CHALMERS
UNIVERSITY OF TECHNOLOGY

Exploring a preferable workflow for conducting LCA in a BIM environment

From a perspective of a construction company

Master's Thesis in the Master's Programme Design and Construction Project Management

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Department of Civil and Environmental Engineering
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ABSTRACT

Construction industry has been proved to have an enormous influence on environment due to its characteristic of heavy material consuming. Life cycle assessment (LCA) was introduced under this situation to support project stakeholders to make environment friendly decisions. Building information modelling (BIM) is another popular subject in construction industry and it shows the potential to aid LCA with its ability to provide comprehensive and multidiscipline information source. In order to combine LCA with BIM, the question of interoperability between applications must be considered and solved. The purpose of this study is explore a preferable workflow from BIM to LCA by identifies and overcoming potential technical obstacles when a specific LCA application is used in the current BIM environment of the reference company. This study is a design science research and it is based on literature review, study of case, study of software and test of interoperable formats. The result shows that all three tested interoperable formats will lead to certain obstacles. IFC file exported from Revit does not contain sufficient non-graphic information, and complex geometry components has the risk of vanish and property variation. Vico-exported sbXML has the problem of missing version identification, fail digital value formats, lacking resource type description and not widely used by non-Swedish applications. Vico-exported excel spreadsheet cannot display the belonging relationship between material and building components. Excel spreadsheet's obstacles are the easiest to overcome, since Vico Office allows users to customize exporting templates according to their own demand. The result further shows that when compared with Revit, Vico Office serves as a more comprehensive information source with both sufficient graphic and non-graphic information for LCA. Synthetically considering both potential obstacles and quality of information source, a conclusion of using Excel spreadsheet to transfer required BIM information from Vico Office to a specific LCA application in the recommended workflow is generated in this study.

Key words: 5D BIM Simulation, LOD, Information transfer, LCA, Workflow

Utforska en föredra arbetsflöde för att genomföra LCA i en BIM miljö
Ur ett perspektiv av en konstruktion företag

Examensarbete inom masterprogrammet Design and Construction Project Management

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Chalmers tekniska högskola

SAMMANFATTNING

Byggbranschen har visat sig ha ett enormt inflytande på miljön på grund av dess karakteristiska stora material krävande tillverkningsprocesser. Livscykelanalyser (LCA) införs för att stödja projektets intressenter för att göra miljövänliga beslut. Building Information Modelling (BIM) är ett annat populärt ämne i byggbranschen och har visat sig ha potential för att underlätta LCA med sin förmåga att tillhandahålla multidisciplinära och omfattande information. För att kombinera LCA med BIM, måste frågor om interoperabilitet mellan program övervägas och lösas. Syftet med denna studie är att utforska ett acceptabelt arbetsflöde från BIM till LCA. I samband med detta identifierar och övervinna eventuella tekniska hinder när en specifik LCA program används i den aktuella BIM miljö. Denna studie är baserad på litteraturgenomgång, undersökning av fallet, undersökning av programvara och test av interoperabla format. Resultatet visar att alla tre testade format kommer att leda till vissa hinder. Excels hinder är det enklaste sättet att övervinna, eftersom Vico Office tillåter användare att anpassa export mallar enligt deras egen efterfrågan. Resultatet visar vidare att jämförelsen mellan Revit och Vico Office, ger den sistnämnda mer omfattande information för LCA. Med tanke på både potentiella hinder och kvaliteten på informationskällan är en slutsats av att använda Excel för att överföra BIM information från Vico Office till de specifik LCA programmen.

Nyckelord: 5D BIM, LOD, informationsutbyte, LCA, Arbetsflöde

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Preface

This Master of Science thesis was conducted at the Department of Civil and Environmental Engineering at the Division of Construction Management. This thesis is the last assignment of our studies at the Master's Programme Design and Construction Project Management at Chalmers University of Technology. It has been carried out at Peab in Göteborg during the spring of 2015.

We would like to thank everyone involved in our Master thesis process for offering us support and help. First of all, we would like to thank our supervisor at Peab, Andreas Furenberg, for spending so much time for guiding our thesis work, offering us information, opinions and feedbacks. Secondly, a special thanks to our examiner at Chalmers University of Technology, Mattias Roupé, for supporting us with academic issues. Thirdly, we would like to thank Maria Franzén for sharing us information and support us in environmental aspect. Finally, we would like to thank all the involved individuals for supporting us with our complementing meetings.

Göteborg, May 2015

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Notations

3D - Three dimensional
4D - Four dimensional
5D - Five dimensional
ACE - Architecture, Construction and Engineering
BIM - Building information modelling
CAD - Computer Aided Design
IFC - Industry Foundation Classes
LCA - Life Cycle Assessment
LOD - Level of Development
LOI - Level of Information
BREEAM - Building Research Establishment Environmental Assessment Methodology
XML - Extensible Markup Language
SbXML - Swedish Construction Sector Extensible Markup Language
Default_vit - Default_white
Nettokalkyl - Net calculation

1 Introduction

In this chapter, the background information is presented to offer readers a general understanding of the industry's background and the development extent of relevant concepts. After stating the purpose of the thesis, the research questions are proposed in order to help reader have a clear understanding of what questions will be answered in this thesis. Thereafter the case is briefly described and this chapter finishes with limitations and disposition, which will illustrate the research territory and the structure of the thesis report.

1.1 Background Information

Due to the characteristic of heavy material consuming, construction industry has been proved to have an enormous influence on environment and should take a major responsibility of greenhouse gas emissions (Pei et al., 2011). Not only construction activity itself, related manufacture and transportation of construction materials consume considerable energy as well (Patnaikuni et al., 2013). According to the Sweden environmental protection agency (2014), manufacturing industry, construction industry and transportation made up approximately 66% of the total greenhouse gas emission. This situation leads to sustainable demands from both client and government agencies. Therefore developing sustainable processes and using sustainable material to reduce the environmental burden of a construction project from its whole life cycle's perspective has become a main challenge in the AEC (Architect, Engineer and Construction) industry. Life cycle assessment (LCA), also known as life cycle analysis, was introduced under this situation, with a focus on resource conservation and environmental burdens reduction (Lützkendorf, T. 2013). By using technical, environmental and social data, LCA supports stakeholders to make environment-friendly decisions by choosing optimal design proposals, material suppliers and construction materials. However, one feature that blocks the successful application of LCA is that environmental assessment systems demand large amounts of design and construction data in different formats, and this situation is not improved due to construction projects' property of integration insufficiency.

Building information modelling (BIM) is another popular subject in construction industry, and it keeps evolving as a valuable tool for sustainable design and construction (Standel et al., 2014). Presently, BIM applications have the ability to export integrated data including both geometrical and non-geometrical information, which means they have the potential to provide a reliable and comprehensive database for further analysis. It allows the calculation of components' volumes and related greenhouse gas emission based on building characters (Jrade and Jalaei, 2014). By implementing LCA with BIM, time-consuming process of information re-entering and remodelling could be avoided, and it will lead to a more integrated workflow from BIM models to project performance analyses by using one consistent data source.

In order to achieve the proposition, the question of interoperability between applications must be solved. According to Häkkinen and Kiviniemi (2008), there are three common solutions to integrate LAC with BIM: (1) direct file exchange between applications; (2) programming new functionality to existing BIM software; (3) using parametric formats. However, there is no research proving the general applicability of these three solutions (Jalen and Jrade, 2014). This situation necessitates the test of data input and outputs using different interoperable formats, in order to select a more efficient solution.

Moreover, from a perspective of a construction company, the reference company views LCA as a possibility to extent of their BIM application and plans to implement LCA in their BIM environment. This situation necessitates the establishment of workflow between LCA applications and BIM applications. However, since LCA is currently seldom conducted for construction projects (Franzén, 2015), the primarily addressed problem is interoperability between applications. Hence, identifying potential technical obstacles has become the main purpose of this study.

1.2 Purpose and Aim

The overall purpose of this thesis is to explore and try to establish a preferable workflow between 5D simulation and life cycle analysis from a perspective of a construction company.

More specifically, the aim of the thesis is to identify obstacles when a construction company tries to apply life cycle analysis applications into its BIM environment and to produce a solution plan to the problems.

1.3 Research Questions

Based on the purpose and the background information of the thesis work, two research questions are formulated:

1. What LOD (Level of Development) in BIM models is sufficient to achieve 5D simulation and Life Cycle Analysis from a perspective of a construction company?
2. How is a preferable workflow formulated to achieve a satisfying LCA for construction projects by using BIM related information?

In order to answer the research questions, the following sub-questions are proposed:

a. What is the current LOD of the production models in the reference project?
b. What obstacles are identified when BIM related information is used for LCA?
c. Does the reference company need to increase their current LOD of production models to achieve the whole workflow?
d. How could the identified obstacles be overcome?

1.4 Limitations

The thesis is primarily based on tests of data input and output between specified BIM and LCA applications. The BIM applications used in the study are Vico Office and Autodesk Revit, and the LCA applications used are Anavitor and 360optimi. The reference project provided by the reference company includes a finished model in Revit and finished quantity take-off results and cost estimation in Vico Office. Therefore, a limitation is to focus on the applicable formats of previously mentioned applications. Feasibility of information interoperation in different workflows is the main focus of this thesis. Besides, the influence of different solutions on LCA's results and comparisons between different LCA applications are not considered.

1.5 Disposition

The main content of this report will be divided into six main paragraphs.

The first chapter is an introduction describing the scale of the thesis work and introduces the background of the research, which indicates readers that there is a great potential to combine BIM with LCA in construction industry, and the reason of combining them is also mentioned. Accompanying with research purpose and the leading research questions, this chapter finishes with a short case description and a limitation statement.

The second chapter is theoretical framework, which offers readers a supporting knowledge base of what BIM and LCA are, what software is applied, as well as their possibility of combination and key issue to combine.

Thereafter, the third chapter introduces the case and the thesis's working background. It includes the information of the reference company and its vision about BIM and LCA, as well as its BIM environment. Moreover, there is a short description about the case which the authors choose to test.

The fourth chapter describes the research method and the research process. Since the main purpose of this thesis is trying to solve a real issue inside the reference company, a method called design science research is chosen as the research method. The whole working process is described to help readers clarify how authors conducted the work to reach the answers to the research questions.

The fifth chapter is called results, which has been divided into two parts according to the result source. First section of result is what authors gained from the case and software study; second section of result is gathered from the conducted test process.

The sixth chapter is discussion where the result is analysed and discussed by combining findings with previously mentioned theories.

The report is accomplished with a conclusion in chapter seven, containing the answers to the research questions and developed conclusive perspectives of the authors. Moreover, recommendations for the reference company and further research are mentioned as well.

2 Theoretical Framework

In this chapter, a theoretical framework is presented in order to create a knowledge foundation for the study and to have related theories to support it.

2.1 BIM

The concept of building information model was introduced in 1970s, accompanying with the utilization of information technology in construction industry (Chen, 2011). However the term BIM was not popularly used until a meeting of building industry strategists in the early 20th century, in which Laiserin argued cogently that BIM should be the best term to describe the next generation of design software (Smith and Tardif, 2012).
Many practitioners have defined BIM as technologies dealing with only 3D modelling and visualization, which is inadequate (Smith and Edgar, 2008). According to Barlish and Sullivan (2012), people's understanding of BIM are highly affected by their own BIM experience. For example, contractors tend to understand BIM as:

> *Creating and using digital models for design, construction and /or operations of projects.*

A more commonly used and objective definition is stated by National Building Information Modelling Standards (NBIMS) Committee of USA (2010):

> *A Building Information Model (Model) is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward. A basic premise of Building Information Modelling is collaboration by different stakeholders at different phases of the life-cycle of a facility to insert, extract, update or modify information in the Model to support and reflect the roles of that stakeholder. The Model is a shared digital representation founded on open standards for interoperability.*

This definition does not stand on a particular stakeholder's perspective and it defines BIM by viewing the whole life cycle of a facility. Both of the definitions mentioned above will be taken as the underlining definition of the study in order to aid the analysis from both construction companies' and the complete facility life-cycle's angle.

2.1.1 Different Dimensions of BIM

The original 2D drawing serves as a universal language to communicate the 3D world in a two-dimensional platform (Reddy, 2012). 2D drawings use plan and elevation views to present details, sections and specifications of a facility. However this is barely an effective way of information sharing. People's understanding is highly affected by their own interpretation and experience, which will increase the risk of misunderstanding. The most important contributions of 3D BIM is to visualize the content in 2D drawings and define objects in terms of building elements and systems (Azhar. et al, 2012). Instead of just being lines and arcs, the visualized components represent walls, beams and columns etc. Stakeholders come to build a common understanding of the building and its spaces in details (Demchak, 2009). Errors in documentations' cross-referencing can also be minimized, and clashes between components become easily detected. This improves the ability to avoid costly conflict errors in the early design phase. Material quantity take off and design modifications can also be conducted efficiently due to 3D BIM's characteristic of integration (Kim, 2012).

4D represents linking 3D models with time schedule to develop a graphical simulation of the construction process in time dimension (Smith, 2014). Time as an added dimension enables stakeholders to analyse project's feasibility and the workflow plan's rationality intuitionally in an early phase. This will lead to more thorough schedules, site layout and logistic plans.

The fifth dimension of BIM use 3D model data to quantify materials and realize cost estimation (Tamera, 2008). 5D BIM enables the accurate extraction of comprehensive geometric information, which can be directly used by cost consultants (Stanley and Thurnell, 2014). It is conducted by integrating cost date with BIM objects or linking BIM objects with estimating tools. By implementing 5D BIM, cost estimator can reduce the time contributed in generating cost budgets, and more importantly, the accuracy of estimation can also be improved enormously (Smith, 2014).

2.1.2 Information Transfer in BIM Environment

This section of the theory presents necessary knowledge about the document formats used in this study for information transfer.

2.1.2.1 IFC and Its Barriers

Even though BIM has been accepted by most participants in architecture, engineering and construction (AEC) industry, there are still barriers preventing BIM from realizing the ideal scenario presented by BIM experts (Sandberg, 2011). According to Kovacic et al. (2013), general BIM-technology dissatisfactions are derived from problematic information transfers between different software. In order to fulfil the requirements of modelling, energy simulation, scheduling, life cycle analysis, and cost simulation, numerous software and tools are used by project participants. Efficient data exchange between these tools without information losses is the prerequisite for a successfully integrated-design and project management. Industry foundation classes (IFC) is one of the most commonly used formats for data exchange is the AEC industry, and it has become the international standard format due to the characteristic of public and non-proprietary (Gupta, et al., 2014). Many promoters of BIM software generally claim their ability to support IFC (Lockley et al., 2013). However, according to Lockley et al., from a technical perspective, the current commercial BIM authoring tools cannot support the presentation of components' geometric representation sufficiently. Due to this, remodel is often needed after import, and the time effort for creating the new model is not negligible (Kovacic et al., 2013).

Currently there is not any one-platform BIM configuration on the market to fulfil various requirements in AEC industry (Kovacic, et al., 2013). The most common solutions provided by software companies, such as Autodesk, are proprietary interface or plug-ins. However this can only provide exact data transfer under simple geometry condition.

2.1.2.2 XML and sbXML

XML, which stands for Extensible Mark-up Language, is an information storing and sharing format (Anonymous, 2009). It cannot be used to create stand-alone applications, and its only utilization is information containing. As presented by its name, XML is a metalanguage which means it can be used as a base to develop other mark-up languages. These XML-based mark-up languages has their own constrains of data structures and document content (Valentine et al., 2002). With a specifically developed schema, users can define elements and attributes that can appear in a XML document, the default and fixed values, and the order of elements etc.

SbXML is the abbreviation of Swedish Construction Sector extensible mark-up language (Lantto, 2009). It is a XML-based format developed by BSAB developer forum and administrated by the Swedish Building Centre. This format is used for information transfer in the Swedish construction industry. The main content supported by sbXML is quantity take-off lists, time scheduling, bill of quantity etc. There are four main parts in sbXML format (Åkej, 2004):

Document: it contains the general information of the project, for example, document ID, publication date, and document sender and receiver.

List report: it contains all lists referred to in the documents.

Project: project related information. For example, project name, project date, project type etc.

Detail: Data here contains the project content. For example, quantity of resource, price information, schedule plan etc.

There is more detailed specific project information, which is called child element, under these four main parts (Åkej, 2004). Two children elements will be introduced here due to their direct relationship with this study.

Recourse type: resource type is one of the children elements under “Detail”. This element use numbers to describe the type of the resource it is linked to. The value of this element varies from 1 to 9, and they represents:

- 1 — Labour
- 2— Employee, white-collar worker
- 3and 4 — Material
- 5and 6 — Machine
- 7, 8 and 9 — Sub-contractor information

Recourse price: it is also a child element under "detail", and the information it contains are the price currency and price value. Price value is represented by a number, which contains 4 decimal places.

2.2 Level of Development

The information scope of BIM documents is decided by the documents' purpose and the phases, in which these documents are located (Vico software, 2010). Therefore the information richness, level of development (LOD), of BIM documents should be defined according to their purpose and project phase.

According to American Institution of Architects (AIA):

> *The Level of Development (LOD) describe the minimum dimensional, spatial, quantitative, and other data included in a Model Element to support the Authorized Uses associated with such LOD.*

Two other relative definition, Level of Detail and Level of Information, needed to be presented here for a better understanding of LOD. According to *PAS 1192-2:2013* (2013), Level of Detail represents the graphical content of models at different stages, and Level of Information represents the non-graphical content of models at different stages. The abbreviation LOD can stand for Level of Detail in certain context. But in this thesis LOD is understood as Level of Development, which, according to AIA's definition, includes both graphical and non-graphical information.

