		Allows for the creation of "groups" to help manage the quantities	
Useability Cons	Adds more work to designers if done by them.	Adds more work to designers if done by them.	Requires expertise in quantity and cost estimation as well as at least basic level knowledge on the topics of the climate declaration.
	Tool of the ministry requires unit conversions to kilograms without giving conversion factors, increasing the workload of the assessor.		Adds more work to designers if done by them using this method.
	Lack of connection between larger building parts and elements increase the manual labor required to ensure that all materials are taken into account.	Lack of connection between larger building parts and elements increase the manual labor required to ensure that all materials are taken into account.	Might have difficulties to be implemented when used in design-bid-build delivery methods, where the building element level of estimation is done only when contractors are estimating their tenders and the building permit is already applied for.
	The material list may be lacking, as it is reliant on the level of detail of the model.	The material list may be lacking, as it is reliant on the level of detail of the model.	The material list may be lacking, as it is reliant on the level of detail of the model. Extra work if cost estimation done using other classification system than design or if the classification needs to be changed to another to present the carbon assessment.
Speed Pros	Can be done separate from the cost estimate (by anyone) and thus sub-contracted by the responsible parties to allow time to be spent on other things, such as design.	Can be done separate from the cost estimate (by anyone) and thus sub-contracted by the responsible parties to allow time to be spent on other things, such as design.	Going through a resource list that is the result of a quantity estimation process may possibly be faster than compiling a separate list of materials and going through it.
		Faster than the tool of the ministry thanks to the automatic conversion from one unit to another.	Possibility that this method will gradually start picking up speed as resources in a cost database are connected to EPD database during the estimation process, and continue to remain connected when the same resource is used in another estimation project.
		Search tools make this tool faster than the version provided by the Ministry of the Environment.	If unit conversions can be automated using the conversion factors provided by the EPDs, then the process will be most likely faster.
			Updating of the data post-construction may be faster using a Bill of Quantities than a separate material list.
Speed Cons	Most likely slower as an individual work phase than when connected to quantity and cost estimation.	Most likely slower as an individual work phase than when connected to quantity and cost estimation.	Less possibility of buying the climate declaration as a service, unless bought as an add-in to bought quantity and cost estimation services.
	Updating of data may end up being manual and tedious, as there is little connection between building elements and materials (resources) and their quantities. The need for unit conversions and missing conversion factors slow down the time it takes to input quantities significantly.	Updating of data may end up being manual and tedious, as there is little connection between building elements and materials (resources) and their quantities.	Is reliant on the quantity and cost estimation process, which may be unfinished by the time of the building permit application.
Accuracy Pros	Pre-existing table values for the other modules of climate declaration.	Pre-existing table values for the other modules of climate declaration.	Most likely will be easier to update the material list after project completion due to connection to Bill of Quantities and thus procurement, resulting most likely in a more thorough check-up at the end of the project.
	Connection between materials and emission data is clear and transparent.	Connection between materials and emission data is clear and transparent.	If no product is chosen at the time of cost estimation, generic information can be used and later replaced by the EPD of the actual product chosen.
Accuracy Cons	Lacks the supplemental information added by the cost estimator, possibly resulting in missing materials and information.	Lacks the supplemental information added by the cost estimator, possibly resulting in missing materials and information.	No existing templates or table values.
	Level of detail of plans can be inadequate by the time of building permit application resulting in assumptions and missing information.	Level of detail of plans can be inadequate by the time of building permit application resulting in assumptions and missing information.	Level of detail of plans can be inadequate by the time of building permit application resulting in assumptions and missing information.
	Cross-referencing of initial and final carbon estimate may prove to be more difficult than when Bill of Quantities and carbon estimate are connected through resources.	Cross-referencing of initial and final carbon estimate may prove to be more difficult than when Bill of Quantities and carbon estimate are connected through resources.	Is reliant on the expertise and accuracy of the estimator.
	Lack of data and sources in the Excel when comparing to private application and EPD databases.		
Reliability	Reliability depends on the source of information used, assuming all methods use verified EPDs and national emissions databases, resulting in similar reliablity of information.	Reliability depends on the source of information used, assuming all methods use verified EPDs and national emissions databases, resulting in similar reliablity of information.	Reliability depends on the source of information used, assuming all methods use verified EPDs and national emissions databases, resulting in similar reliablity of information.

