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Master in

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Automated procedures for LCA analysis on a BIM project

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

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SOMMARIO

Al giorno d'oggi, considerando tutti gli sviluppi che hanno e sono continuamente in atto nel campo del design, è diventata una necessità importante considerare l'impatto ambientale dei materiali da costruzione che il progettista sceglie. Per questo è stata recentemente introdotta l'analisi Life Cycle Assessment (LCA) che viene utilizzata in diverse valutazioni per valutare l'impatto ambientale.

L'obiettivo è creare una connessione tra il modello BIM e le sue proprietà dei materiali con i database LCA al fine di rendere possibile l'estrazione diretta dell'energia incorporata, dell'impronta di carbonio e di altri indicatori ambientali dal modello BIM. Questa estrazione di informazioni può essere effettuata applicando determinati processi e filtri al modello e quindi utilizzata per eseguire l'LCA in conformità ai criteri di certificazione LEED. Ciò ridurrà un processo lungo e ripetitivo di inserimento di tutte le informazioni dall'inizio negli strumenti LCA già disponibili, poiché l'analisi stessa comporta un'enorme mole di lavoro e controlli per estrarre e valutare gli indicatori ambientali.

Questo processo può trasformarsi in uno strumento utile per la progettazione ambientale degli edifici e contemporaneamente integrare il processo BIM con gli sviluppi sostenibili nel settore AEC.

Parole chiave: Building Information Modeling (BIM), Life Cycle Assessment (LCA), Dichiarazione ambientale di prodotto (EPD), Impatto ambientale, Conformità LEED, Procedure automatizzate

ABSTRACT

Now-days, considering all the developments that have and are continuously occurring in the design field, it has become an important necessity to consider the environmental impact of the building materials that designer choose. For this matter, the Life Cycle Assessment (LCA) analysis has been recently introduced and is being used in different assessments for evaluating the environmental impact.

The goal is to create a connection between the BIM model and its material properties with the LCA databases in order to make possible the direct extraction of the embodied energy, carbon footprint and other environmental indicators from the BIM model. This extraction of information can be done applying certain processes and filters to the model and then used to perform the LCA in compliance with the LEED certification criteria. This will reduce a long and repetitive process of inserting all the information from the beginning into LCA tools that are already available, as the analysis itself involves a huge amount of work and checks to extract and evaluate the environmental indicators.

This process can develop into a useful tool for the environmental design of buildings and simultaneously integrating the BIM process with sustainable developments in the AEC industry.

Keywords: Building Information Modelling (BIM), Life Cycle Assessment (LCA), Environmental Product Declaration (EPD), Environmental impact, LEED compliance, automated procedures

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1. INTRODUCTION

This master thesis is about automated procedures for LCA analysis in a BIM project. The aim of this work is to examine the implementation of BIM-integrated life cycle assessment procedures. The digital evolution and recent developments in the AEC industry have led to an increase in resource consumption and have made the process more complex. As a result, the environmental impacts and the sustainability concept is gaining more attention in the construction field and is being considered since early stages of design in a building project. The reduction of the environmental impact is directly affected by the decision-making process during the design phases by the professionals. The optimisation of the sustainability process in building design can be achieved only by taking the right decision during this phase and by putting the biggest responsibility in the hands of the designers and engineers.

With that in mind, this study explores the BIM integrated procedures for sustainability analysis in the design process and proposes a new integrated tool by using a visual programming interface like Dynamo.

The first three chapters give an overview on the state of art of Building Information Modelling, Life Cycle Assessment, rating systems and standards and the methodology of how they are and can be further integrated to improve the sustainable design process.

In the following chapter, the automated tools for LCA are explored and the results are compared. Firstly, the Tally plugin in Revit is used for the semi-automatic work process. The fully automated LCA process was supported by the software solutions from One Click LCA used with the interfaces of Revit and Simplebim. The calculation results show that, when IFC files are used, even from simple models, large deviations can occur. As a result, the open BIM approach is not yet mature enough to allow BIM-integrated life cycle assessments to calculate fully automatically the LCA results. In addition, there may be obstacles to correctly assign material input with One Click LCA. This happens in the case of composite materials which cannot be displayed correctly. In the case of Tally, the calculation was only possible according to LEED standard, and the stored data sets are mainly optimized for the American market, and there is no interface for reading independent manufacturer EPDs or Ökobaudat database.

For the reasons mentioned above, the next step was to create a separate LCA calculation tool by using Revit, Autodesk Dynamo and Excel. The tool creates a connection between the component-specific materials and the respective material from the specified database catalogue and automates the calculation of the LCA parameters. All the components relevant to the LCA calculation are extracted via Dynamo, although issues may be encountered during the geometrical export of data. For more precise results, however, these are corrected by manual post-processing.

In general, BIM-integrated life cycle assessments are very suitable due to their simple and faster way of working.

2. BUILDING INFORMATION MODELLING

2.1. The definition

Building Information Modeling is a working method which shares a digital representation of physical and functional characteristics of any built object (including buildings, bridges, roads, etc.) which forms a reliable basis for decisions. (BS ISO 29481-1 2010) It is a digital working method in the construction field which provides a great depth of information which is not limited only on the planning and construction phase, but also on the operational phase, in other words, in the entire life cycle of the building. Besides geometric data, the BIM model also contains some other information, such as costs or technical properties, all of these collected in a single data model.

The generally accepted definition of BIM is in National Building Information Modeling Standard defined as follows: "Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward; defined as existing from earliest conception to demolition. A basic premise of BIM is a collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder." (NBIMS 2017)

Building Information Modelling represents in a digital way the physical and functional traits of a facility by creating a single and shared information resource and a consistent base for decision making during the whole lifecycle of the project, from earliest conception to demolition. (RIBA, CPIC) It is a method that creates possibilities for interdisciplinary collaboration based on an n-dimensional virtual presentation of the building. As a result, it can have economic and ecological effects simulated, evaluated and optimized since early phases of the project. (RIBA, CPIC)

2.2. Dimensions of BIM and the BIM process

Often BIM only implements three-dimensional models but it offers significantly more dimensions. In fact, BIM is initially based on 3D planning, but the dimensions also expand in time and cost. This allows the project to start early planning phases that are simulated, validated and subjected to different analyzes by creating higher qualities in the respective dimensions. Also, the dimension of sustainability leads to a consistent consideration regarding energy analyzes and the verification of sustainability certificates and enables new innovations such as the cradle to cradle material catalogue (Forth 2018).

After all, BIM also offers great potential in facility management, to digitally manage the building even in the usage phase and lower the rate of information loss (Forth 2018). In the following, the focus of the BIM method is placed on the designing process, since the building and operation are not object of this work. For the design process, there are some advantages, such as the consistent, automatic derivation of views, floor plans and sections from the model, collision checks between the partial models of different trades and the connection to calculation and simulation programs in order to check for compliance with different standards (Forth 2018). Furthermore, through the digital model, an accurate extraction of the quantities can be made to calculate costs or to be used as a basis for calculating the building life cycle assessment. During the design phase, the decision-making processes is also affected by using the BIM method. Changes can be applied since earlier design phases if the information obtained by the model is available and can be used to calculate further results that might affect the later stages of the design of running compliance checks related to different standards. This also applies in connection with sustainability certificates for sustainable buildings. Through an earlier involvement of the life cycle calculations, there is still a greater and more direct influence on the sustainability of the building design. The early calculation of a life cycle assessment also leads to a more sustainable and optimized solution of the building materials and thereby a higher ecological quality of the building.

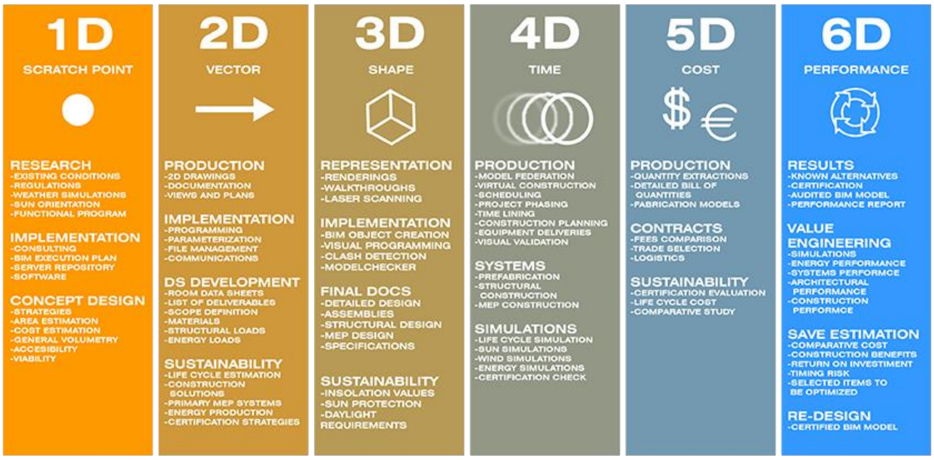


Figure 1 Dimensions of BIM according to bim6d.es

2.3. BIM application methods

Although there is not just one firmly defined method for BIM-supported design, there is a distinction between "Open" and "Closed" BIM and "Big" or "Little" BIM and their combination. "Open" BIM means that open data exchange formats and different program providers can be used, whereas "closed" BIM is based on manufacturer software and whose exchange format remains limited. "Little" BIM means only partial use of the BIM method by individual users, like the use of only the software packages. In contrast, "Big" BIM refers to the continuous use of BIM of all disciplines and over the entire lifespan of the building (Baldwin 2019).

The combination "Little closed BIM" describes the lowest BIM cooperation with only individual BIM-compatible programs. With "Big closed BIM", however, there are several design specialities involved, and the same software is used internally. "Little open BIM "identifies the exchange of data via an open exchange format, but only between a few designers. The most extensive BIM cooperation is "Big open BIM", a complete BIM process where the use of an open exchange format takes place.

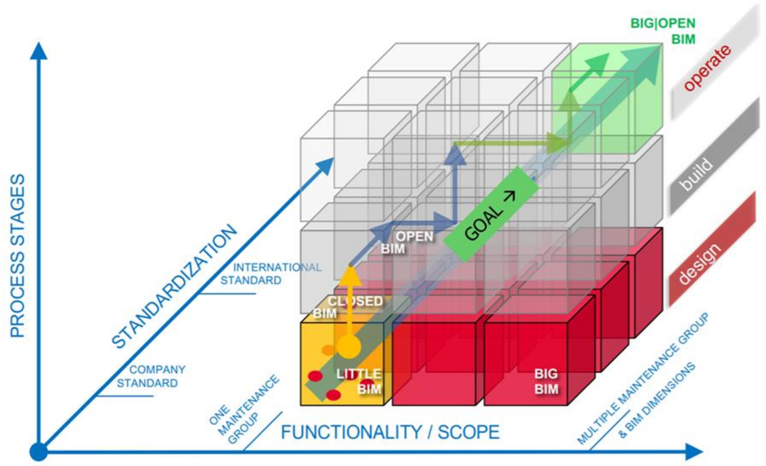


Figure 2 From "Little" BIM towards "Big" BIM (BuildingSMART International)

2.4. Levels of BIM (LOD, LOI, LOG)

LOD in the BIM methodology is understood to mean two different terms. On one hand it is meant as an acronym for Level of Development, on the other hand as an abbreviation for Level of Details. The level of development is also understood as the degree of completion, maturity or elaboration (Forth 2018). The US. representative of building SMART International BIM forum (BIM forum 2019) has the individual levels of development defined.

The level of development should not be confused with the level of detail. By the level of detail of the model, their elements are determined. The AEC UK distinguishes between the following six levels (AEC 2015): symbolic, conceptual, generic, specific, constructive, built.

The level of information (LOI) is understood to mean the "degree of information of an object, which is recorded in the building model or in a BIM database" (Forth 2018). The LOIs are directly related to the LODs. With the property information room types are defined from LOI 100 in order to determine requirements and estimate costs. The creation of a room book and a cost calculation can be achieved with LOI 200. Manufacturer-independent product information specifies the components in the next stage LOI 300. LOI 400 and LOI 500 are based on manufacturer-specific product information for detailed calculations.

These LOIs are also of great importance in the subsequent life cycle assessment. Because in early stages, when less information is available in the design phases, there are initially generic data used. In the construction, however, product-specific data sets are included in the calculation depending on the components installed. (Forth 2018)

2.5. Exchange formats

In the construction industry, there are different exchange formats, which differ according to their complexity of subdivision. With BIM, the data of the models achieve a new level of complexity at which the 2D representation on 3D objects in combination with semantic information about their assemblies is expanded. There is a general difference between "Open" and "Closed" BIM. In the further course of the work, both approaches are explained by using the IFC (Industrial Foundation Class) for the “Open” format and Autodesk Revit "RVT", the most widespread format, for the "Closed" BIM approach.

2.5.1. IFC exchange format

In order to implement the "Big open BIM" approach, the international organization Building SMART was founded in 1995 in the USA and then the other national branches. Their goal is a "successful development, application and dissemination of open IT standards and process definitions for interoperability like the Industry Foundation Classes" (building SMART 2017). Building SMART is an initiative formed of various companies and organizations under the name International Alliance for Interoperability (IAI).

The IFC 2x3 version is widespread and is now supposed to be replaced by the Standard IFC4. IFC is defined in ISO standard 16739 and is based on the data modelling language EXPRESS, which in turn is based on the STEP standard. The organization building SMART Internationally certifies software products that can have an interoperable exchange with the IFC interface.

2.5.2. RVT and PLN exchange formats

Autodesk was the main initiator of building SMART and has come over with the Revit software solution in 2002 for a long-time market-ready and the most widespread product in BIM applications (Eastman 2011). The Revit exchange format is a result of the respective version of the Revit Software. It is abbreviated as "RVT" and is not an open format, which means that it is only available from the three Revit software packages Revit Architecture, Revit Structure and Revit MEP and only from them can be opened. It, therefore, follows the "closed" BIM approach. However, as the market leader with Revit, Autodesk is also a major developer for IFC, which contains less information than a Revit file. It accordingly requires more storage space and can increase in large projects or cause delays.

2.6. Integration of BIM in Green Building Design

In the following sub-chapter, the integration of the BIM method and the sustainable evaluation of buildings will be analyzed with reference to sustainability certification systems and more specifically to the integration of the BIM method with the LCA process.

2.6.1. Potential of the combination of BIM and Green Buildings

The first comprehensive publication on the subject appeared in 2008 by Krygiel and Nies, who describe the combination of "Building Information Modeling" and "Green Building" combined in the term "Green BIM" (Krygiel and Nies 2008; Forth 2018). The Authors point out already existing possibilities through BIM-capable programs influencing the sustainability design of buildings. To the possibilities of influencing the building shape, they include the analysis of the building orientation, environment and facade systems as well as the daylight simulation. The topic of building systems includes water use, energy design, renewable energies and sustainable materials (Krygiel and Nies 2008). As early as 2005, Autodesk had the potential to integrate green Building tools recognized in their BIM-enabled drawing program Revit and in a White Paper presented some of these topics (Autodesk 2005).

In its extensive market analysis, MacGraw Hill Construction (McGraw-Hill Construction 2010) shows great need and demand for BIM-integrated analytical tools regarding sustainable design. In addition, Green BIM is used as a "The use of BIM tools to achieve sustainability and / or improved building performance in a project" (McGraw-Hill Construction 2010).

2.6.2. Integration in the verification process of certification systems

According to Gandhi and Jupp, there is still no specific research into what each process steps or what management strategy to follow for the implementation of Green BIM (Gandhi and Jupp 2013). However, there are already a large number of BIM applications which contribute to green building certificates (Soltani 2016).

As early as 2005, Autodesk had the potential to integrate green Building tools recognized in their BIM-enabled drawing program Revit and in a White Paper presented some of these topics (Autodesk 2005). The steadily growing number of publications shows the increasing scientific relevance of the topic in the following years.

3. LCA STATE OF THE ART

3.1. The Environmental Product Declaration (EPD)

3.1.1. What is the Environmental Product Declaration (EPD)?

Environmentally-friendly construction materials are not a guarantee for sustainability. Construction materials are intermediate products; their influence on the environment depends on many factors, develop their characteristics and properties once they are part of a building. But, with an EPD available, the architect is able to choose the right materials in order to plan a sustainable building and have it certified.

EPDs are documents that communicate a product's environmental impact over a specified portion of its lifecycle. They are developed in accordance with product category rules and the international standard ISO 14025 and use LCA data. The specific stages of LCA that are covered in the EPD as well as the environmental attributes that are measured and reported in it are specified in the PCR. (Environdec 2020)

The EPD is complete and fully transparent information on all the properties and environmental impacts on construction materials. It is not an evaluation, but a source of clear information regarding its ingredients and environmental impacts throughout its entire lifecycle is based on international standards and verified by independent examiners. (Institut Bauen und Umwelt)

Manufacturers of construction materials, experts, public bodies develop the PCR (product category rules) which outlines and defines the requirements of an EPD and the data contained therein based on the respective construction material group. The PCR enables manufacturers of construction materials to create an EPD for their product by determining the data in a lifecycle assessment as required by the PCR thus the manufacturer can declare all of his product data from production of raw materials to the end of building’s life. The EPD is submitted for verification by independent third parties and then published and available online to professionals.

They cover multiple environmental parameters using LCA data, as described in the PCR. Also, specify the unit that is used to calculate all the impacts declared in the EPD. This functional unit is specified in the PCR on which the EPD is based. (GreenCe, USGBC)

The EPDs are developed to:

- Stay in lines with the expectation or the market
- Increase the transparency of environmental impacts
- Differentiate from the competitors
- Reduce environmental impacts and save money

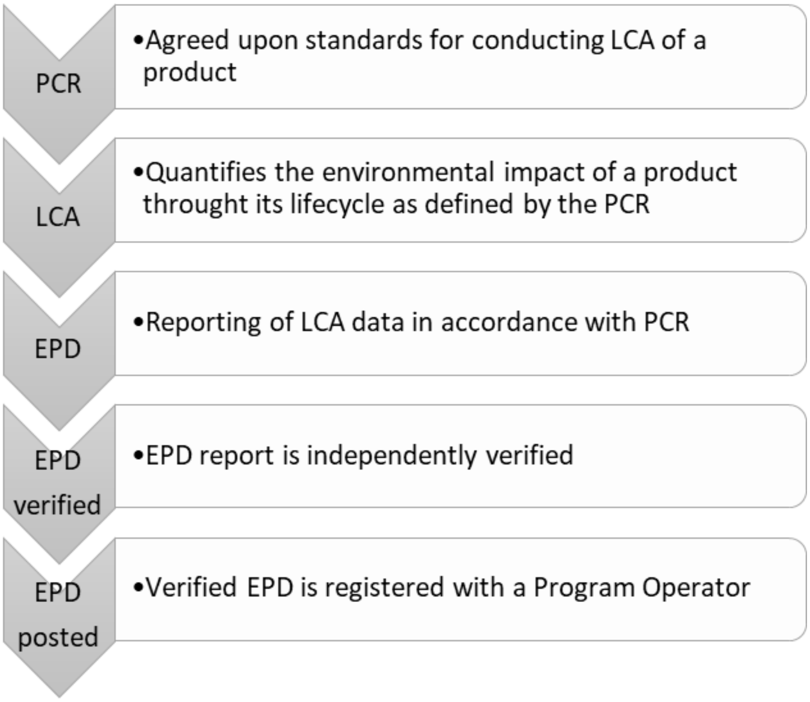


Table 1 EPD development phases (GreenCe, USGBC)

3.1.2. The relation between EPD, LCA and PCR

LCA is fundamental in understanding EPDs; they are science-based studies that evaluate the environmental impact overall or selected stages of its life cycle; this can include extraction of raw materials from the earth, transportation of raw materials to the factory, manufacture of the product at the factory, product transportation from the factory to the store, the product use by the consumer and disposal or recycling possibilities in the end of the product's life. Having transparency through EPD-s organizations can reduce their potential risks and better understand their environmental impacts of their products that they purchase and consumers can use EPDs to compare the environmental impacts of products that they want to buy. (GreenCe, USGBC)

EPDs are based on the results of lifecycle assessment studies which quantify environmental attributes. These studies that contribute to the declarations are then third party verified and can be used in biding procedure or in environmental rating systems such as LEED v4. (GreenCe, USGBC)

The ISOs provide guidelines for LCA but not specific methodologies to be used

ISO 14040: Environmental management – LCA - principles and framework

ISO 14044: Environmental management – LCA - Requirements and guidelines

The LCA info is used to help manufacturer identify and reduce environmental impact of product, which can result in cost-savings and throughout the supply chain by making manufacturers want to choose greener parts which will result in final product with less environmental impacts and make companies want to buy greener end-products.

Sometimes the areas where the greatest amount of environmental impact occurs are not obvious and that is why the PCRs (product category rules) are implemented. They are specific rules, requirements and guidelines for developing EPDs for a particular product category. They are the standard for how to conduct a lifecycle assessment and prepare the EPD for a particular product category. (ISO 14025 - the international standard that stipulates requirements for environmental product declarations)

PCRs standardize:

- LCA for a particular product type
- The way the info is communicated in an EPD

PCR also outlines what environmental impacts are to be measured in the LCA (water use, greenhouse gas emissions, amount of raw material used, toxic substances released). The goal is to include impacts that have significant environmental effects to ensure that these are measure and subsequently communicated in the EPD

3.1.3. Content of an EPD and the environmental indicators

EPDs contain the following information in their content:

1- Program information
(PCR, program operator, registration number, of publication, further information)
2- General product information
(name of the product, logo, contact, manufacturer, scope, declared unit, name of the independent verifier, raw material extraction and transportation, LCA background information, further information)
3- Environmental performance
(potential environmental impacts, use of renewable and non-renewable resources)
4- Interpretation of the results
(environmental impacts in percentages)
5- Differences with previous versions
6- Verification
7- References

In the summary page of the EPD usually are shown the results of the Life Cycle Assessment (LCA) that are completed for the studied material according to the ISO 14040 standards. An example of how these results are provided in an actual building material EPD is showed in the following Figure 3. The environmental impact list of indicators is going to be considered in the following developments of this study to create the list of parameters in the BIM model in order to extract LCA data.

Indicator	Product stage	Construction stage		Use stage							End of life stage				Module D Reuse, recovery and recycling potential	TOTAL
	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 treatment	C4 Disposal		
Global Warming (Kg CO_2-eq /m^2)	2,57E+00	2,59E-02	1,30E-01	0	0	0	0	0	0	0	Not relevant	9,20E-03	0	1,28E-01	MND	**2,86E+00**
Ozone layer depletion (Kg CFC 11-eq/m^2)	8,52E-08	4,96E-09	4,56E-09	0	0	0	0	0	0	0	Not relevant	1,69E-09	0	3,02E-09	MND	**9,94E-08**
Acidification of soil and water (Kg SO_2-eq/m^2)	1,04E-02	1,04E-04	5,28E-04	0	0	0	0	0	0	0	Not relevant	3,68E-05	0	8,12E-05	MND	**1,12E-02**
Eutrophication (Kg PO_4^{3-}eq/m^2)	1,35E-03	2,34E-05	6,90E-05	0	0	0	0	0	0	0	Not relevant	8,33E-06	0	6,18E-03	MND	**7,63E-03**
Photochemical oxidation (Kg ethylene-eq/m^2)	6,30E-04	4,35E-06	3,17E-05	0	0	0	0	0	0	0	Not relevant	1,57E-06	0	2,59E-05	MND	**6,93E-04**
Abiotic depletion of resources-Elements (Kg Sb-eq)	1,28E-06	4,36E-08	6,72E-08	0	0	0	0	0	0	0	Not relevant	2,71E-08	0	1,57E-08	MND	**1,44E-06**
Abiotic depletion of resources-Fossil fuels (MJ)	5,59E+01	4,27E-01	2,82E+00	0	0	0	0	0	0	0	Not relevant	1,47E-01	0	2,92E-01	MND	**5,96E+01**

Table 7 Potential environmental impacts of 1 m^2 DANOPREN® insulation board

Figure 3 Example of the list of environmental indicators of an insulation board EPD

The information obtained by the EPD on a product level will be the information upon which the lifecycle assessment of the whole building will be calculated. The combined data of the single building materials will be used to generate the total environmental impact of the building. Furthermore, it can be related with the relevant stages of the building's lifecycle.

3.1.4. Databases for building materials and EPDs

The complete lifecycle assessment of a product (in this case a building material) from the cradle to the grave, containing the required information to lead in the choice of a sustainable material in an objective and calculated way is an Environmental Product Declaration.

It is now undeniable that the Environmental Product Declarations are a crucial and reliable source of information on the carbon footprint of a certain product by analyzing and calculating the impact of a single material during its whole lifecycle. (One Click LCA)

The amount of literature about EPD and LCA databases is very large and varied, containing many different materials and combinations of them to be analyzed and taken into account. The choice of the material depends on the goal of the design and stakeholders. In this situation, to be able for the interested parties to choose the best alternatives, they need to have access to a reach and reliable database which offers them a precise and accurate source of data. This process takes more value during the design phase as it has a direct result in improving the building before the construction process. In this way, if different databases are available for the designer, they can be able to compare the impacts of different materials in the environment and as a result make the best choice to reduce the overall carbon footprint of their building, comply with environmental regulations and obtain certification credits. (Once click LCA)

3.1.5. EPD databases vs Generic database

It is understood that an **EPD database** is one that puts together a distinguished amount of construction material EPD's from a broad range of countries and productions companies. Each one of these EPDs is the result of the Lifecycle analysis of the sole building material from its manufacturer and available on the free choice of the designer or builder.

