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Carbon footprint of construction products

A comparison of application of individual Environmental Product Declarations and Building Information Modeling software

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The purpose of this study was to investigate the benefits of using software for calculating cradle-to-gate carbon footprint of selected construction products. The assessment of environmental impacts, such as carbon footprint calculation of building materials and assemblies is important, because buildings consume 40% of raw materials globally, and their service lifetime is several decades. A cradle-to-gate carbon footprint calculation was carried out for the same building's selected construction parts by using individually sourced Environmental Product Declarations (EPDs) and by using a Building Information Modeling software. The total greenhouse gas emissions for the seven selected parts resulting from the software's calculation were 41% less compared to the result given by the individual EPDs. However, the software was proved to be fast working, user-friendly and easy to use. The thesis concludes that using product specific EPDs are important when calculating carbon footprint, as different products within the same construction product category have significantly varying greenhouse gas emission rate due to differing country of origin and manufacturing technologies. Further extending the available EPDs in the software database would give a reliable, state-of-the-art application to measure real-life data of carbon footprint of building materials and assemblies.

Keywords	carbon footprint, BIM, EPD, construction product

Contents

1 Introduction

According to the data presented at Statistics Finland, building permits were granted for 30 million cubic meters last year in Finland. Therefore, it is important to make buildings sustainable as they have a huge intake of raw material and electricity over their life time. Buildings under construction in 2015 will be standing until 2100; therefore their design has an effect for decades. Meanwhile buildings are becoming more and more complex structures, and the legislations in order to issue building permits are becoming stricter, more demanding and more stringent year after year. Buildings not only absorb raw materials and energy, but meanwhile they also emit pollutants to soil, water and air starting from their design phase until being demolished. Therefore, it is inevitable to assess their environmental impacts right at the planning phase to avoid any inefficient and ineffective processes and technologies, and use only energy efficient technologies with low emission values to minimize the burden that a building might impose on the environment.

The purpose of this thesis is to compare two different methods of applying cradle-to-gate carbon footprint calculations for selected building materials and assemblies. One of the methods is based on individually sourced Environmental Product Declarations (EPDs), while the other method is a Building Information Modeling (BIM) based cloud software which has inbuilt EPDs. The thesis will show the advantages and disadvantages of both by applying them for seven selected building materials and assemblies, and then make suggestions how the benefits of both methods could be implemented in the future.

In order to support and describe these findings, the Theoretical Background chapter will introduce and describe the concepts used in this thesis, such as Environmental Product Declaration and Building Information Modeling. It will also present the legislative background used in the European Union for calculating carbon footprint and life cycle assessment of buildings. It will also describe these techniques to better understand how they are made, their complexity and why the two methods presented in this thesis have a potential and feasibility in the future. The thesis will also illustrate in the Theoretical Background chapter the necessity of assessing the environmental impacts of buildings and building materials, and where these assessments are adopted, such as building rating systems, like LEED and BREEAM.

2 Theoretical Background

2.1 Sustainable buildings

In 1987, the World Commission on the Environment and Development published a report, titled Our Common Future to the United Nations (UN) where they defined sustainable development. According to it, “Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs”.

According to the Sustainable Buildings & Climate Initiative (SBCI) issued by the United Nations Environment Programme (UNEP), the building sector is responsible for 30% of the greenhouse gas (GHG) emissions globally and consumes more than 40% of the world’s energy. The building sector also consumes 40% of raw materials globally and generates 136 million tons of waste each year only in the USA (Keeler, 2009). Buildings contribute to air, water and soil pollution, to ozone depletion and to global warming. The U.S Green Building Council (USGBC) states that the building sector emits 39% of the total carbon dioxide (CO_2) emissions in the USA which is more than of the other two sectors, transportation and industry separately. From the 40% energy consumption, 10-20% is consumed by materials, for their manufacturing, transportation, construction, renovation and demolition. This energy consumed by the materials is called embodied energy, which can differ from one type of material to another. The remaining 80-90% of energy is consumed in the use stage of the building, while 1% is at the end of life stage. The currently built buildings will be standing until 2115, as the lifetime of a building situated in Finland is considered to be 100 years (Bribián et al., 2011). The currently built buildings will have effect on the next century when they will be demolished. Therefore, it is important to plan ahead for the future and choose energy efficient, recyclable materials and solutions for the buildings.

The positive side is that UNEP predicts a possible 30% energy and emission reduction by sustainable buildings. Compared to the European Union’s (EU’s) appointed targets called Europe 2020, these goals are not only a possibility, but they are a must for EU member states. According to these targets, the GHG emissions have to be reduced by 20% of the 1990’s emission level. Renewable energy has to contribute at least 20% to the total gross energy consumption, and energy efficiency has to be increased to 20%, which means that the given member state’s total energy consumption has to be reduced by 20%. The last target is especially important for the building sector, as it has been described earlier the sector consumes at least 40% of the total energy. Figure 1 shows that in the EU the share of buildings, both industrial and domestic from the total energy consumption reaches 44%.

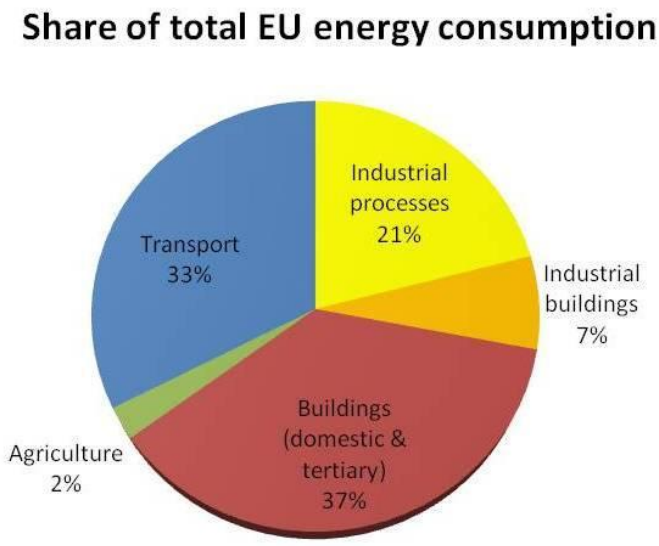

Figure 1: Share of total EU energy consumption, source: glassforeurope.com

In order to fulfil the Europe 2020 targets, sustainable buildings have to be built. A sustainable building means that it uses the resources in a more efficient way compared to a conventional one. A sustainable building uses less potable water, less energy, generates less waste. It takes into consideration the whole life cycle of the building at all levels. It also considers the impacts and emissions pre-construction and during deconstruction. Meanwhile it has low embodied energy, has a healthy indoor environment for the occupants and it is easily accessible by public transportation. Regarding sustainable building construction materials, some of the features are durability, low embodied energy, recycled content, recyclability, packaging, resource composition and low maintenance (Keeler, 2009). As a result LEED (Leadership for Energy and Environmental Design) certified buildings might save 30% energy, use 30-35% less potable water and generate 50-97% less landfill wastes compared to conventional buildings (Krygiel, 2008).

