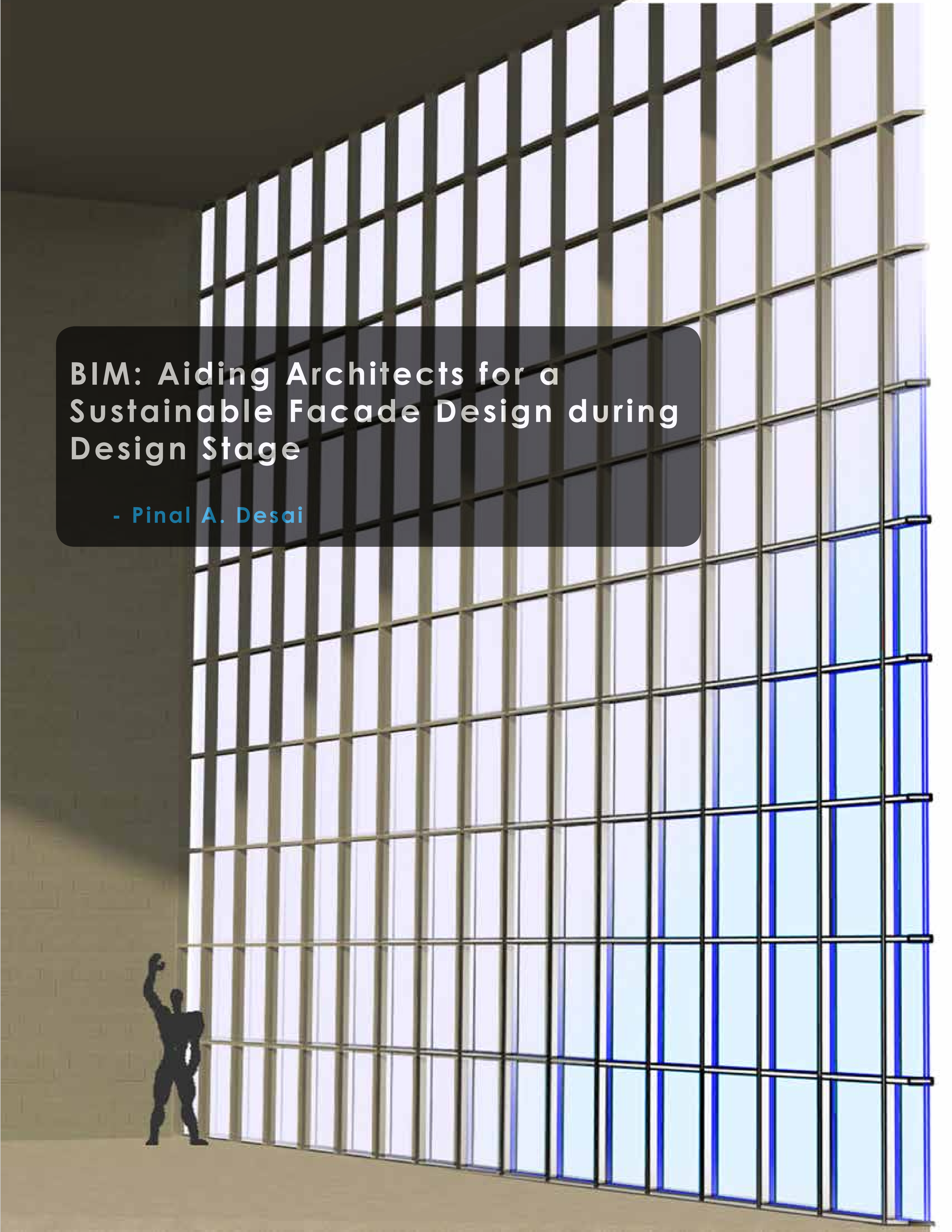
BIM: Aiding Architects for a Sustainable Facade Design during Design Stage

- Pinal A. Desai



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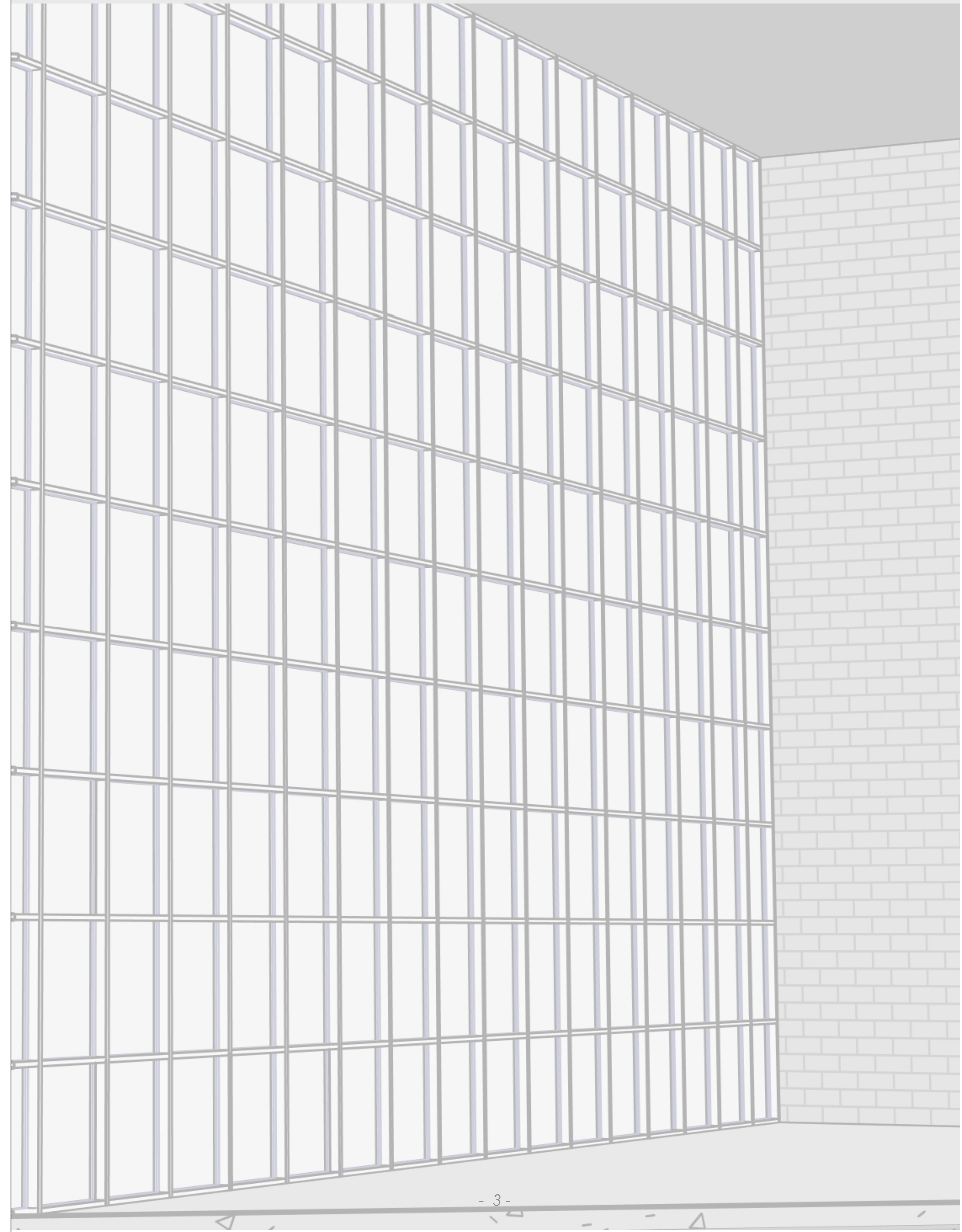