On the other hand, a **generic LCA database** is considered the one that contains a variety of LCAs that are average for a certain group of materials. This LCAs are calculated as an average value of all the materials of that group across different manufacturers.

Consequently, the information from an EPD database is more accurate and can produce more reliable results overall. Nevertheless, the generic LCA database is still a good option to use when the EPD database is missing. (Once click LCA)

Several EPD databases are presented in this study as follows:

- **Environdec, International EPD system**
  This is a database for type III environmental declarations complying with ISO 14025 verified and registered by the International EPD System. The library of is publicly available and the EPDs and PCRs can be downloaded in pdf format. It contains product declaration from various companies worldwide and for the European products it is also in accordance with EN15804. The search engine of the database is easy to use and several filters can be used to search by country, manufacturer, category and other standardization criteria. (Environdec)

- **The EPD registry, Worldwide EPD registry system**
  This is a global database on construction materials EPDs. It is a good choice for products that comply with environmental certifications by LEED, BREEAM, DGNB etc. The EPDs are presented in formats that are useful for designers and architects. The search engine can be used to find materials by country, map, address, name of the product, manufacturer or distance from the construction site. The database is also divided in several subsectors representing Turkish, United Kingdom, European and World construction materials. (Theepdregistry)

- **Institut Bauen und Umwelt-EPD, German EPD system**
  This database is provided by Institut Bauen und Umwelt and offers Environmental Product Declarations from a considerable number of building materials manufacturers. It is an open and public database which provides EPDs in both pdf and XML format, in this way they can directly be used to calculate the LCA of the building. The search engine uses various filters to narrow down the list. The materials can be searched by country, category, manufacturer, PCR, declaration number, language etc. (Institut Bauen und Umwelt)

- **Ireland Green Building Council – EPD, Irish EPD system**
  This is an EPD database provided by the Ireland Green Building Council. It provides a variety of materials from different Irish manufactures and in compliance with ECO Platform EPD, EN 15804 and ISO 14025. The EPDs are open to the public and can be downloaded in pdf format. (IGBC)

- **GreenBook Live – EPD, British EPD system**
  Green Book Alive is provided by BRE Global and is a free online database that offers material EPDs among many other libraries and services related to the improvement of the built environment. It is useful for the designer and builders who want to identify and choose green products with a low impact on the environment. Although, user-wise, I found it more confusing and time-consuming than the other platforms. (GreenBookLive)

- **Spot solutions – EPD, United States EPD system**
  This database is provided by United States EPD system and offers a variety of verified material products and in accordance with many environmental certification systems. It is useful for builders and designers not only in terms of identifying and choosing low impact building materials but it also friendly to BIM tools. Spot solutions offers a Revit plugin for free through which the EPD information can be directly added to the BIM object. The BIM category is also added as a filter in the search engine of the site. The Environmental Product Declarations of EPD Italy are also part of this database. It is considered one of the biggest EPD libraries with more than 100.000 certified articles. (Spot)

3.2. Rating systems, standards and certification of buildings

All rating systems for LCA and building certification approve either ISO or EN based LCA

3.2.1. LEED v.4 and LCA

LEED is a rating system developed by US Green Building Council (USGBC) with its focus in sustainability in the design and construction field. (USGBC) LEED offers the guidelines and assessment mechanisms that outreach towards the optimisation of natural resources, regeneration and restorative strategies, maximisation of the positive impact in the environment and human life providing high-quality environments for the inhabitants. LEED v4 is the most updated version of this rating system. (Vigovskaya, 2018)

Leadership in Energy and Environmental Design (LEED v.4) has included in its list of criteria the LCA evaluation. The certification is divided into eight environmental categories:

- location and transportation (LT)
- sustainable sites (SS)
- water efficiency (WE)

- energy and atmosphere
- materials and resources (MR)
- indoor environmental quality (EQ)
- innovation (IN)
- regional priority (RP)

and LCA analysis is included within the "Materials and resources" category, in the criterion "Building Life-Cycle Impact Reduction". If these requirements are met then 3 out of 110 points can be obtained. In order to satisfy the credits and obtain the certification, it is necessary to model a baseline building that is within the given terms for the location, shape, orientation and function and then demonstrate the ability to reduce the baseline value obtained by 10% for at least 3 of the environmental impact indicators and to not overcome the others with more 5% each. (Once Click LCA)

The environmental impact indicators to be considered are:

- global warming, greenhouse gases, in CO2e
- ozone depletion in the stratosphere, in kg CFC-11
- formation of tropospheric ozone, in kg NOx
- potential acidification of land and water, in kg SO2
- potential eutrophication, in kg nitrogen or kg phosphate
- use of primary energy from non-renewable sources, in MJ (Once Click LCA)

We consider a lifecycle of 60 year for the materials of the structure and the building envelope with a cradle to grave approach and with the quantification of impacts during the production (A1-3), transport to the construction site (A4), use (B1-7) and end of life (C1-4) phases when we calculate the environmental impacts. The LCA environmental impact categories refer to ISO 14044, ISO 14025, ISO 14040, ISO 21930, EN 15804 and to the indications provided by the US Green Building Council, which regulate the baseline building indicators to the indications of ASHRAE. The LEED protocol rewards with 1 additional credit if the choices of construction materials fall on at least twenty products, of at least five different manufacturers, certified with Environmental Product Declaration (EPD).

The Life Cycle Assessment methodology within LEED v4 still has application deficiencies as the analysis conducted concerns only the life cycle of construction, without any consideration on the environmental impacts generated by the use phase of the building, which has always been the phase responsible for the greatest environmental impact.

3.2.2. Living Building Challenge (LBC) and LCA

The Living Building Challenge (LBC) is an international building certification system focused on sustainability. It was founded in 2006 by International Living Future Institute, a non-profit organisation. It is a tool and certification program that promotes advanced sustainability ratings for the built environment. It is applicable to buildings (new construction or renovation), infrastructure, neighbourhoods and communities, landscape and has a different approach from other green rating systems like LEED or BREEAM. (living-future.org)

The LBC version 3.1 is organized into 7 fields that are represented as petals:

- place
- water
- energy
- health and happiness
- materials
- equity
- beauty

Each petal contains a series of requirements which must be met to achieve the Living Certification. (Gardner, 2019) These mandatory and crucial requirements cover a wide range of sustainability concepts including net-positive energy and water, biophilic environment, beauty and spirit. To obtain this certification is required to integrate design strategies and a great amount of collaboration between the group of interests involved in the design process resulting in a quite challenging experience. (Collinge, 2015)

The Red list under the materials petal contains the chemical classes that must be avoided in 90% of the new materials that are chosen to be used in the project. There are 21 general chemicals in the Red list, which can further be broken down into 815 more specific chemicals and be removed from the list of construction materials in the project. Although, there are not any mandatory specifications related to the embodied energy in the materials, except for one that requires that only for the construction phase. In this case, the evaluation of building material selection becomes an important component of the LCA referring to the stages of material extraction, manufacturing process and transportation.

Environmental impact indicators to be considered from the Red List for the architectural and structural materials during LCA:

- the ozone depletion
- the global warming
- the smog formation
- the acidification
- the eutrophication
- the eco-toxicity
- the fossil fuel depletion
- the land use and water use
- the human health cancer
- the human health noncancer
- the human health criteria pollutants (living-future.org)

3.2.3. BREEAM and LCA

(Building Research Establishment Environmental Assessment Method) BREEAM is an English rating system founded and put into practice in 1990 with the focus on environmental standards-based assessment. As cited on the official website "BREEAM is the world's leading sustainability assessment method for master-planning projects, infrastructure and buildings. It recognises and reflects the value in higher performing assets across the built environment lifecycle, from new construction to in-use and refurbishment". BREEAM rates sustainable values in various categories from energy to ecology including the reduction of carbon emissions, green design, resilience, climate change adaptation and respect for biodiversity. (Vigovskaya, 2018)

The BREEAM certification is divided into ten categories:

- management
- water
- health and well-being
- materials
- energy
- waste
- transport
- land use and ecology
- innovation
- pollution

and the LCA analysis is found within the "Materials" category. The obtained score that can be reached to meet the criterion is 5 points, with an occurrence of 6% on the final total result. Reward points are awarded to the project using a program calculation, BREEAM International Calculator Mat01, which measures the environmental impacts related to the building construction to be calculated and places it within a rating system from A + (3 points) to E (0 points). Each environmental impact indicator is assigned a letter from A + to E and a percentage value of the impact weight with respect to the others:

- global warming (21.6%)
- water extraction (11.7%)
- mineral resource extraction (9.8%)
- ODP (9.1%)
- toxicity to humans (8.6%)
- toxicity to drinking water (8.6%)
- nuclear waste (8.2%)
- toxicity to soil (8%)
- waste disposal (7.7%)
- fossil fuel consumption (3.3%)
- eutrophication (3%)
- POCP (0.20%)
- acidification (0.05%)

For the calculation of environmental impacts, a useful life of 60 years is considered in which the production (A1-3), construction (A4-5) and end of life (C1-4) phases are considered.

3.2.4. Conclusion

Each one of the above-stated systems has its own features according to which can be selected and aligned with the project requirements. The choice of the certification program to be pursued belongs to the design team, environmental and sustainability consultant, the investor and depends on different factors like physical context, project goals etc.

In the World Green Building Trends 2018 it is stated that the first environmental reason for building a green project is the reduction of energy consumption (with 66%) as it has been like that since 2008. The two other following reasons are the protection of natural resources and the reduction of water consumption.

With these reasons in mind, the most appropriate certification systems to consider these criteria are LEED and LBC. They are highlighted as primary examples of different levels of Green Buildings Rating System.

In this thesis the proposed processes and filters to extract the quantities for LCA from the BIM model are going the be selected and pursued within the LEED rating system.

3.3. Building life cycle assessment (LCA)

3.3.1. Life Cycle Assessment definition

Life cycle assessment (LCA) means the "compilation and assessment of the input and output influences and the potential environmental impact of a product system in the course of its life" (ISO 14040). First of all, to perform a Life Cycle Assessment, system boundaries and environmental indicators are defined. Basically, however the period of time of a product, goods and services, from the cradle to the grave.

Figure 4 LCA of a building diagram from One Click LCA

3.3.2. Life cycle stages in a building project according to EN 15643

In the standards EN 15643-2 and EN 15978 the general life cycle assessment broken down to the building level by establishing a predetermined procedure to guarantee the comparability of the

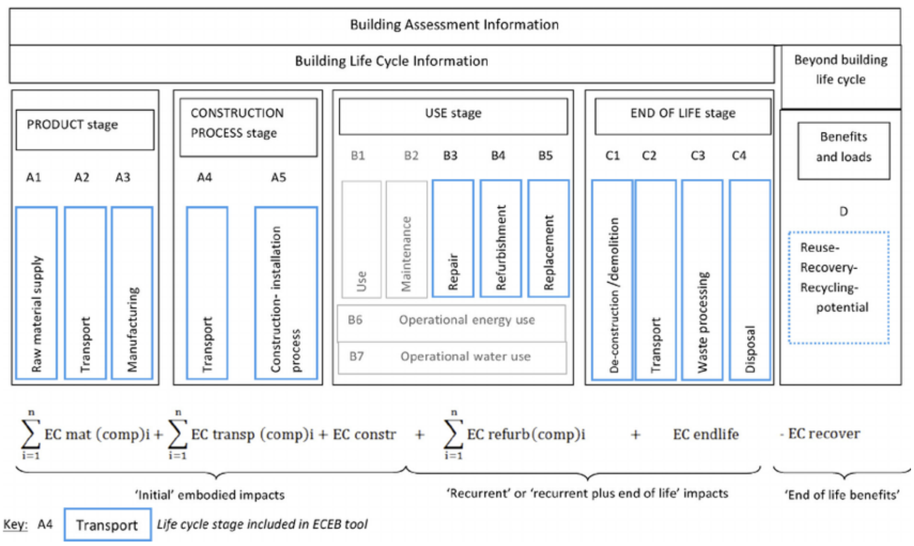


Figure 5 Life cycle stages from BS EN 15978 2011 Sustainability of construction works Assessment

research framework. This is divided into four phases with a total of 16 modules and additional module D. The four phases are the manufacturing phase (A1-3), the construction phase (A4-5) and the usage phase (B1-7) and the phase at the end of the life cycle (C1-4). The phases are complemented with a module D, which opts for reuse, recovery or recycling outside the life cycle and the system boundaries (from the cradle to the grave). (Forth 2018)

3.4. Life cycle methodology

3.4.1. Parameters for LCA calculation and evaluation of environmental impact

The environmental impact indicators to be considered according to LEED standards are:

- global warming, greenhouse gases, in CO_2eq (GWP)
- ozone depletion in the stratosphere, in kg CFC^{-11}eq (ODP)
- formation of tropospheric ozone, in kg NOx or kgC_2H_2eq (POP)
- potential acidification of land and water, in kg SO_2eq (AP)
- potential eutrophication, in kg nitrogen or kg phosphate, kg PO_4^{3-}eq (EP)
- use of primary energy from non-renewable sources, in MJ (ADPF)
  (Green Building Council)

3.4.2. Databases for LCA calculation (European and International)

It is not easy for designer and builders when it comes to choosing the database for performing LCA analysis in terms of reliability and credibility. To comply with the LEED certification criteria, the databases should be recognised by the standards, and this is not always clear by the software providing the service of the LCA inventory. For example, at present, the only databases deemed reliable are Ecoinvent (which however is not specific for the construction sector) and Ökobaudat (however related to the German EPD). (Green Building Council Italia) In addition, those who carry out an LCA building evaluation need of data also relating to the other phases of the building's life cycle: a dedicated database is required to designers who contain data not only related to building products, but also to the other phases of the life cycle (e.g. impacts of energy consumption in the use phase, water consumption, etc.). (Green Building Council Italia)

3.4.2.1. KBOB/Eco-bau/IBP database

KBOB/Eco-bau/IBP is a Swiss database. It is a material-based database and provides information about LCA parameters in regard with the environmental impacts that different building materials have. The information is provided by the surface area (square meters) or mass (kilogram).

This database offers a variety of materials that are commonly used in the building industry accompanied by the environmental data. An ID number is attributed to each material which can also be used in the BIM environment for material identification. (KBOB)

3.4.2.2. Ecoinvent database

In the year 2000, several Swiss Federal Offices and research institutes of the ETH domain agreed to a joint effort to harmonise and update life cycle inventory (LCI) data for its use in life cycle assessment (LCA). (Frischknecht, Althaus, Jungbluth, Dones 2005) The Ecoinvent database consists of more than 2500 products and services related to LCA.

The information which is chosen to be downloaded by the database is converted in XML-file and it is saved in the local PC. XML files facilitate the process of interoperability between Life-Cycle inventories and LCA performing software.

3.4.2.3. Ökobaudat database

The Ökobaudat database provides information for building LCA in relation to benchmarks and in compliance with different environmental certification standards. It is a free of charge database and is based on GaBi data sets. The Ökobaudat contains data records from environmental product declarations, which are also known under the abbreviation EPD (Environmental Product Declaration) and are defined in the standard DIN EN 15804.

Ökobaudat consists of generic data sets to a large extent. In Germany, the IBU (Institut für Bauen und Umwelt - Institute for Building and Environment) is making intensive efforts to provide more product-specific data sets for construction products in the form of standardized EPDs. (Lambertz, Theißen, Höper and Wimmer 2019)

The database has a standard interface (API – application programming interface) for the exchange of information with other tools and applications and is also equipped with the authorisations for the corresponding materials. The API documentation is provided in HTML and PDF formats in the zip.file. (T Brockmann 2019) Ökobaudat provides information for building LCA in relation to benchmarks and in compliance with different environmental certification standards.

3.4.3. LCA application methods

3.4.3.1. Conventional method

This method is mostly practised currently by many construction companies. Also, the procedure is used by the generic LCA tool, which are mentioned above like Spreadsheet-based and Online component catalogues. The calculations start from first extracting the bill of quantities in a manual way from the 2D, 3D project or in an automatic way from a BIM model. Then the values are inserted in the tool to be multiplied with the environmental impact indicators to generate the LCA results. The indicators are either put manually in the tool or connected with the LCA database. The whole process depends on the building phase of the project as it needs to have enough information to perform the LCA. In the end, the process is time-consuming in general and can reflect a high error rate since the calculations are performed manually. Another disadvantage is that the information flow goes in only one direction as the LCA results are not connected to the model and this can make the decision-making process more difficult and complicated. In addition, an expert with specialised knowledge on the field is needed to perform the procedures and calculations for LCA with conventional tools.

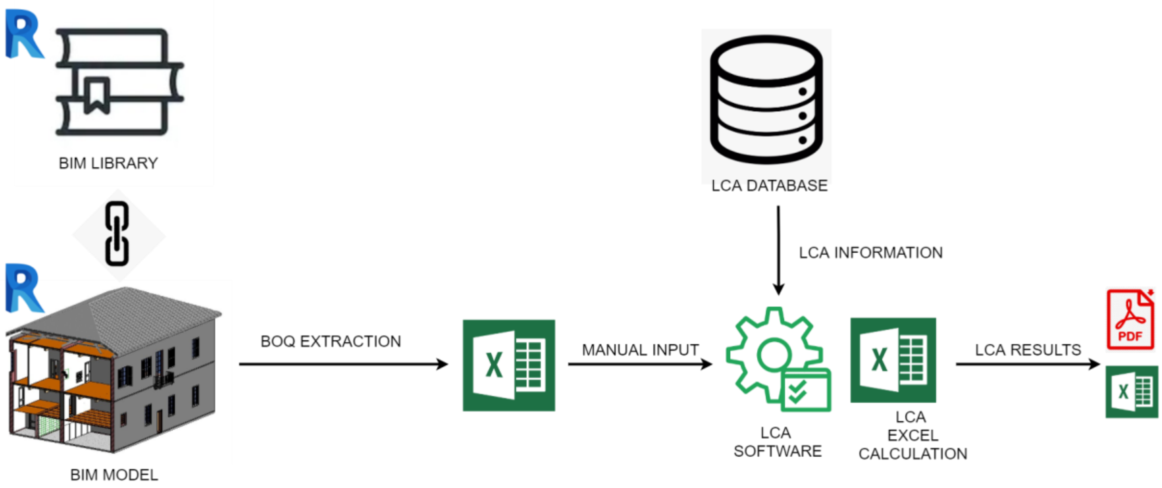


Figure 6 LCA conventional method diagram

3.4.3.2. Static method with BIM tools

This method provides the LCA calculation from the BIM model information by third party LCA tools. The information is extracted by the BIM model in a standard exchange format that makes it possible for the tools to do the calculations.

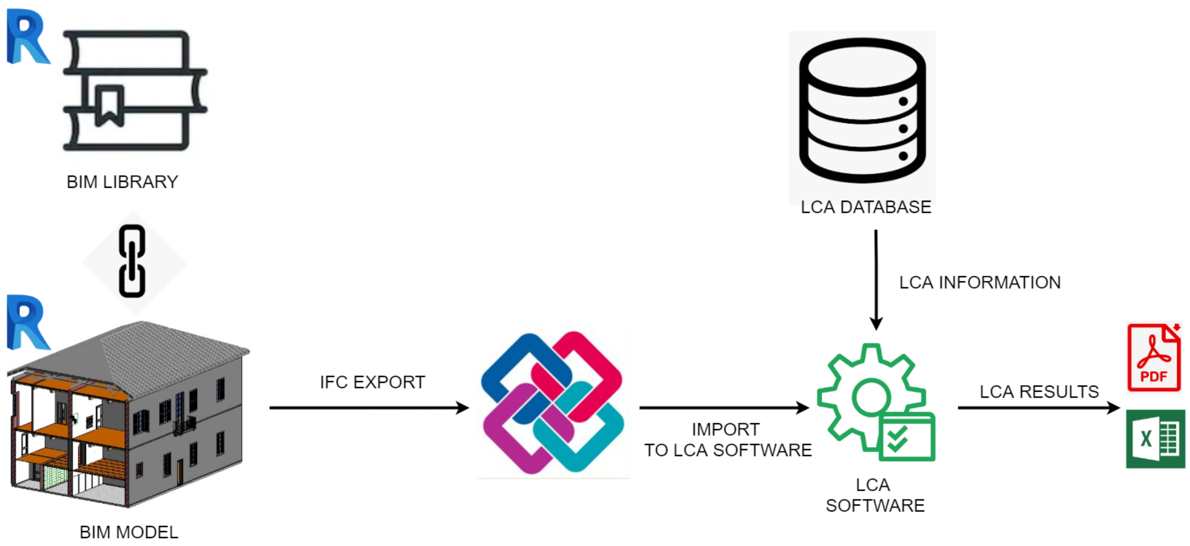


Figure 7 LCA static method diagram

For example, the use of an IFC file of the BIM model, in this case, provides direct access to the model by avoiding the repetition of data insertion in the LCA tool. Anyway, the information passes in only one direction, from the BIM model to the LCA tool and not in the opposite. Interoperability issues can appear when changes are made to the BIM model, and the data has to be reloaded in the tool. The positive sides of this method are that it excludes the manual entry of the data since the beginning by replacing it with IFC or gbXML format exchange and there can be achieved a more result of LCA analysis than in with the conventional methods. The drawbacks of the static LCA approach can be

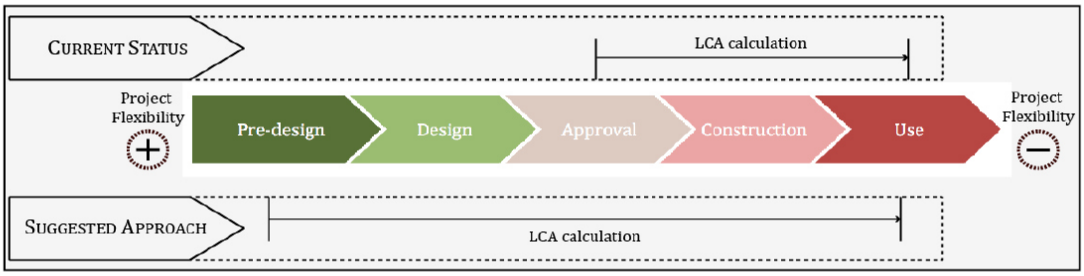


Figure 8 Integration of LCA in a BIM environment. Static approach for LCA and BIM (According to Anton & Diaz 2014)

related with the changes of the BIM model and reloading the information in the LCA calculation tool. Also, the data extracted in the exchange format (IFC, gbXML) is limited, and loss of information can occur as a result of interoperability issues. In this case, the results of the assessment may be incomplete or inaccurate. The technical systems are not included in the LCA calculations as they usually do not have the required LOD for the procedure. Instead, they are added to the final results as a percentage on the total sum.

3.4.3.3. Dynamic BIM integrated method

This method can be implemented if a BIM Model is available from which the Bill of Quantities is automatically extracted. After this, a parametric tool can be used to link the extracted BOQ with an LCA database and perform LCA analysis. The quantities from the BIM model have to be mapped and related to the LCA parameters in order for the procedure to work. The building phase has a crucial role in this process as well. The dynamic method gives the opportunity to assign the LCA values to the BIM model again and complete the information. The decision making is not yet easy, but in this case, it is possible to have direct feedback during the design process. By integrating BIM and LCA tools, there is the possibility to give a solution to some of the main disadvantages. Three of the principal pillars of sustainability (environmental, economic and social) could be taken into account since the early design phases and, in this way, approached more effectively. (Diaz 2014)

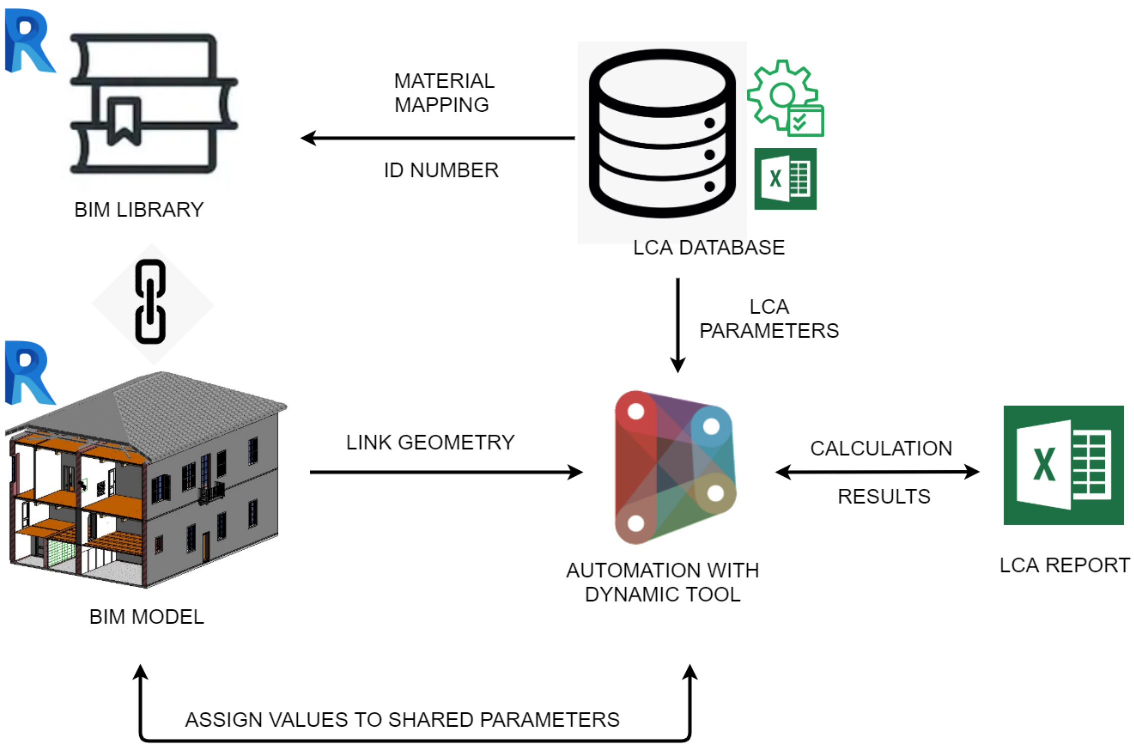


Figure 9 LCA dynamic method diagram

LCA is becoming more important every day for the construction environment and for designer seeking new methods to include this kind of analysis in their design work and the overall construction process. As is it a very time-consuming procedure requiring the assistance of specialised professionals, it is the right moment to seek more direct and less time-consuming solutions. The integration of LCA data of buildings in the BIM platform is an encouraging opportunity among the AEC industry.