44 Diagram by the Author

7.0. Discussion

The update to the Finnish construction law of 1999 and the relevant decrees by the Ministry of the Environment are coming to force in 1.1.2025. Aim of the new law is to enforce digitalisation and sustainable practises in the Finnish construction industry as well as to integrate the law into regulations and directives coming from the European Union. The new legislation and its accompanying decrees will create a legal framework based on a similar common European Level(s) system that regulates emissions and will try to guide the construction industry into a more sustainable way of working.

According to the decrees on material lists and climate declaration by the Ministry of the Environment, the main designer of a construction project will be responsible for presenting a material list of the components of the building as well as a climate declaration assessing the environmental impacts of the projects before applying for a building permit. Both the negative and positive impacts of the project to the environment are to be assessed, i.e., the carbon footprint and handprint respectively. The positive impacts do not take away from the negative ones and thus the two are entirely separate values in the climate declaration. This requirement will cover most buildings, including residential buildings, offices, schools, and healthcare buildings. Buildings that will not require a climate declaration are few and specific, such as summer homes, religious buildings, unheated warehouses, and infrastructure buildings.

The contents of the material list are meant to guide the party responsible for the climate declaration to consider all parts of the building. The material list must contain nearly all building elements, and a list of materials within those building elements by type and origin, i.e., whether the materials are concrete, plastic, ceramic or glass, and whether the materials are new, recycled, reused, renewable or hazardous. The few materials that can be excluded include site equipment, packaging, IT systems and separate nails, screws, and sealants. Up to 5% of the materials that ought to be included, can be omitted, if necessary. This is to ease the work of the assessor.

The Level(s) framework website provides interested parties with a tool with which they can produce a material list. This tool was tested during the writing of this thesis, although it lacks the necessary components to assess the environmental impacts of the materials required by the decree on climate declaration.

The decree on climate declaration covers the methodology and information sources to be used when assessing the environmental impact of a construction project over the life span of usually 50 years. As previously mentioned, the climate declaration should be based on the material list produced and must be given to the Building Control authorities when applying for a building permit. Furthermore, if there are changes to the composition of the material list during the construction an updated material list and climate declaration must be presented at the end of the project. The manager on the site is responsible for keeping tabs on any changes to materials between design and handover. All data must be presented in either a building information model (BIM) or other “machine readable” format, i.e., Excel or similar.

The climate declaration assesses the global warming potential (GWP) of the project. The GWP is measured in units of kg CO_2e. The assessment is divided into different modules based on the life cycle stages of a product. The first three modules, A1-A3, cover the emissions caused by the extraction of raw materials, transport of the raw materials to the production site and actual manufacturing of the product. The information regarding these emissions can either be found in product specific Environmental Product Declarations (EPDs) made using the EN 15804:A2 standard, or by sourcing generic data from a national emissions database such as www.co2data.fi. Modules A4 and A5 correspond to the transport of the material to the construction site and site operations respectively. These can be estimated using table values given by the Ministry of the Environment or more accurately using site specific distances and fuel consumption for example, if the estimator so chooses to do so. The more accurate estimates will require proof and source materials to be submitted along with the climate declaration to the Building Control.

Modules B1-B3 that cover product use, maintenance and repair can be excluded from the climate declaration as they are deemed to either have only minimal impact on emissions or too difficult to forecast. Module B4, product replacement, will be included in the assessment. Replacements can be forecast relatively easily based on the lifespan of the product installed. Module B5, refurbishments, is also excluded as these kinds of projects will either be so large-scale that they will be considered their separate renovation project that need their own climate declaration and building permit, or too difficult to forecast during early design phase. Modules B7 and B8 covering operational water use and user activities are also excluded due to same reasons of minimal impact and difficulty of forecasting.