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SUMMARY

Introduction and personal motivation:

This thesis was initiated by VMRG. In one of the meetings at VMRG attended by some of VMRG member companies and few architect, it was observed that there was a gap of information provided by the manufacturers and those used b the architects: the Manufacturer's BIM model was not used by the architects. One of the proposals to close this gap was by creating a BIM based library of available elements. A starting point was to begin with curtain wall facade windows.

Furthermore, it was observed during the initial literature research phase that BIM and sustainability were both emerging topics. With EPC laws getting stringent every few years to achieve an almost carbon neutral building by 2020, it is essential that the new BIM library must aid the architects to achieve this goal. Thus, the focus of this thesis was formed.

Research Focus:

The research focuses on a hypothesis of a BIM based library for curtain wall facade window elements. These are considered as standard elements with no structural load. The focus of the research is within the Netherlands. The main research question of this thesis is:

How to effectively define the contents of a 'BIM library for curtain wall facade window elements' such that it guides architects towards a sustainable facade design during the design stage.

To answer this, 15 sub-research question are used as a guide to finally answer the main research question. These sub research questions are divided into 5 categories: Sustainability, façade, BIM+Technology, BIM+ Manageent and finally Hypothesis of the library.

Method:

Two methods were chosen. First, a literature research was performed in fields of Sustainability, Facade and BIM. BIM was studied from management as well as technology point of view. The current available libraries were studied.

The second method consisted of field research- interviews and case studies. Architects and Sustainable Engineers were chosen. Case studies included an overall BIM/ Sustainability analysis as well as an analysis of material choices for a new curtain-wall facade for Orange hall in Architecture faculty of TU Delft. The detailed method is available in chapter *1.6: Report overview.*

Finally, a guideline for generic library is drawn based on which 2 case studies are considered to define the contents of the BIM library. This is tested through a hypothetical 24x24x10 (LxBxH) cube. Final conclusions are drawn: by first answerng the research question and the sub-questions and connecting the overall aspect of sustainability with BIM Library.

Results:

Questionnaire: Architects did not prefer using BIM in the conceptual design stage. Furthermore, literature review from TNO (give source) confirmed that during the initial stages, the geometric detail of the profile is not important at all to the designers. It is observed that the architecture firms create their own library of windows. This helps in creating clear 1:100 scaled drawing and for detailing at scale 1:5 etc, a separate detailed drawing is possible.

It is observed that the EPBD as well as EPC and the Dutch legislation are focused in achieving low carbon emissions. Thus, the focus of the thesis should be to aid architects in achieving building designs that consume low carbon. GHGs are released during the operation of the building, where fuel and electricity is used for heating/ cooling and lighting, and exterior facade influences the interior climate directly. Moreover, GHGs are also released during the production of these elements (embodied energy). The embodied energy related data can be directly obtained from NIBE and ICE. These are the available open source information.

Conclusions:

The proposed library should have generic data. This should not be an exhaustive list of available manufacturers but rather a library from which the manufacturers can be selected based on the performance related information. This library must be used for making Simulations for generating energy related data and helping the architects to select the right window type based on frame material, glass as well as infill type. Green House Gas emissions were selected to measure the environmental impact of the products. The data is available from NIBE ad ICE database. Since these are based on calculations for the Netherlands, the available information on materials is specific to the Netherlands. The parameters relating to operational energy, embodied energy and EPC are summarized and data for a generic library is created.

Furthermore, a formula is proposed for comparing products. The formula gives the yearly consumption of the chosen elements by comparing the yearly operational energy as well as the yearly embodied energy by dividing the GHG emissions with service life. In order to use this formula, it is proposed to make this information a possibility within the BIM environment by software developers.

The proposed library should be used after the conceptual design phase. This means that studies relating to massing, program defining as well as defining the amount of transparent facade should be already done. The library helps in selecting the material and performance of the windows which gives a better idea about selecting a product.