It can be a way of including environmental criteria on the same level as other features in the early design phases in terms of selecting materials, products and elements. In other words, it highlights the importance of environmental criteria during the decision-making process. (Diaz 2014)
In further focus will be the integration of life cycle assessments in the BIM process as well as its advantages and disadvantages. Díaz and Antón have analysed it in a detailed SWOT analysis by emphasizing the strengths and weaknesses of the integration of LCA and BIM in the context of efficient decision making in early planning phases worked out. In this case, the big challenge is the semantic linking of the LCA model with the BIM model. The areas and volumes are determined automatically. But the goal is a fully automated LCA process, which can be implemented using an integrated BIM and LCA model. As a result, the data consistency is higher; the verification process for sustainability certificates is more precise as well as there is an increase in efficiency by shortening the processes. (Soust-Verdaguer, García-Martínez 2017) The major difficulty is the mapping each item in different LCA phases, especially the usage phase and end-of-life phase. In most studies, there was a manual intervention to adjust and add volume and properties of the materials. Therefore, they ask for more research to improve and standardize the BIM integration of life cycle assessments and suggest user-friendly handling of the calculation tools.

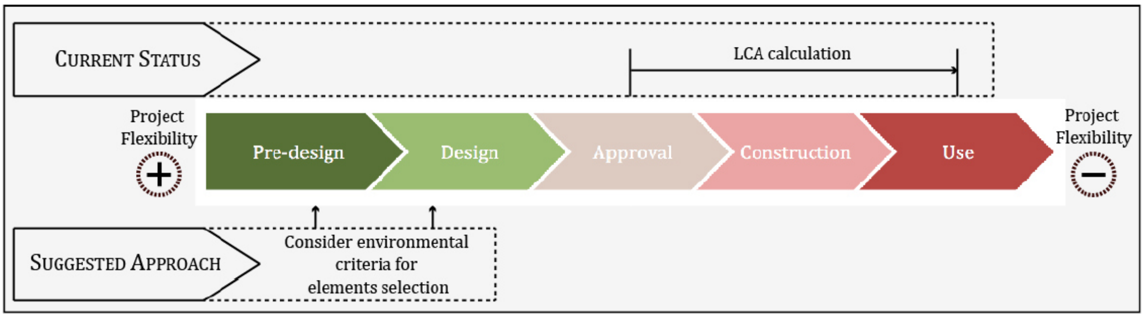


Figure 10 Integration of LCA in a BIM environment. Dynamic approach for LCA and BIM (According to Anton & Diaz 2014)

STRENGTHS

- Higher capacity for accommodating the three pillars of sustainability
- More extended use of environmental criteria by various stakeholders
- Increased efficiency with regard to environmental assessment
- Avoidance of manual data re-entry
- More information available about the project during early phases
- Higher effectiveness of environmental assessment
- Possibility to compare predicted environmental performance with real performance

WEAKNESSES

- Different stakeholders involved in the construction industry must be trained
- LCA process and way of presenting data are not standardized
- Lack of environmental data for carrying out LCA
- Assumptions have to be made for LCA calculation increasing uncertainty
- Further development needed concerning interoperability between BIM and LCA software

OPPORTUNITIES

- It is becoming compulsory in the construction sector to consider environmental criteria.
- There is increased demand for sustainable constructions in the market
- These tools already exist. It is just a matter of integrating them to generate synergies
- There is a real need of a tool with such features in the market
- There is a direct need to change the way of working in the construction industry
- BIM is already becoming more widely accepted in the construction industry

THREATS

- Sometimes construction industry stakeholders are not aware of the importance of considering environmental aspects among project criteria at an early stage.
- Some stakeholders may refuse to implement this step due to the effort required for integrating the tool in the early design phases
- There is a lack of research and development in the construction industry
- There is a wide variety of stakeholders with different characteristics involved in the construction industry that hinders standardization in the industry
- There is a lack of interoperability between the different software systems

Table 2 SWOT analysis according to Diaz and Anton

3.4.4. LCA tools for the built environment

3.4.4.1. Classification of tools

According to (Hollberg 2016) the LCA tool can be classified into four categories: generic, spreadsheet-based, component catalogues and BIM-based tools. (Table 3)

- Generic tools are used for LCA procedures for products and processes. The calculations are done manually in the form of tables. The generic tools are often used to perform LCA analysis for the creation of EPDs for construction materials. The tools are suitable for LCA experts and not friendly to other non-specialised parties as they require wide knowledge on the field

- Spreadsheet-based tools are based on the manual input of the information (bill of quantities) in an excel spreadsheet. The calculations for the environmental impact values are done by using formulas previously integrated in the spreadsheet which multiply the quantities with the factors of environmental impact

- Online component catalogues are also based on the manual input of the component quantities. The bill of quantities is generated after that and is multiplied by the environmental impact factors in order to have the final LCA values of the project.

- BIM-based tools are different plugins which can be installed to BIM-based software. The automatically generated Bill of Quantities from the BIM software is then combined with the environmental information from the plugin database to perform the LCA analysis and obtain the impact values. The challenge, in this case, is the process of matching the material names.

Type	Name	3D model	Energy demand calculation	Embodied impact calculation	Optimization	Online / Offline	Country	Website
Generic LCA tools	Gabi			●		Off	Germany	www.gabi-software.com/software/
	SimaPro			●		Off	Netherlands	www.pre-sustainability.com/simapro
	OpenLCA			●		Off	Germany	www.openlca.org/
	Umberto			●		Off	Germany	www.umberto.de/en/
Spreadsheet-based tools	Envest 2*			●	○	On	UK	www.envest2.bre.co.uk/index.jsp
	SBS Building Sustainability		○	●		On	Germany	www.sbs-onlinetool.com
	Ökobilanz Bau		○	●		On	Germany	www.oekobilanz-bau.de/oekobilanz/
	eTOOL		○	●		On	Australia	www.etoolglobal.com/about-etoollcd/
	Athena Impact Estimator		○	●		Off	Canada	www.athenasmi.org/our-software-data/overview/
	Legep		●	●	○	Off	Germany	www.legep.de/
	Elodie		●	●		Off	France	www.elodie-cstb.fr/
	GreenCalc+			●		Off	Netherlands	www.greencalc.com/index.html
Component catalogues	EcoSoft			●		On	Austria	www.ibo.at/en/ecosoft.htm
	Bauteilkatalog			●		On	Switzerland	www.bauteilkatalog.ch/ch/de/Bauteilkatalog.asp
	eLCA		○	●		On	Germany	www.bauteileditor.de/
	BEES			●		On	US	www.nist.gov/el/economics/BEESSoftware.cfm
CAD integrated	Impact	●	○	●		On	UK	www.impactwba.com/index.jsp
	Cocon-BIM	○	●	●		Off	France	www.eosphere.fr/
	Lesoai	○	●	●		Off	Switzerland	www.lesosai.com/de/index.cfm
	360optimi	●	●	●		Off	Finland	www.360optimi.com/en/home
	Tally	●	○	●		Off	US	www.choosetally.com/

○ Partial functionality / additional software needed / external calculation
● Full functionality
* No new licenses sold, now integrated in Impact

Table 3-Current computer-aided LCA tools (Hollberg Ruth, 2016)

3.4.4.2. BIM integrated tools

Revit – One Click LCA®

OneClickLCA (Bionova Ltd. 2017) from the Finnish company Bionova Ltd. was developed in the course of the European Union's Horizon 2020 research and innovation program and with the research name "One Click LCA - transforming the construction industry through automated, affordable and scalable solution for assessing and improving the environmental impacts of construction projects and products" funded one million euros (CORDIS 2016).

OneClickLCA offers direct support for the verification process for sustainability certifications, among others according to BREEAM, LEED, HQE and DGNB (*One Click LCA (2015)*). Also, it can directly interact with different interfaces of BIM programs like IFC4, Revit, Archicad, Excel, gbXML, SimpleBIM etc.

The platform uses an algorithm that combines the BIM materials with the available LCA data sets and closes the automation gap in the impact assessment. The material mapping process is done by an integrated tool that links to it the LCA data. It is a fully automatic LCA calculation program and like Tally, it can be considered a semi-dynamic tool. (Forth 2018) In addition, different language names are taken into account at the same time and numerous international LCA databases and EPD data sets are available.

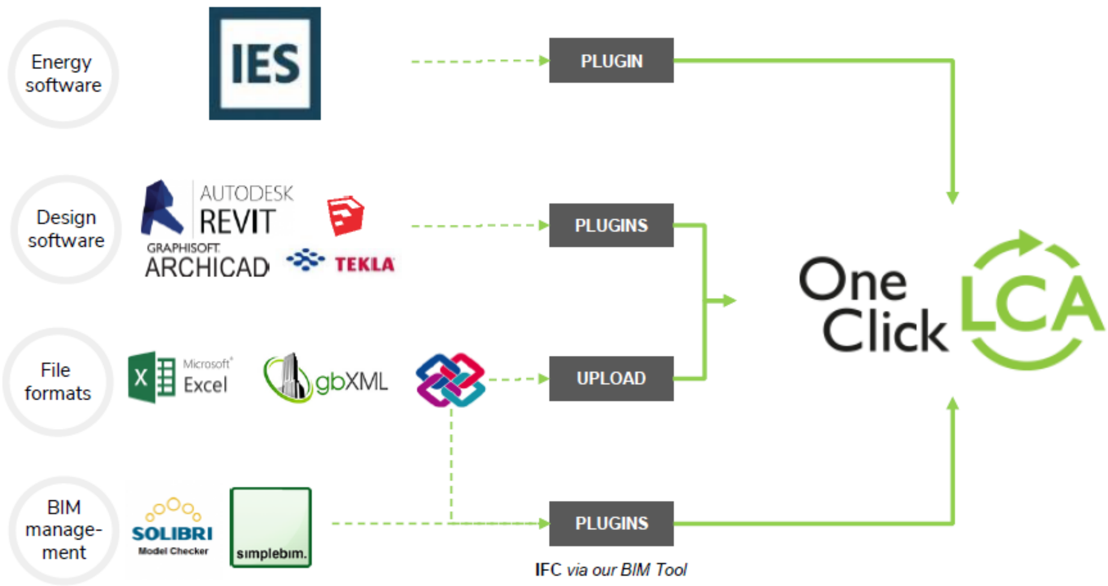


Figure 11 One Click LCA integration with Revit and BIM tools (One Click LCA)

Revit - Tally®

Tally® is an Autodesk® Revit® application that allows architects and engineers to quantify the environmental impact of building materials for whole building analysis as well as comparative analyses of design options. While working on a Revit model, the user can define relationships between BIM elements and construction materials from the Tally database. (Autodesk, Tally 2020)

It incorporates data for lifecycle assessment during the process of building design. Tally is a plugin that can be installed to Revit software and is easy to use without requiring special practice or learning.

Tally™ software allows designers to link BIM elements and building materials to an environmental information database and generate impact reports. (Cristiane Bueno, Márcio Minto Fabricio, 2016)

The Revit materials have to be linked manually with the corresponding LCA data, which is why it is only a semi-automatic work process. (Forth 2018) The LCA calculation is based on GaBi data and 78 product-specific EPDs. As an output, a report is automatically generated with the presentation of results by life cycle phase, material groups, Revit categories and their combination. Tally is compliant with the LEEDv4 standards. Tally takes the following Revit categories into account: ceilings, curtainwall posts, curtain wall elements, doors, floors, roofs, stairs, foundations, load-bearing frames, load-bearing supports, walls and windows (Tally 2020).
"Tally gives its users the power to conduct whole building LCAs during design and to use LCA data to run comparative analyses of various design options that show their differing environmental impacts." (Kierantimberlake 2020)

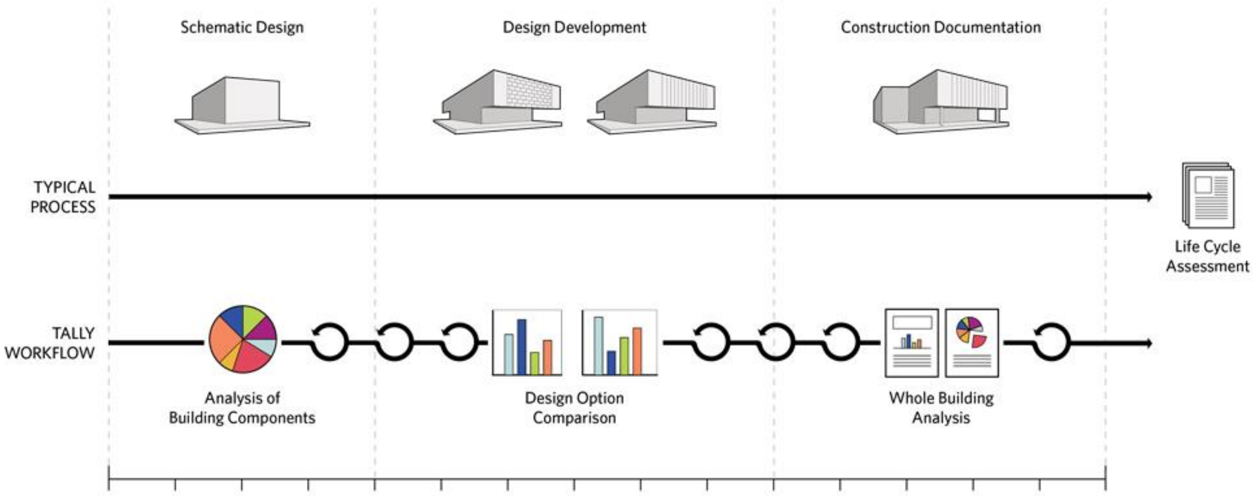


Figure 12 Tally LCA workflow and BIM integration (Kierantimberlake 2020)

4. LCA PROCEDURE WITH BIM INTEGRATED TOOLS

4.1. Revit model and LCA tools

The model used for this LCA test analysis is a model that is built and used in the previous modules of this course. It is designed in Revit Architecture based on the point cloud data of an old historical building. The model is designed by including new parts and structural renovations. In this research the model is considered as a new architectural design and are assigned new materials from the integrated tools databases with the purpose of performing an example of LCA analysis, testing LCA BIM integrated tools and comparing results from different tools. In this case, the material selection is based in the assigned materials and elements from Revit, and the wall elements and materials are the main focus of the analysis. The material mapping process is applied for the materials of the wall layers and the structure of the building. The focus is on the integration of different tools of LCA analysis with the BIM model and the interoperability advantages and issues coming forward in this study.

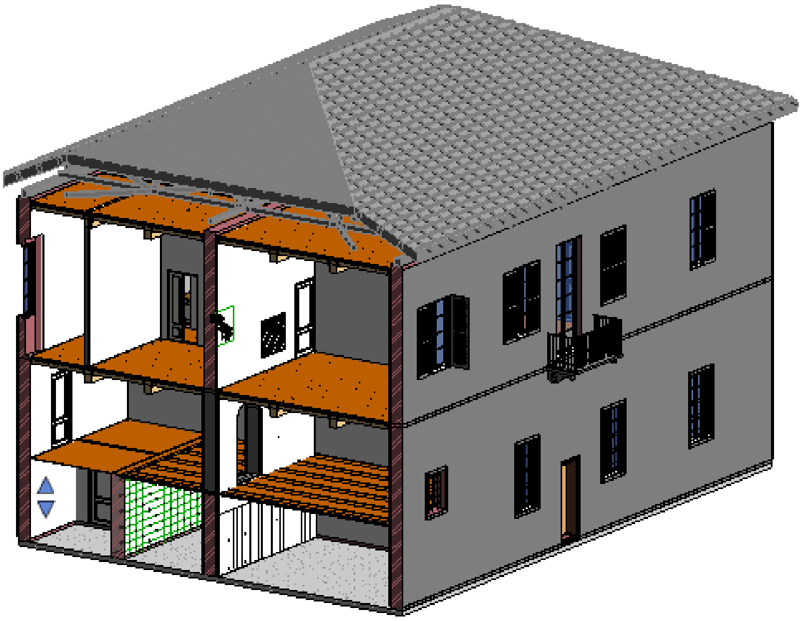


Figure 13 Revit model used for the LCA study and tests

Two LCA BIM-integrated tools are used to perform LCA analysis and produce the environmental impact results, One Click LCA and Tally. They are both provided as Revit plugins and are able to operate with BIM software which is one of the main reason why they were chosen to run this analysis. This complies with the static method of LCA with BIM integrated tools in a direct approach which is mentioned in the above chapters. Interoperability issues and the level of the integration of each tool with the BIM software were another important matter on the choice of these LCA tools. As Revit plugins they directly create the link of the model with the material database, already integrated in the tool, and perform the LCA analysis by exporting the results in Excel format. They also have the ability to interact with IFC format.

4.2. LCA procedure with One Click LCA

One Click LCA software can be used in three different ways to perform LCA analysis and calculate environmental impacts. (One Click LCA (2015))

- LCA procedure in the online application by manually inserting the data from the extracted BOQ
- LCA procedure with Revit Plugin and One Click LCA cloud
- LCA procedure by importing IFC model and using Simple BIM

One Click LCA can analyse and calculate results for the complete Cradle-to-Grave stages of LCA from A1 stage to D stage. In this study, the special attention was paid to the A1-A1 stages, which is going to be the focus in the LCA analysis with the dynamic Revit integrated tool explained in the last chapter. The LCA analysis for the model was performed in two of the three aforementioned ways; it was performed the LCA procedure through the Revit integrated Plugin and the procedure by importing the IFC model through Simple BIM.

4.2.1. LCA procedure with Revit Plugin and *One Click LCA* cloud

Through this method, the One Click LCA has minimized the manual entry of data in the quantification of the environmental impact values. (One Click LCA (2015)) The plugin is easy to use and time saving compared to traditional LCA calculation procedures. Integrated into the Revit Add-ins section, it can be easily accessed and used directly from the software.

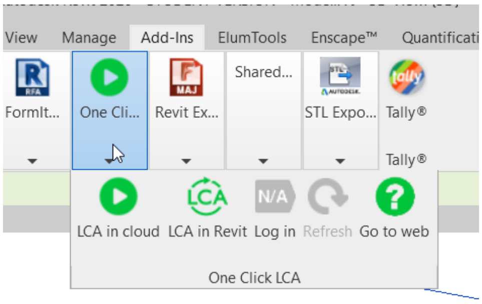


Figure 14 Once Click LCA Revit integrated Plugin

Through the plugin it was possible to link the model elements and Revit materials with the One Click LCA material database which provides a large variety of EPDs from different geographical regions, manufacturers and standards which can also be added as a filtering component during the material mapping. During this study analysis, the materials of Ökobaudat database were selected to be assigned to the model as it is also the chosen LCA database to be integrated with the dynamic integrated tool in the following works for this thesis and explained in Chapter6, in order to have a more similar approach and results in between methods for LCA analysis. The analysis is performed only for the wall structure and envelope layers (internal and external). The mapped material choices were saved through the plugin and assigned to the Revit model by appearing in the Type properties as “Green Building Properties”. This can be considered as a semi-dynamic approach from the tool in relation with the BIM software and workflow.

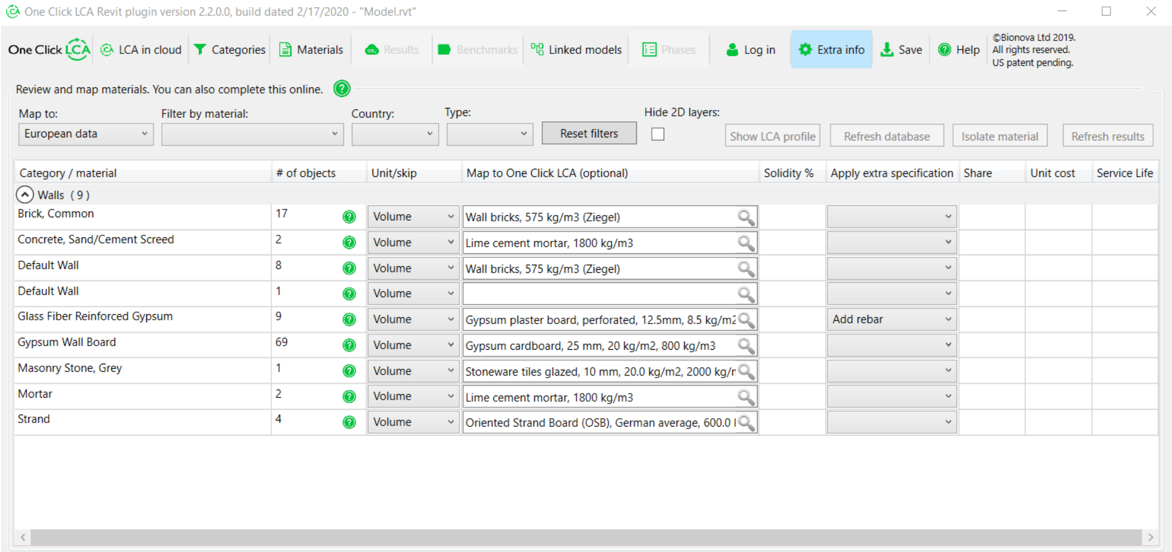


Figure 15 Material mapping with Once Click LCA plugin in Revit model

The LCA analysis was performed after the materials were linked with the Revit quantities through the “LCA in cloud” tab in the plugin, which redirected the procedure in the online page of One Click LCA. The obtained results, in this case, calculated for the early design phase of the object, are demonstrated through a variety of graphical data and can be easily viewed and evaluated by the user. The results were calculated for six environmental impact categories, as shown in the picture.