Lastly, modules C1-C4 covering demolition, transport, processing, and disposal of waste are included but are permitted to be estimated using table values provided by the Ministry of the Environment. Module D covers the carbon handprint of the building, i.e., the positive effect the building has on the climate by means of carbon capturing and use of renewable energy sources, for example.

In addition to the modules corresponding to life cycle phases, the climate declaration must be divided into two parts: The site and the building. The GWP must be stated in kg $CO_2e/m^2/a$ and in total kg CO_2e for the 50 year assessment period.

There are no benchmarks or thresholds yet, although they will be implemented in the future by another decree by the State Council.

To assist in the production of a material list and climate declaration, the Ministry of the Environment has provided a free emissions database, www.co2data.fi, and an Excel-based estimation tool that can be used by anyone. There are also private applications on the market for the specific purpose of making a material list and climate declarations, such as the Finnish OneClickLCA. Both tools were tested for purposes of this study using a single-family house to benchmark the two tools against the possibility of making the material list and climate declaration as a part of the quantity and cost estimation process, the feasibility of which was the topic of this thesis.

Both tools had many positive aspects, such as integrated emissions data and/or EPD search tools, as well as ready-made table value calculators and reports for Building Control. What was somewhat lacking was the connection between building elements and materials and the process with which to produce the material list. In addition, the reliability of the material list generated by a designer has been questioned in some cases. This criticism arises mainly due to the nature of construction projects: The Level of Detail (LOD) of the designs and BIM in the early phases of design, and the procurement processes that happen late in the design process or even during the construction phase. As discussed in the chapter 3.4.3. discussing project delivery methods, the LOD in the BIM of the building may be insufficient to consider all the materials that are going to be installed. During early design phases and before the building permit application, the current Common BIM Requirements do not require the designers to model surfaces or consider different methods of construction. These are items that the cost estimator, however, must consider or the budget of the project will be too small. The added oversight caused by the connection to budget would support doing the climate declaration at the same time as cost estimation. However, the choice of delivery method may influence the phase of the project where the cost estimation is done using the methods described in chapter 4.2., i.e., using building elements, activities, and resources. For some clients, a more generalised estimate done using €/m^2 values or space designated costs may be sufficient to establish a budget, thus negating the need for such an accurate cost estimate at the time of building permit application.

By connecting building elements, activities and especially resources into suitable emissions data, the updating and checking of the lists generated may prove to be less difficult at the end of the project as procurement could keep tabs on the Bill of Quantities and correct any changes as they procure the services and building parts. By integrating a cost estimation software and the resources contained within to an EPD platform or database, the cost estimator could connect resources to EPD using for example a drop-down menu and the information contained within the EPD file could be transferred into the cost estimate. This connection could also remain in-place inside the software for faster carbon calculations in following projects. One of the main obstacles when using especially the tool provided by the Ministry of the Environment was the need for unit conversions into kilograms from square meters, cubic meters and so on. Most EPDs examined for this thesis contained one or more conversion factors, which when digitalised and integrated into the cost estimate could automate most of the unit conversions, thus speeding up the entire process of producing the climate declaration.

7.1. Comparison of Results

This chapter looks at the research questions posed in the beginning of the study and whether the questions were answered.

Is it feasible to perform carbon footprint estimation simultaneously with quantity and cost estimation?

Yes. There are no significant obstacles to performing carbon footprint estimation simultaneously with quantity and cost estimation. The proposed method described in chapter 5.0 and in Appendix 3 is possible to implement. The information that the material list and climate declaration decrees demand is usually contained within product specific EPDs or the national emissions database. Some EPD databases, such as ECO Portal, have modern, accessible interfaces, meaning that information can be moved between various software. There are no obvious hindrances caused by the legislation or decrees either, as the format in which the information must be delivered to the Building Control seems to be very loosely defined. The two tools tested provide significantly different outputs, the tool of the Ministry of the Environment being an Excel-file while OneClickLCA is browser-based and prints PDF reports. “Machine readable format” seems to be the only prerequisite for the submissions.

How could Building Element-Activity-Resource -based estimation recipes be enhanced to withhold carbon emission data as well?