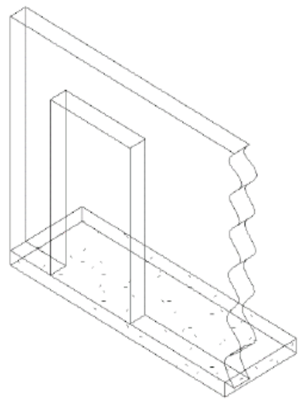
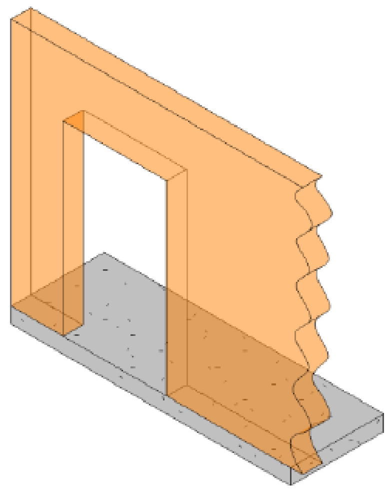
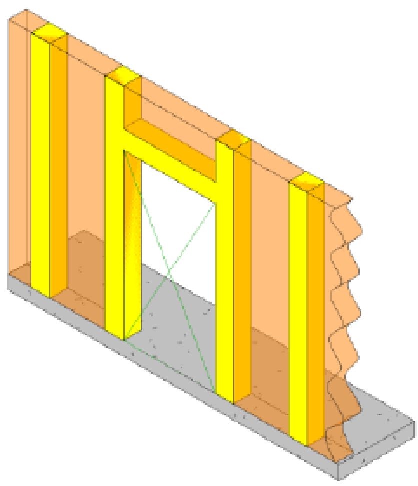
The AIA organization released *AIA E202 Building information Modeling Protocol Exhibit* in 2008 to define the amount of details in a particular BIM Model (Jeffrey, 2014). Five levels of LOD, from LOD 100 to LOD 500 are defined, but they do not contain any graphical content to represent what each level should look like or detailed instructions for the utilization of models in each LOD. The latest version of this document, *AIA G202-2013 Project Building Information Modeling Protocol Form*, includes the authorized uses of each LOD, but it still has not specific requirements for what should be included in a model at each stage. In order to let the AEC industry participants have a high level of reliability and clarity of BIM models on each LOD, BIMForum established *LOD Specification* under an agreement with the AIA. This specification defines and articulates characteristics of model elements at different LOD. It provides modellers with a clear picture of what should be included in a BIM deliverable and allows downstream users understand clearly the usability and limitation of a received BIM model (BIMForum, 2014). In order to have a more comprehensive understanding of the content and authorized uses of each level, both ATA and BIMForum's definitions for each LOD are listed below. The AIA's definitions and uses for LOD100 to LOD500 are explained in Table 2.1. And interior wall (Masonry) specifications from BIMForum are illustrated below in Table 2.2 as an example. LOD specifications for other building components are included in the appendix.

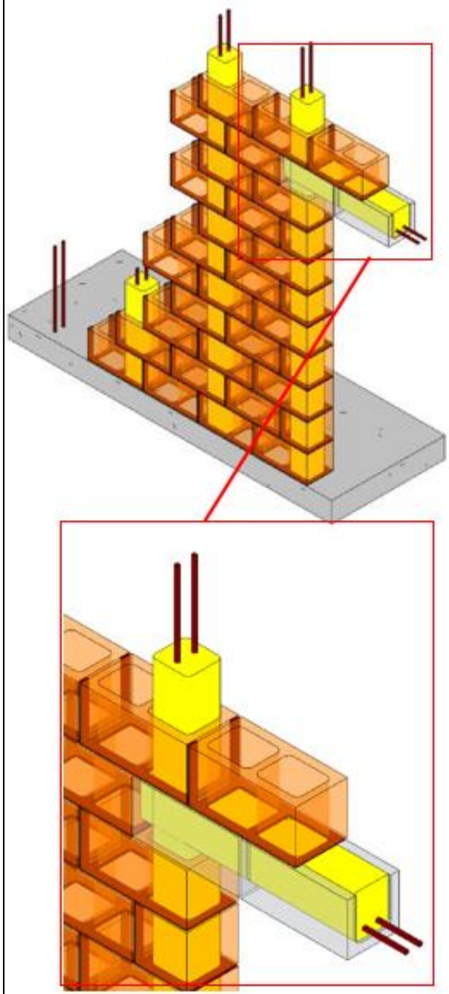
Table 2.1 Fundamental definitions of LOD (AIA, 2013b)

LOD	Explanation and authorized uses	
LOD 100	Explanation	The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.
	Analysis	Model Element may be analysed based on volume, area and orientation by application of generalized performance criteria assigned to other Model Elements.
	Cost estimation	The model may be used to develop a cost estimation based on current area, volume or similar conceptual estimating techniques (e.g., square feet of floor area condominium unit hospital bed, etc.).
	Schedule	The Model Element may be used for Project phasing and determination of overall Project duration.
LOD 200	Explanation	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
	Analysis	The Model Element may be analysed for performance of selected systems by application of generalized performance criteria assigned to the representative Model Elements.
	Cost estimation	The Model Element may be used to develop cost estimates based on the approximate data provided and quantitative estimating techniques (e.g., volume and quantity of elements or type of system selected).
	Schedule	The Model Element may be used to show ordered, time-scaled appearance of major elements and systems.
	Coordination	The Model Element may be used for general coordination with other Model Elements in terms of its size, location and clearance to other Model Elements.
LOD 300	Explanation	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

	Analysis	The Model Element may be analysed for performance of selected systems by application of specific performance criteria assigned to the representative Model Element.
	Cost estimation	The Model Element may be used to develop cost estimates suitable for procurement based on the specific data provided.
	Schedule	The Model Element may be used to show ordered, time-scaled appearance of detailed elements and systems.
	Coordination	The Model Element may be used for specific coordination with other Model Elements in terms of its size, location and clearance to other Model Elements including general operation issues.
LOD 400	Explanation	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
	Analysis	The Model Element may be analysed for performance of systems by application of actual performance criteria assigned to the Model Element.
	Cost estimation	Costs are based on the actual cost of the Model Element at buyout.
	Schedule	The Model may be used to show ordered, time-scaled appearance of detailed specific elements and systems including construction means and methods.
	Coordination	The Model Element may be used for coordination with other Model Elements in terms of its size, location and clearance to other Model Elements, including fabrication, installation and detailed operation issues.
LOD 500	Explanation	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

Table 2.2 Level of Development, interior wall (Masonry) (BIMForum, 2014)

LOD	Explanation	Illustration
LOD 100	A schematic model element or symbol that is not distinguishable by type or material. Types, layouts, and locations are still flexible.	
LOD 200	A schematic model element or symbol that is not distinguishable by type or material. Types, layouts, and locations are still flexible.	
LOD 300	Element modelling to include: floor element with design-specified locations and geometries Required non-graphic information associated with model elements includes: • Member size, depth, and material with sloping geometry • Spacing and end elevations • Design loads • Deflection criteria	
LOD 350	Element modelling to include: • Members modelled at any interface with wall edges (top, bottom, sides) or opening through wall • Any regions that would impact coordination with other systems such as but not limited to: o Bond Beam & Lintel Regions o Reinforcing & Embed Regions o Jam Regions	

LOD 400	Element modelling to include: ● Reinforcing ● Connections ● Grouting Material ● Jams ● Bond Beams ● Lintels ● Member fabrication part number ● Any part required for complete installation	

The fundamental definitions for different levels used by *LOD Specifications*, are identical to those published in Project Building Information Modelling Protocol From, with two exceptions:

> *First, the working group identified the need for an LOD that would define model elements sufficiently developed to enable coordination between disciplines – e.g. clash detection/avoidance, layout, etc. The requirements for this level are higher than those for 300, but not as high as those for 400, thus it was designated LOD 350. The AIA documents do not include LOD 350, but the associated Guide and Instructions references it.*
>
> *Second, while LOD 500 is included in the AIA's LOD definitions, the working group did not feel it was necessary to further define and illustrate LOD 500 in this Specification because it relates to field verification. Accordingly the expanded descriptions and graphic illustrations in this Specification are limited to LOD 100-400.*

2.3 Life Cycle Analysis

Life cycle assessment (LCA), also known as life cycle analysis, is defined by *US Environmental Protection Agency (2015)* as,

> *A technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave.*

Another definition has been given by *ISO 14040* as,

> *Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle.*

According to the definition by ISO (2006), LCA was understood as a tool used to assess the environmental influence and resource utilities during a product's whole life cycle, as well as other aspects such as life cycle costing, resource efficiency and even human health and social impact (Singh, A. et al. 2013; Lützkendorf, T. 2013). With the analysing ability extension, the possibility of LCA's working scale and relevant content kept increasing (Lützkendorf, T. 2013). As there is an enormously increasing demand for a large scale analyser, LCA was summarized as a methodology for analysing and assessing not only environmental burden of materials and products, but also services along their entire life cycle (ISO, 2005). Meantime, it was also used as a scientific research method aiming to analyse current and future impacts of a decision on a product's life cycle, even in a perspective of public service area or business area (Buyle, M. et al. 2103; Kohler & Lützkendorf, 2002).

2.3.1 Concept Development and Extension

Studies on LCA can be dated back to late 1960s and early 1970s, when environmental issues such as energy and resource efficiency, pollution control and solid waste started to be concerned by the public (Buyle, M. et al. 2103). According to Guinée et al. (2011), one of the first studies was conducted by the Midwest Research Institute (MRI) for the Coca Cola Company in 1969, aiming to quantifying the resource requirements, emission loadings, and waste flows of different beverage containers. The appearance of two follow-ups of this study marked the beginning of the development of LCA, as we know it today. After a rapidly growing interest in this subject since early 1980s, the Swiss Federal Laboratories for Materials Testing and Research (EMPA) published a general list, stating the necessary data for doing LCA. Buyle et al. (2013) also stated that during the same time period, the idea about LCA was introduced into the construction industry, with a certain focus on the utility of resources. The next decade was a remarkable growth period of LCA standardization, during that time the International Organization for Standardization (ISO) was involved as well (Buyle, M. et al. 2103). Guinée et al. (2011) regarded the beginning of 21st century could be called a continuous development decade, during which life cycle thinking was introduced into practice, as well as the importance of supporting tools through better data and indicators was highlighted.

As the development of the concept, LCA now is no longer a concept or a method grounded in environmental science (Lützkendorf, T. 2013). Lützkendorf (2013) claimed that LCA has expanded its focus from originally description and evaluation of energy, material flows and their impact on environment to a methodology used for assessing the influence of a choice in the whole life cycle of a product, moreover, the product could be in more than only environmental science and engineering. The scope of life cycle LCA was enlarged from environment further to economic, social and cultural protection aims (Kohler, 1999).

2.3.2 LCA in Construction Industry

Construction industry has been proved to have a significant influence on environmental issues due to one of its characteristics, which means there is an enormous amount of material used during the construction process (Neto and Filho, 2013). Kohler and Moffatt (2003) stated that a construction includes more than 60 basic materials and accounts for more than 2,000 different products. Zhang et al. (2013) also pointed out that construction works should take major responsibility of the overall energy use, as well as the consumption of material and un-environmental friendly emissions. Zhang et al. (2013) also stated that due to this fact, considering how to reduce environmental impact of construction activities, developing more sustainable materials and processes to minimize CO_2 emissions in nature has become a main challenge in the civil construction industry. Under this background, LCA was introduced into construction industry with a focus on environmental impact. It has been used to preparing eco-balances for buildings and constructed assets, construction products, building components and structures (Lützkendorf, 2013).

2.3.2.1 Aim of Conducting LCA in Construction Industry

The goal of introducing LCA into construction was to contribute to resource conservation and reduce adverse burden on environment through optimizing of building components, building services and structures, as well as analyse, assess and systematically manage energy and material flows (Lützkendorf, 2013). Neto and Filho (2013) confirmed this point of view as LCA aimed at investigating and evaluating the scale and significance of potential impacts on environment throughout construction projects' life cycle. Moreover, accompanying with the LCA findings are evaluated with respect to the defined objective and scope, decisions or recommendations are expected (Neto, and Filho, 2013).

2.3.2.2 Function and Importance of LCA in Construction Industry

Vince et al. (2008) proposed that LCA could provide an adequate instrument for environmental decision support. According to Zabalza et al. (2009), the LCA, in the simulation of construction phase, offer constructors an opportunity to analyse and assess the environmental impact, by conducting comparisons between the most commonly used materials, such as the choice between ceramic blocks or concrete blocks for building walls, or the assessment of the application of a granite floor instead of wood. Moreover, LCA has also been applied into decision making in the strategic field of construction industry, due to its capability of identifying characteristics of materials associated with selecting suppliers, for better waste management and financial policy-making (Zabalza et al., 2009). Lützkendorf

(2013) pointed out that LCA is responsible for collecting technical, environmental and social data, aiming to have a positive influence on construction projects.

With the development of the LCA method, a new application based on LCA occurred. Aiming to do more advanced assessment, a combination of LCA and life cost evaluation is proposed (Lützkendorf, 2013). Lützkendorf (2013) also stated that the result of project cost calculation should be supportive for the assessment result of economic evaluation and environmental performance.

According to the above statements, it is important that LCA keeps focus on material changes allocated in the construction industry, which in recent years have substituted raw materials such as stone and wood, who have a low environmental impact, for others materials of greater impacts (Neto and Filho, 2013). However Kohler and Moffatt (2003) emphasize the difficulty in developing a LCA in the construction industry, since a building can include more than 60 basic materials and approximately 2,000 different products, each of which has its own life cycle. Another important concern is the site location where the project will be constructed, since the degree and type of environmental impact in a particular location varies from each other, which means it may make the results of the LCA assessment very differently (Neto and Filho, 2013).

2.3.3 LCA and BREEAM

BREEAM is the abbreviation for Building Research Establishment Environmental Assessment Method (BREEAM, 2015). It was first launched in 1990, and it has become one of the most comprehensive and widely recognized method for environmental assessment and rating system of all kinds of buildings. It helps and encourages designers, client and others to reduce the carbon emission and consider low impact design. BREEAM assessments evaluate building's specification, design, construction and usage, and it presents a broad range of categories and criteria which includes energy and water use, internal environment, pollution, transport, material, waste, ecology and management processes. BREEAM contains a range country based specific schemes to adapt for local conditions and BREEAM SE is one of these schemes. The scheme International intends for projects anywhere in the world.

According to BRE Global Ltd (2014), the institution who established BREEAM, building components that could be included in LCA are external walls, external windows and roof lights, foundations, internal floor finishes, vertical structural frame, upper floors, basement/retaining walls, external solar shading devices and its access structures, ground/lowest floor, internal ceiling finishes, internal walls and partitions, roof, stair and ramp, balustrades and handrails, internal doors, internal wall finishes and internal windows. Within the elements mentioned above, external walls, external windows and roof lights, internal floor finishes, upper floors, internal walls and partitions and roofs are mandatory to be calculated. Those optional calculation components are also recommended to be considered in order to receive higher BREEAM rating result.

2.3.4 Combine BIM with LCA

One feature of environmental analysis is that they are performed after the generation of necessary construction documents (Jalen and Jrade, 2014). The lack of integration between environmental analyses and the main BIM simulation processes may lead to inefficient afterward modification to meet certain environmental criteria. Another feature which is common to all environmental analyses system is that they demand large amounts of design and construction data in different formats, and the accuracy of analysis depends on the quality and availability of data from all phases of the project (Alwan et al., 2015). However, this situation is not enhanced due to ACE industry's characteristics of insufficient integration, communication and technological collaboration.

By combining LCA with BIM, ACE industry has the possibility to simplify the process of achieving a building with high environmental performance (Jalen and Jrade, 2014). BIM applications contain build-in intelligent objects, which enable the exportation of both geometrical and non-geometrical information from multi-discipline models and databases. By using these information, the time consuming processes of remodelling and data re-entering will be omitted, and more importantly, analysis results will be originated from the same model based data source. This combination of LCA and BIM also has the potential to support the analysis of a building's system from the early design stage, which includes the selection of materials, construction methods and building systems. Therefore, BIM is gradually used in sustainable design and energy performance analysis (Li et al., 2012). However, due to the lack of one-platform BIM-LCA configurations, the test of data inputs and outputs using different interoperable formats is still a necessary process of LCA implementation (Jalen and Jrade, 2014).

2.4 Vico Office

Vico office is an integrated solution concerning 5D BIM in which Building owners, general contractors, and construction managers use 5D virtual construction software to conduct risk analysis, manage project budgets, and optimize schedules in construction projects (Vico Software, 2015a).

2.4.1 Purpose of using Vico Office

As an integrated tool to achieve project coordination, quantity take-off, cost estimation, project scheduling and production control, Vico office allows users to use models exported from most of the commonly used applications, such as SketchUp, Tekla, ArchiCAD, and Revit (Vico Software, 2015b). Besides, Vico office allows users to use sources from different roles such as design teams, engineers and subcontractors to estimate, schedule and construct a new project on a computer before ever breaking ground. Accompanying with integrating models, Vico Office could add detailed information to every building component, such as material lead time, human resource demand per unit and hourly handcraft cost per unit (Bannan, 2009). The program develops project simulation from a single level of graphic to a comprehensive level, which includes both 3D graphic data and time dimension information, as well as budget information.