Figure 16 LCA calculation results and Carbon Heroes Benchmark (One Click LCA)

	Result category	Global warming kg CO_2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	
A1-A3	Construction Materials	1,47E5	2,57E2	3,27E1	4,69E−4	4,62E1	2,76E6	Details
A4	Transportation to site	1,56E3	7,18E0	1,56E0	3,08E−4	8,79E−2	4,44E4	Details
A5	Construction/installation process							Hide empty
B1-B5	Maintenance and material replacement							Hide empty
B6	Energy use							Hide empty
B7	Water use							Hide empty
C1-C4	Deconstruction	7,52E3	2,43E1	5,83E0	1,4E−3	6,76E−1	1,84E5	Details
D	External impacts (not included in totals)	−9,48E3	−1,65E1	−3,77E0	−4,95E−5	−7,8E−1	−1,47E5	Details
	Total	**1,56E5**	**2,88E2**	**4E1**	**2,18E−3**	**4,69E1**	**2,99E6**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 506.0 m2	3,08E2	5,7E−1	7,92E−2	4,3E−6	9,27E−2	5,9E3	

Figure 17 Life cycle assessment result and A1-A3 phase highlighted (One Click LCA)

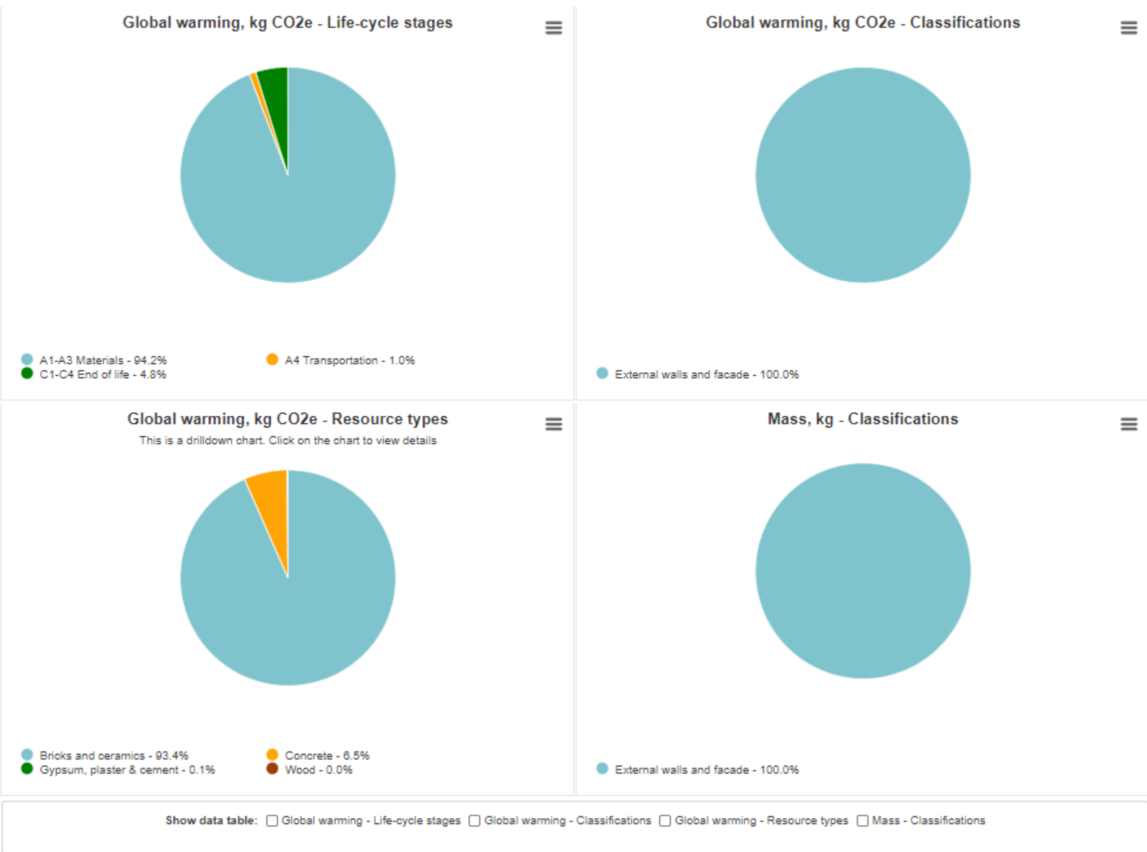


Figure 18 Life Cycle overview of Global warming (One Click LCA)

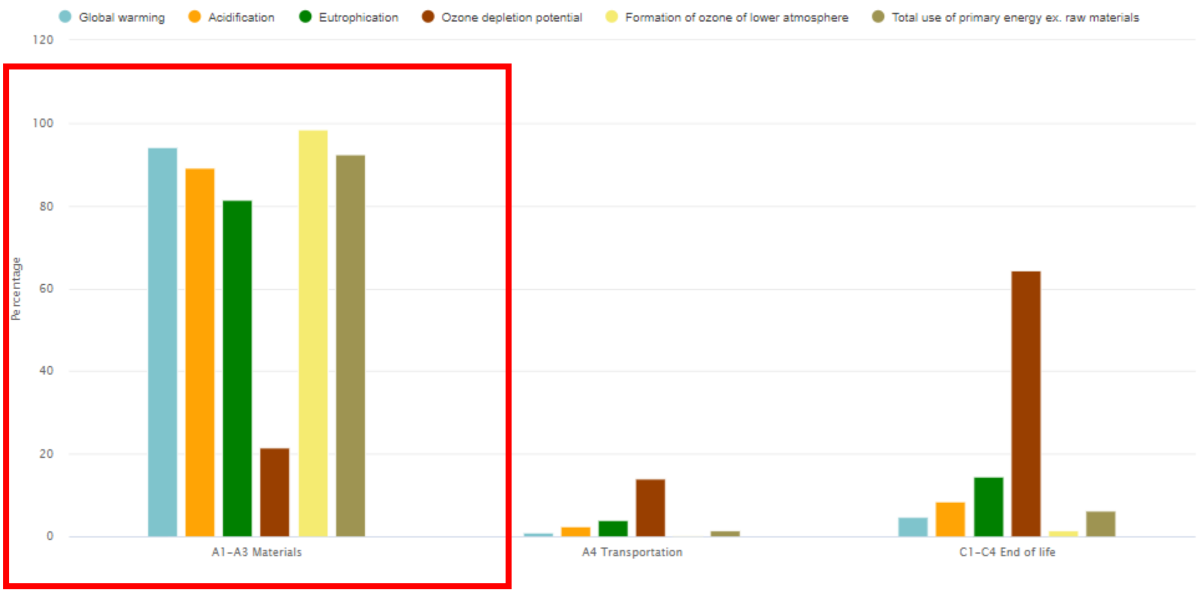


Figure 19 Results by life-cycle stage (One Click LCA)

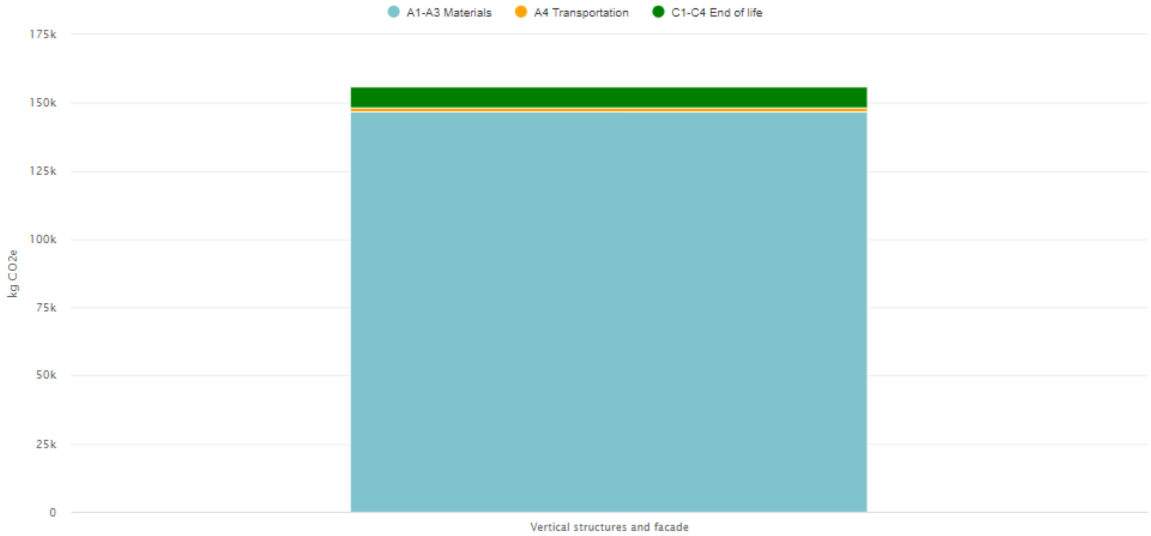


Figure 20 Global warming (GWP) breakdown (One Click LCA)

4.2.2. LCA procedure by importing IFC model and using Simple BIM

The second approach for performing an LCA analysis was by importing the IFC model in Simple BIM and then exporting the material quantities in an Excel report to further upload in the Once Click LCA online platform. The analysis, again, was performed for the wall structure and layers (internal and external) by excluding from the extraction report the other components of the building. This is one more interoperability option that the tool offers to integrate with BIM software. Although, during the use of this method, were spotted more missing data and errors in the extraction of the material quantities. As a consequence, different results were obtained from the two different approaches. This demonstrates about interoperability problems that the IFC format can create during exporting and importing the information through different BIM software.

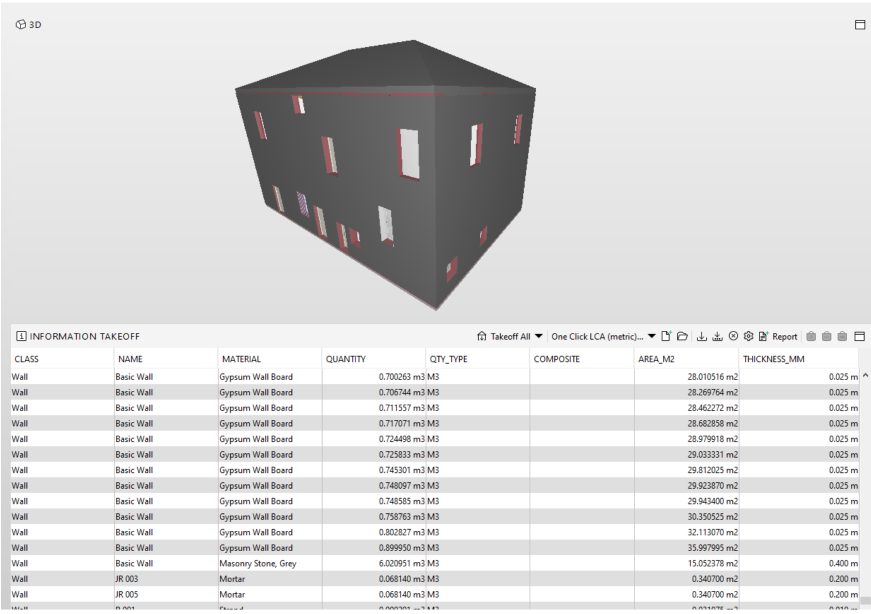


Figure 21 Material takeoff for Once Click LCA analysis

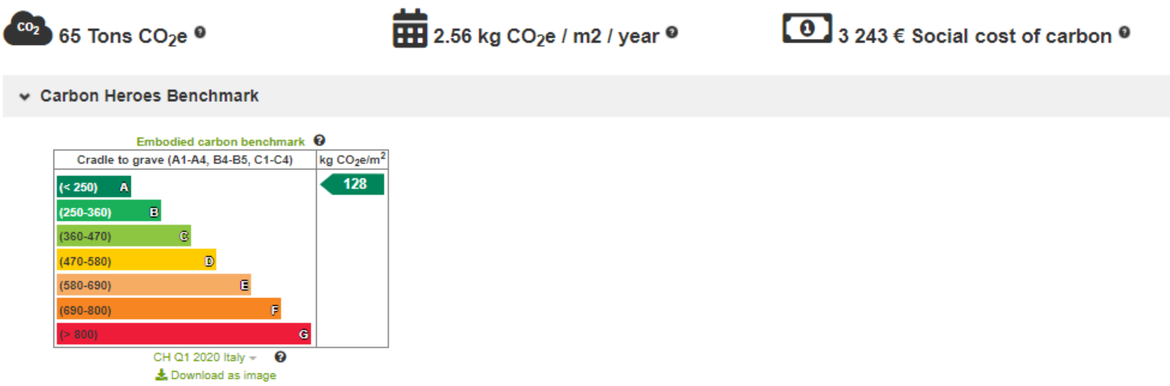


Figure 22 LCA calculation results and Carbon Heroes Benchmark (One Click LCA)

	Result category	Global warming kg CO_2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	
A1-A3	Construction Materials	5,37E4	5,67E1	8,2E0	8,44E−7	4,13E0	7,97E5	Details
A4	Transportation to site	7,23E2	3,33E0	7,25E−1	1,43E−4	4,08E−2	2,06E4	Details
A5	Construction/installation process							Hide empty
B1-B5	Maintenance and material replacement	9,28E3	9,13E0	2,45E0	1,12E−8	7,01E−1	1,82E5	Details
B6	Energy use							Hide empty
B7	Water use							Hide empty
C1-C4	Deconstruction	1,12E3	7,95E0	1,45E0	8,47E−9	7,8E−1	2,04E4	Details
D	External impacts (not included in totals)	−2,85E3	−4,72E0	−9,2E−1	−1,82E−6	−2,08E−1	−5,1E4	Details
	Total	**6,49E4**	**7,71E1**	**1,28E1**	**1,44E−4**	**5,65E0**	**1,02E6**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 506.0 m2	1,28E2	1,52E−1	2,53E−2	2,84E−7	1,12E−2	2,02E3	

Figure 23 Life cycle assessment result and A1-A3 phase highlighted (One Click LCA)

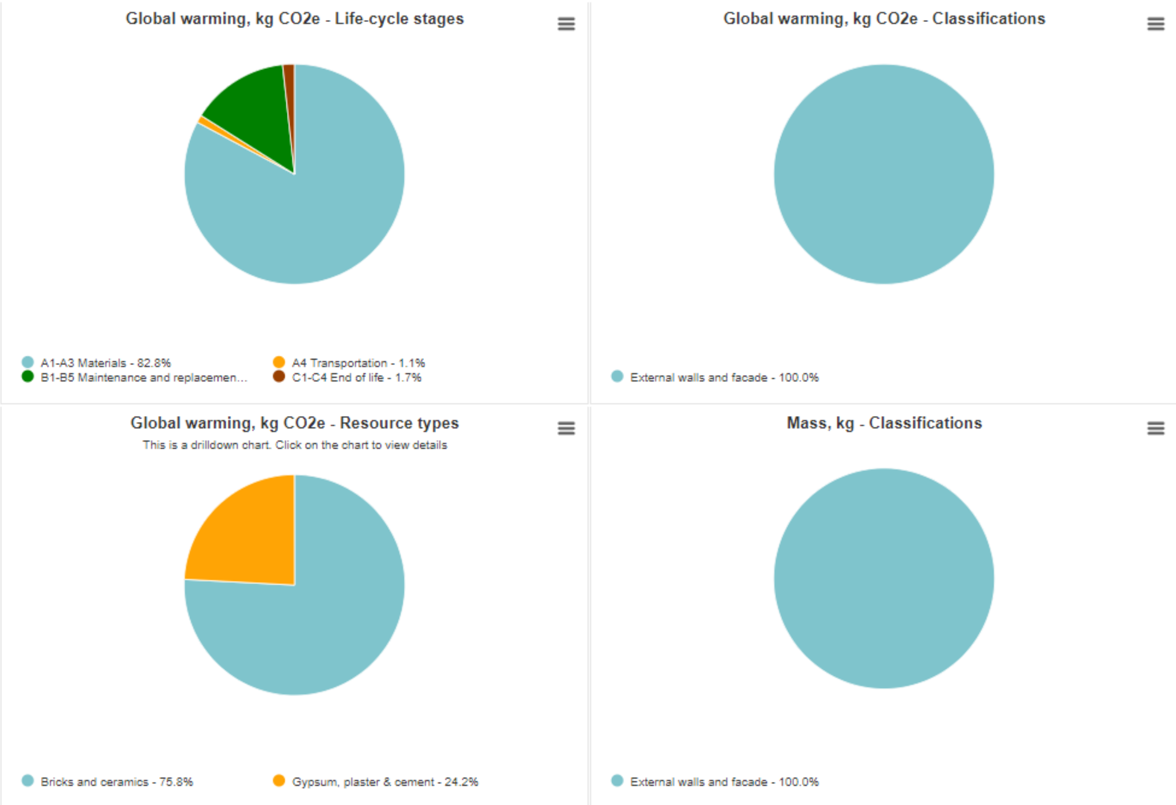


Figure 24 Life Cycle overview of Global warming (One Click LCA)

4.3. LCA procedure with Tally

Tally is another BIM integrated tool to perform LCA analysis directly from the Revit model. It is installed as a plugin in the Revit add-ins tab. Tally performs the LCA analysis by considering North American standards and location conditions. It considers eight environmental impact categories in comparison with One Click LCA and six of them are compatible in between the two tools. In this case, as well as in the One Click LCA plugin, the information is extracted directly from the BIM model as an automated procedure which decreases the margin of error and loss of information compared to other static methods. The materials are directly mapped in the plugin, and the LCA analysis is run by generating a report in Excel and PDF format. The results are easily understood and evaluated by the user and presented in a graphic way. Similar to One Click, Tally improves the decision-making process during the design phase regarding the environmental impacts by offering this semi-dynamic operating tool integrated with BIM software.

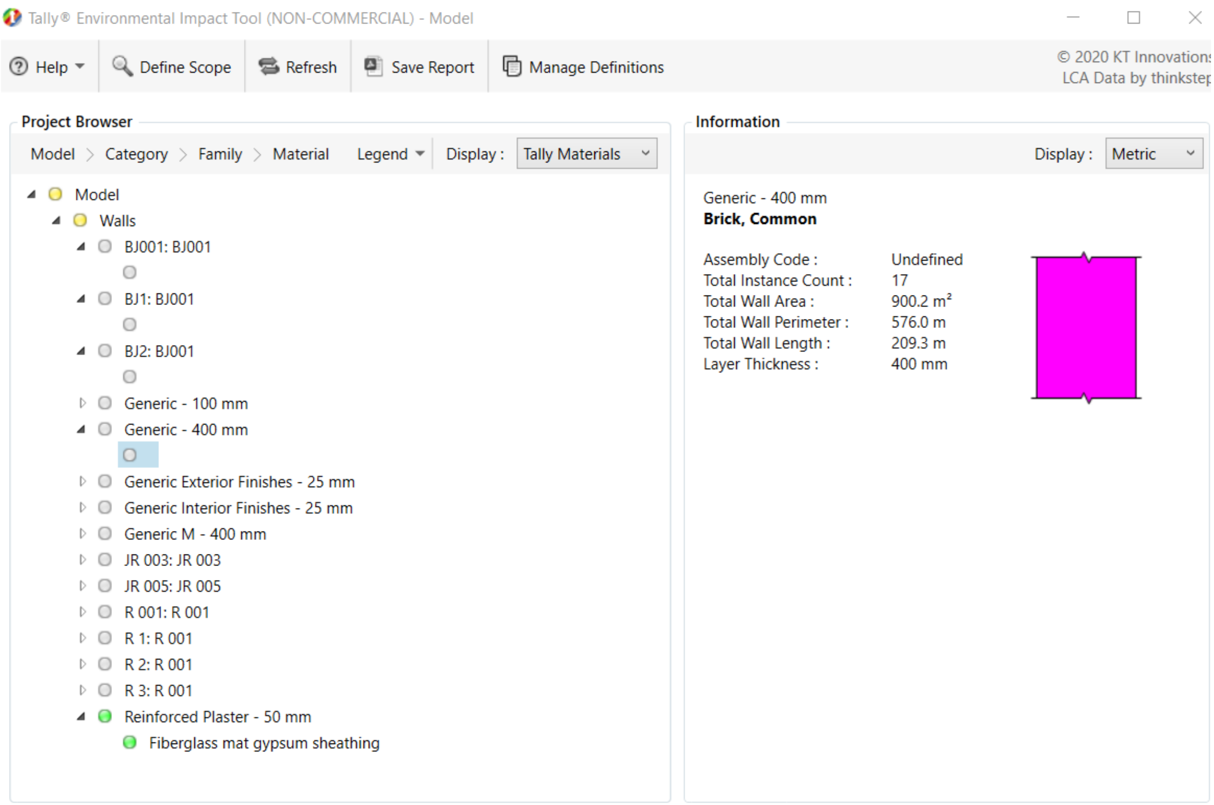


Figure 25 Tally material mapping process

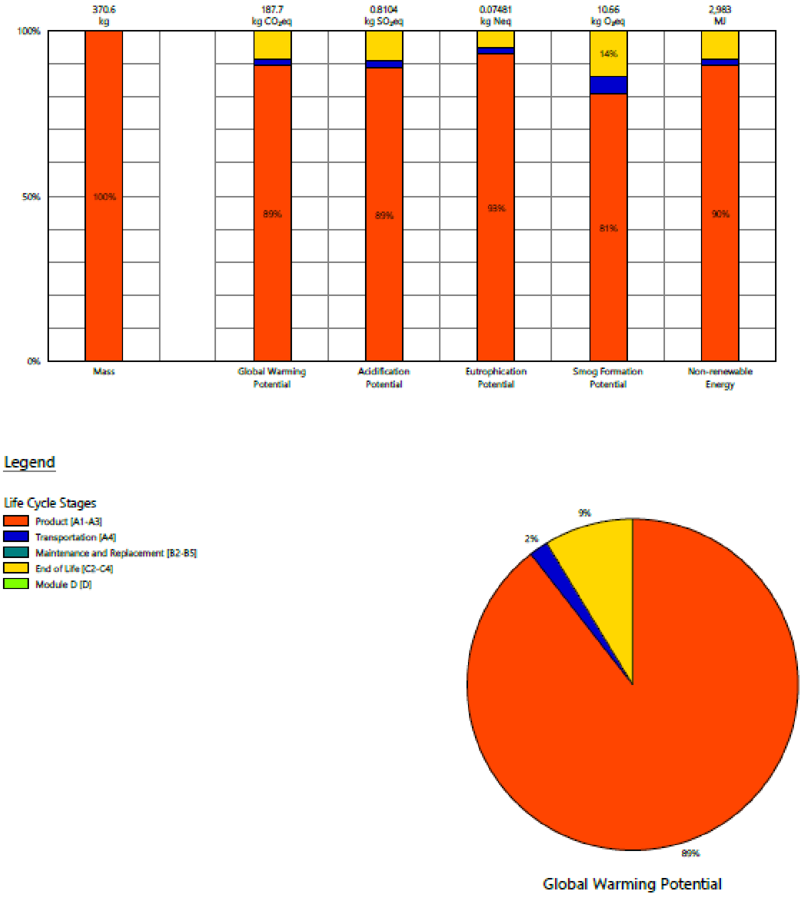


Figure 26 Tally report and results per life cycle stage

4.4. Conclusions

The LCA results are affected by the differences in EPD databases between Once Click LCA and Tally analysis. Using databases that differ as a result of chosen geographical areas can produce different outcomes as the LCA analysis depends on the selection of the material.

Another important conclusion comes out regarding the interoperability of the tools with the BIM model and its level of detail. Since the geometrical and semantic data is directly extracted from the BIM model to perform the LCA analysis, the level of detail has a high impact on these calculations. Various issues were recorded during both procedures as a result of the lack of details in the analysed model.

On the other side, the automated approach in the extraction of the material quantities from the model has lowered the error margin in the obtained information and eliminates as much as possible the loss of information compared to static and traditional methods.

	One Click LCA	Tally
Type	Online platform and software, BIM integrated Plugin	BIM integrated Plugin
Open BIM interoperability	IFC, gbXML, Excel file upload, manual data entry, direct Revit interaction	IFC, direct Revit interaction
Material Databases	Large database of materials and EPD from several geographical regions and manufacturers, Several filters available by material, database, region, manufacturer	Custom database based on the GaBi database
Certification	Compliance with several Building Certifications Standards	Compliant with North American standards
BIM integration	Plugin, Design Authoring	Plugin
Tool advantages	Large material database Integrated Sustainability Certification Several ways of data visualisation and interpretation Carbon designer tool Baseline design offered and can be modified	Very well integrated with Revit software Accurate comparative results in between design solutions and different material choices

Table 4 Comparison table of Once Click LCA and Tally BIM integrated tools

5. LCA AND BIM INTEGRATION WITH AUTOMATED APPROACH

5.1. BIM model

It is very important to understand the geometry of the model and the structure of information in it in order to be able to run a successful LCA analysis and obtain a valid environmental impact result from the BIM model. BIM models build by different software are structured differently. (Critiane Bueno 2018)

The model used in this study was build in Revit, and as a result, the component of the model are categorised according to Revit hierarchy structure. For the dynamic integrated LCA process, the Revit data structure has to be combined with the necessary LCA environmental information.

The general information related to the environmental impact in the BIM model is categorised as level zero information for the LCA. Every component in a Revit model falls under a specified category which contains the information of the first LCA level. Categories are divided into subdivision which are known as “Revit families”. Furthermore, “Types” is the term used to identify different Revit families like a wall type that is composed by several layers.

In Revit, each element contains identification data like the dimensions or the material. This is considered as the second level of information that is contained in a Revit element. (Genova 2018)

The third level of information in Revit built model would be the material unit. Each material in Revit contains numerical information about its volume and area. Usually, the Revit materials contain also the sub-materials. For example, the wall material contains the brick material and the mortar material. This would be the deepest level of information in a BIM model. (Alexander Hollberg, 2018)

In this case, for the software to be able to extract an accurate value of the material quantity, each one of the materials and sub-materials should be separately modelled in Revit. Otherwise, the LCA results would not be accurate. The other solution is to choose from the material database the material that has already calculated the percentage of the sub-material (like the mortar in the brick wall). This can be possible with the Ökobaudat material database.

5.2. BIM maturity for LCA integraion

Integrating BIM and LCA would be a very beneficial approach in developing automated procedures for the calculation of the environmental impact. In order for this to happen the BIM model should reach a certain level of information that enables an automated tool to perform the LCA procedure. (Alexander Hollberg, 2018)

The level of development (the LOD) is the crucial factor for a successful LCA calculation in a BIM model. The necessary information considered as input for the procedure depends on the model LOD and the capability of the software to reach that level and quantify the built elements. (Bernadette Soust-Verdaguer, 2016)

In order to link the LCA data with the BIM model, it is necessary to link respectively, the material from the chosen LCA database and the type of material in the BIM model. This procedure can be achieved by assigning the same identification number (ID number) to the material in database with the one in Revit. If this procedure is accomplished in a correct way, then it is possible to pursue an LCA calculation since the early design phases of the building. (Cristiane Bueno, 2017)

The BIM maturity, in this case is very important to the process. A quality structured model should contain materials that are correctly correspondent to the ones that are being planned to use from the chosen LCA database. The material mapping between the LCA database and the model should be done manually, although it is a time-consuming process.