Furthermore, considering that in the current scenario, the sustainable engineers are a guide to the architects for designing

Future Research:

Based on the boundary conditions, methods of research and conclusions, the following recommendations are drawn for future studies:

- This research only considers GHG of the environmental Impact. A total Environmental impact can be a good research point.
- Limitations in NIBE, ICE and EPC are observed. A possibility could be to redefine the data available.
- Possibility of using BIM and BIM libraries for sustainable design in other phases of Project delivery- such as Pre-design stage, construction stage and post occupancy stage.
- Possibility of BIM library for other components of the building such as structure, HVACs etc.
- Possibility of connecting design related information to constructors and facilities managers as well as feedback from facilities manager to architects
- Possibility of other component libraries for working of the tool to maximum potential.
- Applying the library and tool to a project and possible improvements
- Possibility of using non-standard curtain walls and innovative and adaptive systems.
- BIM object standards: for the objects that are available from the manufacturers.
- Possibility of applying library to deferent country, especially the developing countries where the database of embodied energy is not so easily available and the building regulations are not well defined when it comes to performance based parameters.

ACKNOWLEDGEMENTS

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I would like to take this opportunity to thank Dr.-Ing Tillmann Klien for introducing me to the thesis topic and mentoring me through the essential beginning phase of the thesis. This thesis topic was initiated by VMRG, knowledge-exchange consultant for the International Facade Master.

In addition, I thank Ir. Arie Bergsma for the facade Input ad help me in integration of the topics, and Ir. Winfried Meijer for the BIM input and specially the management part, where I had no prior formal education or practical experience. I thank Prof. dr. ir Andy van den Dobbelsteen for the sustainability related insights and always guiding me in the relevant direction regarding writing a good thesis and scope of my work. I learned a lot from the short meetings. I also thank Michela Turrin and Thalea for taking out time and helping me clear my thought process regarding my the computational part as well as the embodied energy part of my thesis.

I thank Ingrid and Bert for their valuable comments on my presentations and supporting me with the theoretical inputs and connecting me with the right sources for information.

In addition, I thank all the participatng architects for taking out time for the interviews. I appreciate the willingness of the architects and manufacturers to contribute to the planned workshop, which unfortunately, due to time restrictions, was impossible to orgaise and match schedules.

I take this opportunity to thank my family for being always so supportive. My Father taught me how to persevere. His ideology that ‘every situation and every person offers something positive to learn from’ kept me going and looking for opportunities. My mother taught me how to be down to earth. Her gentle and motivating words always comforted me, especially when I was delayed during my thesis. My brother always kept up my mood by being the happy sibling. I am at peace that even though I am away, we share our usual banter.

My friends in delft were my biggest support- Thalia, Antonio, Puttakhun, Melissa, Yi Chien, Irina, Tatiana, Robert Jan, Paavan as well as my inter-disciplinary friends from other faculties: Harsh, Prakhar, Nisarg, Punit, Saumil, Vrishika were like my second family and especially, Anish who was my strongest supporter and did not let me quit.

In retrospect, this thesis has helped be independent in my thought process and helped me gain a broad perspective in fields of BIM and Sustainability, two terms I was not familiar with two years ago when I first came to The Netherlands. This thesis has helped me bond better with people and grow as an individual. As I always believe, ‘a person who stops learning is a person who is old!’

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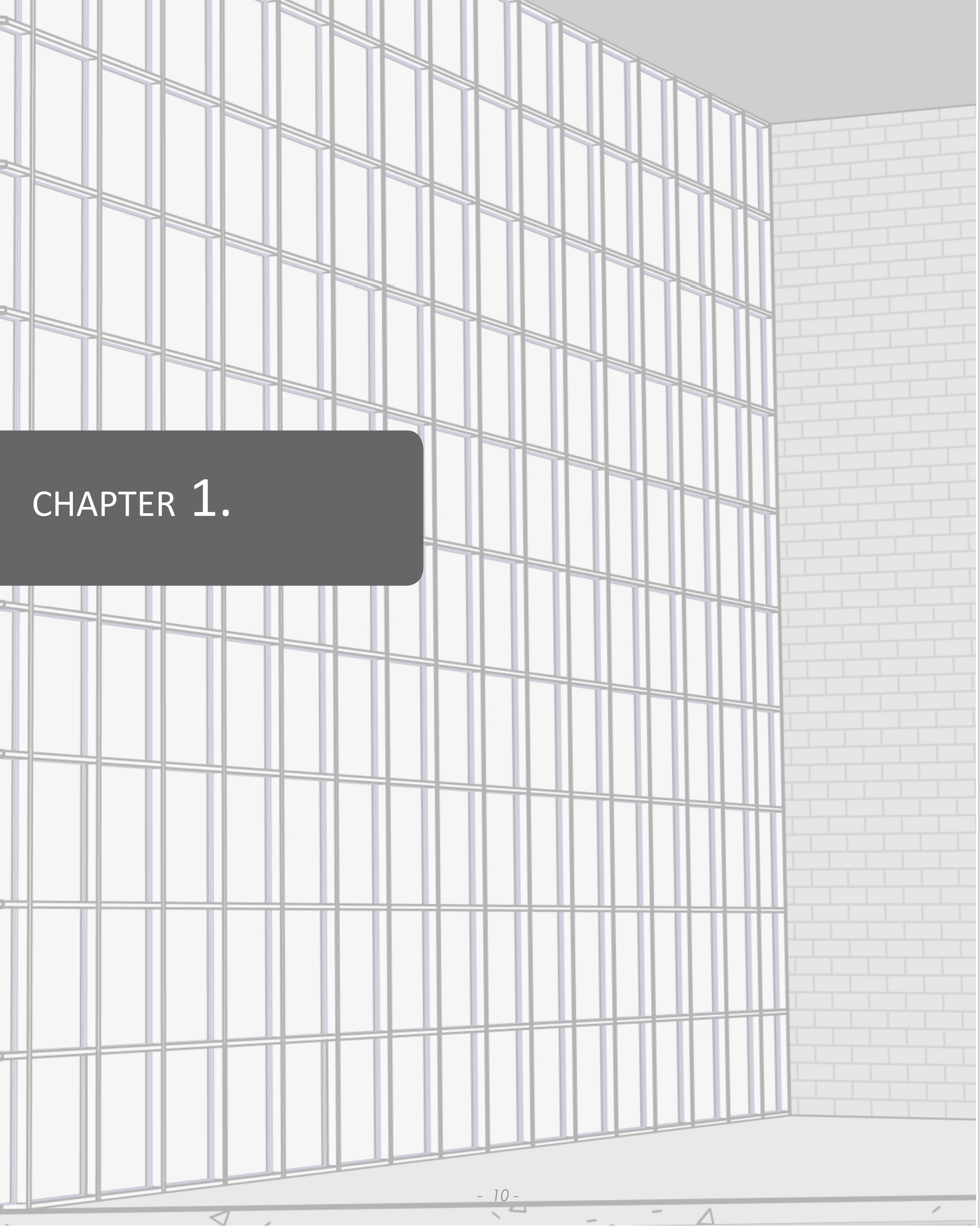


CHAPTER 1.