The ultimate goal for sustainable buildings would be to reach the Living Building Certificate (Krygiel, 2008; Keeler, 2009) where the building does not generate any pollution to soil, air, nor to water, cleans its own waste, and provides its own energy and water. By these it can possibly reach “net zero water” and “net zero energy” titles. It mitigates impacts during both design and construction phases to reduce any further impacts it might have over its use phase.

2.2 Rating Systems

To measure and compare different buildings several rating systems were invented. These rating systems came to life due to globalization, consumer awareness and due to the expectations of the earlier mentioned sustainable development. For companies it might be important to have a certified office building as it is associated with good reputation, shows social responsibility, environmental awareness, and ensures a healthy working environment for its workers. It also wins consumers and partners as more and more customer prefers to engage in business with companies that are conscious about climate change and other impacts related to the environment. For governments it is also important to have such rating systems as like in the USA the LEED Rating System is often used by the city councils to regulate what kind of buildings can be built in the area (Krygiel, 2008). In the USA certain cities only let buildings with Gold or Platinum LEED Certificate to be built; therefore only plans about high-performing buildings get the building permits.

The rating systems set the guidelines and target efficiencies for sustainable buildings all over the world. The most notable advantages of the rating systems are that they are transparent, measurable, quantifiable and verifiable (Keeler, 2009; Fowler, 2006). It stimulates the sector and the market to change as the demand for certified buildings is increasing. The disadvantages of the rating systems are that they only require minimal performance; have the same requirements globally and do not take into account the local differences. Some critics say that they are upright unnecessary as the current state of the environment and consequences of the climate change would require these qualities from a modern building regardless of any rating systems (Keeler, 2009).

Some countries invented their own rating system while others use international systems. The two most well-known and widely used rating systems are BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design). Both have several rating systems depending on the type of the building, like schools, industrial buildings or hospitals. Both use similar methodology and include the same aspects. These aspects include energy and water use, transportation, waste and pollution generation, indoor environment quality. The certificates can be awarded to already existing buildings and buildings that are only in their design stage.

2.2.1 LEED Certification

The LEED Certification System was developed by the USGBC; currently the LEED 2009 is in force. In the certification process buildings have to collect points and the certificate is awarded according to the number of points they have reached. The total available points are 110 including 10 extra points. The certification levels are Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+ points). There are five categories and two extra categories for the ten extra points. Each category has at least one prerequisite that is not worth any points but is required for the final certification. The categories have credits that are worth points, some only one point while other credits are worth five or six points. The point system uses the U.S. Environmental Protection Agency's (EPA's) Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts' (TRACI's) environmental impact categories and then each credit's weight was determined (Cottrell, 2011). TRACI uses the following impact categories amongst others: acidification, smog formation, eutrophication, human cancer, human non-cancer, and human criteria effects. Above the prerequisites there are minimum program requirements that have to be fulfilled by each submitted design. These requirements are to be in compliance with the regional environmental laws, to have minimum floor area and minimum occupancy rate.

The categories of the LEED Certificate are as follows (for detailed list see Appendix 1):

- Site Selection (SS – total 26 points),
- Water Efficiency (WE – total 10 points),
- Energy & Atmosphere (EA – total 35 points),
- Material & Resources (MR – total 14 points),
- Indoor Environmental Quality (IEQ – total 15 points),
- Innovation and Design Process (extra category, ID – total 6 points),
- Regional Priority Credits (extra category, RP – total 4 points).

For the SS category the LEED System appreciates brown field constructions, sites being easily reachable by public transportation and bicycles, encourages storm water collection, and the reduction of light pollution, heat island effect and construction pollution. The WE category gives out points for the decreased amount of potable water use. The EA category values energy efficient technologies, tracking of energy performance, and installation of renewable energy appliances. Regarding the MR category the LEED gives points for building and material reuse, construction waste management, recycled content, regional and rapidly renewable materials and certified wood (Cottrell, 2011). Cottrell (2010) also recommends conducting a life cycle assessment (LCA) for building materials on a cradle-to-grave cycle to ensure a more sustainable material selection. From the awarded points it can be seen that LEED values locally sourced materials and materials that either have recycled content or its source is renewable, like bamboo, cork or wool. The IEQ category is meant for the well-being of the occupants and includes issues regarding managing air contaminants, using less harmful materials, providing day-lighting and increasing ventilation. The two extra categories ID and RP give extra points for innovative strategy that is not valued at the other categories or where the design outperforms the benchmarking of the set guidelines. The RP gives extra points for regionally exceptional performance. All in all LEED values most the reduction of impacts on climate change, the greatest benefit for IEQ while focusing on energy efficiency and reduction of carbon dioxide.

The Guidebook recommends submitting two reviews, called split review, one after completing the construction documents and one after the construction. This way the plans can be changed in the design stage. According to the Guidebook there is higher success with earning the certificate if the building is submitted for the split review than if only for the final one. However it is not mandatory as the split review has increased price over the one-time submission. If the submitters are not satisfied with the decision they can appeal against it for a price. If there is any question regarding the credits it can be submitted for Interpretation Ruling (CIR) for a fee and it works on precedent base.

The LEED Rating System is criticized to be “green-washing” and to look good only on paper in advertisements and as a plaque on the wall (Forbes magazine, 2014). As the certification system is solely based on computer simulated results and not on the actual documents showing the electricity consumption, the whole system being efficient is just a promise that might never be fulfilled, while non-certified buildings might be turning out to be more energy efficient. The LEED is criticized to be only a plaque and a press release.

Regardless of the criticism LEED Certification is achieving serious amount of applications. According to their database currently more than 37 000 projects have been awarded with a certification, while other 40 000 projects are waiting to be certified. From Finland currently 159 projects are listed as either certified or under certification.

2.2.2 BREEAM

Building Research Establishment Environmental Assessment Method (BREEAM) is one of the oldest and most reputable rating systems globally. It was founded in the United Kingdom in 1990 and serves as basis for several rating systems (Keeler, 2009). BREEAM is used in more than 60 countries; some already have national Council for BREEAM while others use the international system. Since its launch more than 425 000 projects have been certified and in total more than 2 million have registered for assessment.

BREEAM assesses building performance in ten different categories. These categories are the following:

- Management
- Health and Well-being
- Energy
- Transport
- Materials
- Waste
- Water
- Land Use and Ecology
- Pollution
- Innovation

Each category has credits just like at LEED, and there are also pre-requisites, minimal standards that a building has to achieve for certification. The certification has four levels, Pass, Good, Very Good and Excellent. A new construction can be registered for split viewing, once in the design stage and mandatorily after construction. According to BREEAM's manual their targets are to mitigate the environmental impact buildings impose, encourage the market of sustainable buildings and provide a trustworthy, environmental label for buildings.