2.4.2 Functions of Vico Office

According to Laiserin (2008), Vico office focuses on the three linchpins of every project: constructability, quantity take-offs, and location-based scheduling. These core competencies are presented through different modules in the software and help provide the users with a solution concerning to more aspects of the project. The software consists of a core module, which can be seen as the system's cornerstone, and a set of complementary modules, which are integrated in the same environment (Vico Software, 2015c). More importantly, every component shares the same integrated database, which makes it possible to achieve total homogeneity of the information (Vico Software, 2015a). The mentioned modules includes:

Constructor. This 3D modelling view provides a platform for architectural, structural, and MEP modelling. By combining these pieces form the production models, the module sets the basis for feasibility, scheduling and cost planning.

Estimator. Vico's 5D estimating and costing panel provides a detailed quantity plan for cost calculations. These model-based quantities drive scheduling, cost planning and the baseline budget.

Control. Vico's 4D flow line scheduling panel is used for planning, optimizing and controlling project schedules. This function links time and space in a new location-based view.

5D Presenter. Vico's 5D visual presentation environment tells the whole project lift cycle, it integrates construction process, schedule and cost plan in one view.

Cost Manager. Vico's 5D budgeting environment provides complete projects under monitoring and cash flow visibility. It presents in a graphical representation of project cost variance.

Change Manager. The function creates a comparison environment between before-changes and after-changes, track revisions for consistency across all representations. It is able to keep everyone working from the latest revisions.

To sum up, Vico Office extends the basic 3D model with more features such as constructability analysis and coordination, quantity take-off, 4D location-based scheduling and production control and 5D estimating (Vico Software, 2015b).

What really makes Vico Office unique is the tight integration between model geometry and the quantity take-offs, cost plan, and schedule of the construction project (Vico Software, 2015a). From a perspective of simulation, this means that every time the design changes, which happen a lot in construction process, the schedule and estimate are immediately updated. It takes a few weeks for contractors to produce the same answer in the traditional way.

On the perspective of operations, Vico Office helps general contractors and construction managers orchestrate material procurement, delivery, and human resource utility with the result of Vico's analysis and reports (Vico Software, 2015c). Superintendents can walk on site with a tablet and enter in the percent of work completed for each of the sections that has been pre-simulated earlier. This time related data provides a schedule forecast and shows the team where potential problems will arise in the following few weeks, so as to solve them in an early phase or prevent them from happening.

2.5 Anavitor

Anavitor is an application, used to effectively conduct LCA. It represents a calculating concept that evaluates the environmental impact according to the methodology of LCA and Life Cycle Cost by using the result of present calculations (Åkej AB, 2015). Anavitor is a collaboration between Åkej AB, who owns and manages the application, and IVL Swedish Environmental Research Institute, who is responsible for environmental data of building materials, transportation resource and energy resources.

Due to the need of an application that could be available for end users who are not LCA specialist, but have a need to broaden the basis for decision-making with environmental impact and life cycle costs, Anavitor was developed (Erlandsson et al., 2007). It is such a tool to give this sort of end users an idea of the LCA with related environmental and economic information, based on the evidence they produced in common IT tools without help of external consultants. Besides, Anavitor's features aim to find innovative and viable alternatives for existing or potential environmental problems, instead of identifying deficiencies. Moreover, in a perspective of long term, Anavitor will not only be used to analyse the available options, but also to find environmental performance that can be transformed into environmental criteria.

2.5.1 Functions of Anavitor

Anavitor is the first LCA application that is not designed as a "self" application, but must always be seen as a supplement to an already existing application (Åkej AB, 2015). Erlandsson et al. (2007) also stated that in order to increase the availability of life-cycle-based calculations like LCC and LCA, the application of Anavitor was designed to adapt to the existing software such as CAD or spreadsheet program. By leveraging existing data to generate needed information is a basis for Anavitor and a fundamental prerequisite for a cost-effective approach to achieve life cycle calculations. Therefore the aim is to add a new function and generating the relevant report in existing software by using the part of the application called Anavitor Client.

From an end user's perspective, it must be quick and easy to obtain life-cycle assessments, and it shall be possible without the competence of expertise (Erlandsson et al., 2007). The best scenario is that the user makes project calculation as usual and LCA was conducted after calculation result is saved in Anavitor Client. In order to make it possible, a description about the life cycle impacts of the most frequent resources must be done. Anavitor system is designed for this to be done centrally in the part of the application called Anavitor Resource (Erlandsson et al., 2007). The project resource consumption must be crossreferenced to the environmental resource recipe, which is predefined in Anavitor Resource. This process also includes unit conversion from imported data to the data contained in Anavitor. Moreover, the environmental resource recipe was stored in Anavitor environment.

2.5.1.1 Client

According to Åkej AB (2015), the interface to the application, which only covers parts that are relevant to the information located on the end user. Furthermore, Anavitor Client enables the user to:

- Read a defined file with information including at least one material compilation.
- Complement the imported file so as to improve or supplement the assessment base or to administer and report on read file in a better way.
- Analyse the calculation result for construction project and generate general and business custom reports.
- Compile and group calculation results from several projects, for example by organizational affiliation, type of project or other features.

The consolidated results made Anavitor available as an interface in the same software as the very first calculation of projects was made (Erlandsson et al., 2007). And it was regarded by the user as the arrival of a new functionality in the usual applications.

2.5.1.2 Resource

Anavitor Resource is the core of Anavitor's data management system (Erlandsson et al., 2007). It is also the prerequisite for a cost effective way to update and manage the project resources and to maintain and manage the project quality when calculations are made at several places in the organization. The available data in the construction sector to import into Anavitor are normally limited to cover only one construction stage such as repairing, new construction project, renovation or extension. Besides, the information of the project is logically structured in different ways by internal unique identification number and naming method, so they must be linked to a fewer number of general resources in Anavitor who are carriers of various characteristics such as weight per unit, maintenance intervals, longevity, cost and environmental impact. These actions of linking are conducted inside Anavitor resource, which can be understood as the core step of conducting the LCA.

2.5.1.3 Environment

Anavitor Environment includes an environmental database of LCA data for different aspects, such as materials and energy, as well as activities like transportation (Erlandsson et al., 2007). LCA data is divided into different environmental impact categories such as CO2 equivalents for climate impact and SO2 equivalents for acidification. These values of the single-impact categories can then be standardized so that their relative importance can be analysed as well. This is done directly in Anavitor environment so that a single unit is obtained for the different impact categories. Hence the ability to evaluate the relative importance of a single factor in various environmental impact categories can lead to make it possible to develop an environmental index.

2.5.2 Perspectives of Using Anavitor

This section is divided into two parts based on different perspectives of Anavitor's users.

2.5.2.1 Constructor's Perspective

Erlandsson et al. (2007) stated that using Anavitor could result in a few positive outputs. First of all, Anavitor is a good tool to take building's environmental impact into consideration under the big picture in which the proportion of clients who sets the energy and environmental standards in their request for quotations (RFQs) increasing rapidly. Then inputs required by Anavitor are mostly generated information in construction projects, which means the use of Anavitor therefore entails little additional work. By using Anavitor's function, construction companies can calculate buildings' environmental impact, which has a much higher cost for manual calculations today, in a more cost-effectively way.

2.5.2.2 Architect's Perspective

Erlandsson et al. (2007) also confirmed the positive feedbacks from architects during their cooperation progress. Firstly, Anavitor is able to create quality and profitability of construction projects by assess the options in a better way and make a qualified choice with a holistic approach integrated design and cost with environmental consideration. Secondly, Anavitor is able to help architects provide customers with a better basis in early stages, which increases the possibilities to propose and gain support for interesting solutions when the focus is shifting from short-term cost cutting to long-term product quality. Thirdly, Anavitor helps architect's role and importance grows with the implementation of BIM, as well as generating LCA and LCC results. Through Anavitor, architects would be able to get into the LCA in a rational way in the organization and introduce LCA as part of their offering to the customer.

2.6 360optimi

360optimi is a cloud-based sustainability metrics platform that supports over 60 specific sustainability analysis applications for various users and different usage (Bionova Ltd, 2015d). The primary idea of 360optimi is One Platform N Solutions, which means it enables specific applications to be set up based on the 360optimi platform. The entire philosophy of 360optimi is developed around flexibility and easy customization (Bionova Ltd, 2015c).

2.6.1 Aim and Use of 360optimi

360optimi aims to offer users a cloud based resource platform where standard-compliant LCA applications with a broad usage possibility enable user to conduct LCA at the whole scale of their business areas (Pasanen, 2015). The platform creates a foundation for building new customized applications, reports and other related analysis tools. These mentioned tools can be built based on users' own requirements or usages, and related specifications can be co-developed by both application designers and application users (Bionova Ltd, 2015c). The usage scale covers manufacturing, hospitality, construction, as well as environmental management. It is built with a zero-coding customization philosophy and allows tailored applications to be programmed for such specific needs as construction LCA, power electronics LCA, building accessibility, environmental labelling, mineral-based products EPD generation, and etc. Especially in urban planning and construction industry, 360optimi supports the full life-cycle of cities, from urban planning LCA to project LCA to tracking in-life building performance and again renovation LCA with the aid of local data (Pasanen, 2015).

2.6.2 Function and Modules of 360optimi

From a perspective of construction industry, 360optimi is a cloud-based sustainability metrics software, aiming to conduct the LCA process for construction projects in an efficient way (Bionova Ltd, 2015a).

The functioning process of 360optimi platform is an integrated calculating process without dedifferentiating function modules (Pasanen, 2015). The calculations are conducted based on the chosen tools for targeted applications, which include EN 15978 for construction project LCA, 15804 standard for Environmental product declarations for construction products and CEEQUAL-compliant infrastructure LCA and water footprint tools, as well as several others (Bionova Ltd, 2015c). It serves to conduct LCA and life cycle cost, as well as other kinds of operating sustainability metrics for various purposes, such as solutions and tools for life-cycle efficiency, practice tracking, scoring, data collection, corporate reporting and etc., all together around 60 applications. Publishing data from the software for different industries is also achievable when it is desirable (Pasanen, 2015).

As results of the calculations, a range of different environmental impact categories as well as output flows are presented. The impact categories can be customized and the most common ones are global warming, acidification, eutrophication, ozone depletion and formation potential of tropospheric ozone. Besides, the considered impact sources generally include: construction materials, transportation to site, construction and installation process, maintenance and material replacement, energy use, water use, deconstruction and external impacts (Bionova Ltd, 2015e). These vary for the specific calculation application, for instance, LCA for LEED does not consider energy or water use.

3 Case

This chapter describes the context within which this study has been conducted. The context is based on the reference company's written documents, both internal and public, as well as conversations with staffs who work in the company.

Peab is the reference company of this thesis study. It is one of the leading construction and civil engineering companies in the Nordic region with approximately 14 000 employees and a turnover exceeding 45 billion Swedish crowns in the year of 2014 (Peab AB, 2015). Peab has a wide range of working area including civil engineering, construction, industry and property development etc.

3.1 Peab's Vision about BIM and LCA

According to Peab's CTO, the company's current vision about BIM is to use it as an integrated tool in their main work processes, aiming to carry integrated information and enable these information to flow fluently between different applications, activities, work processes and even systems. More specifically, Peab's information source is evolving from isolated documents to a model based database with the help of BIM. Presently, Peab has a short term specific plan to develop from a starting status of introducing 3D models into every project to a finishing line where Peab is able to use models together with integrated information in different work processes. Besides, the plan includes several periodical objectives, such as building up a solid knowledge base for BIM implementation, a certain amount of projects would use 4D and 5D BIM simulation until a certain time point etc.

Moreover, a pyramid of BIM implementation is mentioned (Figure 3.1). It indicates three basic BIM implementation phases in Peab. The lowest level represents a base phase in which BIM is only applied from a perspective of 3D models. While on the middle level, project quality and quantity take-off are involved and it can be regarded as the adoption phase. The highest level, which is a preferable scenario of implementing BIM, stands for the company-wide applying of 5D BIM simulation, which includes 3D visualization, scheduling and cost estimation.

Currently, traditional LCA processes are seldom conducted in Peab's projects due to their characteristic of time and labour resource consuming. Instead, Peab has a will to apply LCA with the aid of BIM. The implementation of LCA was regarded as a branch or an extension of their BIM vision to expend the benefit of BIM. More specifically, this extension could not only improve the competitiveness of the company but more importantly, help Peab's projects achieve both ecological and economic efficiency.

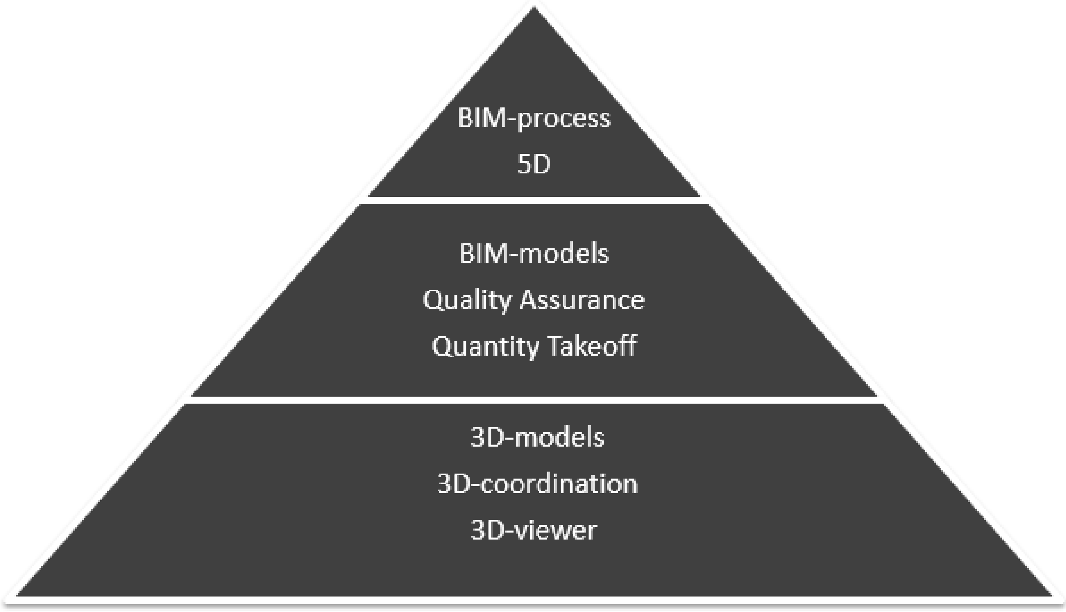


Figure 3.1 The BIM Implementation Pyramid in Peab

3.2 Peab's BIM Environment

According to the pyramid, the position of Peab is on the top of the first level and moving towards the second level of the pyramid. Instead of only using 3D models in some pilot projects, the staff has started using models in projects in a company-wide range. Another aspect about the BIM environment is staff composition. The CTO has a team of three BIM specialists in different directions. The CTO himself focuses on the BIM development and related strategies, the other two specialists respectively focus on basic BIM implementation and a more advanced aspect of 5D simulation. Another fact mentioned by the CTO is that there is a need for BIM specialists inside the company, since the implementation process creates an increasing demand of specialism support. The work content of BIM specialists is not limited in solving BIM problems of on-conducting projects, they will also play a crucial role in Peab's strategy of rising up the bottom level of BIM knowledge. By conducting educations which cover a wide range of staff, the company want to enable a certain amount of staff to use BIM as a qualified coordinator. Currently Peab has educated almost 100 engineers within a range of 10 regions inside Sweden.

The other aspect is software. The most commonly used BIM applications in the company are Autodesk Revit, Solibri Model Checker and Vico Office, and their uses are modelling, clash detection and 5D simulation respectively. Besides, the consideration of preferable LCA applications has started.

3.3 Case Description

Under the recommendation of an internal BIM specialists, Landmärket is chosen as the reference project. It is a residential project located in the city of Skellefteå.

The project was started in March of 2015 and will be finished in December 2016. The owner of it is HSB Housing Company and Peab is one of the main contractor. The Revit model of the project used in this thesis consists of two residential buildings, building A and building B, and a whole foundation.

Instead of using the traditional method of 2D drawings, Peab chooses to use 5D BIM simulation in both design and construction phase for the project. Besides, it is regarded as a pilot project as well, aiming to test the work process of 5D BIM simulation in the construction phase. This is the main reason that Landmärket is recommended for this study. Therefore, the expectation of this project is not only the buildings themselves, but also inspirations for 5D simulation implementation in other regions of Sweden.

4 Method

This chapter of the thesis will describe the research methodology and research processes.

4.1 Methodology

Due to the main purpose of this thesis is to realize the integration of LCA in the BIM environment of the reference company, Design Science Research is chosen as the methodology. Design Science Research focus on solving real world problems (Dresch et al., 2015). Subsistent theories are applied, tested and modified through researchers understanding, experience and capabilities to develop an innovation (Hevner et al., 2004). This innovation, which could be an artefact or a recommendation, will serves as a satisfactory solution for the problematic situation, and the validity and usability of the innovation need to be evaluated and justified. In other words, this research method is used to construct and evaluate solutions that can transform the current situation into a better status (Dresch et al., 2015).

This thesis started with acquiring fundamental knowledge in the targeted studying area. The effort of this period of time is mainly focusing on searching and understanding background knowledge in BIM and LCA, studying the chosen case, and studying software manuals and tutorial videos. After acquired sufficient knowledge of the software utilization, LCA applications was tested in the current BIM environment of the reference company during the next two months. This test was supported by both internal and external specialists. Obstacles of applying LCA applications were identified and analysed with the aid of both literature and specialists, and feasible solutions for successfully conducting LCA are presented. The process of this study is displayed in Figure 4.1.