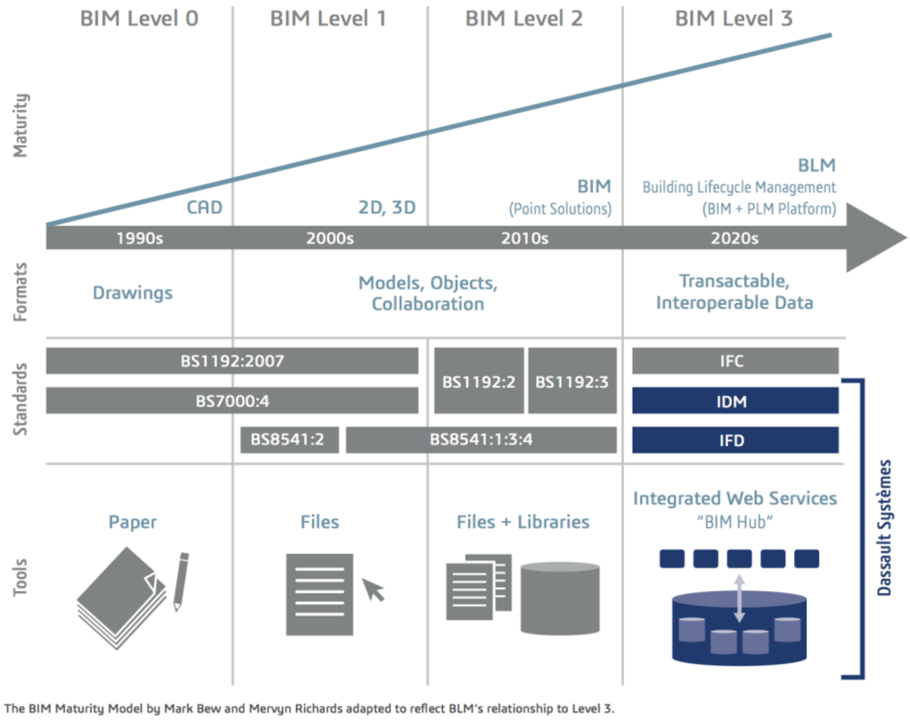


Figure 27 BIM Maturity Matrix (Dassault systems)

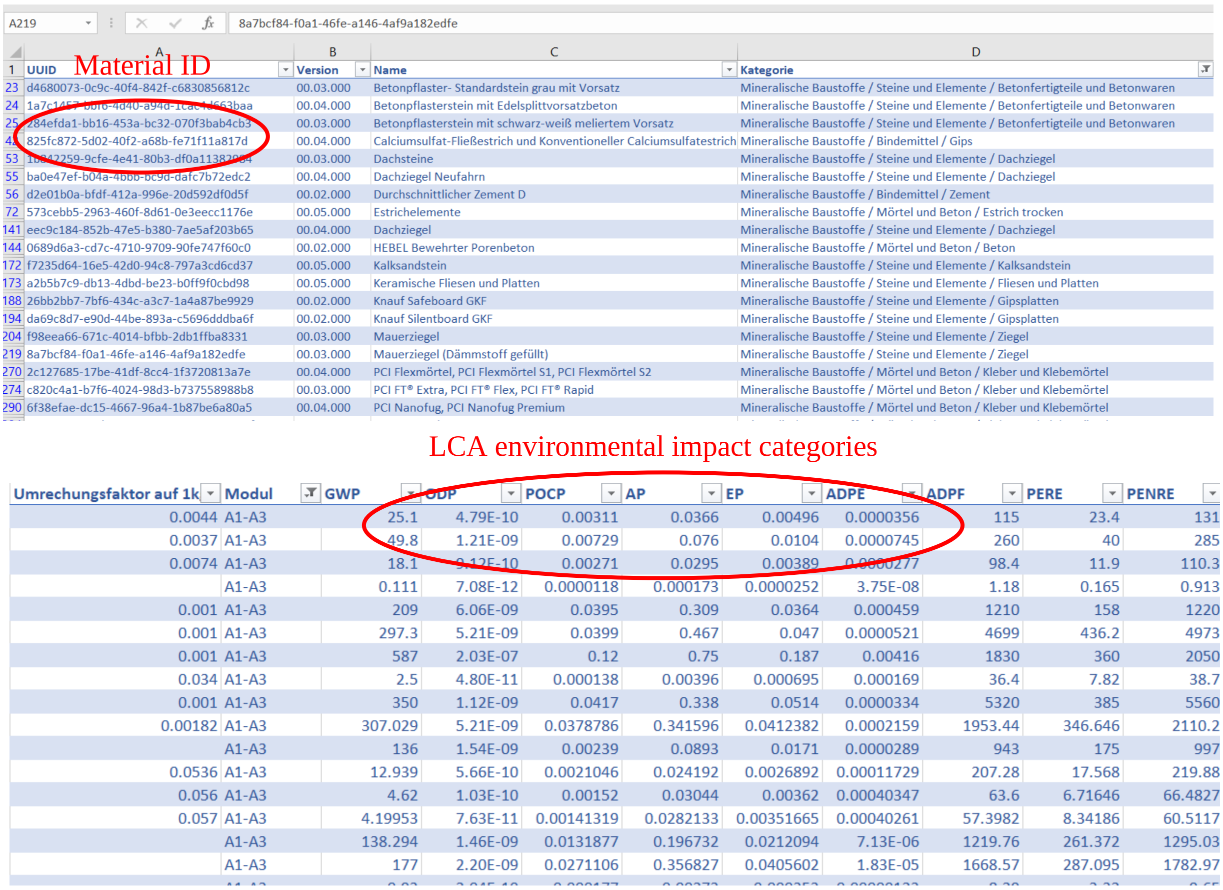
5.3. Level of development in BIM-LCA integration

The level of development is the level of geometry and the level of information combined in one element. (M.Dupuisa, 2017) The LOD of the BIM model has a significant role in the LCA calculation process and the precision of results.

To the integration of BIM and LCA with automated procedures, the model should have a defined volume for each element and all the layers should be separately modelled. It is necessary to have an accurate extraction of the volumetric data from the Revit elements and also other information like the name and type of the material, the construction phase and the composition. As a result, the data entry in the BIM model becomes a very important task that requires responsibility and great precision.

5.4. Material-based LCA database

In the material LCA database, the information about the environmental impact corresponds individually to each of the materials. Each of them has an identification number (ID number) which can be used to name the respective material in the BIM model. The Ökobaudat LCA database is a material database; therefore it is chosen to be used in this study. Also, other reasons why it is chosen are that it is provided for free and in Excel format (the PDF format provided databases would not be valid to use) and has a very rich building material dataset compliant with the EN 15804 standard.



	A	B	C	D
1	UUID	Version	Name	Kategorie
23	d4680073-0c9c-40f4-842f-c6830856812c	00.03.000	Betonpflaster- Standardstein grau mit Vorsatz	Mineralische Baustoffe / Steine und Elemente / Betonfertigteile und Betonwaren
24	1a7c1457-bbf6-4d40-a94d-1cac4d663baa	00.04.000	Betonpflasterstein mit Edelsplittvorsatzbeton	Mineralische Baustoffe / Steine und Elemente / Betonfertigteile und Betonwaren
25	284efda1-bb16-453a-bc32-070f3bab4cb3	00.03.000	Betonpflasterstein mit schwarz-weiß meliertem Vorsatz	Mineralische Baustoffe / Steine und Elemente / Betonfertigteile und Betonwaren
42	825fc872-5d02-40f2-a68b-fe71f11a817d	00.04.000	Calciumsulfat-Fließestrich und Konventioneller Calciumsulfatestrich	Mineralische Baustoffe / Bindemittel / Gips
53	1b842259-9cfe-4e41-80b3-df0a11382984	00.03.000	Dachsteine	Mineralische Baustoffe / Steine und Elemente / Dachziegel
55	ba0e47ef-b04a-4bbb-bc9d-dafc7b72edc2	00.04.000	Dachziegel Neufahrn	Mineralische Baustoffe / Steine und Elemente / Dachziegel
56	d2e01b0a-bfdf-412a-996e-20d592df0d5f	00.02.000	Durchschnittlicher Zement D	Mineralische Baustoffe / Bindemittel / Zement
72	573cebb5-2963-460f-8d61-0e3eecc1176e	00.05.000	Estrichelemente	Mineralische Baustoffe / Mörtel und Beton / Estrich trocken
141	eec9c184-852b-47e5-b380-7ae5af203b65	00.04.000	Dachziegel	Mineralische Baustoffe / Steine und Elemente / Dachziegel
144	0689d6a3-cd7c-4710-9709-90fe747f60c0	00.02.000	HEBEL Bewehrter Porenbeton	Mineralische Baustoffe / Mörtel und Beton / Beton
172	f7235d64-16e5-42d0-94c8-797a3cd6cd37	00.05.000	Kalksandstein	Mineralische Baustoffe / Steine und Elemente / Kalksandstein
173	a2b5b7c9-db13-4dbd-be23-b0ff9f0cbd98	00.05.000	Keramische Fliesen und Platten	Mineralische Baustoffe / Steine und Elemente / Fliesen und Platten
188	26bb2bb7-7bf6-434c-a3c7-1a4a87be9929	00.02.000	Knauf Safeboard GKF	Mineralische Baustoffe / Steine und Elemente / Gipsplatten
194	da69c8d7-e90d-44be-893a-c5696dddba6f	00.02.000	Knauf Silentboard GKF	Mineralische Baustoffe / Steine und Elemente / Gipsplatten
204	f98eea66-671c-4014-bfbb-2db1ffba8331	00.03.000	Mauerziegel	Mineralische Baustoffe / Steine und Elemente / Ziegel
219	8a7bcf84-f0a1-46fe-a146-4af9a182edfe	00.03.000	Mauerziegel (Dämmstoff gefüllt)	Mineralische Baustoffe / Steine und Elemente / Ziegel
270	2c127685-17be-41df-8cc4-1f3720813a7e	00.04.000	PCI Flexmörtel, PCI Flexmörtel S1, PCI Flexmörtel S2	Mineralische Baustoffe / Mörtel und Beton / Kleber und Klebemörtel
274	c820c4a1-b7f6-4024-98d3-b737558988b8	00.03.000	PCI FT® Extra, PCI FT® Flex, PCI FT® Rapid	Mineralische Baustoffe / Mörtel und Beton / Kleber und Klebemörtel
290	6f38efae-dc15-4667-96a4-1b87be6a80a5	00.04.000	PCI Nanofug, PCI Nanofug Premium	Mineralische Baustoffe / Mörtel und Beton / Kleber und Klebemörtel

Umrechungsfaktor auf 1k	Modul	GWP	ODP	POCP	AP	EP	ADPE	ADPF	PERE	PENRE
0.0044	A1-A3	25.1	4.79E-10	0.00311	0.0366	0.00496	0.0000356	115	23.4	131
0.0037	A1-A3	49.8	1.21E-09	0.00729	0.076	0.0104	0.0000745	260	40	285
0.0074	A1-A3	18.1	9.12E-10	0.00271	0.0295	0.00389	0.0000277	98.4	11.9	110.3
	A1-A3	0.111	7.08E-12	0.0000118	0.000173	0.0000252	3.75E-08	1.18	0.165	0.913
0.001	A1-A3	209	6.06E-09	0.0395	0.309	0.0364	0.000459	1210	158	1220
0.001	A1-A3	297.3	5.21E-09	0.0399	0.467	0.047	0.0000521	4699	436.2	4973
0.001	A1-A3	587	2.03E-07	0.12	0.75	0.187	0.00416	1830	360	2050
0.034	A1-A3	2.5	4.80E-11	0.000138	0.00396	0.000695	0.000169	36.4	7.82	38.7
0.001	A1-A3	350	1.12E-09	0.0417	0.338	0.0514	0.0000334	5320	385	5560
0.00182	A1-A3	307.029	5.21E-09	0.0378786	0.341596	0.0412382	0.0002159	1953.44	346.646	2110.2
	A1-A3	136	1.54E-09	0.00239	0.0893	0.0171	0.0000289	943	175	997
0.0536	A1-A3	12.939	5.66E-10	0.0021046	0.024192	0.0026892	0.00011729	207.28	17.568	219.88
0.056	A1-A3	4.62	1.03E-10	0.00152	0.03044	0.00362	0.00040347	63.6	6.71646	66.4827
0.057	A1-A3	4.19953	7.63E-11	0.00141319	0.0282133	0.00351665	0.00040261	57.3982	8.34186	60.5117
	A1-A3	138.294	1.46E-09	0.0131877	0.196732	0.0212094	7.13E-06	1219.76	261.372	1295.03
	A1-A3	177	2.20E-09	0.0271106	0.356827	0.0405602	1.83E-05	1668.57	287.095	1782.97

Figure 28 Ökobaudat LCA database

6. BIM-LCA INTEGRATED TOOL WITH DYNAMO

6.1. Revit and Dynamo

In Revit is possible to create the BIM model containing all the information needed for each object, creating in this way an object-based data BIM model. There are many ways to create a parametric tool to calculate LCA results and several are already developed. (Hollberg, 2016) One way to achieve that is by using visual programming tools like Dynamo. To calculate the results via parametric tools, it is needed to obtain the input information from the BIM model. So, the data that should be included in the BIM model should be complete and responsibly inserted in the object. All the information that is going to be used as input should come from a single BIM model. (Hollberg, 2016)

In this thesis, the relevant information needed for the LCA calculation (geometrical and semantic) is extracted from the BIM model via Revit software and environmental impact information is taken from the free Ökobaudat database in Excel format. Dynamo is used to create the dynamic link between the model and the databank. The script can be run from Dynamo (Dynamo player) and directly write and visualise the results in the BIM model (Revit platform).

So the parametric tool which was created in Dynamo runs the connection between the model and the database, simultaneously reads information from the model and the databank (geometrical and environmental) and uses this information to run the LCA calculations and produce the results. These results (the six environmental impact categories) are reported through an Excel file and also added directly to the Revit list of shared parameters (Energy analysis parameters)

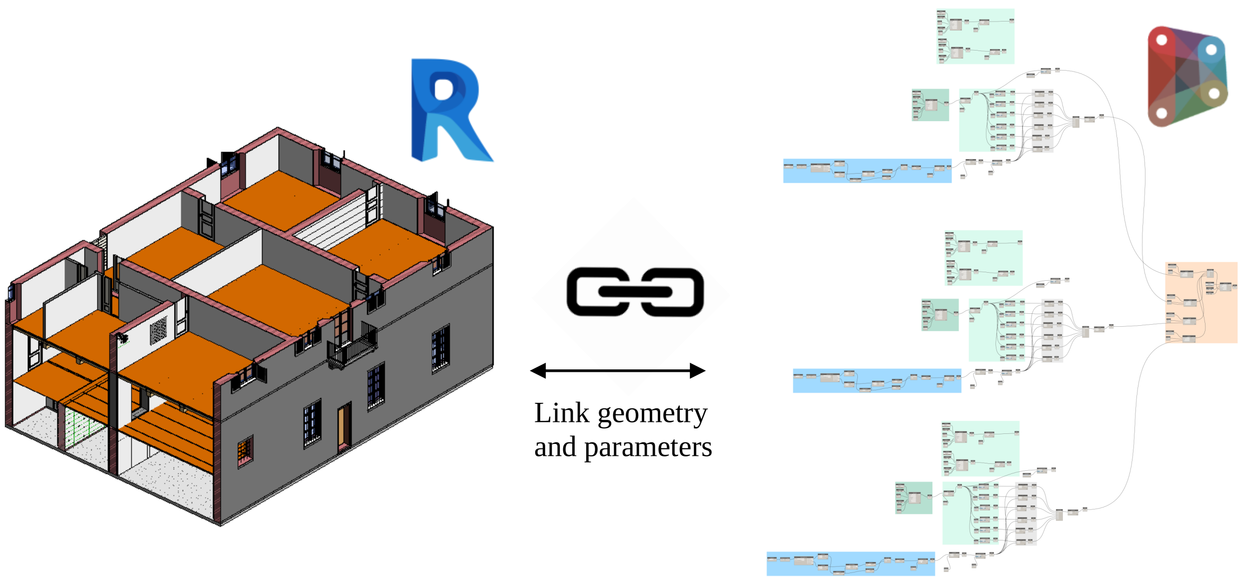


Figure 29 Revit model link with the Dynamo script

6.2. Concept and methodology

Creating a dynamic tool with a direct result approach over the BIM model is the most beneficial way to impact the decision-making process during the design of a building. The followed method to achieve that was by creating a link between the BIM model and the LCA database (in this case the Ökobaudat database in Excel format) by using a Dynamo several Dynamo scripts.

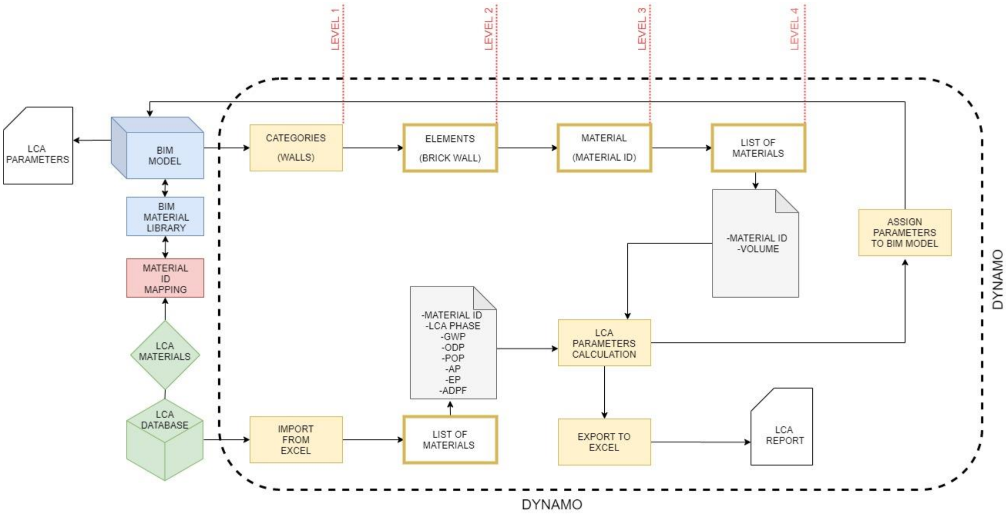


Figure 30 Dynamo script concept

The first script is used to create a list of shared parameters for each of the element type in the model. The second script is used to link and read the data from the Ökobaudat Excel sheet and from the BIM model. After that, the LCA calculations are run to obtain the final results for the environmental impact parameters. The next script is used to assign the calculated values back to the BIM model in the created environmental parameters list in real-time. The results can also be exported as an Excel report.

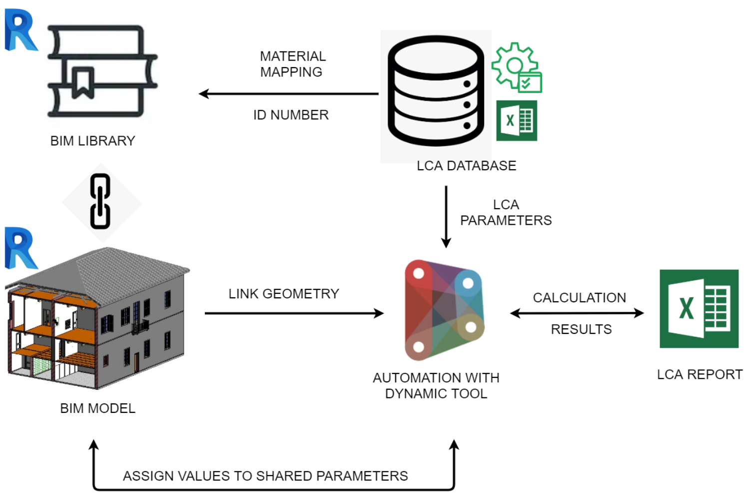


Figure 31 BIM-LCA integration with dynamic approach diagram

One important factor for this procedure to be successful is the material mapping process. It is a manual procedure that links the material ID from the database with the Revit material that is assigned to the element. Once the same ID number is assigned to the material in Revit, the Dynamo tool can run the necessary calculation for each of the element categories and types that we choose from the model. The results are calculated, monitored in real-time with the existing possibility of changing the design solution during each phase of the design.

6.3. Creating shared parameters in Revit with Dynamo according to the LEED list of LCA parameters

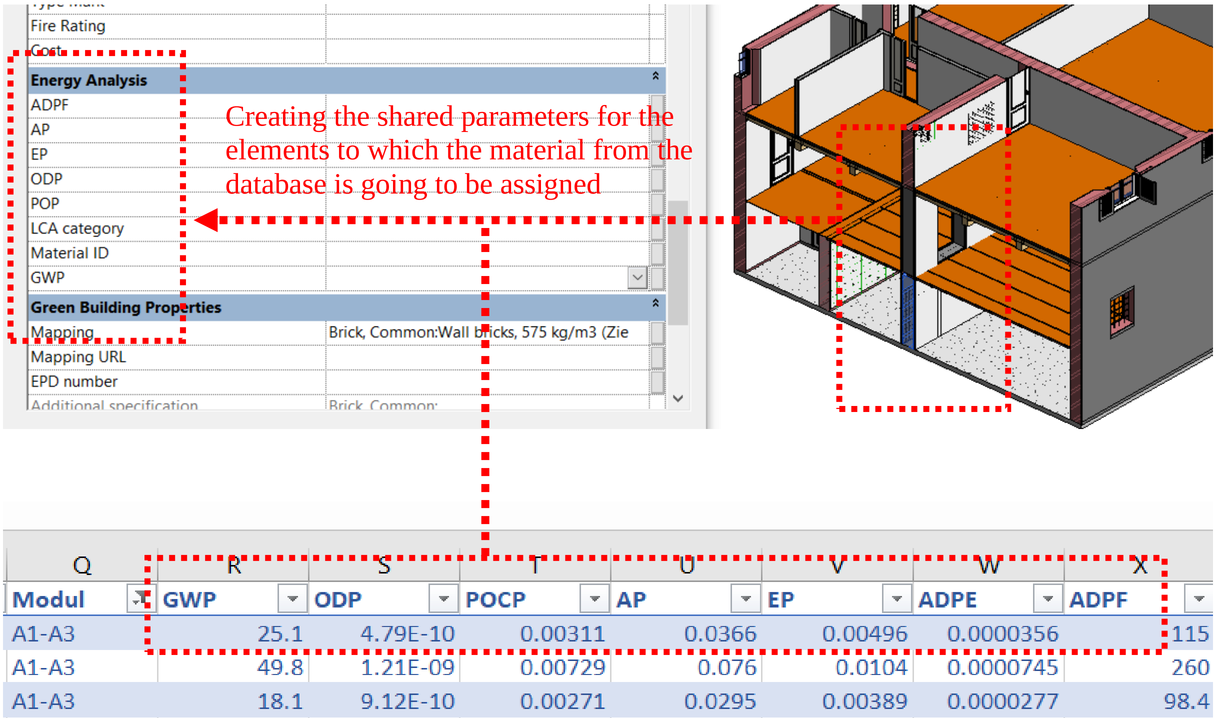


Figure 32 Creation of the shared parameters in Revit

Creating custom parameters for materials in Revit as an ID parameter and inserting as ID value the ID number from the Excel Database (Ökobaudat Database). The main goal of this study was to create the link between the BIM model and the LCA results and have them calculated and visualised in real-time during each of the design phases. In order to do that it was necessary to create in the BIM model (assigned to each element) a list of shared parameters corresponding to the six environmental impact categories mentioned in the LEED standard and the LCA database.

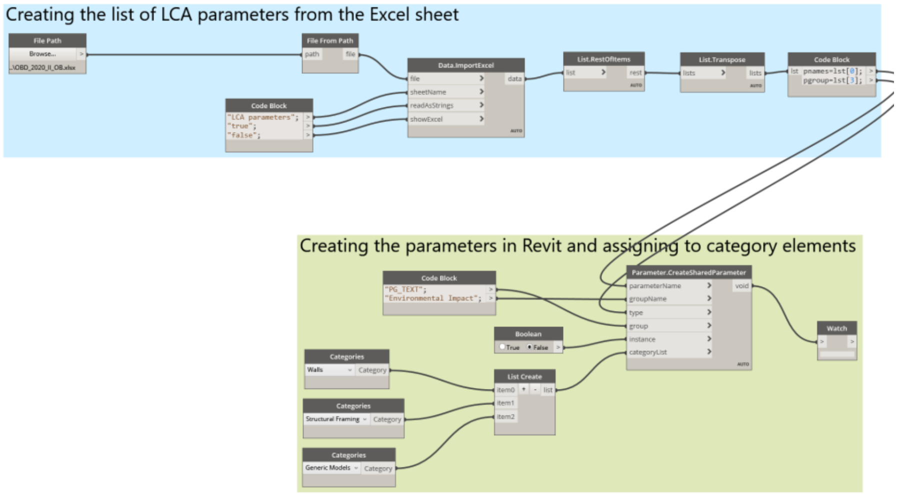


Figure 33 Dynamo script for the shared parameters

6.4. Mapping of the materials in Revit

This is the most important process of the BIM-LCA integration and needs to be done very responsibly and accurately in order to obtain a realistic result. In this study, the chosen way to do the material mapping is the manual way, and this was the biggest challenge. A material parameter is created for each material that is assigned to the respective element in Revit and to which is given as a value the ID number of the material from the LCA database. In this way, every material used in Revit is linked to the respective material from the database. This creates the relation between the geometrical information in the Revit element (volume, area, dimensions) and the environmental impact information of the material chosen from the database. Once this connection is identified the Dynamo script can be used to calculate the LCA parameters.