This has been illustrated in chapter 5.0. in Figure 36. The resources used in cost estimation recipes introduced in chapter 4.2. would be the most logical units to be connected to EPD data as resources represent individual materials, such as gypsum boards and paints. If no specific product and thus EPD is known at the time of the assessment, the resource could be connected to the generic emissions data in the national emissions database. Life cycle modules that can be estimated using table values such as A4 and A5, transports and site operations, could be, but do not need to be, connected to resources.

How does the presented method of CO_2 footprint estimation compare to other methods?

The full assessment can be found in Table 11 in chapter 6.0., and as Appendix 9. All tools have their pros and cons, although the prototype developed seems to have more pros in terms of useability, accuracy and speed than performing carbon assessment separately from quantity and cost estimation. The downsides of the prototype are caused by processes external to the estimation, such as low level of detail and lack of need for recipes-based cost estimation in the very early phases of the project. The reliability of the three tools and methods is based on the sources of information used and the level of detail of planning, thus making the three comparable in this aspect. The major benefits of the prototype developed are the easier updateability during and after construction, as well as better oversight due to the carbon assessment being tied to the budget of the project.

8.0. Conclusions

This study aimed to identify whether simultaneous carbon, quantity and cost estimation was feasible. Based on the thorough literature review and analysis of the tools currently available, there are no significant obstacles to performing such a simultaneous action, provided that the project phasing and level of detail of the design permit it. The results indicate a potential for merging of these three tasks. This is especially the case when taking to account the ease at which a budget based on a Bill of Quantities can be updated during the procurement process compared to a separate material list generated from a design software, possibly without cost data. The actions taken by a cost estimator to fill in the gaps of the design in cases such as missing information on surfaces and production methods can significantly alter the CO_2 footprint estimated during the process of climate declaration production.

According to the data gathered for this thesis, the climate declaration of a building must contain the emissions and emissions savings from the manufacturing, use and disposal phases. Some data, such as the emissions from the site operations during construction or the energy use data from building operation are derived from tables or estimated using aggregated data gathered from operating similar buildings in the past. Unlike the site operations and use examples, the emissions data for the materials used in the construction project must be listed in much greater detail with each building part and individual material contained within the building parts listed individually with their individual global warming potential stated. The decree on the material list also states that all materials must be sorted by type and origin. As stated earlier in chapter 3.5.4. discussing the reliability of the climate declaration, only 5% of emissions and energy use can be neglected. Other than the allocated 5%, an accurate GWP in kg CO_2e of the defined product or a reasonable generic supplement must be given. For example, in a gypsum board wall, both the gypsum boards, the frame parts and the insulation within must all be quantified, and their emissions estimated. To come back to the first paragraph of this chapter, these are things that an experienced cost estimator can consider without the frame, or the insulation modelled.

Sources for the building parts' emissions can vary, but mainly Environmental Product Declarations or the national www.co2data.fi database should be used. If neither source has the data required, then third-party emissions sources will also be permitted.

A common way of estimating quantities and costs in building projects is to use the building element-activity-resource style of estimation. This method assists in creating a list of materials needed for the various building parts, especially if the same material is used in multiple building elements, such as gypsum for walls and suspended ceilings.

The climate declaration must be done before the application for the building permit, but also in the end of the building project whenever there have been changes to the building plans during the construction phase. As anyone who has worked in construction knows, changes to designs are practically inevitable.

In conclusion, the legal framework, and the data available online seem to point in the direction that simultaneously performing quantity, cost and carbon estimation could be viable and more efficient than performing carbon estimation separately from the other two tasks. Both connecting materials from a BoQ into the EPDs and updating the climate declaration at the end of the project seem easier done using a list that is used during the construction phase, i.e., when procuring materials and sub-contracts. The BoQ and thus climate declaration could be updated from the draft stage into as-built simultaneously as the procurement process progresses, especially when comparing the ease at which a budget based on a Bill of Quantities can be updated when procurement occurs compared to a separate material list generated from a design software with no costs or connection to activities on the site. In addition, actions taken by a cost estimator to fill in the gaps of the design in cases such as missing information on surfaces and production methods may significantly alter the CO_2 footprint estimated during the process of climate declaration production.