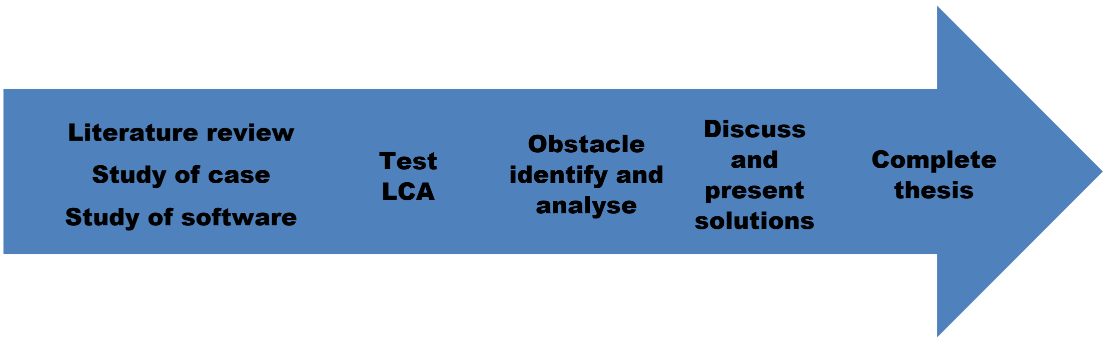


Figure 4.1 The work process of the study

4.2 Literature Review

A systematic literature review aims to establish an updated set of empirical theory framework, as well as the knowledge that can support better understanding of the thesis topic (Dresch. et al., 2014). In order to have a sufficient background knowledge of the targeted topic area, several literature studies have been conducted. It's requisite to have a good understanding of what work has been done in the area, as well as what concepts and theories in the area have been developed (Bryman and Bell, 2011). Meanwhile it stops authors from repeating the existing works. The literature review is mainly focused on published scientific articles and Books concerning the following keywords:

- Building Information Modelling
- Life Cycle Analysis
- Construction Industry
- Level of Detail and Level of Development
- Vico Office, Anavitor and 360optimi

The literature has been chosen under a tendency of construction area since the focus of this master thesis is within construction industry. The scientific articles and books are found through databases such as Chalmers library and recommendations from this thesis's supervisor at Chalmers University of Technology. The main key terms of the searching process are BIM in construction industry, LCA in construction industry and level of development. The literature review was conducted thorough the whole thesis period. The major part of the review was accomplished in the early phase of the whole period and some complementing reviews were conducted in later phases.

4.3 Study of the Case

Authors started with the related document materials of 5D BIM aspect, which includes a BIM manual of the reference company; internal naming protocol for model components' family types, used to identify the material constituents of each family type; and internal regulation of level of detail. The reason of reading the document materials is to establish a general understanding of the BIM environment inside the reference company, more specifically, what work has been done in the reference company to achieve 5D BIM.

Material documents related to the reference project were provided in forms of Revit models and Vico Office documents. Revit models were ungrouped and went through by the authors to study the component family types, components' quantity and their LOD. Cost estimation report was provided in the Vico Office documents which could be displayed by the *Cost Plan* panel in Vico Office.

All these materials were went through by the authors before the test process to get a comprehensive understanding of the reference case. Besides, LODs of building components required by BREEAM was studied as well.

4.4 Study of Software

The main purpose of conducting the learning process is to explore how related software are used in the organization. More importantly, to investigate how information transfer is achieved between different related software. Being different from literature review, study of software not only offered authors a specific knowledge base of the reference software, it also enabled authors to conduct the following research with the specific technical knowledge and skills. According to the research structure, this process could be divided into two sections. The first section is about 5D BIM software and the second section is about LCA software.

In the first section, a media-based learning program was conducted, aiming to obtain information about the software Vico Office and learn how to use the software. Meanwhile the learning program was also supported by a Vico specialist from the reference company. This specialist was introduced under the recommendation of our supervisor of the reference company. Vico office, as a 5D BIM simulation software, offers the reference company a way to develop their projects into 5D level. Therefore, the motivation of doing the media based learning is to see how the reference company achieves the 5D BIM simulation, and to develop authors' Vico office technique for further research.

The second part of the software studying process is about the LCA software, which refers to Anavitor and 360optimi. There are not so much literatures and tutorial materials about the software, therefore the authors' study was primarily based on information provided by external specialists from the companies of Anavitor and 360optimi. This situation could lead to an opinion bias on these software. The aiming of this learning process is to find out what information is necessary for the software to conduct LCA and in which format the information is needed.

4.5 Test Process and Feasible Solution Acquisition

A specific description is necessary for the test process, since it supports the reliability of the study by showing the way to repeat the work procedure and harvest the same result (Dresch. et al., 2014). In order to identify the obstacles to apply LCA applications in the current BIM environment of the reference company, a test to simulate the workflow from Revit and Vico Office to Anavitor or 360optimi was conducted with the reference project.

Two sorts of information could be used by Anavitor as the import data, IFC file exported from BIM modelling software and sbXML files exported from quantity take-off or cost estimating software. Both of the two sorts were included in this test process. A complete cost estimation report was exported from Vico Office as the sbXML test file. When it comes to IFC file, only building B in the reference project was exported. According to Anavitor (2015), building components carries the most influential information, material, for LCA. Ground components were therefore not included in the exported IFC file. Building A and building B share a great level of similarity in the respect of structure and component types. So only building B was exported in order to reduce file size and test time.

The valid formats for 360optimi are the same as Anavitor. IFC files from modelling software, excel or sbXML from simulation software are available for 360optimi. The content of the IFC file tested in 360optimi is exactly the same with the IFC file tested in Anavitor. When it comes to files from simulation software, according to the specialist of 360optimi, sbXML files are not recommended to be used since the file quality of this format is always low and the information inside sbXML files is always deficient. Hence, excel spreadsheet file is the only tested file from the simulation software. And the content of excel spreadsheet includes the complete cost estimating information of the reference project.

The simulation process was carried out with the support of external LCA specialists who comes from ÅKEJ AB, the company who owns Anavitor, and BIONOVA, the company who owns 360optimi. They were recommended and provided by the thesis's supervisor in the reference company.

Required files from Vico Office and Revit were first exported by the authors and sent to external LCA specialists by email. These files would then be used in a preliminary simulation conducted by the external specialist to identify the possible obstacles when importing them in Anavitor/360optimi. Obstacles emerged from the simulation and recommended solutions were discussed then in face to face meetings between the authors and external specialists.

After the meeting mentioned above, emerged obstacles and recommended solutions were analysed by authors together with internal BIM specialists, who comes from the reference company, to reach feasible solutions. Face to face meetings and e-mail contacts were conducted for this analysis. These feasible solutions were further discussed with external specialists via email to establish a valid workflow from Revit and Vico Office to Anavitor or 360optimi. The process of this workflow test was displayed in Figure 4.2.

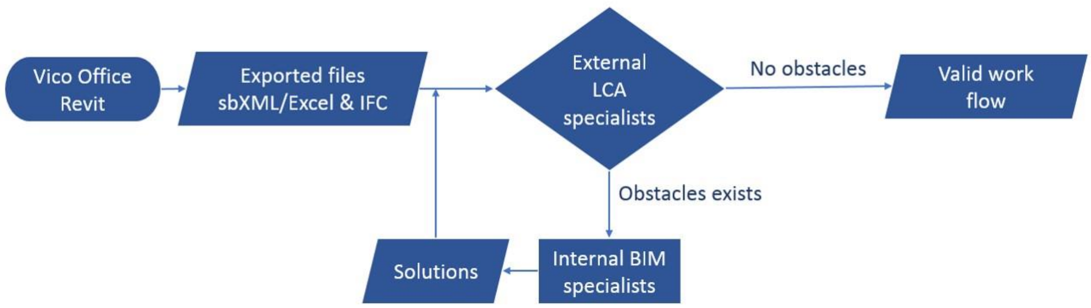


Figure 4.2 The process of work flow test

4.6 Complementing Meetings

The authors of this thesis were located in the reference company's office during the whole study process. Therefore, authors have the convenience to get required information through complementing meetings. For example meetings with one of the thesis's supervisors, who are also the CTO of the reference company, are arranged randomly according to the study needs. One of the purposes of these meetings is to understand the BIM environments and visions of the reference company. The meetings are hold mainly with authors' supervisor, BIM specialists inside the reference company, environmental specialists inside the reference company, and external consultants from LCA application companies.

5 Results

This chapter presents and analyses the empirical data for this study, and it serves to provide a reliable outcome of the exploring process in the reference company. The chapter is divided into two sections to introduce the main result. The first section is the results from the case and software study, and the second section is about results from the conducted test process. In the first section, the LOD of the reference BIM project in the reference company is analysed and feasible workflows are presented from the perspective of the reference company. The second section illustrates the obstacles when authors attempted to implement the related LCA application in the BIM environment of the reference company. Besides solutions to these identified obstacles and a suggested workflow are also stated in this section.

5.1 Results from Case and Software Study

In this section, results from case and software study will be presented. It can be summarized as three sections including the LCA regulation related to the reference project, LOD of the reference project and feasible workflows.

5.1.1 LCA regulation related to the reference project

According to internal environment specialist of the reference company, BREEAM International New Construction and BREEAM SE are used as environmental performance assessment standard for their projects (Franzén, 2015). Within the reference company, BREEAM SE is used for office, industrial building and shopping centre projects. BREEAM International New Construction is used for commercial projects other than those three mentioned above, such as library and hotel. Currently, there is no LCA requirement and mandatory LCA method for residential projects. However, the reference company has the strategy to conduct residential project LCA with the aid of BIM in the future. Hence, BREEAM international New Construction is chosen in this study under the recommendation of the internal environmental specialist.

5.1.2 LOD of the Reference Project

As presented in the theory part, different building components of the reference project have different LODs (BIMForum, 2014). With the project going on, more non-graphic information concerning material, labour, price and subcontractor will be attached to components. This process will lead to the increase of LOD level. Therefore, the authors studied building components in both Revit and Vico Office to present their current LODs. Table 5.1 illustrated the study result. Due to the fact that Vico Office's BIM model is extracted from Revit, components in Vico Office will not have more graphic information than their corresponding components in Revit. The main reason of LOD's variation is the attachment of more detailed non-graphic information in Vico Office. The scope of studied components are consistent with *BREEAM International New Construction's* requirement. Reference project is illustrated by an architect model, hence some structural components required by *BREEAM International New Construction* are not included. These structural components are foundations, structural frames and roofs. There is no external solar shading devices and internal windows in the reference project, therefore their LOD is not studied as well.

Table 5.1 LOD of building components in both Revit and Vico Office

Components Required by BREEAM	LOD of Revit Components	LOD of Vico Office Components
Exterior Wall	300	300
Exterior Windows and Roof lights	200	200
Interior Floor Finishes	300	350
Upper and Ground Floors	200	300
Basement Walls	200	200
Interior Ceiling Finishes	200	200
Interior Walls and Partitions	300	300
Roofing (Excluding Structural Roof)	100	100
Stairs and Ramps	300	300
Balustrades and Handrails	300	300
Interior Doors	350	350
Interior Wall Finishes	Not contained	Not contained
External Solar Shading Devices and Access Structures etc.	Not contained	Not contained
Foundations	Not contained	Not contained
Vertical Structure Frame	Not contained	Not contained
Interior Windows	Not contained	Not contained
Roof (Structure)	Not contained	Not contained

Exterior wall components in Revit model reach the LOD 300. They illustrate the specific overall thickness which accounts of different layers and major openings are model with precise dimensions. Material and type information are included in the type parameter of *Structure* and *Function* respectively. These information mentioned above meet the requirements of LOD 300 in *Level of Development Specification*. According to BIMForum (2014), LOD 350 requires wall assembly contains hosted objects such as windows and doors, and headers and jambs at openings to reach LOD350. In the reference project, headers and jambs are not modelled within the wall assembly, but included in the models of doors and windows. This is because of the limitation and character of Autodesk Revit. Window and door models have reached minimum LOD 350, which will be presented later. Therefore, even though the LOD 350 requirements are not fully met, exterior wall components in Revit have reached and beyond the LOD 300. Exterior wall components in Vico Office have the same LOD like components in Revit, but they more detailed material information are attach in *Cost Plan*.

Interior wall component in Revit illustrate their overall thickness and other geometric information required by LOD 300. Bathroom walls illustrate detailed layers within the wall assembly. Other interior walls do not contain layers in their assembly but still express the specific overall thickness. Opening for windows and doors are modelled with precise dimension. Fire rating information is included the Revit's *Floor Plans*. These fulfil the requirement of LOD 300. When considering LOD 350, major framing elements, such as king studs, diagonal bracing and headers, are required. These framing elements are lacking in the reference project and headers are modelled within the window and door assembly because of the character of Revit. Therefore, like exterior walls, interior walls have not reached LOD 350 but fully reached and even exceeded the requirements of LOD 300. Higher LOD levels require more comprehensive graphic information in BIM model, so even interior wall components in Vico Office contains more information about material, they still remain having LOD 300.

Exterior windows components in Revit reach LOD 200. Locations and nominal sizes are specified. Frame and glazing elements have a precision of 1mm. These graphic information not only fulfil the requirement of LOD 200 but also reach LOD 300. Non-graphic information contained by exterior window components are their functionality characteristics. In order to reach LOD 300, finish types, glass types and windows' performance characteristics should be attached to the Revit components. The corresponding component in Vico Office contains information of finishes types. However, they still cannot reach LOD 300 due to the lack of glass types and performance characteristics.

Interior door components in Revit have reached LOD 350. These components have specified door panels, headers and jambs, and their operation characters could be identified from the models' graphic information. Hardware set functionality and types are indicated by the family type name. Spatial requirements for operation are illustrated in the *Floor Plans* of Revit. The criteria used to distinguish different LOD for interior doors are mainly focus on graphic information. Therefore, even though non-graphic information about sealants and brackets are included in Vico Office, the LOD of its interior door components are still 350.

Ground and upper floor components in Revit have met the criteria of LOD 200. Components are modelled with specific size and locations which has already reach the LOD 300's graphic requirement. When non-graphic information is studied, only concrete material information is attached in Revit's model. Therefore, it is deficiency for floor components in Revit to reach LOD 300. Corresponding components in Vico Office have reached the LOD 300 by include required non-graphic information.

Interior floor finishes' components in Revit have LOD 300. They are modelled based on specific material types and accurate thickness and scope. The corresponding components in Vico Office including non-graphic information of material and manufacture, and have fulfil the criteria of LOD 350.

According to *Level of Development Specification*, only two LOD levels, LOD 100 and LOD 200, are defined to describe ceiling finishes components (BIMForum, 2014). The ceiling finishes components in Revit illustrate their overall thicknesses, scope, and the depth of suspended ceiling, which fulfils the requirement of LOD 200. No non-graphic criteria is formulated, therefore corresponding components in Vico Office also has LOD 200.

Construction stair components in Revit fulfil the requirement of LOD 300. Stair treads, risers and stringers are included in the models and nominal dimensions are illustrated as well. When considering the LOD 350, support elements such as hangers and brackets need to be included in the model. There is no non-graphic information required in this category, hence stair components in Vico office also have LOD 300.

Railing components is both Revit and Vico Office have LOD 300. Their assembly includes railings, balusters and posts, and the main material information is included in their *family type name* in Revit. When considering LOD 350, secondary railing support elements, such as bracing supports should be modelled.

Roof components included in the reference project are only the roofing surface layers. They contain detailed material and dimensional information within the Revit model and Vico Office. However, LOD 200's requirement of spatial allowance for structural deck and framing system are lacking in the reverence project. Therefore, even though roofing elements has exceed the requirement of LOD 100, they still haven't met the requirement of LOD 200.

Basement walls of the reference projects are served as shallow foundations of the building. According to *Level of Development Specification,* LOD 300 require these elements to illustrate the sloping surfaces of the ground, and elements' overall sizes and external dimensions. Non-graphic information should include concrete strength, reinforcing strength, and geotechnical information. Basement wall components in both Revit and Vico Office fulfil the criteria mentioned above, except including geotechnical information. Therefore, LOD 300 is not met, but they have reached and exceeded LOD 200.

Except the model analysed by authors, other structure models produced by the reference company have reached higher LOD. Models that contain prefabricated concretes and steels include the connection and cooperation items between building components, and they have been used for clash detection inside and between disciplines.

5.1.3 Feasible Workflows

According to the meetings with the CTO, the reference company is able to offer related data for LCA in two different ways, which makes it possible to form two different workflows to conduct it for current BIM projects.

As showed in Figure 5.1, the first workflow starts from the 3D models in the modelling tool, which is Revit for the reference company, and then it branches into two directions. Both by using the data from 3D models, one branch conducts LCA and the other one conducts 5D simulation. More specifically, BIM models are firstly exported from Revit in IFC format and then imported directly into a specific LCA application. Then the LCA application reads data from the IFC files and generates the assessment result and the first branch comes to an end. In the second branch, BIM models and embedded information are delivered through a "plug-in" function in Revit to the related simulation application, which is Vico Office in the reference company. Both the BIM models and embedded information will then be used as the resource for the 5D simulation process. Vico Office can be connected seamlessly with Revit and generates related simulation results.

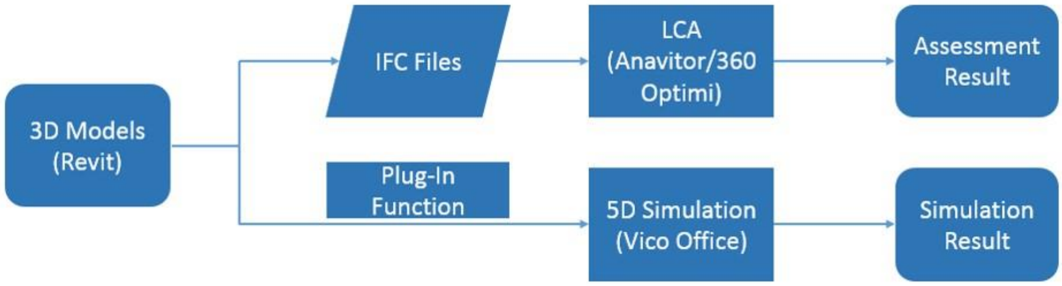


Figure 5.1 The first feasible workflow.