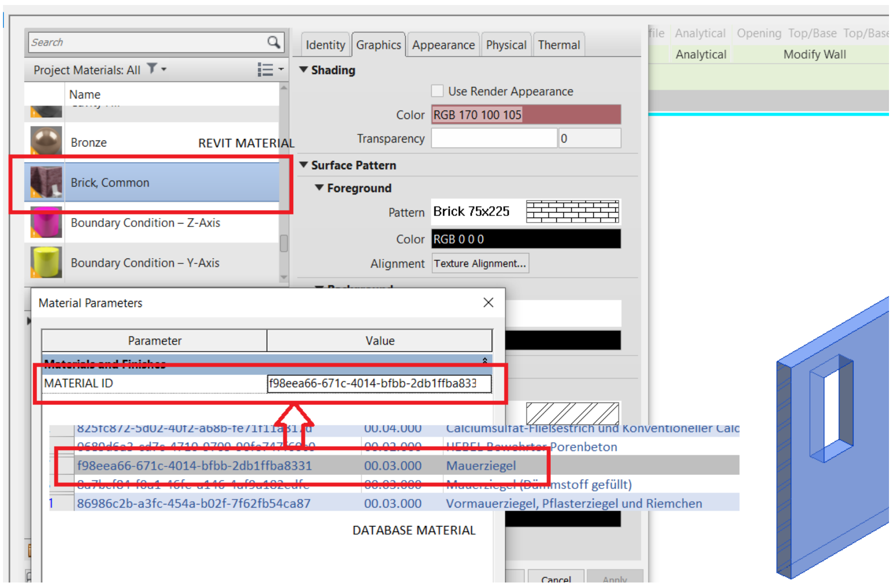


Figure 34 Material mapping in Revit

6.5. Extracting required information from the building elements

The dynamo script was used to extract the necessary geometrical information from the BIM model to perform the LCA calculations. The volume of the material is used as input in the formulas to calculate the environmental impact values. The extracted values are in cubic meters.

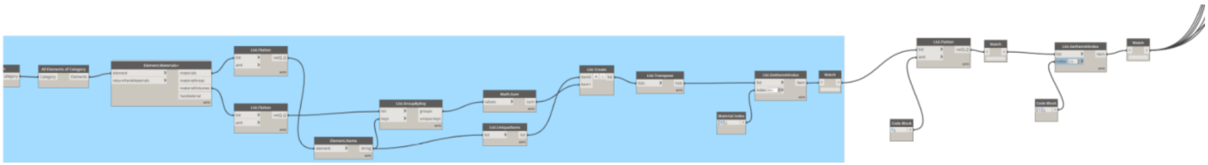


Figure 35 Dynamo script for the material volume extraction from the Revit elements

6.6. Linking the LCA Excel database with the created parameters

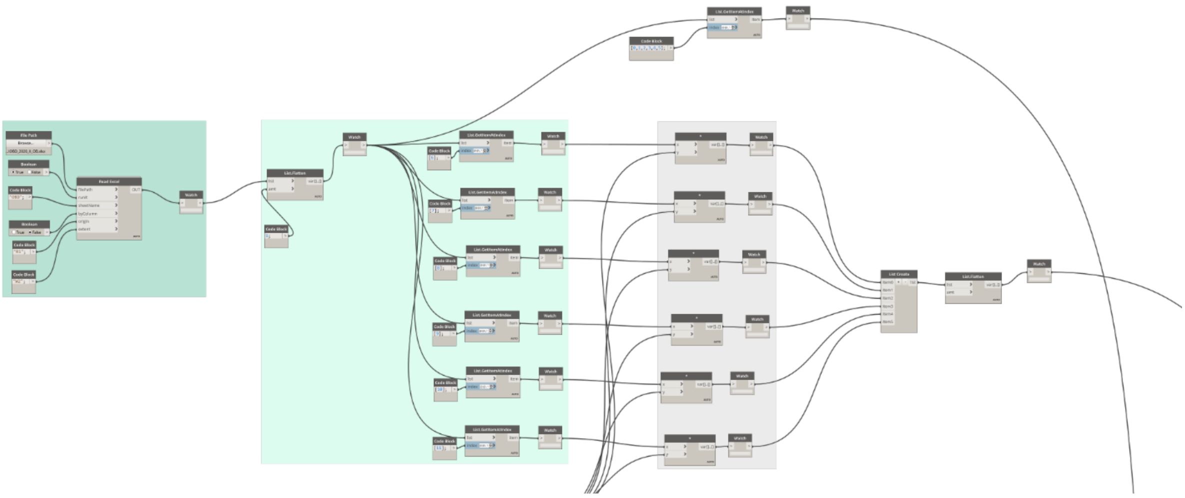


Figure 36 Dynamo script for calculating the LCA values

6.7. Exporting to excel the LCA results

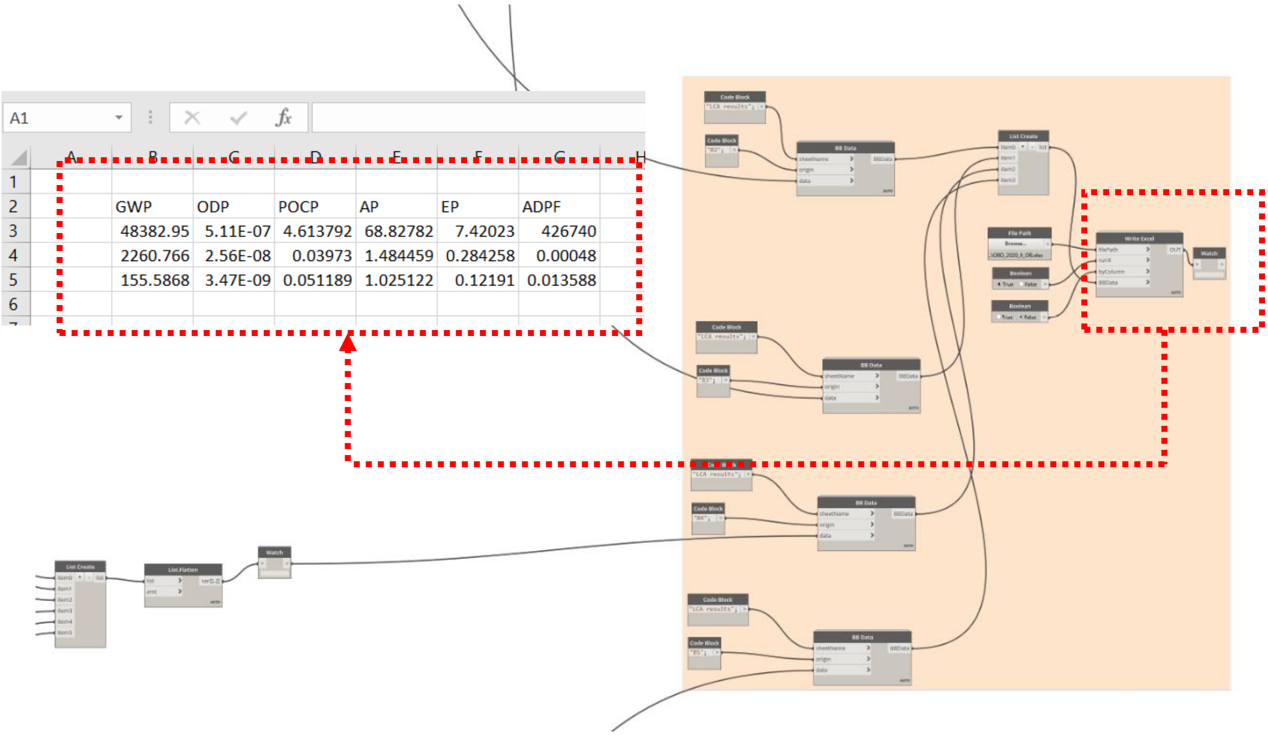


Figure 37 Dynamo script for exporting LCA results in Excel

6.8. Assigning environmental impact values to the Revit model

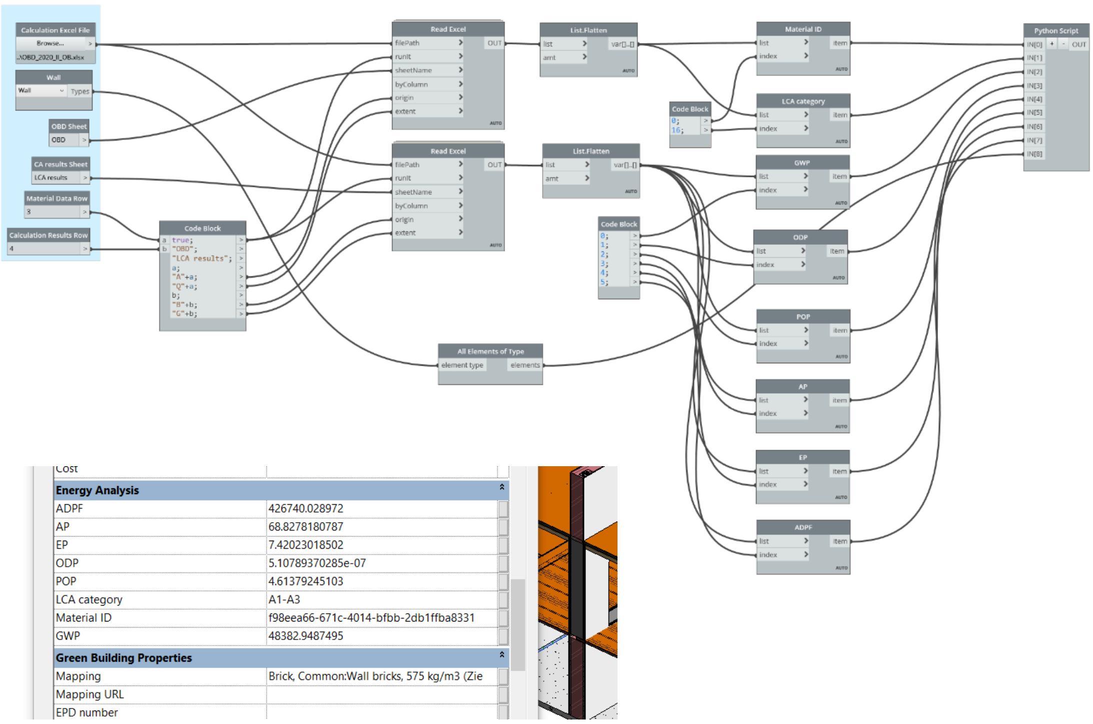


Figure 38 Assigning the calculated values to the BIM model

6.9. Dynamo player

Dynamo player was used to run the scripts in the end in order to simplify the procedure. Often the dynamo scripts become heavy and complicated to run and also very difficult to be understood from other users that are not the developer or that do not have certain Dynamo knowledge.

Dynamo player is a plugin published by Autodesk that comes with Revit and can automatically run prepared Dynamo scripts by pressing the "play" button. It provides a simplified way to run complicated Dynamo scripts. It also provides filters for the visible scrips and a current view of the status of the script. (Autodesk 2020)

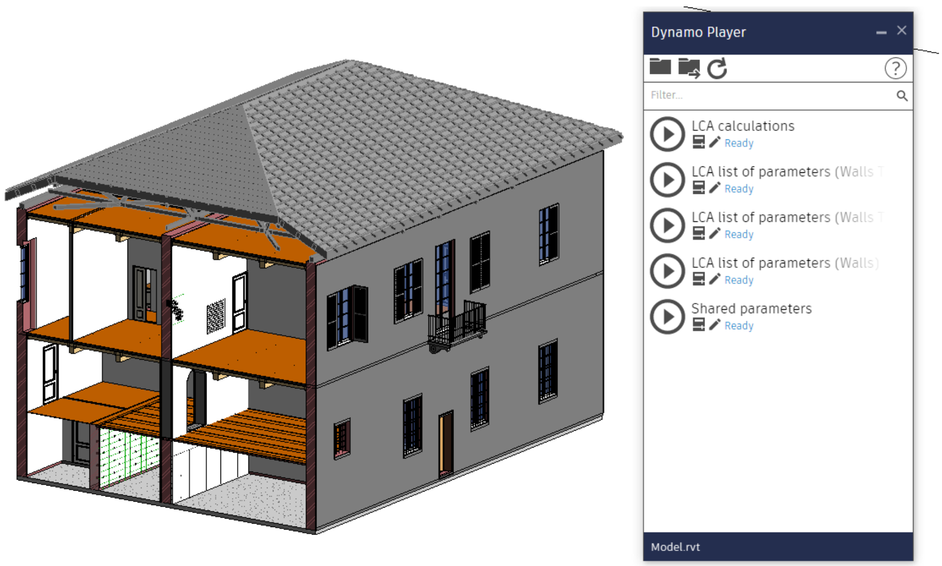


Figure 39 Dynamo player interface

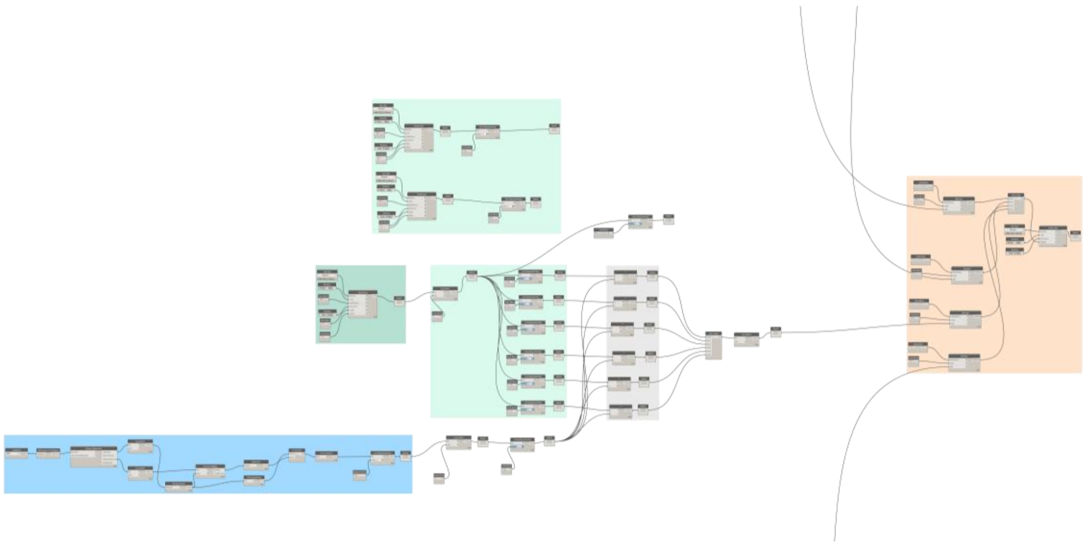


Figure 40 Dynamo script

7. CONCLUSIONS

The integration of BIM and LCA presents great potential for the developing future of sustainable design and the AEC industry. Being able to extract and use the information from the BIM model and linking it with existing LCA databases leads to early possibilities of calculating and visualising the environmental impacts. This means that sustainable developments can be integrated in the early stages of design during which would be easier and affordable to make the changes.

This thesis aimed to explore these fully automated procedures for the integration of BIM and LCA in order to eliminate the use of third party tools and expertise, to speed the LCA process and include it in all design phases of the project, particularly since the design and early decision-making phase.

For this purpose, an automated LCA tool was created with the help of Dynamo interface and tested with a BIM model. It was possible to obtain the LCA calculations for the building envelope for the A1-A1 phases of the building life cycle and to assign the information into the BIM model in real-time. The tool can be further developed and used to run a full LCA analysis in a BIM project. It would be a significant added value to the design and building process and a very handful tool for the professionals to help in their efforts of reducing the carbon footprint of the design. This will also save time and reduce project costs. The BIM integrated LCA calculation process can be taken further by adding the parameter of costs and generating the LCC, which will be very welcomed by the construction industry. It will be obtained this way a parallel workflow of the design process and the environmental analysis since the beginning. As a result, there will be no need for external expertise in the end of the project planning.

Another benefit of the automated LCA procedure integrated in the BIM environment would be the reduction of human mistakes, which usually happen during the static and traditional method of calculation. The repetition of the information entry would be eliminated as the data would be directly and instantly linked to the project model. This will make the LCA more reliable and accurate.

Furthermore, the possibility of monitoring the environmental impact of the design throughout all the process will affect the choices for every building material and element and comply with the increasing demands of the public regarding the energy consumption and the resources.

There are also limitations coming up along with the benefits of this process. During the study and work for this thesis, several challenges and limitations were encountered. The level of development of the BIM model has a significant role in the process and the results obtained. The model should have a sufficient scale of development regarding the semantic and geometric information in order for the tool to extract it. The modelling style in the BIM process also affects the well functioning of the integration process. For example, the wall should be modelled in separate layers in order for them to possess the necessary volumetric information. The information entry in the model should be disciplined and continuously monitored to prevent also human errors. A crucial point in this work was the material mapping in order to create the link between Revit native materials and LCA database. This process was done manually and needed special attention and precision. This step needs to be considered and discussed in the future for possible automation in order to prevent manual mistakes. The type of the LCA database that is chosen for the tool can also be a challenge. In this case, the choice was limited by the availability of it (free of charge), by the type of format in which it is offered (Excel format is needed) and the richness of materials it contains.

To conclude, it can be stated that LCA-BIM integration via automation is a process that will be taking a big emphasis in the near future. The literature study and present developments are showing that. Although, there is still a significant amount of research and work to overcome the limitations that are appearing in the present work for the BIM-LCA integration tool.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEC	Architecture Engineering Construction
BIM	Building Information Modelling
BOQ	Bill of Quantities
BREAM	Building Research Establishment Environmental Assessment Method
EPD	Environmental Product Declaration
GWP	Global Warming Potential
IFC	Industry Foundation Classes
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LEED	Leadership in Energy and Environmental Design
LOD	Level of Development
LOG	Level of Geometry
LOI	Level of Information
PCR	Product Category Rules

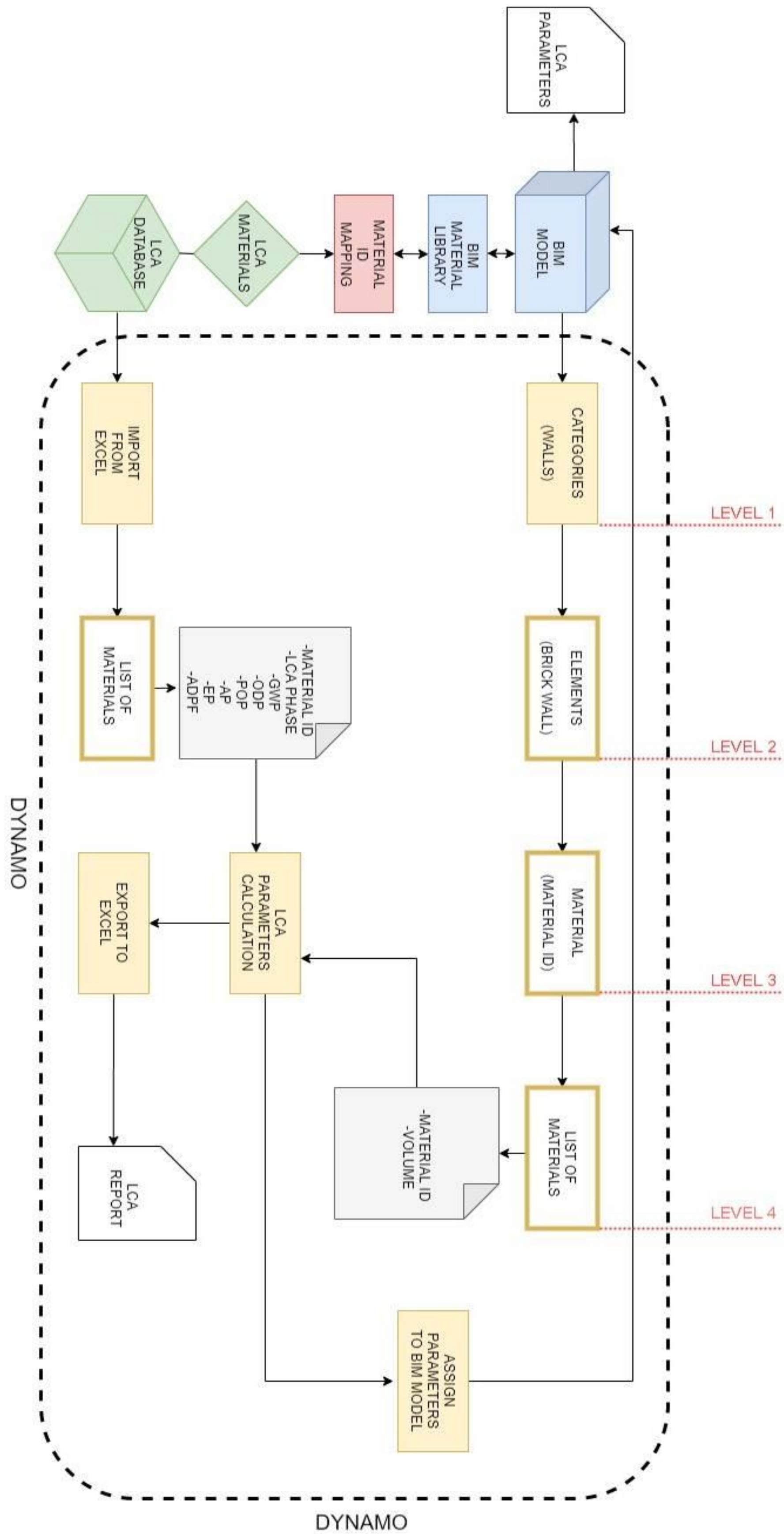
APPENDICES

APPENDIX 1: ÖKOBAUDAT DATABASE LAYOUT

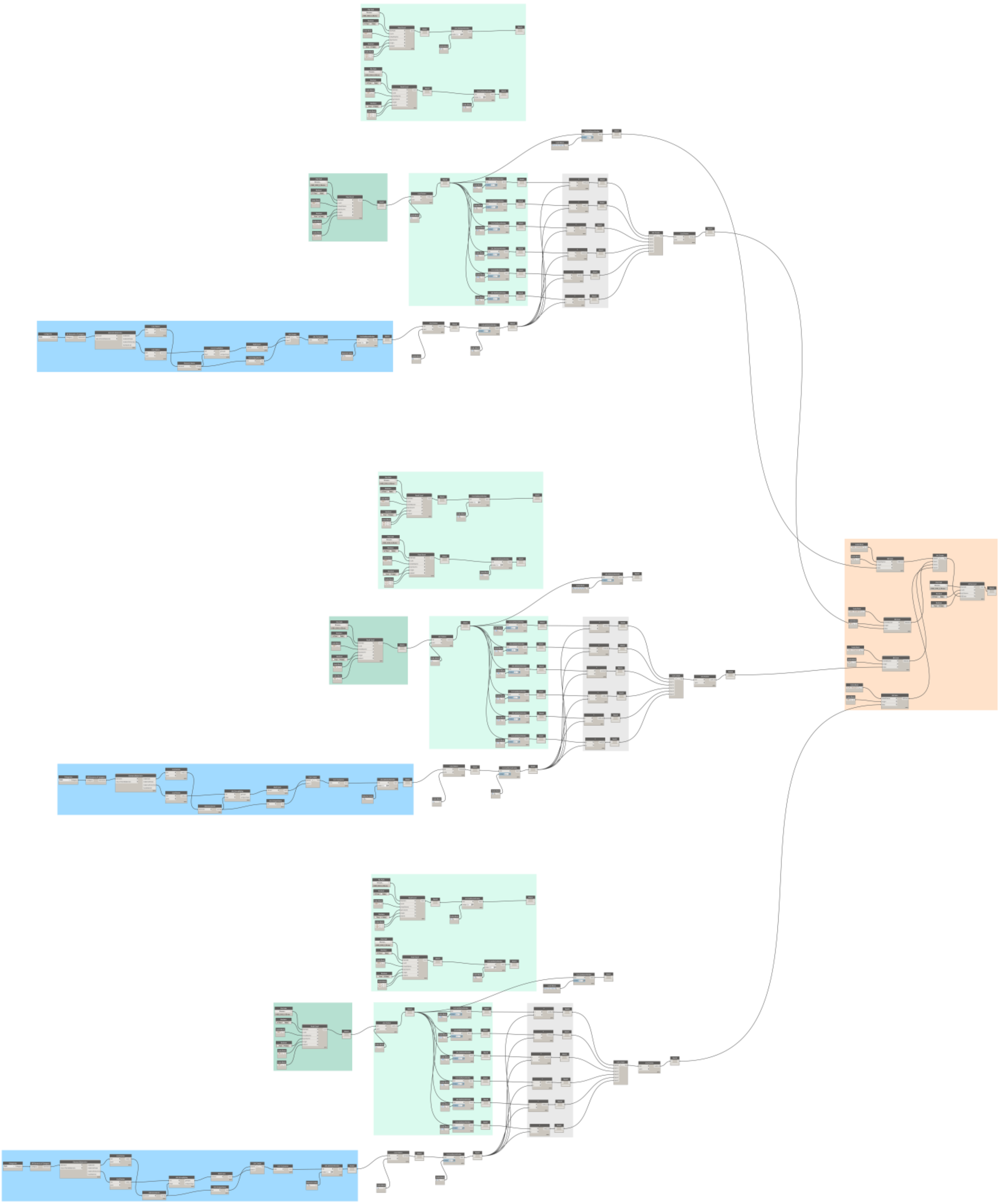
1	UUID	Version	Name	Kategorie	Typ	Bezugsgroesse	Bezugseinheit
23	d4680073-0c9c-40f4-842f-c6830856812c	00.03.000	Betonpflaster- Stan	Mineralische Baustoffe / Stein	average dataset	1	qm
24	1a7c1457-bbf6-4d40-a94d-1cac4d663baa	00.04.000	Betonpflasterstein	Mineralische Baustoffe / Stein	specific dataset	1	qm
25	284efda1-bb16-453a-bc32-070f3bab4cb3	00.03.000	Betonpflasterstein	Mineralische Baustoffe / Stein	specific dataset	1	qm
42	825fc872-5d02-40f2-a68b-fe71f11a817d	00.04.000	Calciumsulfat-Fließ	Mineralische Baustoffe / Binde	average dataset	1	kg
53	1b842259-9cfe-4e41-80b3-df0a11382984	00.03.000	Dachsteine	Mineralische Baustoffe / Stein	average dataset	1000	kg
55	ba0e47ef-b04a-4bbb-bc9d-dafc7b72edc2	00.04.000	Dachziegel Neufahr	Mineralische Baustoffe / Stein	average dataset	1000	kg
56	d2e01b0a-bfdf-412a-996e-20d592df0d5f	00.02.000	Durchschnittlicher Z	Mineralische Baustoffe / Binde	average dataset	1000	kg
72	573cebb5-2963-460f-8d61-0e3eecc1176e	00.05.000	Estrichelemente	Mineralische Baustoffe / Mört	average dataset	1	qm
141	eec9c184-852b-47e5-b380-7ae5af203b65	00.04.000	Dachziegel	Mineralische Baustoffe / Stein	average dataset	1000	kg
144	0689d6a3-cd7c-4710-9709-90fe747f60c0	00.02.000	HEBEL Bewehrter P	Mineralische Baustoffe / Mört	average dataset	1	m3
172	f7235d64-16e5-42d0-94c8-797a3cd6cd37	00.05.000	Kalksandstein	Mineralische Baustoffe / Stein	average dataset	1	kg
173	a2b5b7c9-db13-4dbd-be23-b0ff9f0cbd98	00.05.000	Keramische Fliesen	Mineralische Baustoffe / Stein	average dataset	1	qm
188	26bb2bb7-7bf6-434c-a3c7-1a4a87be9929	00.02.000	Knauf Safeboard GK	Mineralische Baustoffe / Stein	specific dataset	1	qm
194	da69c8d7-e90d-44be-893a-c5696dddba6f	00.02.000	Knauf Silentboard G	Mineralische Baustoffe / Stein	specific dataset	1	qm
204	f98eea66-671c-4014-bfbb-2db1ffba8331	00.03.000	Mauerziegel	Mineralische Baustoffe / Stein	average dataset	1	m3
219	8a7bcf84-f0a1-46fe-a146-4af9a182edfe	00.03.000	Mauerziegel (Dämm	Mineralische Baustoffe / Stein	average dataset	1	m3
270	2c127685-17be-41df-8cc4-1f3720813a7e	00.04.000	PCI Flexmörtel, PCI	Mineralische Baustoffe / Mört	average dataset	1	kg
274	c820c4a1-b7f6-4024-98d3-b737558988b8	00.03.000	PCI FT® Extra, PCI F	Mineralische Baustoffe / Mört	average dataset	1	kg
290	6f38efae-dc15-4667-96a4-1b87be6a80a5	00.04.000	PCI Nanofug, PCI N	Mineralische Baustoffe / Mört	average dataset	1	kg
294	285ae869-97d4-4032-8269-767c9371e71f	00.03.000	PCI Seccoral 1K	Mineralische Baustoffe / Mört	representative dataset	1	kg
298	0656d750-b06e-420c-b210-45ac7702d562	00.03.000	PCI Seccoral 2K Rap	Mineralische Baustoffe / Mört	average dataset	1	kg
399	f658f1b6-156a-4361-8dcb-cb1e67391551	00.03.000	Silka Kalksandstein	Mineralische Baustoffe / Stein	average dataset	1	m3