Unfortunately, the level of detail of plans during the building permit phase and the differences in project delivery methods may hinder the quantity and cost estimation process required for the carbon assessment prototype to work. However, it must be stated that a climate declaration based on material quantities extracted directly from a low-level building information model will most likely be even less reliable than a climate declaration made using even just a building-element level cost estimate, where the activities and resources are still present in their generic recipes and forms, and no exact product to be installed on the site is known. The generic data could easily be replaced to product data later.

Without thresholds, the parties generating climate declarations will have a hard time telling whether their buildings are sustainable or not. The first years after the implementation of the new construction law will focus on collecting and aggregating data to help set the thresholds for future climate declarations.

One thing to note from the author’s point of view is that while the climate declaration templates all talk about the classification format of Building2000, most cost estimation is still done today using the Building80 classification system. This statement is based on over four years of cost estimation lecturing and software consulting done by the author in over a hundred construction companies around Finland. Only twice during this time has there been a case where cost estimates have been done using Building2000. This discrepancy may require additional inputs from the software developer who chooses to start working on a possible product, meaning that someone will need to convert the cost groups in Building80 match with Building2000, unless the Building Control will take the climate declaration in the older classification system format. Nevertheless, as both classification systems are used to describe parts of the same building, they contain the same information if in a little different format and this will most likely not be a major issue.

Based on the findings of this study, it is likely that the company behind this thesis assignment will continue looking into the topic of integrating quantity, cost and carbon estimation as the results seem promising and the obstacles do not seem impossible. Future studies on the topic could address the differences between the various delivery methods and the willingness of the client or developers’ side to begin more exact cost estimation process earlier in the project. With the advent of alliancing and similar cooperation methods, the industry seems to be more open to discussion, onboarding their contractors earlier, and opening their books more often to other stakeholders. All these trends will play a role in furthering the feasibility of more accurate and most of all, simultaneous, quantity, cost, and carbon estimation.

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.

22.06.2023 — Henrik Hassinen

Location, Date — Signature of the student

Bibliography

Admicom Oy, 2022. *Admicon-Tocoman Website.* [Online]
Available at: https://admicom.fi/tocoman/

Admicom Oy, 2023. *Tocoman Estimation.* [Online]
Available at: app.tocoman.fi/estimation
[Accessed 30 March 2023].

Anupoju, S., 2022. *The Constructor website.* [Online]
Available at: https://theconstructor.org/building/density-construction-materials/13531/

Braune, A. L. E. K. Q., 2021. *Benchmarks for Greenhouse Gas Emissions from Building Construction.* Stuttgart: Deutsche Gesellschaft für Nachhaltiges Bauen.

Council of State, 2023. *MRL-kokonaisuudistus hankeikkuna.* [Online]
Available at: https://valtioneuvosto.fi/hanke?tunnus=YM014:00/2018
[Accessed 13 2 2023].

Dalborg, M. D. J., 2019. *Environmental Product Declaration, Gyproc GN 13,* Kirkkonummo: The Building Information Foundation RTS.

ECO Platform, 2023. *ECO Portal.* [Online]
Available at: https://www.eco-platform.org/epd-data.html
[Accessed 23 February 2023].

ECO Platform, 2023. *ECO Portal.* [Online]
Available at: https://www.eco-platform.org/eco-portal-access-point-to-digital-product-data.html
[Accessed 23 February 2023].

European Commission c, 2022c. *Level(s) in Action.* [Online]
Available at: https://environment.ec.europa.eu/topics/circular-economy/levels/lets-meet-levels/levels-action_en

European Commission, 2022a. *How does Level(s) work?.* [Online]
Available at: https://environment.ec.europa.eu/topics/circular-economy/levels/lets-meet-levels/how-does-levels-work_en

European Commission, 2022b. *Level(s) - Sustainable performance in buildings.* [Online]
Available at: https://academy.europa.eu/mod/scorm/player.php

European Commission, 2022d. *Bill of Quantities, materials and lifespans excel template: for estimating (Level 2) and recording (Level 3) purchases of material quantities and costs (version 1.2).* Brussels: European Commission.