1. INTRODUCTION

The EPBD Directive for the EU countries requires all new buildings to be (almost) energy neutral by 2020. In this regard, the Dutch government has initiated standards to reduce the CO_2 emissions. In the Netherlands the energy consumption of new buildings is subject to performance based legislation, based on the Energy Performance Coefficient (EPC). The norm has been compulsory for almost 15 years and the latest revised norm is published in NEN 7120. the determination method of energy performance NEN 5128(2004) based on standard conditions in average Dutch household.

For a sustainable building, the use of energy is the point of concern for clients and designers. To make this possible, clients and AEC industry should work closely together in developing plans to make the transition to low carbon buildings feasible in order to meet the CO_2 emission target, and BIM can play a key role. BIM by its definition, theoretically contains all the information necessary for a project competition in a single 3d model. This sounds easily said than done, but if used correctly, it can help avoiding in huge amounts of rework, with several other advantages. An emerging capability within BIM environment is energy simulation. For the energy analysis packages, the designers usually receive feedback on their design; such as how much energy the building will use, what are the anticipated CO_2 emissions and if the building will pass performance criteria (such as: LEED or BREEAM). BIM applications for energy analysis have been introduced to improve this process but mostly at the design stage.

Facade on the other hand, can directly influence the amount of electrictity and fuel used for heating/ lighting and ventilation and hence, directly influence the buildings energy performance.

Since 2007 the GSA has required BIM use on all major projects and, although not required at this time, they are encouraging “accurate energy estimates in the design process” (Autodesk, 2008). The UK government has already mandated use of BIM for all governmenta projects. The Dutch government is not far behind- about 20% of the current projects use BIM and the number is expected to rise in the comig years.

BIM can reduce the costs associated with traditional energy (or sustainability analysis), while also realizing the benefits associated with energy analysis. by “making the information required for sustainable design, analysis and certification routinely available simply as a byproduct of the standard design process” (Autodesk, 2005). Although it has been debatable about how much is the influence, BIM has shown potentials in reducing cost associated with raditional energy. This is not possible using traditional 2D tools, which require that a separate energy analysis be performed at the end of the design process, thus reducing the opportunities for the early modifications that could improve the building’s energy performance. (Azhar, Farooqui).

Thus, these topics -BIM, Sustainability and Facade are researched within the thesis. The realm of individual topics are very large. Thus, only the factors influencng the design stage are considered.

1.1. PROBLEM STATEMENT

BIM and sustainability are both emerging topics in the Netherlands. It would be ideal if the two could be merged into a singular platform where architects can work with while designing the building and use it right from the start where major decisions are taken.

However, currently BIM is mostly used when tender/ construction stage has reached. Architects do not prefer to use BIM in the initial phases due to many reasons. One of them being the unavailability of a catalogue of products. At one of Brain-storming sessions at VMRG, a solution was to have a library of facade elements in BIM that architects can use in the early design stages.

On the other hand, there is not enough knowledge

Disclaimer: This research is a part of Master Thesis that is initiated by VMRG on how can BIM support sustainable design in the initial design phases. This thesis therefore, focuses also on the available sustainable design tools and its shortcomings and a possibility of combining it into the digital BIM Library.

1.2. RESEARCH GOAL

To find the feasibility of a BIM based library for window elements. since the project focuses on curtain wall facades, only non-load bearing elements are considered. Furthermore, the library is aimed for designer's use at the designing stage, where the major decisions are yet to be taken and design changes do not affect major design decisions. The library only looks at window elements, however, different materials will be considered.

The research is focused at the Dutch market and is an attempt to close the gap between the information provided by manufacturers and the information required by the architects.

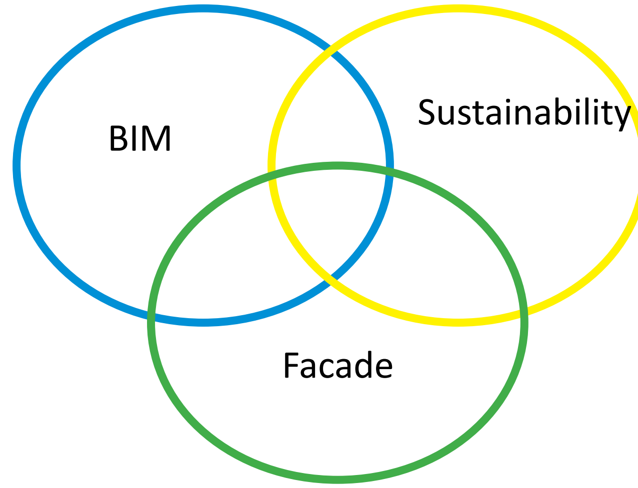


Figure 1.a Indicating the goal of the thesis.

1.3. RESEARCH QUESTION

Main:

How to effectively define the contents of a 'BIM library for curtain wall facade window elements' such that it guides architects towards a sustainable facade design during the design stage.

Sub Questions:

Sustainability

1. How to measure sustainability for the built environment in general and for window in specific?
2. What are the Dutch and international norms and tools to calculate sustainability?
3. What parameters relate to sustainable facade design?