Q	R	S	T	U	V	W	X	Y	Z
Modul	GWP	ODP	POCP	AP	EP	ADPE	ADPF	PERE	PENRE
A1-A3	25.1	4.79E-10	0.00311	0.0366	0.00496	0.0000356	115	23.4	131
A1-A3	49.8	1.21E-09	0.00729	0.076	0.0104	0.0000745	260	40	285
A1-A3	18.1	9.12E-10	0.00271	0.0295	0.00389	0.0000277	98.4	11.9	110.3
A1-A3	0.111	7.08E-12	0.0000118	0.000173	0.0000252	3.75E-08	1.18	0.165	0.913
A1-A3	209	6.06E-09	0.0395	0.309	0.0364	0.000459	1210	158	1220
A1-A3	297.3	5.21E-09	0.0399	0.467	0.047	0.0000521	4699	436.2	4973
A1-A3	587	2.03E-07	0.12	0.75	0.187	0.00416	1830	360	2050
A1-A3	2.5	4.80E-11	0.000138	0.00396	0.000695	0.000169	36.4	7.82	38.7
A1-A3	350	1.12E-09	0.0417	0.338	0.0514	0.0000334	5320	385	5560
A1-A3	307.029	5.21E-09	0.0378786	0.341596	0.0412382	0.0002159	1953.44	346.646	2110.2
A1-A3	136	1.54E-09	0.00239	0.0893	0.0171	0.0000289	943	175	997
A1-A3	12.939	5.66E-10	0.0021046	0.024192	0.0026892	0.00011729	207.28	17.568	219.88
A1-A3	4.62	1.03E-10	0.00152	0.03044	0.00362	0.00040347	63.6	6.71646	66.4827
A1-A3	4.19953	7.63E-11	0.00141319	0.0282133	0.00351665	0.00040261	57.3982	8.34186	60.5117
A1-A3	138.294	1.46E-09	0.0131877	0.196732	0.0212094	7.13E-06	1219.76	261.372	1295.03

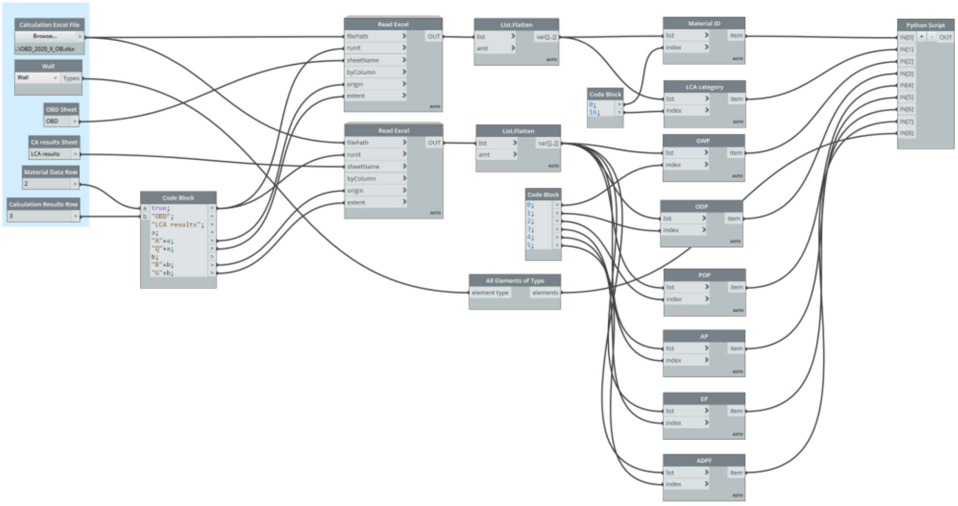
APPENDIX 2: DYNAMO SCRIPT CONCEPT

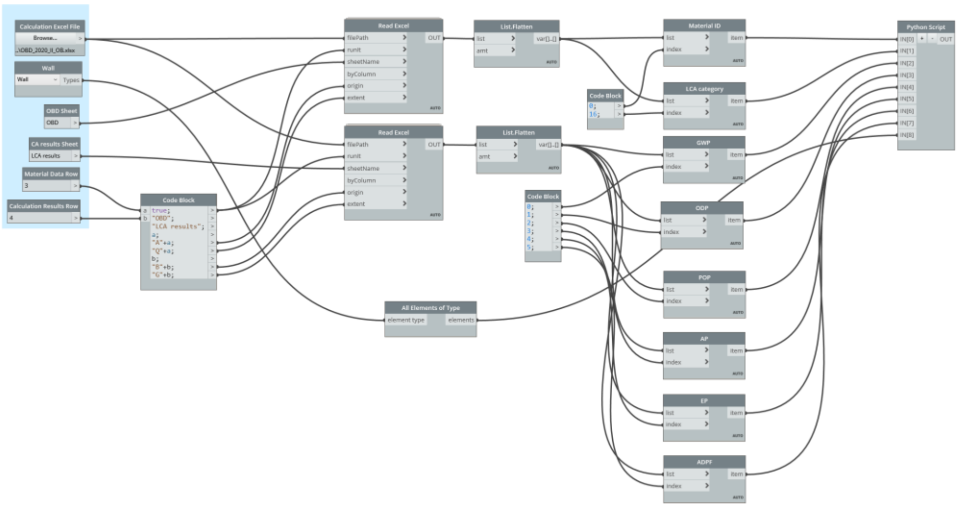


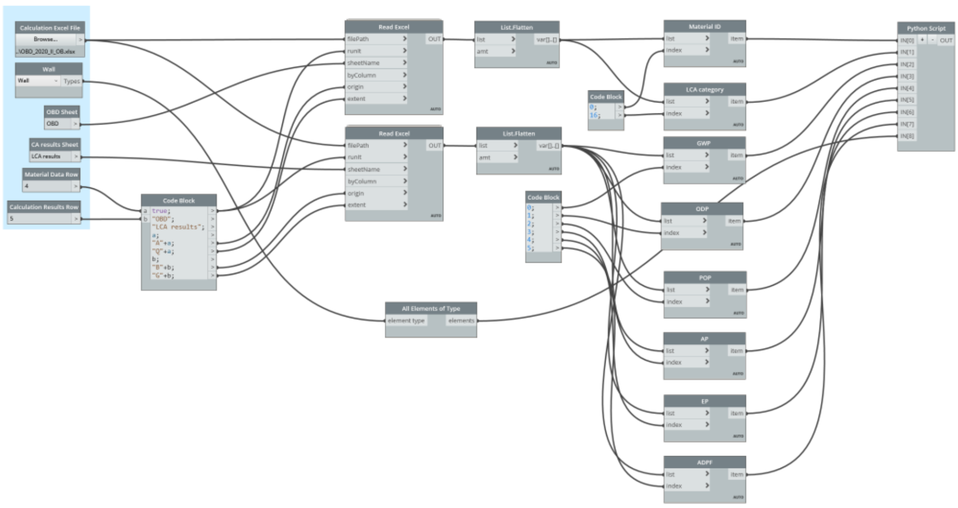
APPENDIX 3: DYNAMO SCRIPT FOR LCA CALCULATIONS AND EXCEL EXPORT



APPENDIX 4: DYNAMO SCRIPTS FOR ASSIGNING PARAMETERS TO THE MODEL







APPENDIX 5: FULL REPORT FROM ONE CLICK LCA (REVIT PLUGIN INTEGRATION)

9/6/2020 One Click LCA - LCA Made Easy

Main > Residential building > Residential 3 >Life-cycle assessment, EN-15978

Residential 3 - Life-cycle assessment, EN-15978 Project basic information

Result report: Residential 3

Project	Residential building - Residential 3
User	Orjola Braholli - 2020.09.06
Tool	Life-cycle assessment, EN-15978
Details	Building life-cycle assessment according to the European Standard EN 15978. This LCA software covers life cycle stages from cradle to grave with separate reporting to product stage, construction process, use stage, operational energy, and end of life. This LCA software and related datasets are compliant with ISO 14040/14044 or EN 15804. It is compliant with the Active House Specification requirements.
General information	
Type	Free-time residential buildings
Country	Italy
Address	Italy
Gross Floor Area (m²)	506
Number of above ground floors	2
Frame type	concrete

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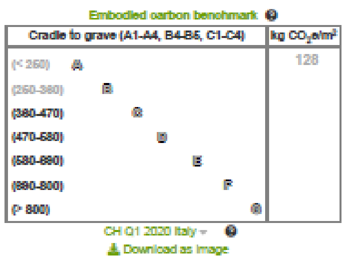
65 Tons CO_2e | 2.56 kg CO_2e / m2 / year | 3 243 € Social cost of carbon

Carbon Heroes Benchmark



Results

Help

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9/6/2020 One Click LCA - LCA Made Easy

Life-cycle assessment results

	Result category	Global warming kg CO_2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	
A1-A3	Construction Materials	5,37E4	5,67E1	8,2E0	8,44E−7	4,13E0	7,97E5	Details
A4	Transportation to site	7,23E2	3,33E0	7,25E−1	1,43E−4	4,08E−2	2,06E4	Details
A5	Construction/installation process							Hide empty
B1-B5	Maintenance and material replacement	9,28E3	9,13E0	2,45E0	1,12E−8	7,01E−1	1,82E5	Details
B6	Energy use							Hide empty
B7	Water use							Hide empty
C1-C4	Deconstruction	1,12E3	7,95E0	1,45E0	8,47E−9	7,8E−1	2,04E4	Details
D	External impacts (not included in totals)	−2,85E3	−4,72E0	−9,2E−1	−1,82E−6	−2,08E−1	−5,1E4	Details
	Total	**6,49E4**	**7,71E1**	**1,28E1**	**1,44E−4**	**5,65E0**	**1,02E6**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 506.0 m2	1,28E2	1,52E−1	2,53E−2	2,84E−7	1,12E−2	2,02E3	

Completeness (-) and plausibility checker (grade: E)

! **No scope selected for this design** ×

LCA Checker overall grade: E. Grade is based on data you have provided. ×

LCA Checker overall grade: E

LCA Checker checks the embodied impacts plausibility. These results reflect plausibility for 506.0 m2 project of type component evaluations only with frame type concrete frame with scope consisting of structure and enclosure, finishings and other materials. To edit these parameters open LCA Parameters query. The result is intended as indicative of the plausibility; and exceptions may occur.

No.	Check description	Project value	Threshold value	Typical value	Unit	Type	Validated ?
1	**Brick mass credible:** Brick mass is unusual	409.205	0.0 - 100		kg/m2	✖	
2	**Finishes mass credible:** Has no materials	0.0	greater than 10		kg/m2	✖	
3	**Concrete mass credible (concrete frame):** Has no materials	0.0	700 - 1650		kg/m2	✖	
4	**Insulation mass credible:** Has no materials	0.0	1 - 21		kg/m2	✖	
5	**Glass and openings mass credible:** Has no materials	0.0	2 - 25		kg/m2	✖	
6	**Horizontal materials mass:** Has no materials	0.0	100 - 1300		kg/m2	✖	
7	**Glass mass credible:** Has no materials	0.0	1 - 13		kg/m2	✖	
8	**Roofing bitumen mass credible:** Has no materials	0.0	0.5 - 4		kg/m2	✖	
9	**Gypsum board mass credible:** Gypsum board mass is unusual	75.603	3 - 40		kg/m2	✖	
10	**Too few materials to be credible:** Project has unusually little data	6	greater than 20		nr.	✖	
11	**Too dominant single material:** Project has single too dominant input to be credible	77.353	less than 50		%	✖	
12	**Project mass credible (concrete frame):** Project mass is unusual (concrete frame)	514.066	800 - 1900		kg/m2	✖	
13	**Embodied carbon credible (concrete frame):** Embodied carbon value is unusual (concrete frame)	106.173	150 - 800		kg CO2e/m2	✖	
14	**Gypsum board and plaster mass credible (no cement):** Value seems unusual but is within allowable deviation range	81.067	0.0 - 80		kg/m2	⚠	
	Validated checks						

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No.	Check description	Project value	Threshold value	Typical value	Unit	Type	Validated ?
15	Structure mass credible	514.066	greater than 150		kg/m2	✓	
16	Replacements share credible	17.275	10 - 100		%	✓	
17	Vertical materials mass	514.066	50 - 700		kg/m2	✓	
18	Wood mass credible (concrete frame)	0.0	0.0 - 50		kg/m2	✓	
19	Mortar mass credible	5.464	0.4 - 50		kg/m2	✓	

Most contributing materials (Global warming)

No.	Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)	Sustainable alternatives
1.	Wall bricks ?	42 tons CO_2e	77.4 %	show sustainable alternatives
2.	Gypsum cardboard ?	6,1 tons CO_2e	11.3 %	show sustainable alternatives
3.	Stoneware tiles glazed ?	3,2 tons CO_2e	6.0 %	show sustainable alternatives
4.	Gypsum plaster board, perforated ?	2,6 tons CO_2e	4.9 %	show sustainable alternatives
5.	Lime cement mortar ?	0,27 tons CO_2e	0.5 %	show sustainable alternatives
6.	Oriented strand board (OSB), generic ?	tons CO_2e	0.0 %	show sustainable alternatives

Graphs

Life-cycle overview of Global warming

Pie Bar Column Treemap

9/6/2020 One Click LCA - LCA Made Easy

Show data table: ☑ Global warming - Life-cycle stages ☐ Global warming - Classifications ☐ Global warming - Resource types ☐ Mass - Classifications

Global warming - Life-cycle stages

Item	Value	Unit	Percentage %
A1-A3 Materials	54 000	kg CO_2e	82.84 %
A4 Transportation	720	kg CO_2e	1.11 %
B1-B5 Maintenance and replacement	9 300	kg CO_2e	14.31 %
C1-C4 End of life	1 100	kg CO_2e	1.73 %

Global warming - Classifications

Item	Value	Unit	Percentage %
External walls and facade	65 000	kg CO_2e	100.0 %

Global warming - Resource types

Item	Value	Unit	Percentage %
Bricks and ceramics	49 000	kg CO_2e	75.84 %
Gypsum, plaster & cement	16 000	kg CO_2e	24.16 %

Mass - Classifications

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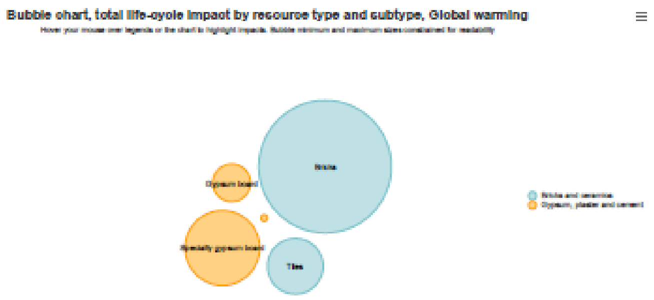
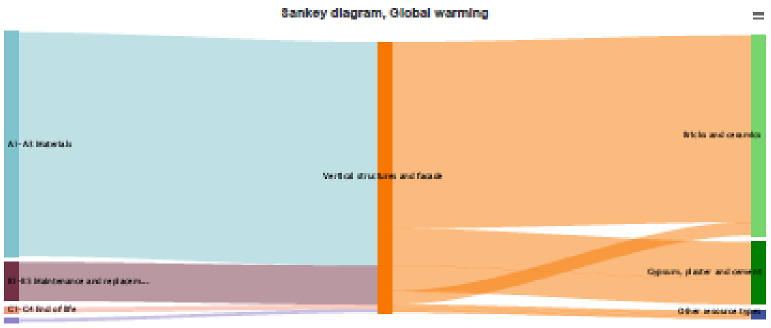
Item	Value	Unit	Percentage %
External walls and facade	300 000	kg	100.0 %

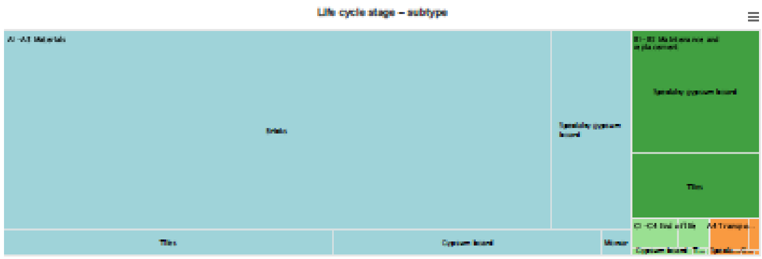


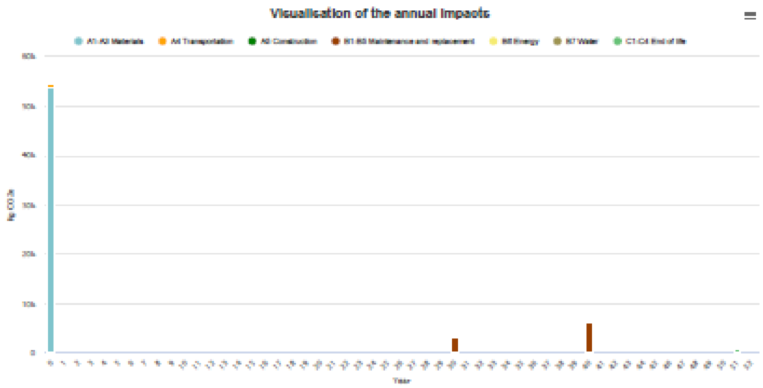
Configure your chart



Treemap , Global warming

9/6/2020 One Click LCA - LCA Made Easy





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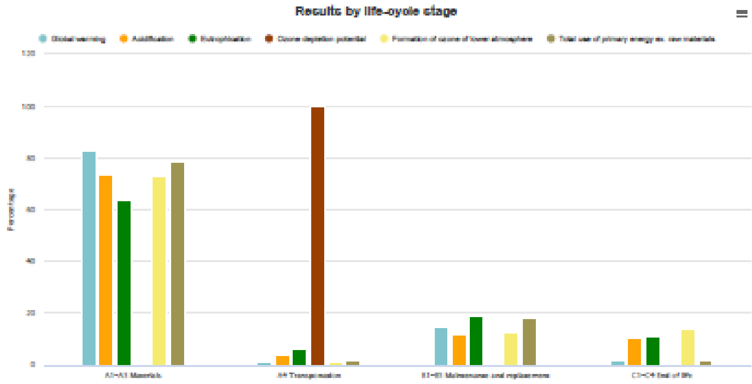
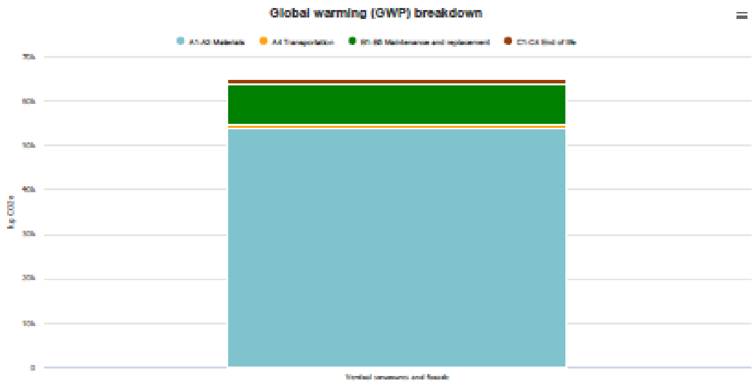
9/6/2020 One Click LCA - LCA Made Easy





Show breakdowns for all categories

Data sources

https://www.360optimi.com/app/sec/design/results?entityId=5f53f0de2ae48158e4fe7290&childEntityId=5f55305d9e52d71e50b7216d&indicatorId=Buil… 7/8

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Sources

Resource name	Technical specification	Product	Manufacturer	EPD program	EPD number	Environment Data Source	Standard	Verification	Year	Country	Upstream database	Density	Product Category Rules (PCR)	N al P
Gypsum cardboard	25 mm, 20 kg/m2, 800 kg/m3			OKOBAUDAT	-	Oekobau.dat 2017-I	EN15804	verified	2016	[germany]	GaBi	800.0	EN15804	-
Gypsum plaster board, perforated	12.5mm, 8.5 kg/m2, 680 kg/m3			OKOBAUDAT	-	Oekobau.dat 2017-I	EN15804	verified	2016	[germany]	GaBi	680.0	EN15804	-
Lime cement mortar	1800 kg/m3			OKOBAUDAT	-	Oekobau.dat 2017-I	EN15804	verified	2016	[germany]	GaBi	1800.0	EN15804	-
Oriented strand board (OSB), generic	9.5-28.5 mm (0.37-1.12 in), 610 kg/m3 (38.1 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	610.0	EN15804	-
Stoneware tiles glazed	10 mm, 20.0 kg/m2, 2000 kg/m3			OKOBAUDAT	-	Oekobau.dat 2017-I	EN15804	verified	2016	[germany]	GaBi	2000.0	EN15804	-
Wall bricks	575 kg/m3		Ziegel	IBU	EPD-AMZ-20140244-IOG1-DE	Oekobau.dat 2017-I, EPD Mauerziegel Arbeitsgemeinschaft Mauerziegel	EN15804	Verified	2015	[germany]	GaBi	575.0	PCR Ziegel, 07/2014	O E

https://www.360optimi.com/app/sec/design/results?entityId=5f53f0de2ae48158e4fe7290&childEntityId=5f55305d9e52d71e50b7216d&indicatorId=Buil... 8/8

APPENDIX 6: FULL REPORT FROM ONE CLICK LCA (IFC EXPORT)

Main > Residential building 4 > Residential building 4 >Life-cycle assessment, EN-15978

Residential building 4 - Life-cycle assessment, EN-15978 Project basic information

Result report: Residential building 4

Project	Residential building 4 - Residential building 4
User	Orjola Braholli - 2020.09.07
Tool	Life-cycle assessment, EN-15978
Details	Building life-cycle assessment according to the European Standard EN 15978. This LCA software covers life cycle stages from cradle to grave with separate reporting to product stage, construction process, use stage, operational energy, and end of life. This LCA software and related datasets are compliant with ISO 14040/14044 or EN 15804. It is compliant with the Active House Specification requirements.
General information	
Type	Free-time residential buildings
Country	Italy
Address	Italy
Gross Floor Area (m²)	506
Number of above ground floors	2
Frame type	concrete

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156 Tons CO_2e 6.16 kg CO_2e / m2 / year 7 796 € Social cost of carbon

Carbon Heroes Benchmark

Embodied carbon benchmark

Cradle to grave (A1-A4, B4-B5, C1-C4)		kg CO_2e/m^2
(< 260)	A	
(260-380)	B	308
(380-470)	C	
(470-580)	D	
(580-690)	E	
(690-800)	F	
(> 800)	G	

CH Q1 2020 Italy

Download as image

Results

Help

9/10/2020 One Click LCA - LCA Made Easy

Life-cycle assessment results

	Result category	Global warming kg CO_2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	
A1-A3	Construction Materials	1,47E5	2,57E2	3,27E1	4,69E−4	4,62E1	2,76E6	Details
A4	Transportation to site	1,56E3	7,18E0	1,56E0	3,08E−4	8,79E−2	4,44E4	Details
A5	Construction/Installation process							Hide empty
B1-B5	Maintenance and material replacement							Hide empty
B6	Energy use							Hide empty
B7	Water use							Hide empty
C1-C4	Deconstruction	7,52E3	2,43E1	5,83E0	1,4E−3	6,76E−1	1,84E5	Details
D	External impacts (not included in totals)	−9,48E3	−1,65E1	−3,77E0	−4,95E−5	−7,8E−1	−1,47E5	Details
	Total	**1,56E5**	**2,88E2**	**4E1**	**2,18E−3**	**4,69E1**	**2,99E6**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 506.0 m2	3,08E2	5,7E−1	7,92E−2	4,3E−6	9,27E−2	5,9E3	

Completeness (-) and plausibility checker (grade: E)

! No scope selected for this design ×

LCA Checker overall grade: E. Grade is based on data you have provided. ×

LCA Checker overall grade: E

LCA Checker checks the embodied impacts plausibility. These results reflect plausibility for 506.0 m2 project of type new construction, whole building with frame type concrete frame with scope consisting of structure and enclosure, finishings and other materials. To edit these parameters open LCA Parameters query. The result is intended as indicative of the plausibility; and exceptions may occur.