2.3 Life Cycle Assessment

The earlier sub-chapters have established the requisite for calculating the environmental burden caused by buildings and how they can be compared in an easily comprehensible way by anyone who is not involved in the building sector. In this sub-chapter the background calculations of the rating systems will be summarized and tell about the regulations and standards used for constructions work in the European Union.

Life cycle assessment (LCA) is a method to calculate the environmental impact of a product, service over its entire life, i.e. life cycle. The method exists since the 80's while the first LCA calculations for buildings were made in the 90's (Wang et al., 2011). The purpose of the LCA is to identify the environmental effects a product or service can have from cradle-to-grave and it is used in a wide range of operations. The cradle-to-grave term means that the effects are taken into consideration throughout the whole life starting from the raw material extraction until the disposal of the product, including the manufacturing, production, distribution and operation and all the related transportations. LCA is used to support a wide range of decisions and applications. It can be used for product optimization, benchmarking, design purposes, eco-labelling, product comparisons, strategic decision-making, production improvement and as a support for environmental policies.

According to Vogtländer there are 2 types of LCA: the classical LCA and the so-called 'Fast Track' LCA. The classical LCA is the one that is described by the ISO standards, ISO 14040:2006 and ISO 14044:2006. It means that the person who is conducting the LCA study has to be familiar with these two standards and apply the requirements of them. The ISO 14040 describes the principles and framework of the LCA and defines the terms and phases used in LCA studies. The ISO 14044 specifies the requirements and provides guidelines for the terms and phases described in ISO 14040. According to them an LCA study first must state the goal and scope of the study, that is to define the context of the study, and how and whom the results will be communicated to. It has to give the technical details such as the functional unit, system boundaries, assumptions and limitations of the study. In the scope the selection of the impact categories and category indicators have to be also described. These impact categories depend on the purpose of LCA study itself and it can include ozone depletion, human toxicity, acidification, climate change, eutrophication. The second phase of the LCA is the life cycle inventory analysis (LCI). LCI consists of defining the input and outputs of the system by creating a flow diagram for them. These inputs are usually energy, transportation and materials, while the outputs are waste and emission to soil, air and water, and the manufactured goods, products and services. The inventory consists of a well structured data system where every process and sub-process is listed with their own inputs and outputs. It takes time and effort to gather all the data needed for such an inventory. A classical LCA's main purpose is to compose such an inventory for different processes (Vogtländer, 2010). The next phase of the LCA is the life cycle impact assessment (LCIA), which is the other main goal of the classical LCA. In the LCIA phase the results of the life cycle inventory analysis are evaluated. After assigning the LCI results to the different impact categories and normalization, that is expressing the different impact potentials and consumption of resources on a common scale in order to aid comparison of impact categories, the impact categories are calculated to end-point indicators (such as human health, ecosystems and resources). Then the end-points are concluded in a single factor. Once the LCIA has been completed the study has to be interpreted. The interpretation phase of the LCA consists of the evaluation of the results, identification of significant issues, and evaluation of completeness, sensitivity and consistency. Finally the conclusions, limitations and recommendations can be prepared.

The EU issued in 2010 the ILCD Handbook to regulate the LCA calculations in the EU. The book is so complex, it has more than 400 pages, and detailed that it is mostly used by LCA researchers and scientists. The Handbook is consistent with the two ISO standards but it has further requirements, while it goes beyond the standards in describing LCA methodology and technical descriptions.

Meanwhile the 'Fast Track' LCA uses the results of LCI and LCIA made by classical LCA. There are readily available databases where the different outputs of a process have been already calculated and just the amounts of input have to be given. Such database is the Ecoinvent that has more than 4500 LCIs or the GaBi database where just for construction materials they have 2981 different processes. These databases have already calculated the LCI for different processes taking into account various technologies, country or region specific distinctions. Other software, like SimaPro can create the inventory flow for the studied system, has the database for the LCI and give the results of LCIA. The user can define the impact categories one wants to study and the results will be given by the program. With this 'Fast Track' LCA the user can save several days or weeks compared to the classical LCA. In case of a building it would take months to calculate the LCA for every input material or process. Therefore it is recommended to use these databases that already contain the LCI and LCIA. For whole-building LCA the user still has to be aware of the ISO standards and in the EU also with the regulations, the EN 15978.

2.3.1 Carbon footprint

Gasses that are associated with trapping the heat inside the atmosphere are called greenhouse gases (GHGs). Carbon footprint (CF) of a product or service means the net sum of GHG emission caused during its lifetime or other predefined duration. The most common GHGs listed by EPA are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). The unit for CF is called carbon dioxide equivalent (CO_2e), which means that the amount of emissions for all GHGs have to be converted to CO_2. This is done by the so called Global Warming Potential, which shows how much one mass-unit of the given GHG equals in mass-unit of CO_2. Therefore according to Table 1, 1 gram of CH_4 equals to 21 gram of CO_2e.

Table 1: Examples of GWPs of different GHGs, source: UN Framework Convention on Climate Change

Species	**GWP for 100 years**
CO_2	1
CH_4	21
N_2O	310
SF_6	23 900
HFC-23	11 700
Perfluoromethane	6500

CF is similar to LCA and many users consider the expressions interchangeable, even though they are not. They are quite similar in many aspects, both being environmental assessment tools and being controlled by international standards. The carbon footprint analysis is also an environmental assessment tool like life cycle assessment, but while LCA covers all the environmental impacts chosen for the study a product or service might have throughout its life time or any indicated time period, CF only covers GHG emissions. LCA can also contain the GHG emissions included in CF, it appears at the life cycle impact assessment phase and it is often referred to as Global Warming Potential (GWP), Climate change or greenhouse effect, and the unit is the same CO_2e.

CF accounting is also managed by international standards like LCA. The main standards are PAS 2050, ISO 14067 and the Greenhouse Gas Protocol (GHG Protocol). PAS 2050 includes similar requirements as the ISO standards for carrying out LCA calculations. PAS 2050 lists the GHGs to be included in a CF report, how biogenic and fossil carbon sources have to be treated, how carbon storage and offsetting have to be included in the calculations. It also sets requirements for data sources and quality, and criteria for global warming potential data.

2.3.2 The EN 15978 Standard

The EN 15978 is a European Standard whose purpose is to “provide calculation rules for the assessment of the environmental performance of new and existing building” (EN 15978, 2011). Just like the ISO standards it describes methodology and framework on how to carry out an LCA designed for buildings. It first outlines the possible scope and goal of the study, and then specifies technical details such as functional equivalent and reference study period. Functional equivalent means the representation of the required technical characteristics and functionalities of the building, such as the building type (office, factory), occupancy and required service life.