Finnish Environmental Insititute, 2022. *Rakentamisen päästötietokanta, UKK.* [Online]
Available at: https://www.hiilineutraalisuomi.fi/fi-FI/Tyokalut/Rakentamisen_paastotietokanta/Usein_kysytyt_kysymykset(59988)

Finnish Environmental Insitute, 2023. *Rakentamisen päästötietokanta.* [Online]
Available at: https://co2data.fi/rakentaminen/
[Accessed 20 February 2023].

Finnish Environmental Insitute, 2023. *Rakentamisen päästötietokanta.* [Online]
Available at: https://co2data.fi/rakentaminen/
[Accessed 20 February 2023].

Finnish Government, 2021a. *HALLITUKSEN NEUVOTTELUT VUODEN 2022 TALOUSARVIOESITYKSESTÄ, HALLITUKSEN NEUVOTTELUSSA HYVÄKSYTYT ILMASTOKIRJAUKSET 9.9.2021 , HIILINEUTRAALIUDEN SAAVUTTAMINEN,* Helsinki: Finnish Government.

Finnish Government, 2021b. *Luonnos hallituksen esityksestä rakentamislaiksi eduskunnalle,* Helsinki: Finnish Government.

Finnish Government, 2022. *Hallituksen esitys rakentamislaiksi ja siihen liittyviksi laeiksi HE139/2022,* Helsinki: Finnish Government.

Gaasbeek, A., 2019. *Pre-Sustainability.com.* [Online]
Available at: https://pre-sustainability.com/articles/what-the-revised-en15804-epd-standard-means-for-you/
[Accessed 17 March 2023].

Harju, M., 2015. *Energiatodistus Helsinginkatu 18,* Helsinki: Suomen Energiakatsaus Oy.

Hietanen, J., 2022. *Tietomallintaja.* [Online]
Available at: https://www.tietomallintaja.fi/2022/07/01/ei-hiilijalanjaljen-laskentaa-ifc-malleista/
[Accessed 17 March 2023].

Kangas, H.-L. S. P. K. P. R. E. L. D., 2019. *Taloudellisten kannusteiden käyttö vähähiilisen rakentamisen ohjauksessa TALO-hankkeen loppuraportti,* Helsinki: Ministry of the Environment.

KIRA-Innohub Ry, 2021. *KIRAHub.* [Online]
Available at: https://kirahub.org/ytv2020-paivityshanke-osaksi-kansallista-yhteentoimivuuden-maarittelya/
[Accessed 8 March 2023].

Koskela, M., 2022. *Uudet kestävän rakentamisen vaatimukset.* Helsinki, Ministry of the Environment.

Kuittinen, M., 2022. *Perustelumuistio rakennuksen materiaaliselosteesta.* Helsinki: Ministry of the Environment.

Kuittinen, M. e. a., 2021. *Luonnos: Perustelumuistio Ympäristöministeriön asetus rakennuksen ilmastoselvityksestä,* Helsinki: Ympäristöministeriö.

Ministry of the Environment, 2019a. *Rakennusten hiilijalanjäljen arviointityökalu.* [Online]
Available at: https://ym.fi/documents/1410903/38439968/Rakennusten-hiilijalanjaljen-arviointityokalu-9.12.2019-D4EE18D2_E07C_48A2_88A5_D266705A0498-149235.xlsm/f3182a07-d5f5-b879-d663-1d28003cf5a4?t=1603259829955

Ministry of the Environment, 2019b. *Rakennuksen vähähiilisyyden arviointimenetelmä,* Helsinki: Ministry of the Environment.

Ministry of the Environment, 2021. *Rakennuksen vähähiilisyyden arviointimenetelmän ohjeen luonnos lausuntokierrosta varten 6/2021,* Helsinki: Ministry of the Environment.

Ministry of the Environment, 2022a. *Ympäristöministeriön asetus rakennuksen materiaaliselosteesta (Luonnos 30.9.2022).* Helsinki, Ministry of the Environment.