The second workflow is mapped in Figure 5.2. It also starts from 3D models in Revit. By using the "plug-in" function, Vico Office connects Revit to conduct 5D simulation and generate simulation results. After these steps, it exports data of construction materials in a valid form for the LCA application. The valid form is always considered between excel spreadsheet and XML file. Thereafter, this workflow reaches the LCA process. The LCA application conducts analysis through importing the available files and read the needed data. In the end, the assessment result of LCA is generated.

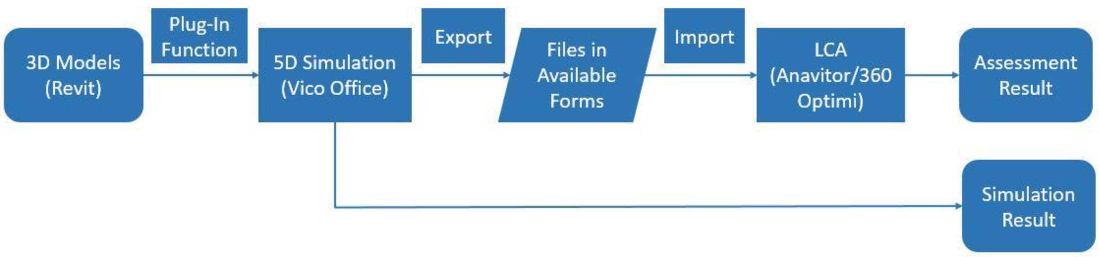


Figure 5.2 The second feasible workflow.

5.2 Results from Test Process

In this section, results from the test process are presented. It mainly includes two parts, which are identified obstacles and possible solutions.

5.2.1 Barriers Occurred

The identified barriers are divided into two sorts, one of which is the occurred obstacles when IFC files are tested in the first workflow. The other sort is the occurred obstacles when Vico-exported files are tested in the second workflow.

5.2.1.1 Obstacles when LCA Applications Importing IFC

When IFC files are tested during the study process, the obstacles are not the same in different applications. Hence the identified obstacles are presented based on tested LCA applications.

5.2.1.1.1 Anavitor

There is an obstacle of component missing when IFC files are imported into Anavitor. The IFC import result of Anavitor was contrasted with the components contained in the original Revit Model to identify the missing component. Table 5.2 displays the contrasted result.

Table 5.2 Contrasted result between original Revit model and import result of Anavitor

Component category	Component quantity in Revit	Identified quantity in Anavitor
Ceiling	106	106
Door	183	183
Floor	311	311
Roof	7	7
Stair	11	11
Wall	754	754
Window	269	269
Air Terminals	16	0
Casework	607	0
Curtain Panel	21	0
Curtain Wall Grid	12	0
Curtain Wall Mullion	64	0
Duct Fittings	17	0
Duct	17	0
Electrical Equipment	86	0
Electrical Fixtures	3	0
Fascia	1	0
Furniture	232	0
Generic Models	4	0
Lighting Devices	17	0
Mechanical Equipment	2	0
Plumbing Fixtures	87	0
Railings	35	0
Specialty Equipment	35	0
Stairs: Run	11	0
Stair: Support	82	0
Total	2990	1641

The identified categories include ceiling, door, floor, roof, stair, wall and window, and the miss identified categories includes air terminal, casework, curtain panel, curtain wall grid, curtain wall mullion, duct fitting, duct, electrical equipment, electrical fixture, fascia, furniture, generic model, lighting device, mechanical equipment, plumbing fixture, railing, specialty equipment, stair run and stair support. There is no component missing inside the identified categories. Since no component is missing in the Revit-exported IFC file, the reason of the miss-identified categories is that Anavitor did not complete the import implementation.

Moreover, another obstacle occurred is the deficiency of material information in the tested product model. When using IFC file as import document, building components themselves need to contain the material information in order for LCA applications to identify materials used by a construction project. Therefore, material information contained by identified components is further studied and the results are presented below.

Wall components can be divided into exterior walls and interior walls based on their function. Exterior walls include their material information in the type parameter of *Structure*, which enable the information extraction by Anavitor when IFC file is imported. When interior walls are studied, only bathroom walls describe their materials specifically in the type parameter of *Structure*. Therefore, there are also no difficulties for Anavitor to identify their materials by using IFC files. Figure 5.3 illustrates the material information contained by bathroom walls.

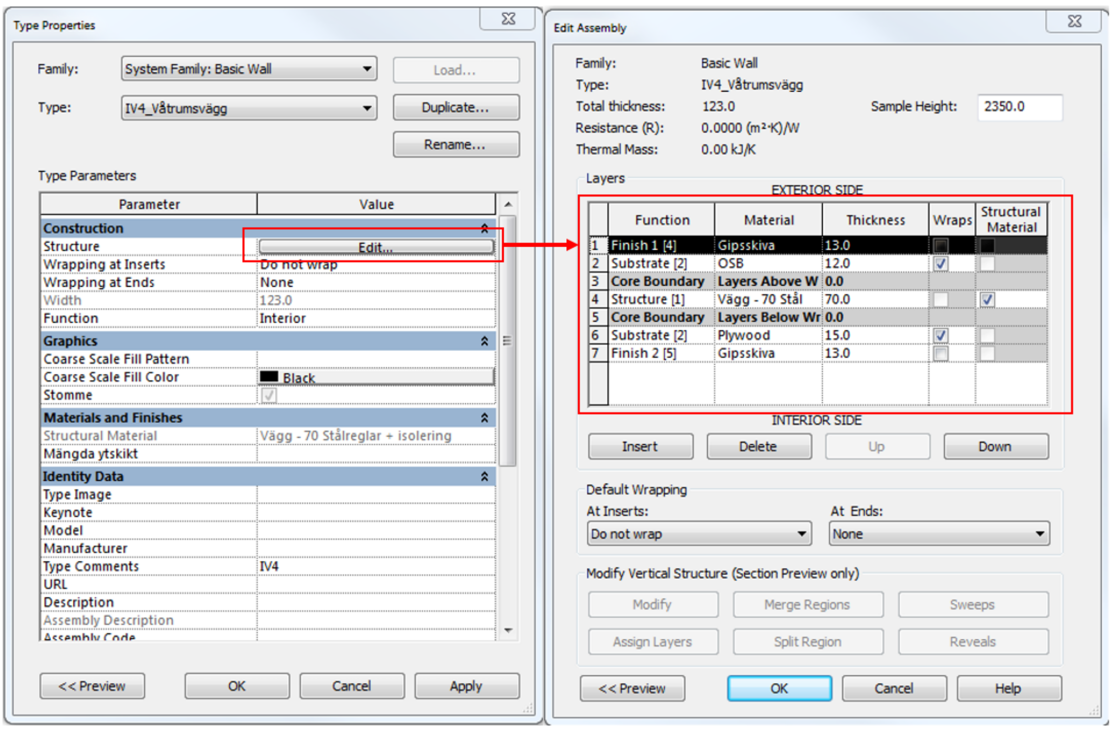


Figure 5.3 Bathroom wall's type parameters of Structure in the reference project

Other interior walls do not directly express their material compositions in family type name or type parameter of *Structure*. By using pre-configured codes in the family type name, type parameters of *Keynote* and *Type Comments*, the material composition could be traced in the reference company's internal resource recipe of Vico Office. Hence, due to the lack of material information in the models themselves, LCA applications cannot identify the material composition of these wall components directly by using only IFC file. Figure 5.4 shows an example of the other interior walls' type parameter of Keynote and Type comment.

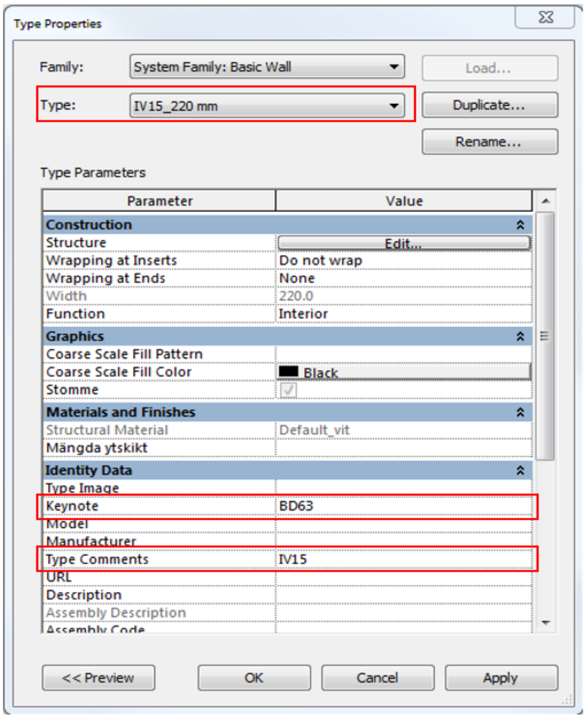


Figure 5.4 Example of the other interior walls' type parameter of Keynote and Type comment in the reference project

Floor components are also distinguished by their materials. All the floor components display their materials in both family type name and type parameter of *Structure*. Therefore, the material information of floor can be read by Anavitor directly.

The reference project contains two different types of ceilings, compound plaster ceilings and compound acoustic ceiling. Compound plaster ceilings display the main material plaster in both family type name and type parameter of *Structure*. Compound acoustic ceiling models do not contain material informaiton directly. Instead, these information can be traced in the internal resource reciepe of Vico Office by using codes in family type name and type parameters of *Keynote*.

The category of stair consists of concrete and steel stairs and all these components show their material information in family type names. Therefor, these informations can be directly read by Anavitor.

All window models in the reference project use dimentions and performance characters as their family type name. For example, *FÖ_9x13* represents opening window with the width of 900mm and height of 1300mm. Specified material information is not included in the model, but can be traced in Vico Office using code in family type name and type parameter of *Keynote*.

Material information should be attached to the requied building components in order for applications to conduct LCA. Therefore, BIM modelers shoud be provided with a modeling guidline which desplays the obigatory graphic and non-graphic information content for certain building components, which insure the infromation suficciency of a BIM document.

5.2.1.1.2 360optimi

When IFC file was imported, 360optimi use their pre-configured import mapper documents to identify and select components which are required by the chosen LCA standard. Therefore, components beyond the scope of the standard will not be identified and considered in the analysis process. This mechanism sets a requirement for Revit or IFC models: model components themselves must contain clarified material information, such as concrete, wood, steel etc., in the components' properties. Therefore, like the result presented in the section of Anavitor, components that do not contain material information in the type parameter of *Structure* or family name cannot be mapped directly after the import process. For example, some wall components in the reference project use "*Default_white*" as a material representative in the type parameter of *Structure*. When these wall components are imported, 360optimi will have difficulties to identify their material. "*Default_white*" does not only represent one single specified material or material assembly. It appears in many wall components which should have different properties. Detailed material information of these wall components are located in Vico Office and have to be traced by using code in family type name and *Keynote*. This example was presented in Figure 5.5. When the reference project was imported, these wall components will be identified as errors with an error symbol.

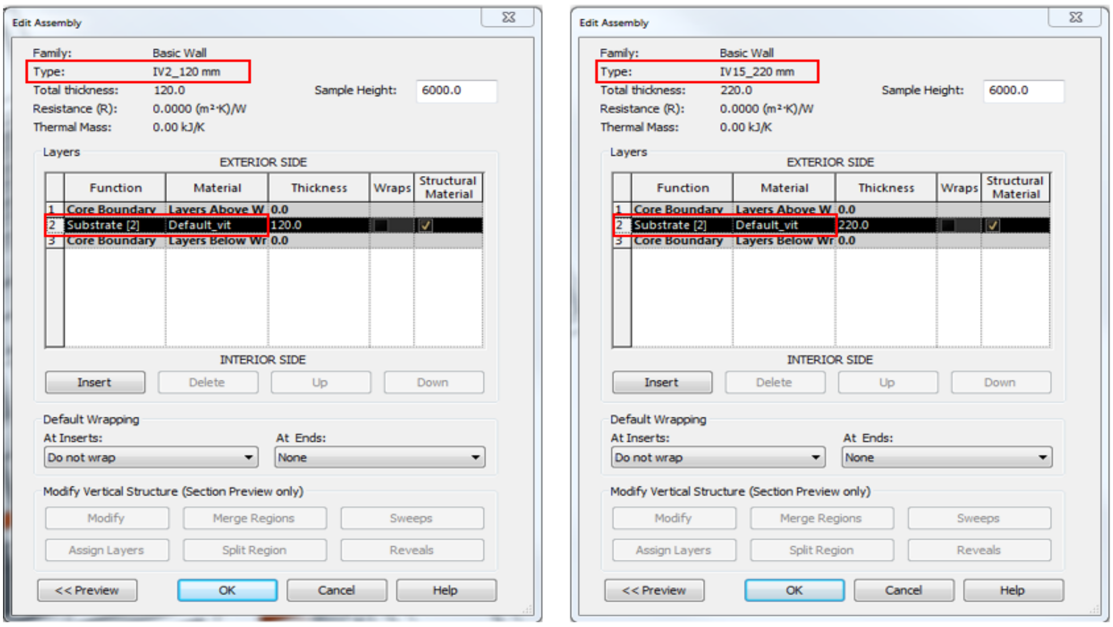


Figure 5.5 Default_white is used in different wall types

5.2.1.2 Unqualified Files when LCA Applications Testing Vico-Exported Files

When two kinds of files are tested during the study process, the obstacles differ from each other according to different applications and file formats. Hence the identified obstacles are presented separately based on tested LCA applications and file formats.

5.2.1.2.1 Anavitor Testing sbXML files

Obstacle occurs during the test of the second workflow. Since sbXML can be directly exported from Vico Office and can also be used by Anavitor, authors think using this format will be the most direct way to conduct the second workflow. Hence, authors attempt to use sbXML files directly exported from Vico for Anavitor, with the aid of external specialists. But as a result, these sbXML files from Vico Office are not qualified enough for Anavitor. During the meeting with the external Anavitor specialists, they pointed out several fatal problems when Anavitor tried to use these sbXML files. Generally speaking, as one sort of different XML file formats, sbXML file must follow a specific rule called schema, which means the content of the sbXML has to follow the appointed structure. While the Vico-exported sbXLM files are not able to satisfy this requirement.
More specifically, the first problem is that there is a missing item in the Vico-exported files, which is used to describe which version of the software is used when this file is exported. It results in the disability of Anavitor to decode and read the information inside the sbXML file (see Figure 5.6).


```
  <?xml version="1.0" encoding="ISO-8859-1"?>
- <sbXML xsi:noNamespaceSchemaLocation="http://www.akej.se/sbXML/1.9/sbXML19.xsd"
  - <Dokumentdata>
    - <Dokument>
        <Kod KodlisteReferens="DOKTYP" KodVarde="CIM Project"/>
        <DokumentId/>
      </Dokument>
    - <Sandning>
      - <Skapad>
        - <SkapadAv>
            <IdentifikationFtg/>
          </SkapadAv>
          <Datum>2015-03-09</Datum>
          <Applikation KodlisteReferens="CF" KodVarde="Vico Office" Version=""/>
        </Skapad>
      </Sandning>
    </Dokumentdata>
  - <ListForteckning>
    - <KodlisteForteckning>
        <KodListeId>BSAB96:BD</KodListeId>
        <Inbaddad>false</Inbaddad>
      </KodlisteForteckning>
    - <KodlisteForteckning>
        <KodListeId>BSAB96:PR</KodListeId>
        <Inbaddad>false</Inbaddad>
      </KodlisteForteckning>
    - <KodlisteForteckning>
        <KodListeId>ENHET</KodListeId>
```


Figure 5.6 An example of lacking software version.

The second problem is that the format of digit values, such as quantity and price, in the Vico-exported files do not match with the schema. According to the external specialists, one of whom is responsible for formulating the schema, the value in a right format is required as four decimal place. However, different values in the Vico-exported sbXML files are always described in wrong formats, such as five or more decimal place or even with a random amount of spaces, which leads to a consequence that Anavitor is not able to read these values. Figure 5.7 shows the value format in the Vico-exported files.

```
- <DetaljPost>
    <ID>198</ID>
  - <Parent>
      <ID>1</ID>
    </Parent>
    <Detaljtyp>33</Detaljtyp>
  - <Basklass>
      <Kod KodlisteReferens="SBEF:Byggdel" KodVarde=""/>
    </Basklass>
    <Uttolkadkod>BD_3</Uttolkadkod>
  - <MangdInfo>
      <Mangdtyp>33</Mangdtyp>
    - <Mangdnetto>
        <Mangd Mangd="1.00000 " Enhet="-"/>
      </Mangdnetto>
      <Mangdtext>STOMME</Mangdtext>
    </MangdInfo>
```

Figure 5.7 An example of the value format in Vico-exported sbXML files.

The third problem is that the resource type description is lacking in the Vico-exported sbXML files. As described in the theory of this report, the schema states that different resource types should be described with different numbers from 1 to 9. However, the Vico-exported sbXML files describe all the resource type as 0, which make it impossible for Anavitor to recognize and identify the resource category. Figure 5.8 illustrates the description of the resource type in the Vico-exported sbXML files.

```
- <DetaljResurs>
  - <Resursdata>
    - <ResursInfo>
      - <Resurs Resursbenamning="Sammansatta">
        - <ResursIds>
            <Kod KodlisteReferens="Resurskod" KodVarde="BD_40"/>
          </ResursIds>
        - <Typ>
            <Resurstyp>0</Resurstyp>
          </Typ>
        - <Resurspris>
          - <Pristyp>
              <Kod KodlisteReferens="SD" KodVarde="UE"/>
            </Pristyp>
            <Pris Valuta="SEK" Belopp="0.00000 "/>
          </Resurspris>
        </Resurs>
      </ResursInfo>
```

Figure 5.8 The description of resource type in the Vico-exported sbXML files.