The standard determines four life cycle stages of a building: Product stage (A1 – A3), Construction Process stage (A4-A5), Use stage (B1 – B7), End of Life stage (C1 – C4). Each stage has its sub-stages, modules. Appendix 2 contains the display for modular information for the different stages of the building assessment.

Product stage:

- A1: Raw materials extraction
- A2: Transport
- A3: Manufacturing

Construction Process stage:

- A4: Transport
- A5: Construction and installation

Use stage:

- B1: Use
- B2: Maintenance
- B3: Repair
- B4: Replacement
- B5: Refurbishment
- B6: Operational energy (HVAC, hot water, lighting)
- B7: Operational water

End of Life stage:

- C1: Deconstruction/Demolition
- C2: Transport
- C3: Waste processing
- C4: Disposal

The standard identifies the source of data for the assessment as the Environmental Product Declarations (EPDs). Then it introduces the boundaries of each module, what processes have to be included in the calculations and which ones should not be. Most of the modules' boundaries are straight forward the one exception is the Use stage. In this stage, only processes related to those appliances and materials can be included that are building-integrated technical systems. These systems include HVAC installations, lifts, escalators, security installations, communication and automated control systems and sanitation. It does not include office electronics, refrigerators, washing machines, dishwashers and all similar electronic equipment.

Further on, the standard lists the indicators and their units that have to be included in the assessment. These indicators are amongst others are global warming potential, eutrophication potential, use of net fresh water and hazardous waste disposal. Then, the calculation method is described. Finally, the method for reporting is outlined, which includes the representation of the data, the used data sources and what general information has to be presented.

The standard recommends the use of EPDs through all stages of building life cycle. Having checked two EPD databases, The EPD Registry and The International EPD System, while the first one listed 32 construction products, the second one had 140 products. This amount of 172 construction products is insignificantly small taken into account that both databases are international. It means that from all the construction material producers from all around the world only 172 products have EPDs in these databases. The standard requires each material and building-integrated technical system to have its own LCA calculated. It is an immense work that would require tremendous amount of time and effort especially regarding quality data input.

2.3.3 Environmental Product Declaration

Environmental Product Declarations (EPDs) have been mentioned in the earlier sub-chapter several times. In this sub-chapter the thesis will introduce what EPDs are, how they are generated and what their purpose is.

An EPD is an “independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products” (The International EPD System). Companies can register for an EPD for their products and services. It is a beneficial idea as there are companies that use environmentally friendly approach and technology in their manufacturing and production processes. These companies would like to take the benefits of their investments and promote their products as green and sustainable, and the EPD gives them an internationally acknowledged background. The EPD is useful for customers as well as the EPDs are comparable, accurate, credible and objective. Each EPD is valid for three years, after that they have to be revised and reissued.

EPDs are based on life cycle assessment. The LCA calculation for the EPD depends on the type of the product or service. The method to calculate the LCA is defined by the Product Category Rules (PCR). The PCR determines the rules and requirements for the EPD per product category. For construction products 22 PCR’s are available currently in The International EPD System. The PCR for construction products have their own European standard, the EN 15804 which ensures that the EPDs are derived, verified and presented in a harmonized way. The EPDs and PCR are compliant with both the EN 15978 and the EN 15804 as well, which means that the results of the LCA in the EPD are represented in the same modular table as the stages and modules of building life cycle are described in EN 15978. The EPDs having been reviewed contained results for the modules from the Product stage (A1 – A3 modules), cradle-to-gate, and in cases for the transportation to the construction site (A4) and for the End of Life stage modules about transportation and disposal (C2 and C4). This thesis only focuses on the results from the Product stage (A1 – A3). An EPD also contains general information about the product such as technical characteristics, product and company description, technology of manufacturing and finally the interpretation of the LCA study. In cases the EPD contains information about reference service life, maintenance instructions and disposal scenarios.

EPDs are argued to be difficult to interpret and little known by the stakeholders (Suttleworth, 2013). The designers and architects have little or no recognition at all how an EPD could be beneficial for their building development. Also, as it name says, it is evaluating the products, in our case the construction products solely from environmental perspective. It is lacking the economic and social aspects to which the building sector is very sensitive. Other negative issue about EPDs is that they cost a lot of money, as they have a registration fee for every product type individually and after that a yearly fee for the company. It is very costly especially for small and medium enterprises (SMEs) which have quite often cutting-edge, state-of-the-art technologies, but limited financial resources. For them EPDs could mean a market breakthrough and a potential economic advantage over the competitor companies.

2.4 Building Information Modeling

In the earlier sub-chapters the classical LCA have been introduced and the standards that are used when calculating LCA related to construction works. In this sub-chapter the thesis will outline a recent software development that ensures interoperability between design software and engineering analysis tools. The software can be used for buildings when a classical LCA is not necessary but information and analysis regarding energy efficiency performance, carbon footprint, orientation or day- lighting calculations are essential.

Building Information Modeling (BIM) is not just a file type but a whole process to design and document a construction project. It can be used by designers, architects, contractors and subcontractors and the owner of the building. It is much more than a computer-aided design (CAD). While CAD drawings are rather only a 2D representation of the building where every assembly has to be designed separately and multiple times, BIM gives the possibility to store all the design documents of the same building in one database. The data is interconnected and parametric, if a wall is changed at one drawing, the whole database is updated and nothing has to be changed manually like it should be with a conventional CAD drawing. All the stakeholders can use the same database for their own purposes. It contains not only the data about the building itself, but also about the location. It stores the cost calculations, the agenda for the construction with the starting and finishing times of the work stages. It can also generate predictions of the building performance; calculate energy use, materials flow. It basically helps at all stages of a building development starting from its design throughout its occupation stage. In the occupation stage it makes it easier to locate any appliance in the building and it is easy to update if any maintenance or repair was carried out on the building.

All the data is stored in one database, therefore nothing can get lost, even after decades every detail of the building can be easily accessed and found within minutes. Therefore BIM helps to cut costs over the building development and also makes communication easier. The database is understandable for every user, there is no miscommunication or misunderstanding, and therefore it saves a lot of time. It also saves time as everything is updated automatically once a change has been carried out, and the program recalculates with the new data. The overall advantages of using BIM over a conventional CAD drawing is the 3D simulation which can predict collisions, show environmental variables for different designs, calculate material and time quantities. It gives accurate results not just manually calculated estimations. Eliminates most of the unnecessary efforts, improves communication between stakeholders. It also can calculate the orientation and roof area for solar panels and the cisterns for storm water harvesting. With the use of BIM there is more time to address important matters such as improving design and expediting construction and with it goals and problems can be identified at earlier stage of the design. Figure 2 represents the possibilities and solutions BIM can offer for all the stakeholders of a building.