Facade

4. Types of facade systems?
5. Parameters to define facade at design stage?
6. Role of sustainability in facade design?

BIM + Technology

7. How does BIM help in sustainable design?
8. What are the Green-BIM tools available globally and in the Netherlands?
9. Where does it still need development?

BIM + Management

10. What BIM Design stage is appropriate for the Library?
11. What are current project delivery method based design stages in the Netherlands?
12. How does BIM assist the project delivery method?

Hypothesis: Library

13. What are current window libraries in The Netherlands?
14. What are the available platforms for BIM library?
15. What would the new library look like? Who should use it? When should they use it? on which platform should it be developed? How it is supposed to help in sustainable facade design? Will architects use it? Are there any benefits for the manufacturer?

1.4. SCOPE OF STUDY

Hypothesis:

This study evolved as of research question from VMRG for establishing a BIM library. It evolved from a discussion* between Architects and manufacturers at one of the VMRG meetings in the year 2014. the General expectations from the Library is described as follows

- For architects and sustainable building designers
- Library useful at design stage
- design for facade window elements
- Useful for window choice
- Data from manufacturers provided to the User.

Boundary conditions:

The thesis is related to BIM, sustainability and facade. The right level of BIM Detail is not yet clear. The aspects of sustainability suitable to both BIM and windows needs to be recognised. The thesis only discusses the non-load bearing windows within the facade element. The thesis focuses only on the standard window systems avalable. The non-standard window systems may have slight to large deviations, the specific details of which should be throughly checked with the manufacturers.

The discussion* took place in VMRG Office in Nieuwegien. VMRG envisions 4 topics that are important for the market for the future: Sustainability, Innovation, Flexibility, and Internationalisation. The topic of library first emerged at a meeting with VMRG and members from manufacturers and suppliers of cladding and systems. It was observed within the VMRG members that the BIM model produced by the manufacturers was not useful for the architects, and architects are reluctant to use it. This also reduced motivation within the manufacturers that didn't already use BIM to start using it now, thus the companies that didn't use BIM were at a disadvantage.

Thus, the idea to have a BIM library that has manufacturer data emerged. Since it is only the beginning of the topic, it is observed that there are many directions to which the topic can be taken and VMRG is interested in the conclusions obtained for this topic and proposals for next research topics.

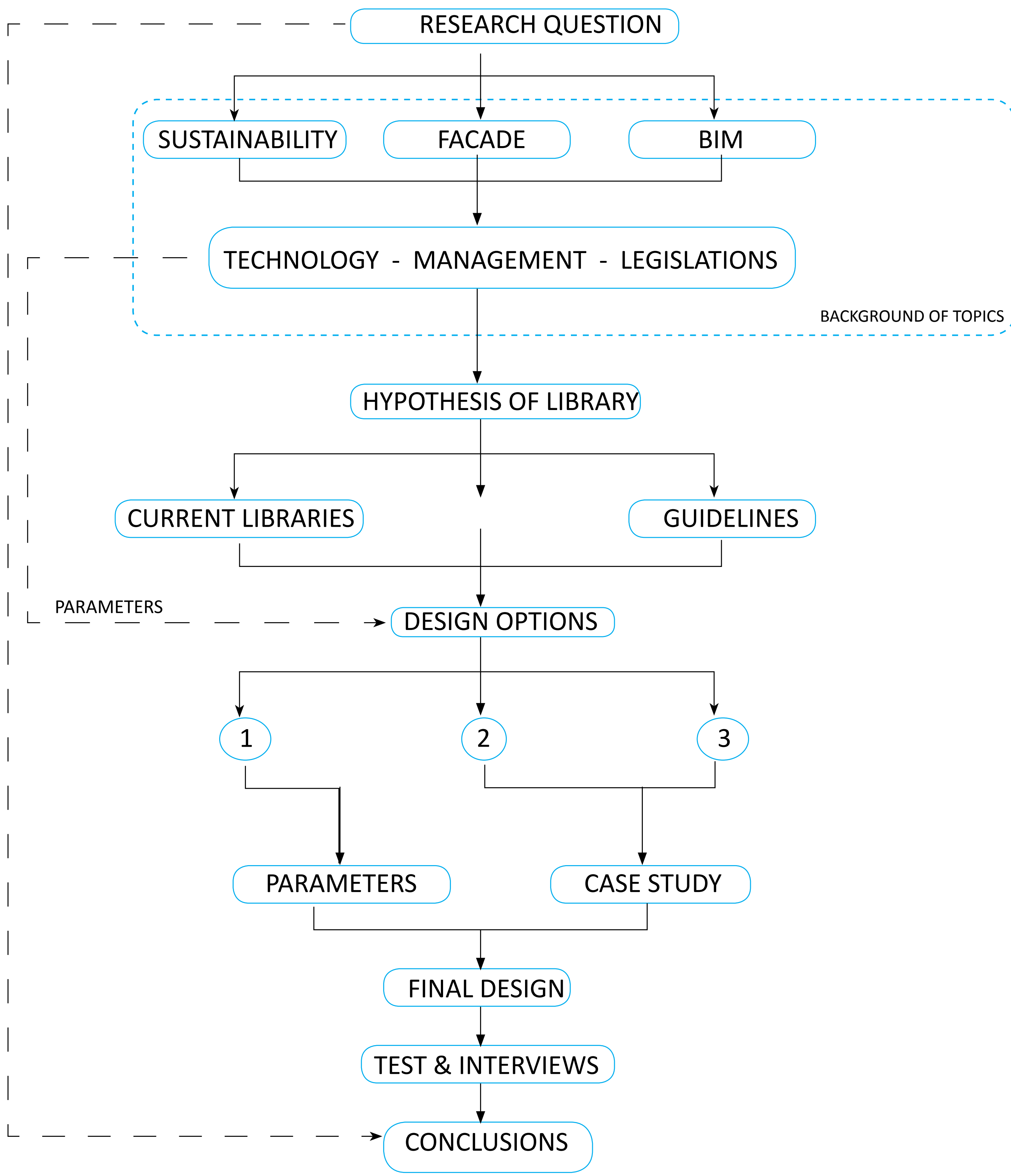
1.5. METHODOLOGY

Background research of BIM, Sustainability, and Facade was made. This included semantics and definitions and going on into defining parameters, current practice and that might be relevant for the library, and understandign what is missing or needed, in terms of the library.