Moreover, authors find out that the Vico-exported sbXML files could only cover three levels of the sub-content in the cost plan spreadsheet in Vico Office and the rest of the sub-content in lower levels is missing. The whole spreadsheet often contains more than 5 levels of sub-contents. It leads to a deficiency of the necessary information for Anavitor to conduct the LCA process.

In summary, all the problems above result in a situation that Anavitor cannot even import the Vico-exported sbXML file, which indicates the failure of using sbXML as the file format in the second workflow between Vico Office and Anavitor. Solving these problems to make the files qualified is beyond the ability scale of the reference company, and there is also a high possibility of other obstacles occurring after fixing previously stated obstacles. Hence the authors draw a conclusion that sbXML files are temporarily unavailable as the file format in the second workflow.

5.2.1.2.2 360optimi Testing Excel Spreadsheet

When an excel file is imported, 360optimi also uses a mapper document to link material information with their LCA database resource. The principle of this mapper document is using key words as connection between material information and a specific LCA resource item. When a certain key word appears in the material description, this material will be identified and calculated according to the corresponding LCA resource item. Each LCA resource item may connect with one or more key words and these key words is configurable.
Excel file tested is directly exported from Vico Office. By using the reference company's pre-configured report template which is named as "*net calculation*", information about building components' code, description, quantity and embedded materials are exported into an excel file. Figure 5.9 displays a short section of the tested file. The rows started from column F contain information about construction materials and labour resource. Each material has a unique material code and a unique material description. The material code serves as the material ID and the material description describes the material names and properties. The material code and the material description only represent what kind of material it is but does not display which building component it belongs to. This mechanism may lead to a disability for 360optimi to select required materials and conduct LCA, since whether a material should be calculated is depend on which building component it belongs to. For example, wood material of exterior walls or interior walls should be calculated, while wood material of casework is out of the scope of consideration, even though they are the same material.

	B	C	D	E	F	G	J	N	O	P	Q	R	T	V	Y	AA	AE	AF
167	BD_3						STOMME							2,624,359		1,303,701	6,836	3,982,110
168		BD_31					Väggar							2,029,654		894,341		2,966,745
169			31_1				Yttervägg trä R45x170				87.86	m2		22,063		25,709		47,772
170				HSD0283136			Glesregling på vägg 28x70, c 600				87.86	m2		1,157		3,339		4,495
171					4201	420100712	28X70mm rpl bygg furu/gran	87.86	1.80	1.15	181.88	m	6.20	1,128				
172					4288	42885210	Spik/skruv f råplan 23	87.86	6.00	1.00	527.18	st	0.05	29				
173					4711	A_23_019_N	Utfyllnad på träväggar - c-avstånd över 0,45 t o m 0,60 m	87.86	0.10	1.00	8.79	tim			380	3,339		
174				HSD0453076			Ytterväggstomme 45x170 C600 bärande hammarband 45x195 mm				87.86	m2		9,357		9,015		18,371
175					4201	420100732	45X170mm rpl bygg furu/gran	87.86	2.90	1.10	280.28	m	18.95	5,311				
176					4201	420121062	45X195mm plh K-24 virke	87.86	1.00	1.15	101.04	m	36.00	3,638				
177					4216	42169486	Syllisolering EPDM cellgummi, 10x150 250 lm/kart	87.86	0.50	1.05	46.13	m	6.36	294				
178					4288	42880000	Fästdon ospecifierade	87.86	0.20	1.00	17.57	kr	1.00	18				
179					4288	42885213	Spik/skruv f råplan 45	87.86	8.00	1.00	702.90	st	0.14	96				
180					4711	A_23_002_N	Bärande väggar av trä t o m tvärsnitt 66 cm2 c-avstånd över 0,45 m t o m 0,60 m	87.86	0.23	1.00	20.21	-			380	7,679		
181					4711	A_23_009_N	Tillägg för tvärsnittsyta över 66 cm2	87.86	0.04	1.00	3.51	tim			380	1,336		
182				KBCGN131V0(4)			Gipsskiva GN 13 mm på vägg, B=1200 mm				87.86	m2		2,860		4,340		7,200
183					4288	42243733	Danogips Montagelim stål och Trä 0,6l	87.86	0.07	1.00	5.86	st	33.34	195				
184					4232	42320010	Gipsskiva GN13/DN13 1200 mm	87.86	1.00	1.07	94.01	m2	28.00	2,632				
185					4288	42885260	Gipsskruv 1-lag	87.86	2.55	1.10	246.02	st	0.13	32				
186					4711	A_24_005_N	Gipsskiva på vägg invändigt	87.86	0.13	1.00	11.42	tim			380	4,340		
187				KBCGU091V1			Gipsskiva GU 9 mm på vägg, B=1200 mm				87.86	m2		2,712		3,673		6,385
188					4232	42320028	Gipsskiva GU 9/DU 9 1200 mm	87.86	1.00	1.07	94.01	m2	25.00	2,350				
189					4232	42320037	H-profil L=3000mm	87.86	0.40	1.10	38.66	m	4.81	186				
190					4288	42880000	Fästdon ospecifierade	87.86	2.00	1.00	175.73	kr	1.00	176				
191					4711	A_24_001_N	Gipsskiva på vägg utvändigt	87.86	0.11	1.00	9.66	tim			380	3,673		
192				KEBP12V_V1			Plywood t=12 mm vägg				87.86	m2		5,978		5,342		11,320
193					4234	42340403	Vänerply bygg oputs12x240x120	87.86	1.00	1.10	96.65	m2	58.17	5,622				
194					4288	42885262	Gipsskruv 2-lag	87.86	20.00	1.10	1,932.98	st	0.18	356				
195					4711	A_24_017_N	Kryssfanérskiva på vägg	87.86	0.16	1.00	14.06	tim			380	5,342		

Figure 5.9 The tested excel spreadsheet example.

5.2.2 Solutions

Based on the identified obstacles and discussions with internal and external experts, the authors reach a solution of choosing the second workflow as recommended. The file format between Vico Office and LCA applications should be selected as excel spreadsheet, instead of sbXML.

5.2.2.1 Anavitor

In the recommended workflow, the excel spreadsheet should include the content of building component code, resource code, material description, quantity, waste rate, quantity unit and resource type. It is illustrated in Figure 5.10.

	A	B	C	D	E	F	G
1	BYGGDEL	RESURSKOD	BESKRIVNING	MÄNGD	SPILL	ENHET	KATEGORI
2	BD_27	42120352	Floormate 250 SL-A-N 1240 70X1185X585	903.67	1.05	m2	3
3	BD_27	ARB-1T(9)	Isolering på mark - cellplast	43.03	1	tim	1
4	BD_27	41510990	Frakt armering(välj o byt ut)	2,281.76	1.18	kg	3
5	BD_27	41540143	Armeringsnät Nps 500 6200 minst 50 st	1,015.56	1.18	m2	3
6	BD_27	4157	Hjälpmedel armering	172.13	1	-	3
7	BD_27	ARB-5A(5)	Armeringsnät och mattor per lag t o m ø 6 mm	34.43	1	tim	1
8	BD_27	41612500	Transport betong välj o byt ut	96.39	1.12	m3	3
9	BD_27	41612300	Betong C 25/30 (k30), stenmax 32, konsistens S1 (P), S2 (T)	96.39	1.12	m3	3
10	BD_27	ARB	Gjutning grundplatta	22.38	1	tim	1
11	BD_27	ARB(1)	Tillägg - platta på mark, tjocklek t o m 12 cm	1.72	1	tim	1
12	BD_27	41612516	Tillägg stenmax 16 mm	96.39	1.12	m3	3
13	BD_27	41612534	Tillägg vinterbtg ? 1/10-30/4	96.39	1.12	m3	3
14	BD_27	41612536	Tillägg varm betong ?	96.39	1.12	m3	3
15	BD_27	41612540	Lossnings-/Väntetid utöver 15 min	172.13	1	min	3
16	BD_27	ARB-2B(5)	Ytavjämning med sloda vid gjutning med laser	17.21	1	tim	1
17	BD_34	420100734	45X220mm rpl bygg furu/gran	480.77	1.1	m	3

Figure 5.10 The excel spreadsheet format in the suggested workflow.

5.2.2.2 360optimi

A feasible solution for problem when 360optimi using excel spreadsheet is to add building component's code before its embedded materials' codes, which is showed in Figure 5.11. By doing this, the relationship between materials and building components are clarified. Besides, building component code, material code and words in material description together can be included in the mapper document as key words to realize the correct LCA.

BD_3						STOMME							2,624,359		1,303,701	6,836	3,982,110
	BD_31					Väggar							2,029,654		894,341		2,966,745
		31_1				Yttervägg trä R45x170				87.86	m2		22,063		25,709		47,772
			31_1	HSD0283136		Glesregling på vägg 28x70, c 600				87.86	m2		1,157		3,339		4,495
			31_1	420	420100712	28X70mm rpl bygg furu/gran	87.86	1.80	1.15	181.88	m	6.20	1,128				
			31_1	428	42885210	Spik/skruv f råplan 23	87.86	6.00	1.00	527.18	st	0.05	29				
			31_1	471	A_23_019_N	Utfylnad på träväggar - c-avstånd över 0,45 t o m 0,60 m	87.86	0.10	1.00	8.79	tim			380	3,339		
			31_1	HSD0453076		Ytterväggstomme 45x170 C600 bärande hammarband 45x195 mm				87.86	m2		9,357		9,015		18,371
			31_1	420	420100732	45X170mm rpl bygg furu/gran	87.86	2.90	1.10	280.28	m	18.95	5,311				
			31_1	420	420121062	45X195mm plh K-24 virke	87.86	1.00	1.15	101.04	m	36.00	3,638				
			31_1	421	42169486	Syllisolering EPDM cellgummi, 10x150 250 lm/kart	87.86	0.50	1.05	46.13	m	6.36	294				
			31_1	428	42880000	Fästdon ospecificerade	87.86	0.20	1.00	17.57	kr	1.00	18				
			31_1	428	42885213	Spik/skruv f råplan 45	87.86	8.00	1.00	702.90	st	0.14	96				
			31_1	471	A_23_002_N	Bärande väggar av trä t o m tvärsnitt 66 cm2 c-avstånd över 0,45 m t o m 0,60 m	87.86	0.23	1.00	20.21	-			380	7,679		
			31_1	471	A_23_009_N	Tillägg för tvärsnittsyta över 66 cm2	87.86	0.04	1.00	3.51	tim			380	1,336		
			31_1	KBCGN131V0(4)		Gipsskiva GN 13 mm på vägg, B=1200 mm				87.86	m2		2,860		4,340		7,200
			31_1	428	42243733	Danogips Montagelim stål och Trä 0,6l	87.86	0.07	1.00	5.86	st	33.34	195				
			31_1	423	42320010	Gipsskiva GN13/DN13 1200 mm	87.86	1.00	1.07	94.01	m2	28.00	2,632				
			31_1	428	42885260	Gipsskruv 1-lag	87.86	2.55	1.10	246.02	st	0.13	32				
			31_1	471	A_24_005_N	Gipsskiva på vägg invändigt	87.86	0.13	1.00	11.42	tim			380	4,340		
			31_1	KBCGU091V1		Gipsskiva GU 9 mm på vägg, B=1200 mm				87.86	m2		2,712		3,673		6,385

Figure 5.11 Solution to the problem related to 360optimi in the recommended workflow.

6 Discussion

This chapter mainly serves as a reflection and analysis of the test results. First of all, authors bring out a concept of information transfer gap, as well as its definition. Then the reasons of the test results are discussed from different perspectives. First of all, two workflows are analysed from a perspective of information efficiency and information source. Secondly, advantages and disadvantages of using different file formats are discussed and meanwhile two workflows are compared from the viewpoint of improvement complexity. In the end of this chapter, constraints of this study are stated and the suggestions for further study are also mentioned.

6.1 Information Transfer Gap

According to Neto and Filho (2013), construction industry has a significant influence on environmental burdens since there is an enormous material consumption during the construction process. Under such awareness, the reference company has a willing to conduct LCA in their projects. However, according to the internal environment expert, LCA is not mandatory to be conducted in Swedish construction industry (Franzén, 2015). Due to the fact that LCA is seldom applied, there is a gap hindering construction project information from being properly used by LCA, as well as LCA setting information requirements for project simulations. This situation could be understood as an information transfer gap. And the definition of information transfer gap is given as: a gap existing between 5D simulation process and LCA process in the construction industry, which hinders information from being efficiently transferred and properly used between simulation applications and LCA applications, in either a manifestation of information error/deficiency or a manifestation of information related file format unavailability.

6.2 Analysis of the Results

In this section, analysis and discussion of the results are presented. It is presented according to two perspectives. One is information source and the other one is problem solving.

6.2.1 Information Source

According to NBIMS (2010), BIM serves as a shared resource of information knowledge basis for facilities during its life cycle. From a viewpoint of applying LCA in a BIM environment, one of the most important differences between the tested two workflows is the information source of the LCA applications. In the first workflow, Revit models serves as the information source of LCA, which means LCA applications extract required information and read necessary data from the model files directly. Hence, in order to conduct LCA comprehensively, both geometric and non-geometric information in the models should be described in proper details. By creating a comprehensive data foundation in the product models, users of the LCA application is able to achieve their work assignments. While the current situation is that the information contained by the Revit model is not sufficient enough to support conducting LCA, especially non-graphic information. A number of building components which are required by the standard of *BREEAM International New Construction* lack material information for LCA. However, it doesn't mean that material information is deficient in the BIM workflow of the reference company. It is attached with corresponding building components in Vico Office during the 5D simulation process. Hence, adding sufficient material information for Revit models repeats what has been done in the 5D simulation process and will lead to extra manual work. It is not preferred from a perspective of a construction company.

In the other workflow, simulation results from Vico Office serves as the information source of LCA. The LCA applications extract required information and read necessary data from the Vico-exported files and accordingly conduct the process. Hence, information in product models is not important for LCA anymore. Instead, the information richness in Vico Office becomes the one that really makes differences. In the reference project, the information contained by Vico-exported files is sufficient to support conducting LCA. It means if all the projects reach the same information richness level as the reference project, LCA is achievable for the reference company.

According to the CTO, the reference company has a preference of developing the second workflow, since the company thinks it is a better integrated process. Besides, he also pointed out the model in the 5D simulation process has a higher LOD than the product model in Revit. Especially, the non-geometric information, such as the consumption quantity of materials, is further developed in the 5D simulation application. The test result confirmed his statement. Therefore, based on their current BIM workflow, conducting LCA by using results of 5D simulation can receive more accurate results with higher efficiency. Under such awareness, the second workflow is more valuable for the reference company.

6.2.2 Obstacles, Solutions and Complexity of Different File Formats

This section presents the identified obstacles, solutions and complexity of solving them. It is stated respectively based on different file formats.

6.2.2.1 IFC

Material information insufficiency is one of the obstacles faced by the authors when IFC files are tested as interoperable file formats. In the reference project, interior walls except bathroom walls, compound acoustic ceilings, windows and interior doors do not contain attached material information within the Revit models, therefore they need to be manually matched with corresponding LCA resource items when IFC files were imported for the first time. Even though the time consumed by this process will be reduced continuously thorough the LCA applications' ability to memorize matching combination, it still adds an extra step of information matching. This situation contradicts with the goal, stated by Jrade and Jalaei (2013) of using one-source model based data. A feasible solution is to provide BIM modeller a modelling guideline which displays the obligatory non-graphic information content for each building component category, especially categories required by BREEAM or other LCA standards.

The main intent of *Level of Development Specification* is to clarify the content and reliability of BIM models, so downstream users could have a clear understanding of the information scope and limitations of models they received (BIMForum, 2014). Therefore, the authors try to employ this specification as reference modelling guideline and find out suitable LODs for BIM projects that required by LCA. In fundamental LOD definitions, specified quantities and dimensions are required from LOD 300 to higher levels (AIA, 2013b). Therefore, building components should reach at least LOD 300 to deliver accurate quantity and geometry information. Non-graphic information is stated in the specification as *may be attached to the model element* from LOD 200 to higher levels, and the fundamental definitions do not present specifically the content of the non-graphic information (AIA, 2013b). Hence, it becomes necessary to consider detailed LOD definitions of different building components. Most detail definitions include material information as one of the mandatory demands for reaching certain LOD levels. Within the building components required by BREEAM, exterior walls, foundations, vertical steel structure elements, basement walls, roof, balustrades and handrails, interior doors and floors are required to have material information attached in order to reach LOD 300 (BIMForum, 2014). For exterior and interior windows, only finisher and glass materials are required from LOD 300 to higher levels. Floor finishers, interior wall finishers and interior walls are required to contain material information to reach LOD 200. Concrete vertical structures, exterior solar shading devices, stairs, roofing and interior ceiling finishers are not mandatory to contain any material information in order to reach certain LOD levels. Therefore, based on the content of *Level of Development Specification*, exterior wall, foundation, vertical steel structure element, basement wall, roof, stair railing, exterior balcony railing, interior door, floor, floor finishers, interior wall finishers and interior walls elements should reach LOD 300 in order to conduct LCA. Exterior and interior windows elements, concrete vertical structures, exterior solar shading devices and interior ceiling finishers should not only reach LOD 300 but also contain other material information required employed LCA standards. The authors contrasted the current LOD of building components in Revit with the minimum LOD requirements developed from *Level of Development Specification*. And the result is listed in Table 6.1.