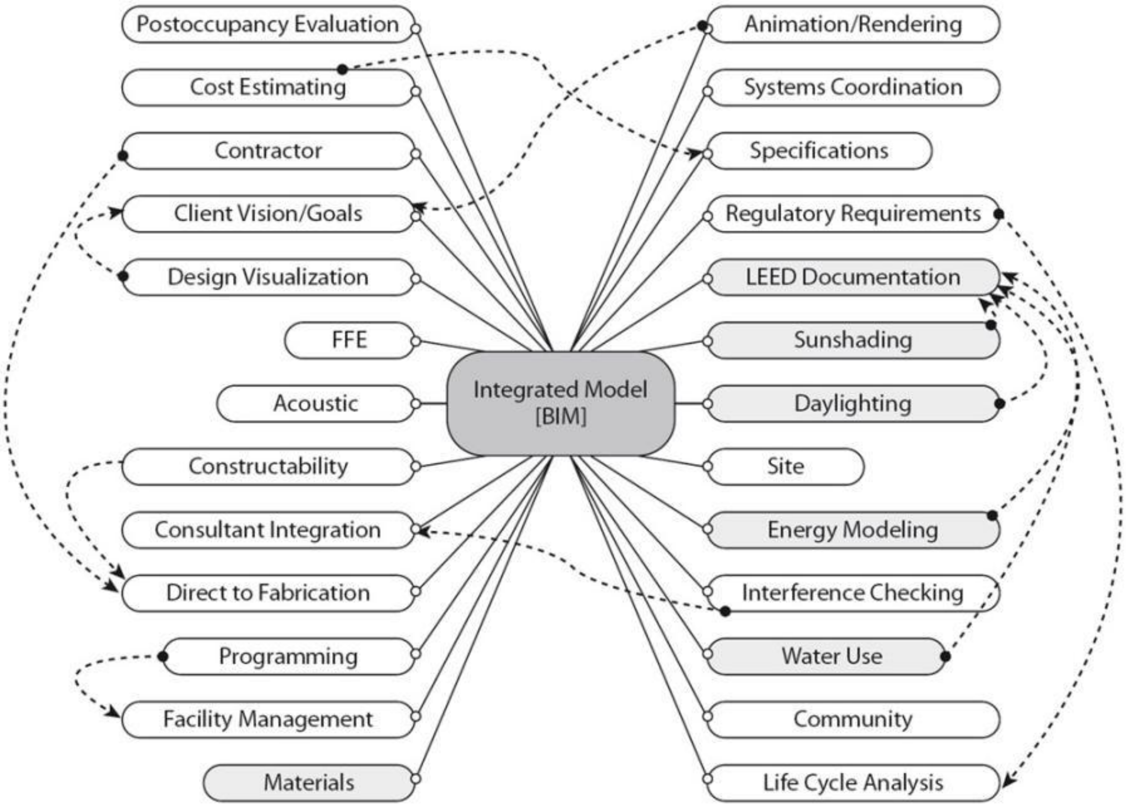

Figure 2: Integrated BIM Model, source: Krygiel, 2008

BIM is in its early stage, and it has serious potential in the future. Buildings are becoming more and more complex structures, the buildings built today have installations that did not exist 50 years ago. They have HVAC, security and telecommunications installations, the available construction materials are endless, and there are other new aspects that have to be considered when developing a new building. The big CAD software development companies like Graphisoft, who owns ArchiCAD, and Autodesk have their own BIM software as well. They realised that a simple 2D drawing is not enough anymore, the building sector needed more. The challenge today is to make BIM well-known and available not only for designers, but for all the stakeholders at every level who encounter the building sector in some ways.

There have been made already developments and further programmes designed based on BIM. Industry Foundation Classes (IFC) is based on BIM and it is a platform neutral data model that allows interoperability between BIM files. It means that if a BIM file has been designed by Graphisoft's software, and it has been saved in IFC format it can be easily opened by Autodesk's software. There are other programs especially designed as engineering analysis tools that can use the data from BIM and can be accessed by the gbXML (Green Building XML) schema. With the gbXML file extension the data from the BIM can be easily transferred to environmental analysis software without data loss. In the analysis software the data can be further modified, then analysed. Such analysis software is IES <Virtual Environment> which is capable of energy analysis, calculations in compliance with LEED and BREEAM Certification Systems, assessing benefits of solar energy for the building and cost calculations.

The building sector has started to use BIM tools extensively. Eastman et al. (2011) claims that 49 percent of US building industry was using BIM tools in 2009, which means it almost doubled from the percentage surveyed in 2007. In the future further increase is predicted and not only in the US market. However, some challenges have to be tackled. These challenges include the development of the IFC format to a more reliable level regarding tracking of changes. Other possibility is to create easily accessible format for end-users, such as home owners who could manage their building performance by BIM tools. Further on BIM tools can be harmonized with legislations, area specific applications, automated control and checking.

BIM tools have and will have huge effect on the building industry as more and stakeholders realize how they can benefit from it. BIM tools can save a lot of money, time and energy for building development teams.

3 Methodology

The interest of this thesis was to compare two different methods of application of cradle-to-gate carbon footprint calculations for selected construction materials and assemblies. The comparison focuses similarities and differences regarding the results, the amount of time and complexity they took to accomplish them.

In this thesis cradle-to-gate carbon footprint calculation for the same BIM building's selected construction materials and assemblies was carried out. The calculation only covers the Product stage (A1 – A3) of a building according to the EN 15978 Standard. The building used for the calculations is represented in Figure 3.

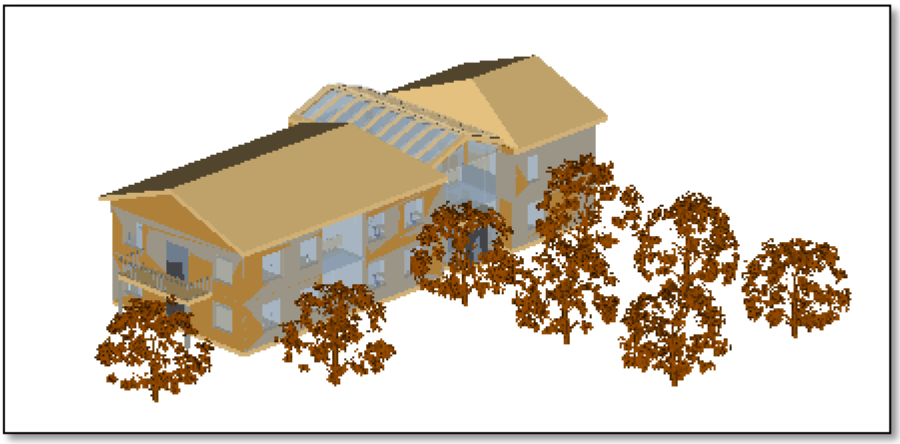

Figure 3: The BIM model used for the calculations

According to Bribián et al. (2011) one square meter of conventional building in Spain requires more than 100 different construction products. For the ease of calculation it was assumed that the building consists of seven different materials and assemblies, and that all doors and windows are exactly the same. Table 2 represents the type of materials and assemblies, and the used amount of each of type.