3 design options are obtained from there. These are compared via case study using BIM and interview with sustainability and BIM experts.

Research and analysis based on available literature formed a major part of the research, in addition to case study of BIM based applications for energy

** The discussion took place in VMRG Office in Nieuwegien. The attendees included Ingrid(VMRG), Bert(VMRG), few archietcts and associate VMRG companies.*



simulations and interviews of professionals in the Netherlands. Since the realm of the thesis research is within the Netherlands, the literature was predominantly selected that was relevant for the Netherlands. Where data was not available or was found insufficient, international standards and norms were studied and applied.

Although the research followed parallel findings in the fields of sustainability, façade and BIM, the report follows a linear structure for clarity of understanding. Thus, since sustainability was covered before façade or bim, its role in façade was included in chapter of façade (chapter 3.8) and the role of both: sustainability and façade was covered in chapter BIM (chapters: 4.2, 4.6)

The three fields of research: sustainability, façade and BIM were studied in terms of Legislations and technology whereas the chapter of management studies all three fields in parallel by first understanding types of project delivery in the Netherlands and further elaborating the façade design process in terms of the most used project delivery method: Design-Bid-Build (or DBB). DBB is also used to understand the role of sustainability and BIM and thus the library in BIM in design stage.

Through the research, a toolkit is developed using Excel. The research is done using frame work of the research questions as guidance and a tool kit developed uses legal and technical framework. The application of the tool kit in perimeter of software systems is also analyzed. This tool kit is aimed to assist in guiding designers towards a sustainable curtain-wall façade design, thus the toolkit proposed answers the main research question.

In order to understand how effective the parameters of the toolkit are, it is tested in a virtual environment and using an example new building. The database used to develop the toolkit is used and efficient systems are selected to reduce the simulation time. The conclusions help us understand how effective is the toolkit in façade design as well as over-all design.

A clear link to the research questions through the thesis is provided after testing the toolkit. Finally, the developed tool is analyzed in terms of its impact in three sustainability spheres: Social, Environmental and economical impact. The impact of the BIM library in the current design process is reviewed and the adoption of the BIM library is also evaluated along with general conclusions about using the library and recommendations from the current research.

1.6. REPORT STRUCTURE

Chapter 1 describes about general introduction of the topics, their scope in the Dutch market and their scope in the thesis. The boundary of the thesis and methodology of the research is also discussed in this chapter.

Chapter 2 details out the topic of sustainability. This chapter outlines the scope of sustainability in general and the topics for consideration within the purview of the thesis. The importance of Green House Gases (GHG) Emissions is discussed and role of the Netherlands in carbon emissions from 1971-2012 as indicated by world research institute. This chapter further details the impact of building industry on carbon emission by dividing this into operational energy and embodied energy. The ability to reduce the GHG is observed highest in the Netherlands in the built environment and facade has a high impact on the operational energy. Thus the relevance of this topic is indicated. It is also seen that carbon emissions should be taken as a comparative value between the different design options. The design options should consider both the values: embodied energy and operational energy value. Cradle to grave or the Life cycle Analysis (LCA) method is chosen. The chapter further details out the ways embodied energy is calculated. Operating energy can be affected by heating, cooling, lighting and ventilation. There are also green building standards that are available to measure sustainable buildings and also to provide guidelines for sustainable constructions. EPC, ZEB, EnerPHit and Passivehaus, GPR Gebouw, Eco-Quantum, GreenCalc+, LEED, BREEAM and BREEAM-NL are studied. EPC, LEED and BREEAM-NL are chosen because they constitute Dutch Legislations, Comparing buildings at international level and Dutch Green Building Rating Standard respectively. As a result of these literature researches, a comparative Total primary energy formula is achieved. Also the flaws in the green building systems are identified and concluded that it is still highly recommended to follow the guidelines.

Chapter 3 details out the topic of facade. The overview of curtain wall facade is given and the functions of the facade are listed, which helps to identify basic parameters for designing a curtain wall facade. Since the thesis focuses on windows, this topic is elaborated. Types of windows based on function are listed. Types of windows based on materials are also listed. The frame materials: wood metal (aluminium and steel) and PVC frames are listed: the common materials in the Dutch window manufacturer market. The transparent material in the window is normally glass. In the Netherlands, the EPC lists 6 types of Glasses possible: Single, Double, HR, HR+, HR++ and HR+++. The difference between each of these is also listed. Types of shading in the window are also listed but this is excluded from the implementation in further analysis as the focus of the thesis is only the window elements- frame and glass. Role of sustainability in facade design is also listed by analysing EPC, LEED and BREEAM-NL parameters that relate to window. Finally, it is observed that EPC related parameters such as U-value,, Air tightness, area of transparent elements, System Efficiencies, overheating, Solar Gains, air change and day lighting relate to Windows. LEED (version 4 published on Oct 3, 2013) indicates 13 criteria that directly or indirectly is influenced by windows. This constitutes to 25 out of the total of 110 credit points possible. These can be divided into Material Based, performance based and social criteria. The BREEAM-NL on the other hand does not define exact criteria based on the window, as many criteria are subjective to the management of the building construction and relates less to the design process. However, the window has a possibility of influencing 20% out of a total of 100% credits. The categories where window influences directly are management, Health and comfort, energy and material. The details are given in the chapter.