Table 6.1 Contrast of current LOD of the reference project's building components in Revit with the minimum LOD requirements developed from Level of Development Specification.

BREEAM Required Components	LOD of Revit components	Minimum LOD requirement for LCA using IFC
Exterior Wall	300	300
Exterior Windows and Roof lights	200	300+ material info
Interior Floor Finishes	300	300
Upper and Ground Floors	200	300
Basement Walls	200	300
Interior Ceiling Finishes	200	300+ material info
Interior Walls and Partitions	300	300
Roofing (Excluding Structural Roof)	100	300+ material info
Stairs and Ramps	300	300+ material info
Balustrades and Handrails	300	300
Interior Doors	350	300
Interior Wall Finishes	Not included	300
External Solar Shading Devices and Access Structures etc.	Not included	300+ material info
Foundations	Not included	300
Vertical Structure (Steel)	Not included	300
Vertical Structure (Concrete)	Not included	300+ material info
Interior Windows	Not included	300+material info
Roof (Structure)	Not included	300

When minimum LOD requirements presented above are fulfilled, information contained by a BIM model will be sufficient for LCA. However fulfilling certain LOD is not a necessary condition for conducting LCA. Currently, specified dimension, quantity and material information are the only requirements for BIM models. Blindly pursuing high or certain LOD will increase the modelling time and the working load of BIM modeller and does not make more contribution for LCA. Therefore, in order to use IFC as the interoperable format, it is necessary for the reference company to have a specific generated Revit modelling protocol that fits LCA applications' claim. Currently, there is no such modelling protocol within the LCA applications' user manuals or their website. And the generation of this document requires the support from LCA companies.

Another obstacle arising in the test is component miss identification. As presented in the result part, when IFC files were tested, not all required building components could be identified by Anavitor. More specifically, except the non-included component categories, railing is the only BREEAM required category which was not identified. Even though railing is not mandatory to conduct LCA, ignorance of this category may lead to lower BREEAM rating result (BRE Global Ltd, 2014). The missing of components is mainly due to Anavitor's disability to support the geometric presentation of railings in the format of IFC. The improving this situation requires the effort of Anavitor's company to develop in import process of IFC so that all BREEAM International required could be correctly identified. However, this solution could be time consuming, and it is already beyond the ability of the reference company. Therefore it is not currently feasible for the reference company to conduct.

When the two obstacles mentioned above are considered synthetically, IFC is not recommended to be used currently and the first workflow is not recommended to be conducted. Since IFC and hardly assure the successful information transfer from Revit to Anavitor. Moreover, it is time consuming and beyond the ability of the reference company to solve IFC related obstacles.

6.2.2.2 SbXML

As stated in Chapter 3, Jalen and Jrade (2014) pointed out that there is a lack of one-platform BIM-LCA configurations, the data inputs and outputs using different interoperable formats between BIM applications and LCA applications are still not efficient enough. Another viewpoint stated in Chapter 3 stated by Kovacic et al. (2013) also confirmed that information transfer between different software could be one of the problems which stops BIM from being developed. In the second workflow authors tested, the inefficient information transfer between Vico Office and the LCA applications has become the barrier that hinder BIM related information from being used in LCA process. As stated in the result section, sbXML as one of the tested file formats used to transfer information from the simulation application to LCA applications, is required with a specific data structure and content constraints (Valentine et al., 2002). But the main obstacle author faced when conducting the test process comes exactly from the unqualified content and structure of Vico-exported sbXML files. Specifically speaking, Vico-exported sbXML files neither follow the required data structure, nor contain sufficient information. As a consequence, it is impossible for other applications to start using the simulation results from Vico Office in the format of sbXML. Besides, as stated in Chapter 3, the accuracy of LCA highly depends on the quality and availability of data from all phases of the project (Alwan et al., 2015). Under such awareness, authors think conducting LCA based on simulation results from Vico Office in format of sbXML is temporarily not achievable.

Although Vico-exported sbXML files are currently impossible to be used due to their low quality, improving the sbXML files' quality has a significant influence on the workflow efficiency. Utilizing a qualified sbXML file as the information transfer file is the most direct way to conduct the second workflow and overcome the gap when Anavitor is chosen as the LCA application. It is because sbXML is particularly designed to be used for information containing and transferring for Swedish construction industry (Åkej, 2004). As long as the files can be properly exported and used, the information can be successfully transferred. Aiming to make Vico Office generate qualified sbXML files, specialists from both construction companies, LCA companies and Vico Software have to work together and update this function. By using a qualified sbXML, no extra operation is needed rather than exporting from Vico Office and importing into Anavitor. Besides, sbXML focuses on the Swedish construction industry, which means the original language of the file is Swedish. It means the consistency of using sbXML files from Vico Office to Anavitor will be very strong. Further, it will enormously reduce the possibility of misunderstanding for Swedish projects and help simplify the work of related Swedish construction engineers.

However, the complexity of achieving sbXML utilization is high. Because first of all, aiming to conduct simulation and generate results, Vico Office is designed to be good at importing information and models from different kinds of software resources, extracting data from other software results, as well as using and integrating these info data (Vico Software, 2015b), rather than sharing own information with other applications for further uses. According to Vico Software (2015b), the software aims to provide users the information they need and help them make better decisions. This motivation has decided that Vico Office is better at generating related reports to users instead of creating databases for other applications, which results in a low exporting capability of sbXML files in the tested workflows of this study. Secondly, it is a time consuming process, which needs all related parties' participation to debug this function of Vico Office.

6.2.2.3 Excel Spreadsheet

As stated in the result section, the obstacle faced by using excel spreadsheet is the disability to express the belonging relationship between material and building components. This problem is identified by specialists from both LCA application companies. It is due to the fact that template used for excel exportation in this study is designed for cost estimation, instead of LCA. However, overcoming this obstacle is not complicated since Vico Office allows users to customize templates according to their own willing and demand. The reference company could generate a specific Vico Office template for conducting LCA. More specifically, when information and data need to be exported into an excel spreadsheet file, a report has to be generated in advance with the aid of a pre-configured template. Through reading the report template, Vico Office functions as filling the right data into the right place of the template, so as to generate a report (Vico Software, 2015c). The data and information which is not required will not be presented. Thereafter, an excel spreadsheet with the same content and layout could be exported. Hence, the pre-configured template is the key element of selecting the necessary information needed by LCA, designing the layout of the excel spreadsheets and overcoming the information transfer gap. When a specific kind of LCA application is appointed, a related Vico Office template could be attached by either the LCA company or the construction company. In order to let Vico Office export a qualified excel spreadsheet for their LCA application, LCA offering companies could prepare this kind of templates as service attachments. As construction companies, a template base containing several internal Vico Office templates related to different LCA applications could be built up according to the scale of used LCA applications and applied LCA standard. However Jalen and Jrade (2014) also pointed out that since the lack of integration between environmental analyses with the simulation processes, inefficient afterward modification is unavoidable. Because one feature of excel spreadsheet is editable, compulsory information which is needed by LCA applications but not included by simulation applications can be manually added after excel spreadsheets are exported. Construction companies could even make related regulations about how to formulate excel spreadsheets used for LCA process.

Synthetically consider the obstacles faced by using sbXML and Excel and the corresponding solutions, Excel spread sheet shows more superiorities. First of all, sbXML is commonly used for information transfer in Swedish construction industry (Lantto, 2009). This means LCA application developed by foreign companies like 360optimi may not support this format. On the contrary, excel spreadsheet has a wide adaptability. Both sides of the information transfer gap are able to use excel spreadsheets. Vico Office is able to export excel spreadsheets with comprehensive content and both LCA applications tested are also able to read excel spreadsheets. Secondly, according to Alwan et al. (2015), one common feature of all environmental analysis systems is that they demand large amounts of design and construction data, and the accuracy of analysis depends on the quality and availability of data from all phases of the project. During the test process, the authors discovered that the reference project of the reference company contains sufficient geometric data and non-geometric information. While how to transfer these data and information from BIM applications to LCA applications has become the key issue. After testing, consulting and modifying, the authors found out that excel spreadsheets showed a high level of modifiability. Vico Office users has the authority to include only necessary information in exported Excel, which meanwhile controls the file size by avoiding unnecessary information. Besides, the layout of the excel spreadsheets can be customized according to the LCA applications' requirements to improve the quality of LCA results. Editing sbXML is not as convenient as Excel, which requires extra aid of external specialists. Thirdly, Jalen and Jrade (2014) stated that there is a shortage of integration between environmental analysis method and the modelling or simulation processes. This situation may lead to afterward modifications towards models or simulation results, in order to meet certain environmental criteria. Accordingly, another advantage of excel spreadsheet is highlighted. The content of excel spreadsheets can be edited after the files are exported from Vico Office, which means it is more convenient to make the files meet related environmental criteria, so as to integrate LCA processes with simulation processes.

6.3 Constraints and Suggestions for Further Study

During the study process, authors realized there are some constraints limiting the process and the result. Hence this section presents the constraints, as well as suggestions for further related studies.

6.3.1 Constraints

The study process is conducted under a limitation of resource, authority and time etc., hence several constraints are proposed in order to clarify the limitation and reduce the possibility of misleading.

First of all, the theory resources of related software completely come from the related software company, including related user's manual, official webpages, interviews and email contact with external experts. Therefore, the perspectives about the software may be perceived as a bit bias and the critical perspectives about the related software may not be sufficient enough.

Secondly, the model of the reference project offered by the reference company is an architect model, which means the structural building components are not presented completely. As a consequence, the LCA result based on this model is not accurate enough. Hence a recommendation is presented that LCA based on structure models will generates a more comprehensive and accurate result. But because the motivation of this study is to study the workflow, and the LCA result is not within the scale of this study, authors choose to ignore this potential constraint.

Thirdly, due to the authority limitation, the authors are not able to access both LCA applications independently during the whole period of the study. As a consequence, some test processes are conducted under the instruction of related external experts during the complementing meetings, and parts of the results of the test process are offered by the external experts. Therefore, there is a possibility that the results cannot represent the objective facts.

Finally, till the end of the study, one of the LCA company still not response with the test result of modified excel spreadsheet. Hence, there is a possibility that information contained in this kind of file is still deficient and there is other barriers which the authors have not met till the end of the study.

6.3.2 Suggestions for Further Study

According to this study, a feasible workflow has been proposed. However information transfer obstacles between both sides of information transfer gap need to be overcome. Hence, focusing on how to bridge the information transfer gap will make enormous contributions for making the workflow more efficient, easy to conduct, as well as accurate. For example, is it necessary for construction companies to make regulations about to which extent of LOD their product models should achieve, or what is the most efficient template for LCA when simulation applications export a certain file format for a specific kind of LCA application.

Moreover, since the fact that LCA is seldom conducted in residential construction projects in Sweden, environmental assessment standard about residential projects is lacking. Therefore, discussion about what standard should be applied about LCA and what content should be covered by these standards will become significantly valuable for the Swedish construction industry.

7 Conclusion Remarks

The main purpose of this master thesis is to explore a preferable workflow from BIM to LCA. In order to achieve this purpose, identifying potential technical obstacles when a specific LCA application is used in the current BIM environment of the reference company is also targeted in this study. This chapter will summarize the final conclusions which have been drawn for this study, by answering the research questions authors proposed.

a. What is the current LOD of the production model in the reference project?

The building components' LOD in the reference project are studied based on the definition stated in *Level of Development Specification*. The LOD of a certain building component is not constant through a project's lifecycle. With the project going on, graphic information's richness level increases and more non-graphic information concerning material, labour, price and subcontractor will be attached to building components. Due to the purpose of this master thesis, only BREEAM International required components are studied. Their LOD in both Revit and Vico Office are displayed in Table 7.1.

Table 7.1 The LOD of the reference project

Components Required by BREEAM	LOD of Revit Components	LOD of Vico Office Components
Exterior Wall	300	300
Exterior Windows and Roof lights	200	200
Interior Floor Finishes	300	350
Upper and Ground Floors	200	300
Basement Walls	200	200
Interior Ceiling Finishes	200	200
Interior Walls and Partitions	300	300
Roofing (Excluding Structural Roof)	100	100
Stairs and Ramps	300	300
Balustrades and Handrails	300	300
Interior Doors	350	350
Interior Wall Finishes	Not contained	Not contained
External Solar Shading Devices and Access Structures etc.	Not contained	Not contained
Foundations	Not contained	Not contained
Vertical Structure Frame	Not contained	Not contained

Interior Windows	Not contained	Not contained
Roof (Structure)	Not contained	Not contained

Vico Office's BIM model is extracted directly from Revit, therefore all building components in Vico Office share the same graphic information with their corresponding components in Revit. However, the LOD growth of some building components between Revit and Vico office results from the non-graphic information increase. Besides, other building components in Vico Office share the same LOD with their corresponding components in Revit. This doesn't mean they consist same amount of non- graphic information. One reason of the unincreased LOD is that even though more non-graphic information is attached to building components in Vico Office, these newly attached information still cannot fulfil the criteria set by higher LOD. Another reason is that graphic information contained by the components in Revit is not comprehensive enough to reach higher LOD. Therefore, even enough non-graphic information is attached in Vico Office, building components still remain in the same LOD.

Some structural component are marked as not contained in the table, since the reference project is illustrated by an architect model.

b. What obstacles are identified when BIM related information is used for LCA?

According to the test processes and the results authors generated, the obstacles mainly focus on the inefficient information transfer from BIM applications to LCA applications. The existing BIM related information is sufficient enough for conducting LCA while how to make these information being used properly for LCA is the main issue. More specifically, when IFC files are used as the information transfer media, interior walls except bathroom walls, compound acoustic ceilings, windows and interior doors does not contain material information, and Anavitor failed to identify railing components. As a result, the LCA process is not able to be conducted in a comprehensive and accurate way. When sbXML files are tested as the information transfer media, Vico-exported sbXML has the problem of lacking version identification, fail digital value format and lacking resource type description. SbXML format also faces the problem of not being consider by non-Swedish LCA application since the files are programmed in Swedish. When excel spreadsheets are tested as the information transfer media, it is acceptable even though there are some small obstacles such as the unclear belonging relationship between material and building components.

c. Does the reference company need to increase their current LOD of production models to achieve the whole workflow from BIM to LCA?

If Revit model is used as the information source for LCA, there is a need for the reference company to increase building components' non-graphic information richness. More specifically, material information is lacking and should be attached in interior walls except bathroom walls, compound acoustic ceilings, windows and interior doors to conduct LCA. Increasing LOD of a certain building components often means the improvements of both graphic and non-graphic information richness. Since all existing BREEAM-required components are already modelled with specified dimensions and quantities in Revit. This fulfils the conditions for conducting LCA for the graphic information's perspective. It is not recommended for the reference company to set higher LOD requirement for building components in Revit since it will increase the work load of BIM modeller and make no contribution for LCA.

Even though some building components in Vico Office share the same LOD with their corresponding components in Revit, more non-graphic information concerning material consumption, labour, price and subcontractor is attached to building components. According to external LCA specialists, the current information extracted from Vico Office is sufficient for LCA from both graphic and non-graphic's perspective. Therefore, there is no need to increase the current LOD if Vico-extracted file is used as the data source for LCA.

d. How could the identified obstacles be overcome?

In order to make the information transferring fluently, the identified obstacles must be solved. Aiming to use IFC files, there are two aspects to fix. On one hand, the material information should be attached with the corresponding building components in the production models. On the other hand, the reason of building components' miss identification must be isolated and solved. Solving the sbXML files related obstacles can be summarized as one way, which is improve Vico Office's exporting ability to make it possible to export qualified sbXML files for LCA use. When aiming to use excel spreadsheet for LCA, construction companies or LCA companies could prepare a Vico Office report template to generate a qualified excel file. The template should be designed according to the LCA applications' requirements, illustrating building components' code before material code in order to clarify the belonging relationship.

Based on the answers to the sub-questions, the main research questions are answered below.

1. **What Level of Development in BIM models is sufficient to achieve 5D simulation and Life Cycle Analysis from a perspective of a construction company?**

The sufficient LODs for BREEAM required components are studied and presented according to both fundamental and detailed definitions in *Level of Development Specification*. Table 7.2 displays the study result.

Table 7.2 The Sufficient LOD for BREEAM required components

BREEAM Required Components	LOD of Revit components	LOD of Vico Office Components	Minimum LOD requirement for LCA using IFC
Exterior Wall	300	300	300
Exterior Windows and Roof lights	200	200	300+material info
Interior Floor Finishes	300	350	300
Upper and Ground Floors	200	300	300
Basement Walls	200	200	300
Interior Ceiling Finishes	200	200	300+material info
Interior Walls and Partitions	300	300	300
Roofing (Excluding Structural Roof)	100	100	300+material info
Stairs and Ramps	300	300	300+material info
Balustrades and Handrails	300	300	300
Interior Doors	350	350	300
Interior Wall Finishes	Not contained	Not contained	300
External Solar Shading Devices and Access Structures etc.	Not contained	Not contained	300+material info
Foundations	Not contained	Not contained	300
Vertical Structure (Steel)	Not contained	Not contained	300
Vertical Structure (Concrete)	Not contained	Not contained	300+material info
Interior Windows	Not contained	Not contained	300+material info
Roof (Structure)	Not contained	Not contained	300

When LOD requirements presented above are fulfilled, information contained by building components will be sufficient to conduct LCA. It means BIM related data source will deliver accurate geometry and material consumption information. However, reaching certain LOD level is actually sufficient but unnecessary to conduct LCA. Since *Level of Development Specification* is design for all AEC industry participants. It restricts it depth of applicability in a specific case. Even though some components in Table 7.2 does not fulfil the minimum LOD requirement, they have already been modelled with specified dimensions and quantities and material information have been attached in Vico Office. Blindly pursue higher or certain LOD will only increase the modelling time and make no contribution. Therefore, it is recommended for either the reference company or LCA application companies to establish their own modelling protocol that fit LCA's claim.