Table 2: Type and amount of materials used

Type of construction product	**Amount of material**
Wooden window	90 pieces
Wooden door	35 pieces
Pre-cast concrete (wall)	260 m^3
Gypsum board (curtain wall)	36 m^2
Parquet flooring	243.75 m^2
Ceramic tiles	81.25 m^2
Copper sheet (roof)	325 m^2

To calculate the cradle-to-gate carbon footprint for the construction materials two different methods were used. The first method was to use a BIM based cloud software, while the other method was to search for individual EPDs for the different materials. The software used is capable of calculating a building's whole life cycle carbon footprint, life cycle cost and life cycle assessment for LEED, for BREEAM and by the EN

15978 Standard as well. In this study only one part of the life cycle carbon footprint indicator was used, the Product stage (A1 – A3). The software also uses EPDs for the calculations regarding materials, but the number of available EPDs in its database is limited. The sources of the EPDs in the database are solely from companies located in the European Union, especially in the Nordic countries and Germany.

For the individual EPDs a report published by VTT (Ruuska, 2013) was used as it contained several construction products. In this thesis it was assumed that the construction products listed in Ruuska's report (2013) were the original materials and assemblies used for the construction of the building. The thesis compares the results of calculating with the original EPDs and by the BIM software.

For the thesis the most identical products to the original ones were selected from the software's database. At times it was difficult to select the most suitable products from the database as there were no matching properties to the original construction product except being the same type. Table 3 contains the main properties of the original construction products and the ones selected in the software's database, including country of origin, size, thickness and density. It can be seen from Table 3 that all of the products selected in the software have different properties than the original ones. In cases also only limited information was available about the product that the software calculates with.

Table 3: Properties of construction materials and input values

Type of construction product	**Properties of materials**		**Amount**
	Original	**BIM software**	
Wooden window	51.6 kg/piece 1.2 m x 1.2 m Sweden	double glazed, aluminium frame 1.23 m x 1.48 m Norway	90 pieces
Wooden door	2.1 m x 1 m 50 kg/piece Sweden	.1 m x 1 m Finland	35 pieces
Pre-cast concrete (wall)	2400 kg/m^3 European average	C20/25 Norway	260 m^3

Gypsum board (curtain wall)	12.5 mm thick 10 kg/m^2 European average12	.5 mm thick Norway	36 m^2
Parquet flooring	11.7 kg/m^2 Germany	pre-finished parquet Finland	243.75 m^2
Ceramic tiles	10.7 kg/m^2 Finland	Finland	81.25 m^2
Copper sheet (roof)	0.6 mm thick 8960 kg/m^3 European average	0.6 mm thick Germany	325 m^2

The amounts used for both type of calculations were the same. For the manual calculation all the input values had to be transferred into kilograms with exception of doors and windows. The cloud software after choosing the material asked for the amount in the given units. These amounts could be added directly from the BIM file easily, while for the manual calculation the original data from BIM had to be recalculated.

The cloud based software immediately calculated the carbon footprint after filling out the survey, while for the manual calculation it was necessary to read through every EPD individually for every construction product used. Table 4 contains the amount of carbon dioxide equivalent for each unit of construction product included in the manual calculations (Ruuska, 2013).

Table 4: Carbon footprint of original construction products

Type of construction product	**Carbon footprint of original products**
Wooden window	42.175 CO_2 e kg/piece
Wooden door	18.450 CO_2 e kg /piece
Pre-cast concrete (wall)	0.1205 CO_2 e kg/kg
Gypsum board (curtain wall)	1.967 CO_2 e kg/kg
Parquet flooring	2.942 CO_2 e kg/kg
Ceramic tiles	0.6125 CO_2 e kg/kg
Copper sheet (roof)	0.9732 CO_2 e kg/kg

4 Results

Bribián at el. (2011) explained in their study about building materials that the same construction material can have different results from their life cycle assessment as different users interpret the system boundaries of LCA variously and end up including separate processes. Also companies use diverse processes for manufacturing the same material. While some of these processes and technologies are considered state-of-the-art others might still use conventional ones. Not just the technologies but also the availability of raw materials can differ from country to country. When calculating with national averages, it might cause considerable variation in the emissions as the raw material for some countries might be abundant while other countries might have to rely solely on export which increases the final emission of the process stage.

Table 5 contains the results of cradle-to-gate carbon footprint in tons of carbon dioxide equivalent calculated for the same building and its construction materials and assemblies by two different methods. The first method adopted emission data from VTT's publication (Ruuska, 2013), and the construction products listed there were treated as the original construction products of the building represented in this thesis. The second method was a BIM based software where only the amount of materials had to be entered and no manual calculations were carried out. The results of the software can be also found separately in Appendix 3. Both methods used EPDs as the base of their calculations.

Table 5: GHG emissions of the original construction products and the software calculated ones

Type of construction product	Amount	GHG emissions Original [CO_2 e ton]	GHG emissions BIM software [CO_2 e ton]	Difference Original = 100% [%]
Wooden window	90 pieces	3.8	10	+163.2 %
Wooden door	35 pieces	0.7	1	+42.9 %
Pre-cast concrete (wall)	260 m^3	75.2	39	-48.1 %
Gypsum board (curtain wall)	36 m^2	0.7	0	-100 %
Parquet flooring	243.75 m^2	8.4	1	-88.1 %
Ceramic tiles	81.25 m^2	0.5	1	+100 %

Copper sheet (roof)	325 m^2	1.7	2	+17.6 %
Total	-	**91**	**54**	**-40.7 %**

It can be seen that there are differences in the GHG emissions, for some materials it is insignificant, while for others such as the wooden window and parquet flooring it is significant. The software gave 163% higher GHG emission for the wooden windows as compared to the original ones, while for the parquet flooring the software's result was 88.1% less. The cradle-to-gate carbon footprint of building materials and assemblies calculated by the BIM software gave 41% less GHG emissions in total than the emissions of the original products. Figure 4 represents the greenhouse gas emissions for both methods side by side. The differences between the two results can be explained by the differences between the used EPDs in the two methods. In Table 3 the properties of all the seven materials and assemblies used in this study were listed. None of the construction products selected from the software's database was an exact match for the original construction product. Even though both methods of calculation are based on EPDs, the results indicate that it is important to use the emission data and EPD of the exact product that is assembled into the building. These differences in the EPDs can be explained by the different countries of origin and the different technologies the companies used in their manufacturing process.