No.	Check description	Project value	Threshold value	Typical value	Unit	Type	Validated ?
1	**Brick mass credible:** Brick mass is unusual	1174.512	0.0 - 100		kg/m2	×	
2	**Finishes mass credible:** Has no materials	0.0	greater than 10		kg/m2	×	
3	**Insulation mass credible:** Has no materials	0.0	1 - 21		kg/m2	×	
4	**Glass and openings mass credible:** Has no materials	0.0	2 - 25		kg/m2	×	
5	**Horizontal materials mass:** Has no materials	0.0	100 - 1300		kg/m2	×	
6	**Gypsum board mass credible:** Has no materials	0.0	3 - 40		kg/m2	×	
7	**Glass mass credible:** Has no materials	0.0	1 - 13		kg/m2	×	
8	**Roofing bitumen mass credible:** Has no materials	0.0	0.5 - 4		kg/m2	×	
9	**Vertical materials mass:** Vertical materials mass is unusual	1341.025	50 - 700		kg/m2	×	
10	**Too dominant single material:** Project has single too dominant input to be credible	93.784	less than 50		%	×	
11	**Concrete mass credible (concrete frame):** Concrete mass is unusual	166.055	700 - 1650		kg/m2	×	
12	**Too few materials to be credible:** Project has unusually little data	5	greater than 20		nr.	×	
Validated checks							
13	**Structure mass credible**	1341.025	greater than 150		kg/m2	✓	
14	**Embodied carbon credible**	308.06	150 - 1000		kg CO2e/m2	✓	
15	**Project mass credible**	1341.025	300 - 3500		kg/m2	✓	

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9/10/2020 One Click LCA - LCA Made Easy

No.	Check description	Project value	Threshold value	Typical value	Unit	Type	Validated ?
16	Project mass credible (concrete frame)	1341.025	800 - 1900		kg/m2	✓	
17	Gypsum board and plaster mass credible (no cement)	0.457	0.0 - 80		kg/m2	✓	
18	Embodied carbon credible (concrete frame)	290.11	150 - 800		kg CO2e/m2	✓	
19	Wood mass credible (concrete frame)	0.001	0.0 - 50		kg/m2	✓	
20	Mortar mass credible	0.457	0.4 - 50		kg/m2	✓	

Most contributing materials (Global warming)

No.	Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)	Sustainable alternatives
1.	Bricks ?	138 tons CO_2e	93.8 %	show sustainable alternatives
2.	Precast concrete wall elements (solid, uninsulated), generic ?	8,5 tons CO_2e	5.8 %	show sustainable alternatives
3.	Precast concrete wall elements (solid, uninsulated), generic ?	0,53 tons CO_2e	0.4 %	show sustainable alternatives
4.	Mortar, cementitious, for waterproofing/surface protection ?	0,17 tons CO_2e	0.1 %	show sustainable alternatives
5.	Oriented strand board (OSB), generic ?	0 tons CO_2e	0.0 %	show sustainable alternatives

Graphs

Life-cycle overview of Global warming

Pie Bar Column Treemap

https://www.360optimi.com/app/sec/design/results?entityId=5f5658ae9e52d71e50bdbaaa&childEntityId=5f5658d89e52d71e50bdbb05&indicatorId=Bu… 3/8

9/10/2020 One Click LCA - LCA Made Easy

Show data table: ☐ Global warming - Life-cycle stages ☐ Global warming - Classifications ☐ Global warming - Resource types ☐ Mass - Classifications

Global warming - Life-cycle stages

Item	Value	Unit	Percentage %
A1-A3 Materials	150 000	kg CO_2e	94.17 %
A4 Transportation	1 600	kg CO_2e	1.0 %
C1-C4 End of life	7 500	kg CO_2e	4.83 %

Global warming - Classifications

Item	Value	Unit	Percentage %
External walls and facade	160 000	kg CO_2e	100.0 %

Global warming - Resource types

Item	Value	Unit	Percentage %
Bricks and ceramics	150 000	kg CO_2e	93.4 %
Concrete	10 000	kg CO_2e	6.49 %
Gypsum, plaster & cement	170	kg CO_2e	0.11 %
Wood	0,29	kg CO_2e	0.0 %

https://www.360optimi.com/app/sec/design/results?entityId=5f5658ae9e52d71e50bdbaaa&childEntityId=5f5658d89e52d71e50bdbb05&indicatorId=Bu… 4/8

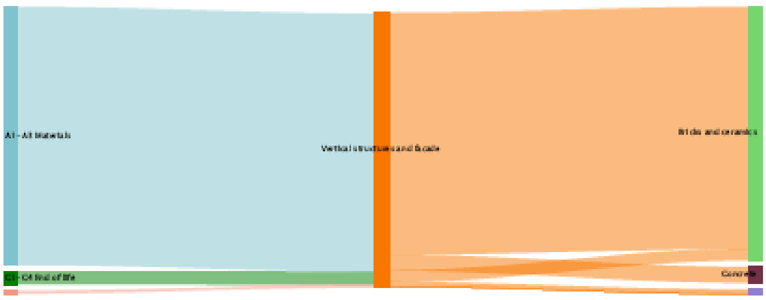
Mass - Classifications

Item	Value	Unit	Percentage %
External walls and facade	580 000	kg	100.0 %

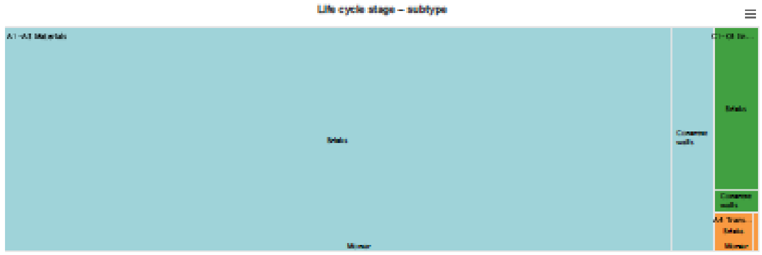
Bubble chart, total life-cycle impact by resource type and subtype, Global warming

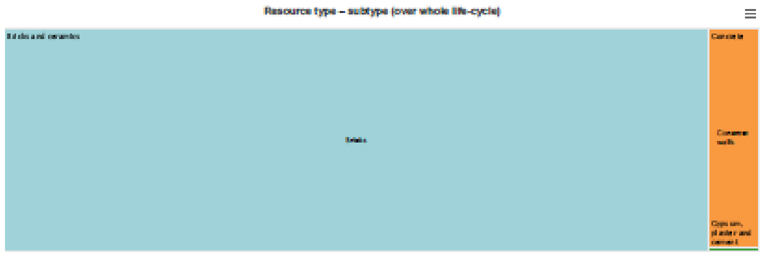
Configure your chart

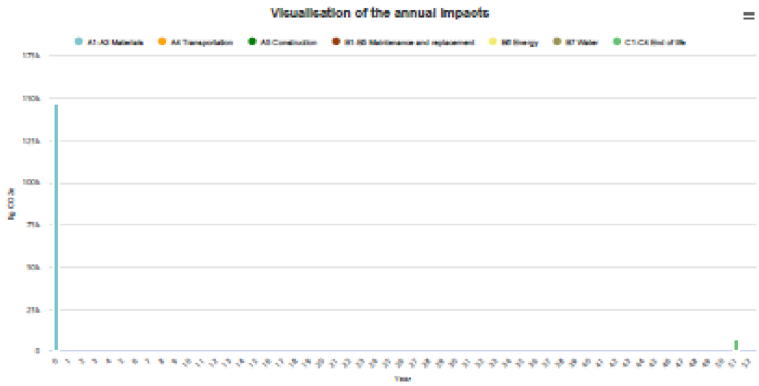
Sankey diagram, Global warming

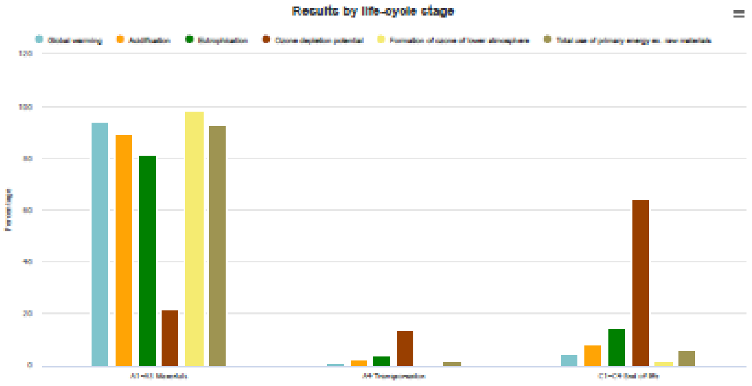


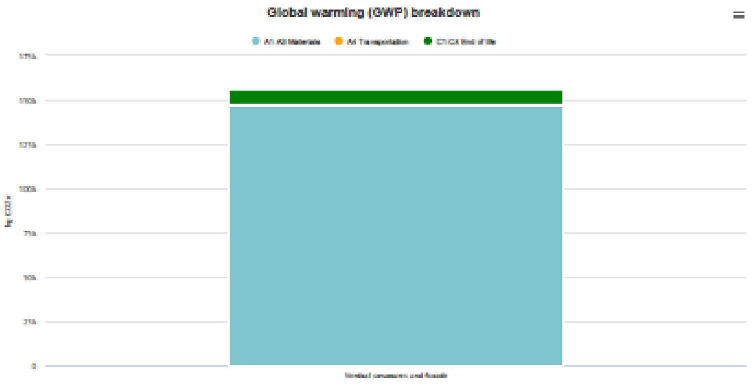
Treemap , Global warming


Life cycle stage – subtype


Resource type – subtype (over whole life-cycle)


Visualisation of the annual impacts





+ Show breakdowns for all categories

Data sources

Sources

Resource name	Technical specification	Product	Manufacturer	EPD program	EPD number	Environment Data Source	Standard	Verification	Year	Country	Upstream database	Density	Product Category Rules (PCR)
Bricks	226x104x60, 226x85x60 mm	NF with holes & solid, RF	Wienerberger	IBU	EPDWIE-20130206-IAB1EN	Bricks Wienerberger AS	EN15804	Verified	2014	[germany]	GaBi	1700.0	PCR Brid 07/2013
Mortar, cementitious, for waterproofing/surface protection	1700 kg/m3 (mixture), 2200 kg/m3 (with spray)	Mapelastic	Mapei	International EPD System	S-P-00912	EPD for Mapelastic, Mapelastic Smart, Mapelastic Foundation, Mapelastic Turbo	EN15804	Verified	2016	[italy]	GaBi	1700.0	PCR 2012:01 Construct products and Construct services, 2.01, 09/03/201
Oriented strand board (OSB), generic	9.5-28.5 mm (0.37-1.12 in), 610 kg/m3 (38.1 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	610.0	EN15804
Precast concrete wall elements (solid, uninsulated), generic	C30/37 (4400/5400 PSI), 40% recycled binders in cement (300 kg/m3 / 18.72 lbs/ft3), incl. reinforcement			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	2400.0	EN15804
Precast concrete wall elements (solid, uninsulated), generic	C40/50 (5800/7300 PSI), 20% recycled binders in cement (400 kg/m3 / 24.97 lbs/ft3), incl. reinforcement			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	2400.0	EN15804

APPENDIX 7: FULL REPORT FROM TALLY

Project Name

9/7/2020

Full building summary

Table of Contents

Project Name

Full building summary

9/7/2020

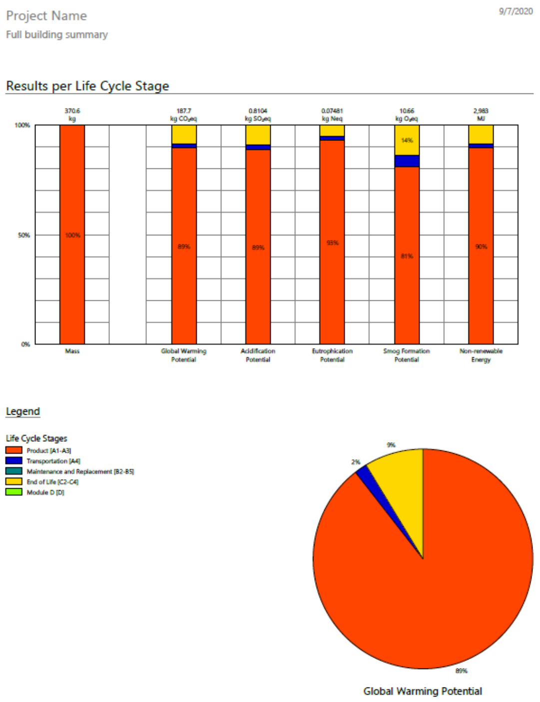
Report Summary

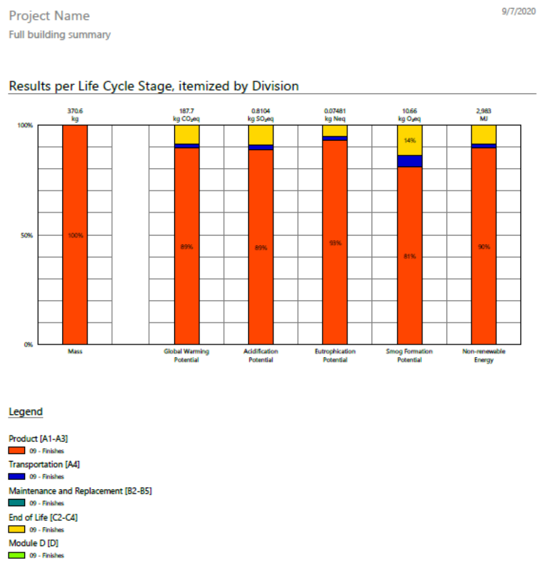
Created with Tally
Non-commercial Version 2020.06.09.01

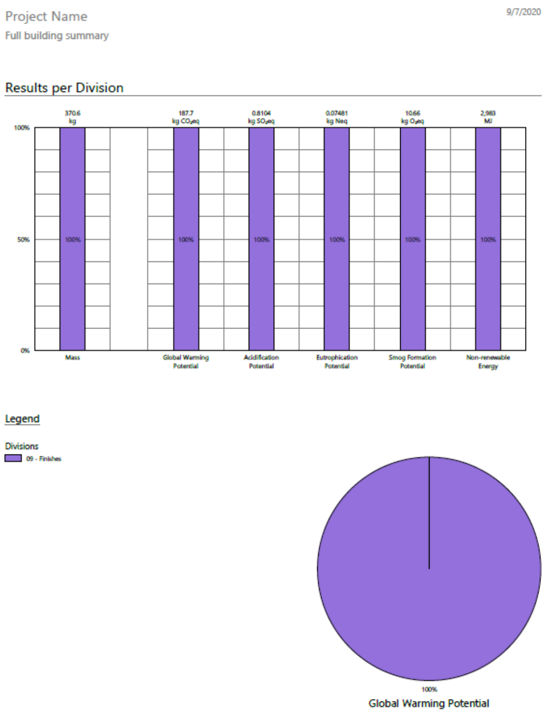
Author	orjola.braholli
Company	BIMA+
Date	9/7/2020
Project	Project Name
Location	Italy
Gross Area	506 m^2
Building Life	50 years
Boundaries	Cradle to grave, inclusive of biogenic carbon; see appendix for a full list of materials and processes

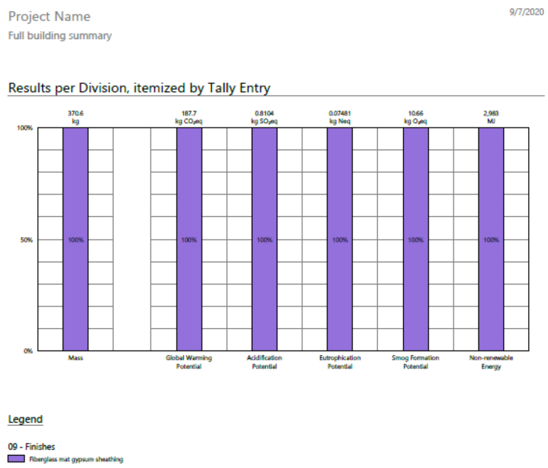
Goal and Scope of Assessment
.

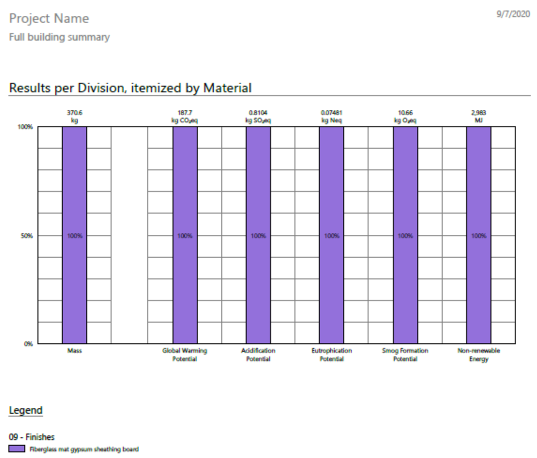
Environmental Impact Totals	**Product Stage [A1-A3]**	**Construction Stage [A4]**	**Use Stage [B2-B5]**	**End of Life Stage [C2-C4]**	**Module D [D]**
Global Warming (kg CO_2eq)	167.9	3.481	0	16.31	0
Acidification (kg SO_2eq)	0.719	0.01613	0	0.07524	0
Eutrophication (kg Neq)	0.06968	0.001313	0	0.003818	0
Smog Formation (kg O_3eq)	8.636	0.5329	0	1.494	0
Ozone Depletion (kg CFC-11eq)	7.190E-006	1.192E-013	0	2.998E-012	0
Primary Energy (MJ)	3,102	50.62	0	279.5	0
Non-renewable Energy (MJ)	2,672	49.41	0	261.3	0
Renewable Energy (MJ)	433.6	1.224	0	18.42	0
Environmental Impacts / Area					
Global Warming (kg CO_2eq/m^2)	0.3318	0.006879	0	0.03223	0
Acidification (kg SO_2eq/m^2)	0.001421	3.187E-005	0	1.487E-004	0
Eutrophication (kg Neq/m^2)	1.377E-004	2.595E-006	0	7.545E-006	0
Smog Formation (kg O_3eq/m^2)	0.01707	0.001053	0	0.002952	0
Ozone Depletion (kg CFC-11eq/m^2)	1.421E-008	2.356E-016	0	5.926E-015	0
Primary Energy (MJ/m^2)	6.131	0.1	0	0.5523	0
Non-renewable Energy (MJ/m^2)	5.281	0.09764	0	0.5164	0
Renewable Energy (MJ/m^2)	0.857	0.002419	0	0.0364	0

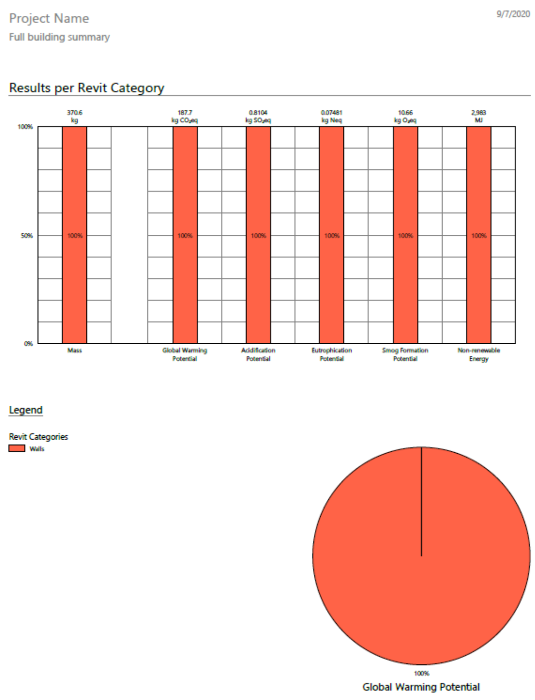

Project Name
9/7/2020
Full building summary
Results per Life Cycle Stage
370.6 kg
187.7 kg CO2eq
0.8104 kg SO2eq
0.07481 kg Neq
10.66 kg O3eq
2,983 MJ
100%
50%
0%
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
Life Cycle Stages
Product [A1-A3]
Transportation [A4]
Maintenance and Replacement [B2-B5]
End of Life [C2-C4]
Module D [D]
9%
2%
89%
Global Warming Potential

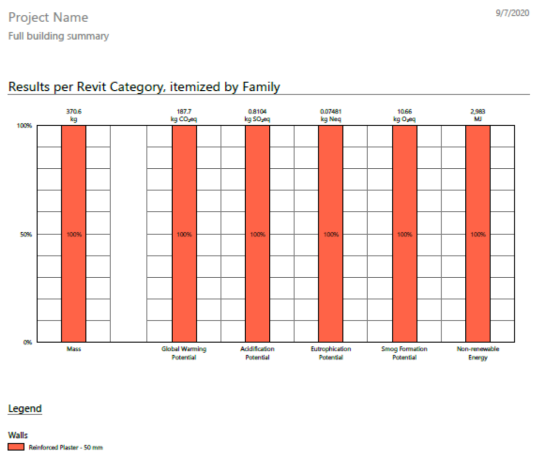

Project Name
9/7/2020
Full building summary
Results per Life Cycle Stage, itemized by Division
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
Product [A1-A3]
09 - Finishes
Transportation [A4]
09 - Finishes
Maintenance and Replacement [B2-B5]
09 - Finishes
End of Life [C2-C4]
09 - Finishes
Module D [D]
09 - Finishes

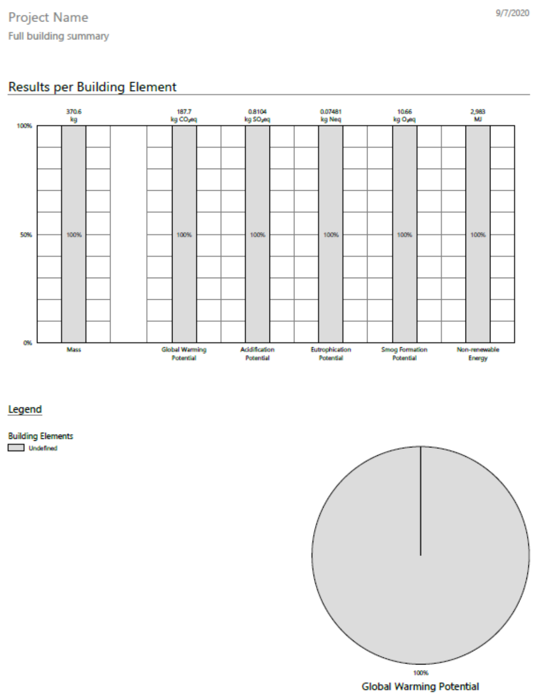

Project Name
9/7/2020
Full building summary
Results per Division
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
Divisions
09 - Finishes
100%
Global Warming Potential


Project Name
9/7/2020
Full building summary
Results per Division, itemized by Tally Entry
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
09 - Finishes
Fiberglass mat gypsum sheathing


Project Name
9/7/2020
Full building summary
Results per Division, itemized by Material
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
09 - Finishes
Fiberglass mat gypsum sheathing board


Project Name
9/7/2020
Full building summary
Results per Revit Category
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
Revit Categories
Walls
Global Warming Potential


Project Name
9/7/2020
Full building summary
Results per Revit Category, itemized by Family
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
Walls
Reinforced Plaster - 50 mm


Project Name
9/7/2020
Full building summary
Results per Building Element
Mass
Global Warming Potential
Acidification Potential
Eutrophication Potential
Smog Formation Potential
Non-renewable Energy
Legend
Building Elements
Undefined
Global Warming Potential