Chapter 4 describes the background of BIM. The chapter starts with introduction to common BIM terms and further elaborates applicability in facade. Since different consultants use different BIM tools, this topic are covered by a small illustration of understanding the different types of softwares for specialise purposes. This chapter elaborates an important point in Level of Development that should be used. This chapter also elaborates on role of BIM in sustainability and details out the outputs received from BIM based energy simulations. The result varies from building orientation selection, Building Massing, Daylight Analysis, Energy modeling, water harvesting and sustainable materials. The possibility of incorporating Green Building Rating softwares is also analysed. It is found that LEED is the most compliant Green Building Rating Software within BIM environment. EPC and BREEAM-NL based indicators are not present directly within the BIM environment; however, non-BIM based softwares are available for these calculations. It also considers some case studies where BIM was used for energy simulation. It is found

Chapter 5 describes about the methods of project delivery in the Netherlands. Design bid build, Design build and Integrated Project delivery are described. It was found that the working method of integrated project delivery was closest to BIM work flow and hence IPD was proposed as the most suitable method. This is also supported by literature reviewed. However, design-bid-build is the most common method used in project deliveries and hence, this method is chosen for façade design process and eventually comparing with role of BIM and sustainability in the design process. A comparative illustration is made by relating the similarities in stages of design between BIM LOD design levels and incorporation of sustainable strategies. The stake holders in façade design are also described, and their role in building phase and BIM application is summarized through literature research and own conclusions.

It was assumed that this library will help the architects during the concept design phase. The interviews with architects help us conclude that they are reluctant to use BIM applications during the concept stage of design. They prefer to form the concepts mostly with 2d sketches. These sketches are then given to the 3d modeller or the BIM manager to generate 3d visuals. During the technical phase, before the tender, the details are added in. however, the architects also did not use the BIM objects from the manufacturers as these are at the detailed stage (definitive design phase). They made their own libraries with generic elements when the conceptual design is translated into 3d visualization (schematic design Phase). Thus, the proposal was made to use the library after the concept design stage but before this technical stage, and not the concept design stage as assumed earlier.

Chapter 6: After understanding the background of topics and their relation to each other, it was essential to understand the current BIM libraries and problems or advantages with it. This is covered in chapter 6 by analysis of 4 libraries: the individual BIM libraries developed within the companies, the 2D libraries, FAB window by Itannex and BIM object. 2D libraries are not BIM based and company's personal libraries are not open source. Hence they were discarded from analysis. The contents included in 2D library are however, discussed through a comparative table. It was observed that Fab-window lacked manufacturer information and non-geometric data which was covered by BIM-object. However, the Fab-window had comparative results in a single platform which made it easy compare products as against BIM object which has individual manufacturer data on different pages. It is also observed from interviews that the architects find the manufacturers libraries too detailed and hence they develop their own libraries. Thus, the scope of the library should be a step before the manufacturer's detail. The library should contain generic elements which can extract performance based GHG emission information and connect manufacturer's models that give the same values. This bridges the gap between the manufacturer and the designer by giving the freedom to designer while being able to communicate to manufacturer

Chapter 7 outlines Guidelines for the Library, based on the previous chapters. This chapter also suggests the 3 types of parameters that define the GHG emissions to be studied to define the library. These are picked up as case studies in the next chapter: by using simulations in a case study of Orange hall of Architecture faculty within TU Delft Campus.

Chapter 8 studies the 3 types of parameters that affect the GHG emissions and legislations. These are EPC based, operational energy based and Embodied energy based. The exact parameters are studied in this chapter and defined into a working tool which also includes re- looking at the equation to define the total GHG emissions for comparing different windows, as well as suggestions of Green Building Ratings depending on the Building Type. Furthermore, the output of the case studies also gives 3 options of applying the tool within the BIM environment. Furthermore, this chapter also tests the toolkit and important conclusions are drawn. Comparative GHG footprint can be calculated. In conclusion, how the tool developed answers the main research question is discussed.

Chapters 9 and 10 connect the final results obtained as well as the thesis research with the initial research questions. This chapter also describes the link of library with all 3 spheres of sustainability- People Planet and Profit. This chapter also discuses effect of using the library in the design process as well as projects prospects of BIM library and tool adoption in the Dutch Architecture- Engineering-Construction industry. The thesis finally culminates in short reflection at the end of this chapter. Recommendations, references and annexure are available in chapters 11, 12 and 13 respectively.

1.7. DEFINITIONS

BIM tools:

Software applications that allow BIM process are called BIM Tools.

Carbon footprint:

A carbon footprint is a measure of the amount of greenhouse gas (GHG) emissions that are released within the boundaries of study. A carbon footprint is often measured in the units of kg or tonnes of CO_2. A true carbon footprint starts at the cradle and measures the release of GHG emissions throughout a supply chain or life-cycle.

Cloud computing:

The practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer is called cloud computing.

Curtain wall:

Curtain wall are building envelopes that provide weather protection to the spaces inside, without carrying loads. In essence, the curtain wall transfers the load back to the floor via support framing. These loads include self load and dead loads such as rain, wind snow and maintenance. These systems take the load horizontally and transfer it downwards through the building's load bearing structure.

Embodied carbon:

Embodied carbon may be defined as the carbon footprint of a material. It considers the amount of greenhouse gas emissions (GHGs) that are released throughout a production supply chain to produce a material or product.

Extensible Mark-up Language (XML):
Extensible Mark-up Language (XML) is a markup language that defines a set of rules for encoding documents in a format which is both human-readable and machine-readable.

Facade:
Its name is derived from the French work literally meaning "frontage" of "face". A building facade is the exterior side of a building with primary performance of protection from external weather

ISO:
ISO (International Organization for Standardization) is an independent, non-governmental membership organization and the world's largest developer of voluntary International Standards.

LOD:
Many people confuse this term as level of detail where as its true definition lies in level of detail. These are described as:

Level of detail
This related to the 3-d detail level the object is drawn to. However, these objects can still be defined in a lower BIM LOD level, if the non-geometric information associated with it is at lower BIM LOD level. However, it should be noted that this is not the true definition of a BIM LOD. The correct definition is described as:

Level of development
In BIM, this is the true definition of LOD, meaning level of development. The geometric aspect of the object can still be simple if related object - information for its analysis/construction (related phase of design) is complete. For a high LOD, the geometric data is also detailed.