Ministry of the Environment, 2022b. *YMPÄRISTÖMINISTERIÖN ASETUS RAKENNUKSEN ILMASTOSELVITYKSESTÄ,* Helsinki: Ministry of the Environment.

Ministry of the Environment, 2022c. *Ryhti-hanke.* [Online]
Available at: https://ym.fi/documents/1410903/39234050/Ryhti_Yleisesite-FI_09.06.22.pdf/4528c9a8-aec3-4dd0-18b1-670f5b021017/Ryhti_Yleisesite-FI_09.06.22.pdf?t=1654783561242
[Accessed 8 March 2022].

Mirzaie, S., 2016. *Pre-Sustainability.com.* [Online]
Available at: https://pre-sustainability.com/articles/the-en-15804-building-product-lca-standard-more-challenges-than-benefits/
[Accessed 17 March 2013].

Mäkelä, P. e. a., 2018. *Rakennusluokitus 2018 Käyttäjän käsikirja.* Helsinki, Statistics Finland.

OneClickLCA Oy, 2023. *About OneClickLCA.* [Online]
Available at: https://www.oneclicklca.com/about-one-click-lca/
[Accessed 8 March 2023].

OneClickLCA, 2023. *OneClickApp.* [Online]
Available at:
https://oneclicklcaapp.com/app/sec/entity/show/63f5b7b10c9c017ecf74591c?entityId=63f5b7b10c9c017ecf74591c
[Accessed 5 March 2023].

OneClickLCA, 2023. *OneClickLCA EPD Hub.* [Online]
Available at: https://www.oneclicklca.com/epd-hub/
[Accessed 23 February 2023].

Prieto, C., 2021. *Environmental Product Declaration: Alcro, Beckers, Tikkurila brand paints,* Stockholm: Building Information Foundation.

Publications Office of the European Union, 2022. *Publications Office of the European Union.* [Online]
Available at: https://op.europa.eu/en/publication-detail/-/publication/f5d52b58-2c95-11ec-bd8e-01aa75ed71a1

Rakennusteollisuus, 2023. *RTS EPD-Ympäristöseloste.* [Online]
Available at: https://cer.rts.fi/epd-ymparistoseloste/
[Accessed 22 February 2023].

Rakennustieto Oy, 2012. *Yleiset tietomallivaatimukset 2012: Osa 3 Arkkitehtisuunnittelu.* [Online]
Available at: https://kortistot.rakennustieto.fi/kortit/RT%2010-11068?navref=Search
[Accessed 28 March 2023].

Rakennustieto Oy, 2016. *RT 10-11223 Talonrakennushankkeen kulku: Toteutusmuodot.* [Online]
Available at: https://kortistot.rakennustieto.fi/resource/juha/content/8473#page=1
[Accessed 30 March 2023].

Rakennustieto Oy, 2016. *RT 10-11226 Talonrakennushankkeen kulku: Kustannusten muodostuminen ja ohjaus.* [Online]
Available at: https://kortistot.rakennustieto.fi/kortit/RT%2010-11226?external_system=Juha&page=1&navref=Search
[Accessed 30 March 2023].

Rakennustieto Oy, 2016. *Talonrakennushankkeen kulku: Rakennushankkeen vaiheet ja osittelu.* [Online]
Available at: https://kortistot.rakennustieto.fi/kortit/RT%2010-11224?external_system=Juha&page=1&navref=Search
[Accessed 23 March 2023].

Rakennustieto Oy, 2016. *Talonrakennushankkeen kulku: Toteutusmuodot.* [Online]
Available at: https://kortistot.rakennustieto.fi/resource/juha/content/8473#page=1
[Accessed 30 March 2023].

Rakentajain Kustannus Oy, 1984. *Yleisseloste Talo80 nimikkeistöjärjestelmän mukaan.* Mikkeli: Länsi-Savon Kirjapaino.

Seppänen, J., 2022. *Product Manager, Rakennustieto Oy* [Interview] (11 November 2022).

Suomen Standardoimisliitto, 2019. *SFS-EN 15804+A2.* Helsinki: Suomen Standardoimisliitto.