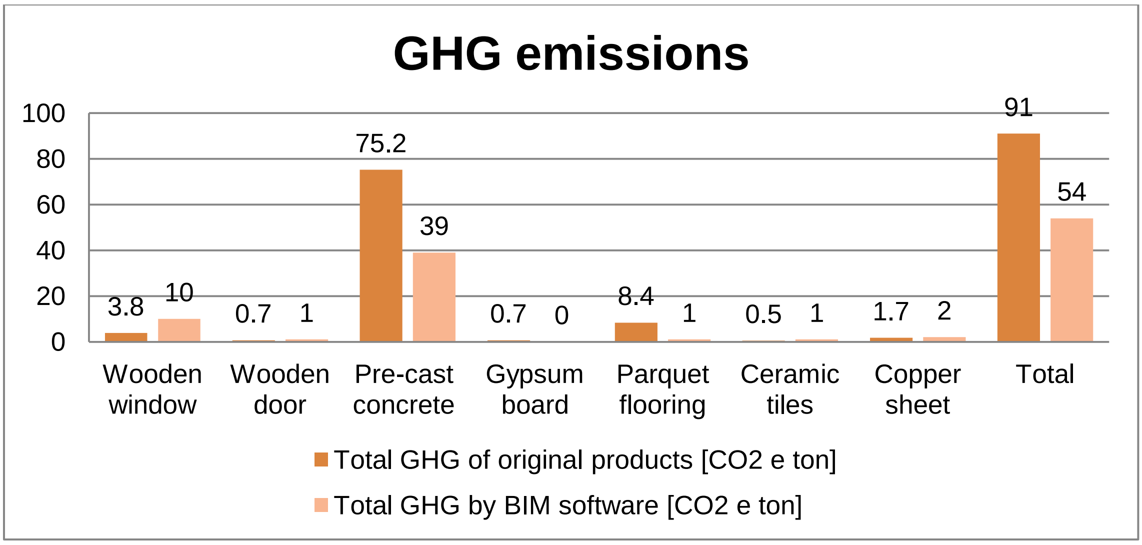

Figure 4: Total GHG emissions

The second aspect of the thesis after examining how efficiently and reliably the cloud based software can calculate carbon footprint of selected construction products, was to explore how user friendly and time-saving it could be. The biggest part for the manual calculation was to find data input for the calculations regarding the emissions of the materials. The research for individual EPDs and their interpretation consumed tremendous time and effort as the checked EPD databases did not cover the whole range of materials that the thesis intended to include.

The cloud based software was very straight forward and time efficient to use. Having the amount of construction materials and assemblies ready from the BIM file it took approximately 30 minutes to input the necessary data. The most time-consuming part using the software was to find construction products in the database that were similar to the original products. No further calculation was necessary with the data from the BIM, as the BIM file included the total amounts for the requested units by the software.

5 Discussion and Conclusion

Assessing the impacts of building construction materials is crucial as the building sector consumes 40% of raw materials globally and 4-8% of world's total energy consumption is associated with construction material manufacturing, transportation, construction, renovation and demolition (Keeler, 2009). As this thesis has presented it is imperative to choose the most sustainable materials for buildings as they have an effect for decades after their development.

The calculation of carbon footprint is a complex and time-consuming procedure where the user has to be familiar with carbon footprint standards, expressions, terminologies, when and how they can be used and how they can be interpreted. Meanwhile, buildings are becoming more and more complex, and the need to cut and understand energy consumption regarding them is more and more essential. The targets of the European Union called Europe 2020 were presented and also the international building rating systems that are meant to promote sustainability within the building sector. Carbon footprint and LCA calculations are an important part of the evaluation for the certification in the rating systems.

In this thesis two methods were used to calculate the cradle-to-gate carbon footprint of construction building materials. One method was using individually sourced EPDs; the second method was a BIM based software application. Both methods covered the same Product stage (A1 – A3) defined in the EN 15978 European Standard. It was investigated how reliable, accessible and time-saving such a software can be.

While both methods have their downsides, it is important to focus on the benefits of each and how they could be combined in the future. The Results chapter of this thesis showed that calculating with a BIM based software gave significant variation from the carbon footprint of the original construction products. It was due to the limited number of available EPDs in the database and their distinction from the original products. However, the software was very user-friendly, fast, no previous knowledge or skill was necessary for its application. Also no calculation had to be done prior to entering the raw data from the BIM data file.

In the Results chapter it was shown why it is important to use product specific EPDs. The GHG emissions calculated by the BIM software were 41% less compared to the original values. The emission results generated from individual EPDs are 100% reliable and represent the emissions declared by the manufacturers of the construction products.

For the future it would be beneficial to have BIM software with higher number of inbuilt EPDs, especially focusing on a wider range of country of origin of manufacturers. This way the software could be applied in a wider range of the world. Including more EPDs would increase the possibility of finding products with more similarities to the ones that the users are interested in; therefore the results of the software would be more precise and accurate. Also changes to the issuance of EPDs should be achieved. Shuttleworth (2013) agrees that EPDs in their current form are not suitable for further adaption into BIM software. EPDs have varying appearance, while containing the same data and properties of the construction products. They should have identical appearance in order to better integrate them into BIM software applications. Also their cost should be decreased to gain better access by manufacturers, and parties, both users and publishers should be educated more about their benefits. Implementing these changes to the BIM software and to the EPDs would result in a cutting-edge, user-friendly emission tracking technology with reliable real-life data for the building industry.

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Appendix 1. LEED 2009 for New Construction and Major Renovation

LEED 2009 for New Construction and Major Renovation

Project Checklist

Project Name

Date

Y	N	?	Sustainable Sites		Possible Points: 26
Y			Prereq 1	Construction Activity Pollution Prevention	
			Credit 1	Site Selection	1
			Credit 2	Development Density and Community Connectivity	5
			Credit 3	Brownfield Redevelopment	1
			Credit 4.1	Alternative Transportation—Public Transportation Access	6
			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
			Credit 4.4	Alternative Transportation—Parking Capacity	2
			Credit 5.1	Site Development—Protect or Restore Habitat	1
			Credit 5.2	Site Development—Maximize Open Space	1
			Credit 6.1	Stormwater Design—Quantity Control	1
			Credit 6.2	Stormwater Design—Quality Control	1
			Credit 7.1	Heat Island Effect—Non-roof	1
			Credit 7.2	Heat Island Effect—Roof	1
			Credit 8	Light Pollution Reduction	1

Y	N	?	Water Efficiency		Possible Points: 10
Y			Prereq 1	Water Use Reduction—20% Reduction	
			Credit 1	Water Efficient Landscaping	2 to 4
			Credit 2	Innovative Wastewater Technologies	2
			Credit 3	Water Use Reduction	2 to 4

Y	N	?	Energy and Atmosphere		Possible Points: 35
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
			Credit 1	Optimize Energy Performance	1 to 19
			Credit 2	On-Site Renewable Energy	1 to 7
			Credit 3	Enhanced Commissioning	2
			Credit 4	Enhanced Refrigerant Management	2
			Credit 5	Measurement and Verification	3
			Credit 6	Green Power	2