2. **How is a preferable workflow formulated to achieve a satisfying LCA for construction projects by using BIM related information?**

As stated in the result section, the second feasible workflow is formulated as preferred in order to conducting a satisfying LCA. As presented in Figure 7.1, the workflow starts from 3D production models. Based on the 3D models and related information, 5D simulation is conducted in the simulation program, which is Vico Office. Thereafter the simulation results are generated, Vico Office uses an excel spreadsheet as the available format with the aid of a pre-configured Vico template. Then LCA applications imports this excel spreadsheet, conducting LCA and generate assessment results.

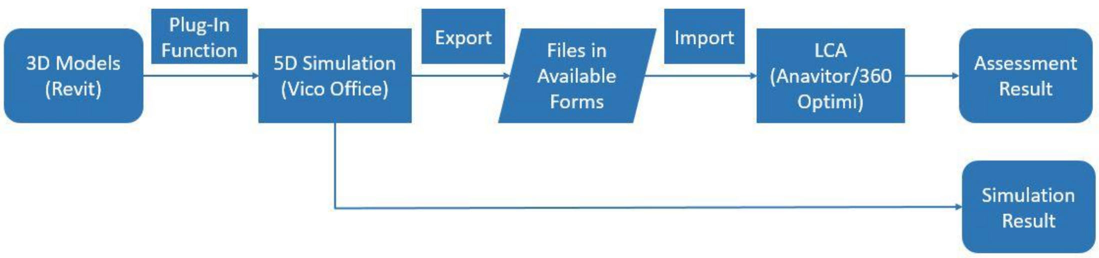


Figure 7.1 The preferable workflow to conduct LCA in a BIM environment

Such a workflow is formulated under a consideration of two aspects. First of all, according to the reference company, LCA is preferred to be conducted after 5D simulation since the result of the simulation process produced by Vico Office contains both accurate geometric information and sufficient non-geometric information, which offers LCA a solid foundation. Meanwhile, it is not necessary to conduct extra works on the existing 3D production models. And this situation is what construction companies expects. Secondly, considering about the complexity of overcoming the identified obstacles, it is obvious that choosing excel spreadsheet is more preferred. IFC files are not stable enough, and choosing IFC means extra manual work on the existing production models. SbXML files lack of feasibility, choosing sbXML is meaningless for LCA applications other than Swedish local ones. Besides, making Vico Office generating qualified sbXML files are difficult to achieve since it refers to develop new functions of Vico Office. However, excel spreadsheet is applicable and stable, choosing excel spreadsheet means only one or several pre-configured templates are needed. More importantly, the templates can be reused and the modifications to the template are not complicated as well.

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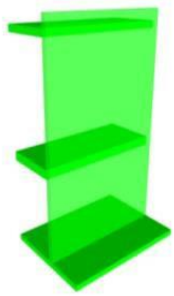
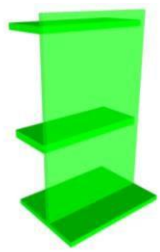
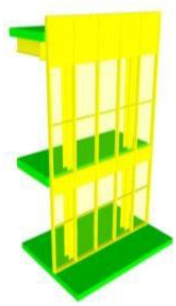
Appendix

B2010 – Exterior Walls

Solid wall construction that is composite in nature; in other words, multiple layers of materials to form an overall assembly.

100	Solid mass model representing overall building volume; or, schematic wall elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible.	
200	Generic wall objects separated by type of material (e.g. brick wall vs. terracotta). Approximate overall wall thickness represented by a single assembly. Layouts and locations still flexible.	 *46 B2010-LOD-200 Exterior Walls*
300	Composite model assembly with specific overall thickness that accounts for veneer, structure, insulation, air space, and interior skin specified for the wall system. (Refer to LOD350 and LOD400 for individually modelled elements) Penetrations are modelled to nominal dimensions for major wall openings such as windows, doors, and large mechanical elements. Required non-graphic information associated with model elements includes: • Wall type • Materials	 *47 B2010-LOD-300 Exterior Walls*
350	A composite wall assembly may be considered for LOD350 only if hosted objects such as windows and doors are provided at a minimum of LOD350. Main structural members such as headers and jambs at openings are modelled within the composite assembly.	 *48 B2010-LOD-350 Exterior Walls*

C1010.10 – Interior Fixed Partitions

100	A schematic model element or symbol that is not distinguishable by type or material. Types, layouts, and locations are still flexible.	
200	Generic wall objects separated by type of material (e.g. gypsum board vs. masonry). Approximate overall wall thickness represented by a single assembly. Layouts, locations, heights, and elevation profiles are still flexible.	
300	Composite model assembly by type with overall thickness that accounts for framing and finish specified for the wall system. (Refer to LOD350 and LOD400 for individually modelled elements) Wall elements are modelled to specific layouts, locations, heights, and elevation profiles. Penetrations are modelled to nominal dimensions for major wall openings such as windows, doors, and large mechanical elements. Required non-graphic information associated with model elements includes: • Wall type • Materials	
350	Structure and finish layers of partition assembly modelled as separate elements. All openings modelled to rough dimensions. Major framing elements such as king studs, kickers, diagonal bracing, and headers are modelled.	
400	Element modelling to include: • Studs and tracks • Bracing • Insulation • Sheathing or wall boards • Openings/penetrations	

B2020 – Exterior Windows

100	Solid mass model representing overall building volume; or, schematic wall elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible.	
200	Windows approximate in terms of location, size, count and type. Units are modelled as a simple, monolithic component; or represented with simple frame and glazing. Nominal unit size is provided.	

B2020.10 – Exterior Operating Windows

100	Solid mass model representing overall building volume; or, schematic wall elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible.	
200	Windows approximate in terms of location, size, count and type. Units are modelled as a simple, monolithic component; or represented with simple frame and glazing. Nominal unit size is provided.	
300	Units are modelled based on specified location and nominal size. Outer geometry of window frame elements and glazing modelled to within 1/8" [3 mm] precision. Operation is indicated. Required non-graphic information associated with model elements includes: • Aesthetic characteristics (finishes, glass types) • Performance characteristics (i.e. U-value, wind loading, blast resistance, structural, air, thermal, water, sound) • Functionality of the window (fixed, casement, double/single hung, awning/project out, pivot, sliding)	
350	Rough opening dimensions Attachment method of window to structure Embed geometry	
400	Frame profiles Glazing sub-components (gaskets) Attachment components	

C2050 – Ceiling Finishes

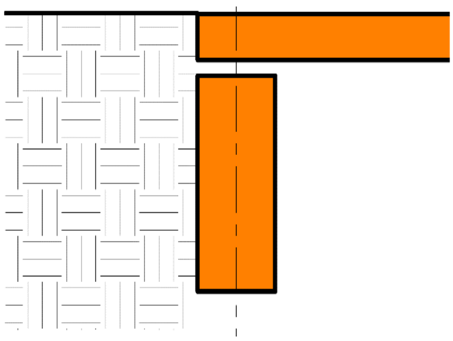
100	Ceiling construction is represented in other composite objects such as floors or rooms; or, schematic model elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible.	
200	Generic assemblies indicative of overall scope and approximate thickness/system depth of suspended ceiling.	

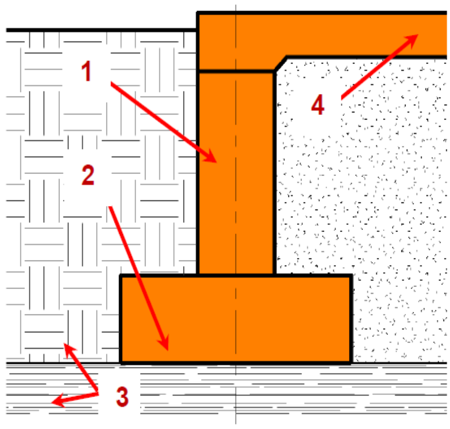
B3010 – Roofing

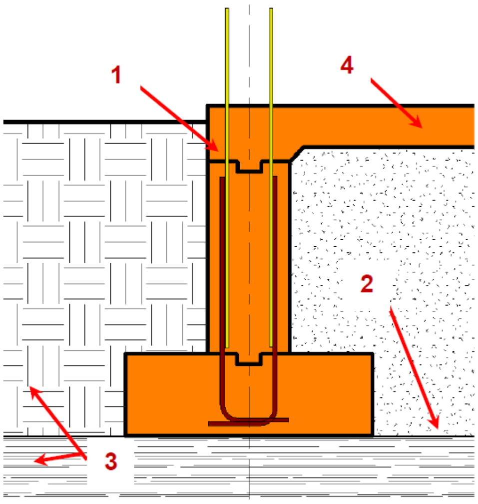
100	Solid mass model representing overall building volume; or, schematic wall elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible.	

200	Generic assembly that contains spatial (layer) allowance for structural slab/deck and/or framing system.	
300	Individual substrate layers are not separately modelled, but they are specified within a composite assembly. Roof structure is modelled separately.	

A1010.10 – Wall Foundations (Shallow Foundations)

100	Assumptions for foundations are included in other modelled elements such as an architectural floor element or volumetric mass that contains layer for assumed structural framing depth. Or, schematic elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible.	
200	Assumptions for foundations are included in other modelled elements such as an architectural floor element or volumetric mass that contains layer for assumed structural framing depth. Or, schematic elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible. *Image Notes:* 1) *Generic wall foundation is modelled.* 2) *Site is generically modelled from geotechnical information in geotechnical report.*	 *1 A1010.10-LOD-200 Wall Foundation*

300	Elements are modelled to the design-specified size and shape of the foundation. Element modelling to include: • Overall size and geometry of the foundation element • Sloping surfaces or floor depressions • External dimensions of the members Required non-graphic information associated with model elements includes: • Concrete strength • Reinforcing strength Element modelling to include: 1) Overall size and geometry of the foundation element 2) Sloping surfaces. 3) External dimensions of the members Required non-graphic information associated with model elements includes: 4) Concrete strength 5) Reinforcing strength 6) Geotechnical bearing strata elevation is modelled from geotechnical report. *Image Notes:* *a) Wall foundation sizes are accurately modelled with footings where applicable.* *b) Bearing elevation is modelled from the geotechnical report.* *c) Geotechnical regions are shown for context and not required to be modelled as part of this element at this LOD.* *d) See slab on grade for related conditions at this LOD.*	 2 A1010.10-LOD-300 Wall Foundation

350	Element modelling to include: • Location of sleeve penetrations • Pour joints • Moisture retarder • Dowels • All exposed embeds or reinforcement such as lintels • Expansion joints • Geotechnical Bearing Strata is modelled from geotechnical report estimates. *Image Notes:* a) *Grade beam sizes are modelled with interfaces to other systems such as but not limited to slab turn downs, key-ways between concrete pours, construction joints and reinforcing dowels into adjacent pours.* b) *Bearing elevation is modelled from the geotechnical report with the addition on interface elements such as void boxes where applicable.* c) *Geotechnical regions are shown for context and not required to be modelled as part of this element at this LOD.* d) *See slab on grade for related conditions at this LOD.*	 *3 A1010.10-LOD-350 Wall Foundations (Shallow Foundations)*
400	Element modelling to include: • Rebar including hooks and lap splices • Dowels • Chamfer • Finish • Coursing for unit masonry defined • Waterproofing	

C1030 – Interior Doors

100	A schematic model element or symbol that is not distinguishable by type or material. Types, layouts, and locations are still flexible.	
200	Units are modelled as a simple, monolithic component; or represented with simple frame and panel. Nominal unit size is provided.	

B1010.20 – Floor Decks, Slabs, and Toppings (Concrete)

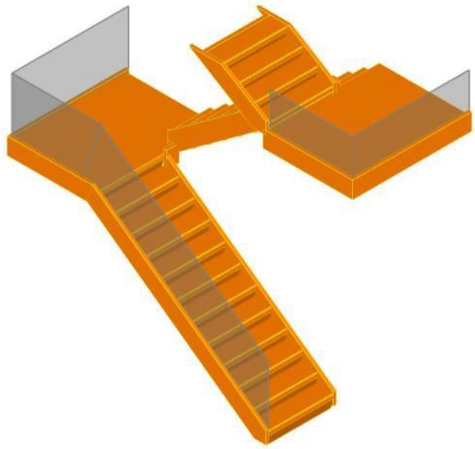
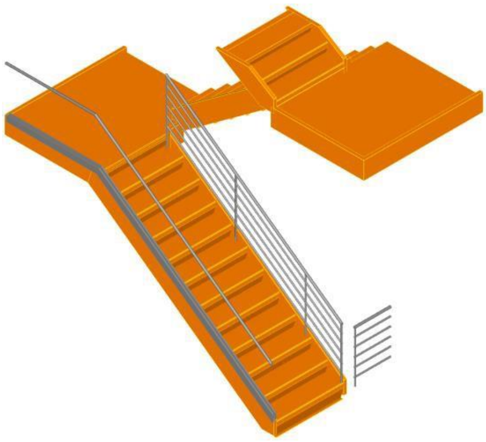
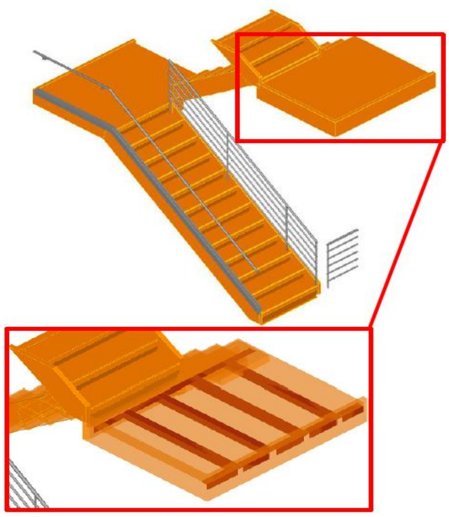
100	Assumptions for structural framing are included in other modelled elements such as an architectural floor element that contains a layer for assumed structural framing depth; or, schematic structural elements that are not distinguishable by type or material. Assembly depth/thickness or component size and locations still flexible.	
200	Element modelling to include: • Type of structural concrete system • Approximate geometry (e.g. depth) of structural elements	
300	Element modelling to include: • Specific sizes and locations of main concrete structural members modelled per defined structural grid with correct orientation • All sloping surfaces included in model element with exception of elements affected by manufacturer selection Required non-graphic information associated with model elements includes: • Concrete strength, • Reinforcing strength • Air entrainment, • Aggregate size • Typical details	

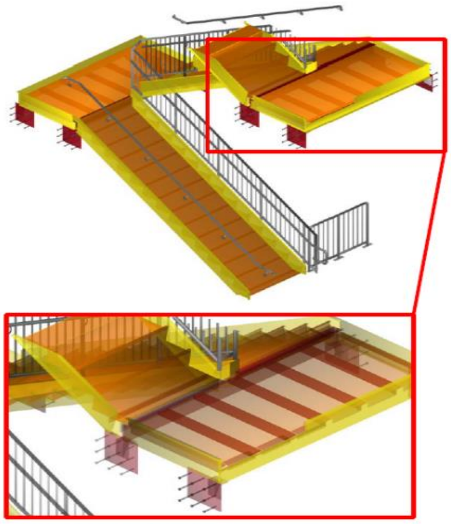
350	Element modelling to include: • Reinforcement called out, modelled if required by the BIMXP, typically only in congested areas • Pour joints and sequences to help identify reinforcing lap splice locations, scheduling, etc. • Expansion Joints • Embeds and anchor rods • Post-tension profile and strands modelled if required by the BIMXP • Penetrations for items such as MEP • Any permanent forming or shoring components • Shear reinforcing and stud rails Required non-graphic information associated with model elements includes: • Embeds and anchor rods • Aggregate, clear clover • Reinforcing spacing • Reinforcing • Live loads • Shear reinforcing and stud rails • Reinforcing post-tension profiles and strand locations • Penetrations for items such as MEP • Finishes, camber, chamfers, etc.	
400	Element modelling to include: • All reinforcement including post tension elements detailed and modelled • Finishes, camber, chamfer, etc.	

B1080.10 – Stair Construction

Includes: Structural framing for exterior and interior stairs including treads, risers, and landings. Includes fire escapes and ladders.

100	Assumptions for all stair systems (including railings, fire escapes, walkways, and ladders) are included in other modelled elements such as a spatial or massing element; or, schematic model element that indicates the approximate overall dimensions of the stair layout.	

200	Generic model element with simplified treads and risers. Nominal overall unit scope shall include: • Nominal plan dimensions (length, width) • Nominal vertical dimensions (levels, landings)	 38 B1080.10-LOD-200 Stair Construction
300	Major stair support elements are modelled (stringers). Treads and risers are modelled to indicate design-specified nosing conditions.	 39 B1080.10-LOD-300 Stair Construction
350	Secondary stair support elements are modelled (hangers, brackets, etc.). Required clearance/code zones are modelled.	 40 B1080.10-LOD-350 Stair Construction

400	All stair elements are modelled to support fabrication and installation.	 41 B1080.10-LOD-400 Stair Construction

C2030 – Flooring

100	Non-graphic information attached to model elements providing assumptions about proposed finish materials.	
200	Generic materials by type (e.g. tile or panelling), approximate thickness and scope in elevation. Generally, materials over 0.25” (10mm) thick are modelled.	
300	Materials are modelled based on specific types (e.g. Tile type CT-1). Thickness and scope are accurately modelled.	
350	Additional non-graphic information to include: • Manufacturer • Model	
400	Pattern layouts Expansion/control joints Edges	