Y	N	?	Materials and Resources		Possible Points: 14
Y			Prereq 1	Storage and Collection of Recyclables	
			Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
			Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
			Credit 2	Construction Waste Management	1 to 2
			Credit 3	Materials Reuse	1 to 2

Y	N	?	Materials and Resources, Continued		
			Credit 4	Recycled Content	1 to 2
			Credit 5	Regional Materials	1 to 2
			Credit 6	Rapidly Renewable Materials	1
			Credit 7	Certified Wood	1

Y	N	?	Indoor Environmental Quality		Possible Points: 15
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
			Credit 1	Outdoor Air Delivery Monitoring	1
			Credit 2	Increased Ventilation	1
			Credit 3.1	Construction IAQ Management Plan—During Construction	1
			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
			Credit 4.3	Low-Emitting Materials—Flooring Systems	1
			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
			Credit 5	Indoor Chemical and Pollutant Source Control	1
			Credit 6.1	Controllability of Systems—Lighting	1
			Credit 6.2	Controllability of Systems—Thermal Comfort	1
			Credit 7.1	Thermal Comfort—Design	1
			Credit 7.2	Thermal Comfort—Verification	1
			Credit 8.1	Daylight and Views—Daylight	1
			Credit 8.2	Daylight and Views—Views	1

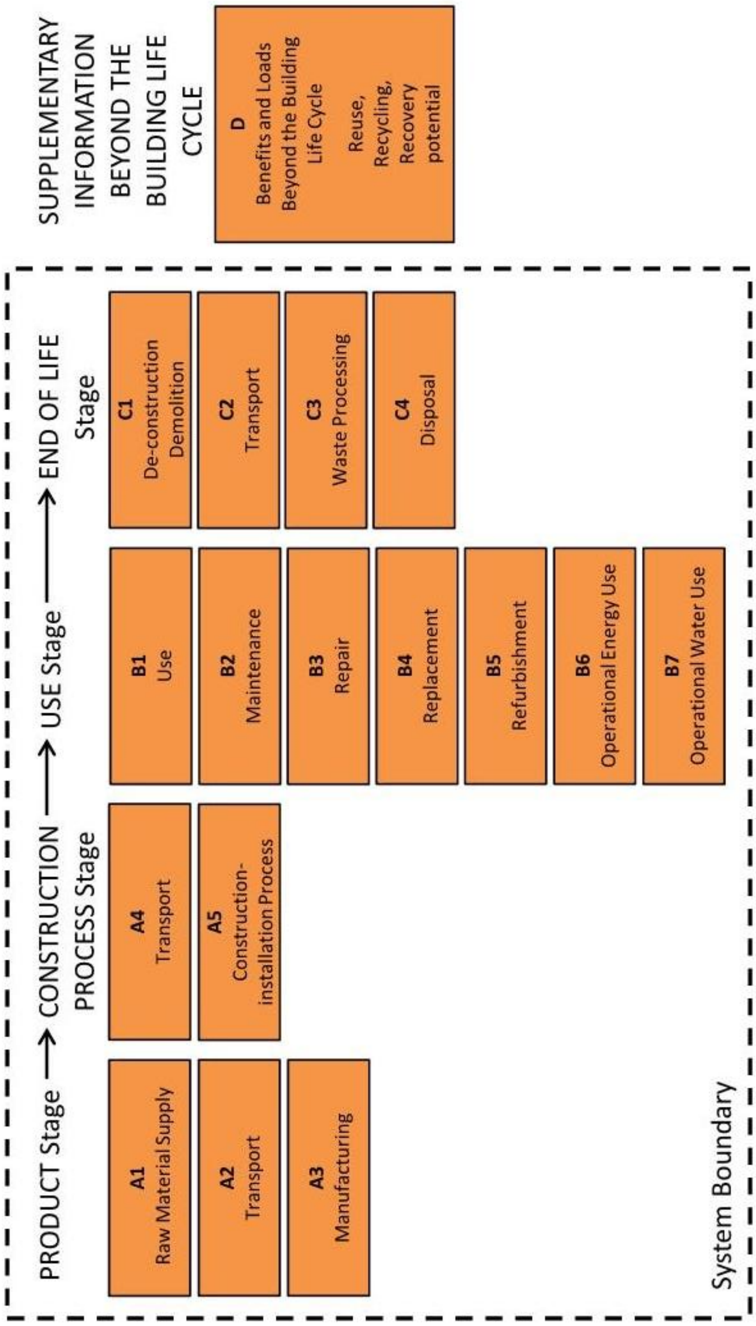
Y	N	?	Innovation and Design Process		Possible Points: 6
			Credit 1.1	Innovation in Design: Specific Title	1
			Credit 1.2	Innovation in Design: Specific Title	1
			Credit 1.3	Innovation in Design: Specific Title	1
			Credit 1.4	Innovation in Design: Specific Title	1
			Credit 1.5	Innovation in Design: Specific Title	1
			Credit 2	LEED Accredited Professional	1

Y	N	?	Regional Priority Credits		Possible Points: 4
			Credit 1.1	Regional Priority: Specific Credit	1
			Credit 1.2	Regional Priority: Specific Credit	1
			Credit 1.3	Regional Priority: Specific Credit	1
			Credit 1.4	Regional Priority: Specific Credit	1

Y	N	?	Total	Possible Points: 110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Appendix 2. Display of modular information of EN 15978



Appendix 3. Results from the BIM software for cradle-to-gate carbon footprint (A1 – A3)

Life-cycle carbon footprint, EN-15978: Construction Materials

Resource	User input	Mass of materials tn	Global warming tn CO2e	Comments	Profile
Construction materials of building > Foundations > Foundation materials					
Concrete C20/25 (B20 M90)	260	624	39		SandnesBetong2014
	Total	**624**	**39**		
Construction materials of building > Structural frame, facade, internal space elements and surfaces > Other facade materials					
Gypsum board, 12,5 mm	36	0	0		Norgips2015
	Total	**0**	**0**		
Construction materials of building > Structural frame, facade, internal space elements and surfaces > Intermediate floors					
Ceramic tile	81.25	1	1		defaultFI
Parquet flooring	243.75	3	1		defaultFI
	Total	**4**	**2**		
Construction materials of building > Structural frame, facade, internal space elements and surfaces > Roofing					
Copper roofing	325	2	2		defaultFI
	Total	**2**	**2**		
Construction materials of building > Structural frame, facade, internal space elements and surfaces > Windows and doors					
Double glazed H window, wood-alu frame, U-value 1.2, hinged	90	5	10		Magnor2013
External wood door, 2,1 x 1 m	35	2	1		defaultFI
	Total	**7**	**11**		