Model Element author:
MEA or model element author is the entity (or individual) responsible for managing and coordinating the development of a BIM Object to the LoD required for an identified project milestone, regardless of who is responsible for providing the content in the model element.

Operational energy:
For the building, this means the energy required to keep the lighting and thermal comfort of the building. The use of renewable on site helps in reducing fuel-dependent energy for operating the building.

Parametric model:
Parametric model is defined by set of parameters that maintains a consistent relationship between elements as the model is changed or manipulated. This means that, when a point, line, surface or volume is linked to an original geometry, a change in the original geometry will result in change of the he linked point, line, surface or volume, based on proportion of change applied.
Parametric modelling is basis for BIM as this makes the available building information reliable, more internally consistent and hence of better quality than object-CAD that is adjusted to use for BIM.

Stake holders:
These are people involved, directly or indirectly to the building process, starting from concept to construction to use and maintenance and in some cases even demolition. Some stake holders have a larger role, like the clients and designers while others such as users (in most cases) have smaller role in defining the outcome out building.

Standard:
A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose

The Industry Foundation Classes:
The Industry Foundation Classes (IFC) data model is intended to describe building and construction industry data. It is a platform neutral, open file format specification that is not controlled by a single vendor or group of vendors.

1.8. ABBREVATIONS

API: application programming interfaces

BIM: Building Information Modeling

BIR: Bouw Informatie Raad

BRE: Building Research Establishment

BREEAM: (Building Research Establishment Environmental Assessment Methodology)

DB: Design Build

DBB: Design Bid Build

DGBC: Dutch Green Building Council

EPBD: Energy Performance of Buildings Directive

EPC/A: Energy Performance Coefficient/ Assessment

EPD: Environmental Product Declarations

EU: European Union

GBR or SBR green building rating/ Sustainable building rating

gbXMl: Breen Building XML

GHG: Green House Gas (emissions)

ICT: Information Communication Technology

IFC: Industry Foundation Classes

IPD: Integrated Project Delivery

ISO: International Organization for Standardization

LCA: Life Cycle Assessment

LEED: Leadership in Energy & Environmental Design

LOD: Level of Detail/ Development

MEA: Model Element Author

NEN: Nederlandse Norm

NNI: Netherlands Normalisation Institute

Rgd: Central Government Real Estate Agency: Ministry of Interior and Kingdom Relations (Rijksvastgoedbedrijf: Ministerie van Binnenlandse Zaken en Koninkrijksrelaties)

RVO: Rijksdienst voor Ondernemend Nederland

Xml: Extensible Mark-up Language

ZEB: Zero Energy Build

CHAPTER 2.

2. SUSTAINBILITY

To compare a product's sustainability value from the other is complex and part of the study is environmental impact study. A full environmental impact study would include Land-use, Water-use Soil-use, Toxicities, resource depletion, embodied energy, service life, end of life and operational energy. However, these aspects are too many for an in-depth evaluation for the duration of the thesis. A good starting point of comparing the products would be embodied energy, service life and operational energy. These are responsible for green-house gases and are typically noted as CO2 emissions or carbon footprint. Table 2.a Explains many more Green House Gases Apart from CO2 that are responsible for the environmental impact. However, to have a comparative value, they are converted to a carbon equivalent or CO2(e) value. It should be noted that the emission value [kg CO_2] mentioned in this thesis is carbon equivalent value of emissions [kg CO_2 (e)].

Greenhouse gases	CO^2 equivalent global warming potential
CO^2	1
Methane (CH^4)	21
Nitrous oxide (N^2O)	310
Perflourocarbons(PFCs)	6500-9200
Hydrofluorocarbons (HFCs)	140-11700
Sulphur hexafluoride (SF^6)	23900

Figure 2.a GHG gasses expressed in carbn dioxide equivalent

2.1. GREENHOUSE GASES

Many researchers and activists have pointed out that if we reap the earth of all of its resources that we will leave ourselves without a place to live. It is no secret that human race is largely dependent on fossil fuels (also in the building industry). Since the industrial revolution, the CO2 levels have risen to a huge proportion and the fact remains that currently around 50% of CO2 emissions from human sources are not re-absorbed and remains in the atmosphere.

Schmidt et al. (2010) analysed how individual components of the atmosphere contribute to the total greenhouse effect. They estimated that water vapor accounts for about 50% of Earth's greenhouse effect, with clouds contributing 25%, carbon dioxide 20%, and the minor greenhouse gases accounting for the remaining 5%. The magnitude of the total greenhouse effect is significantly larger than the initial radiative forcing, underscoring the importance of feedbacks from water vapour and clouds to climate sensitivity. In simple words, it is indicated in

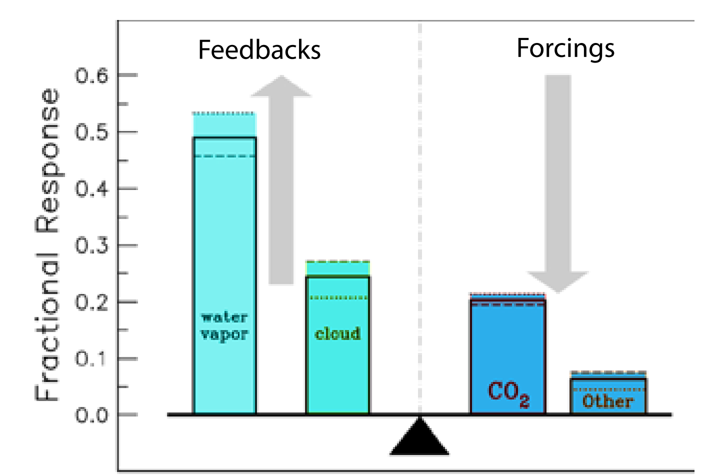


Figure 2.1.a : how individual components of the atmosphere contribute to the total greenhouse effect. (Smidt et al, 2010). Image courtesy: NASA GISS

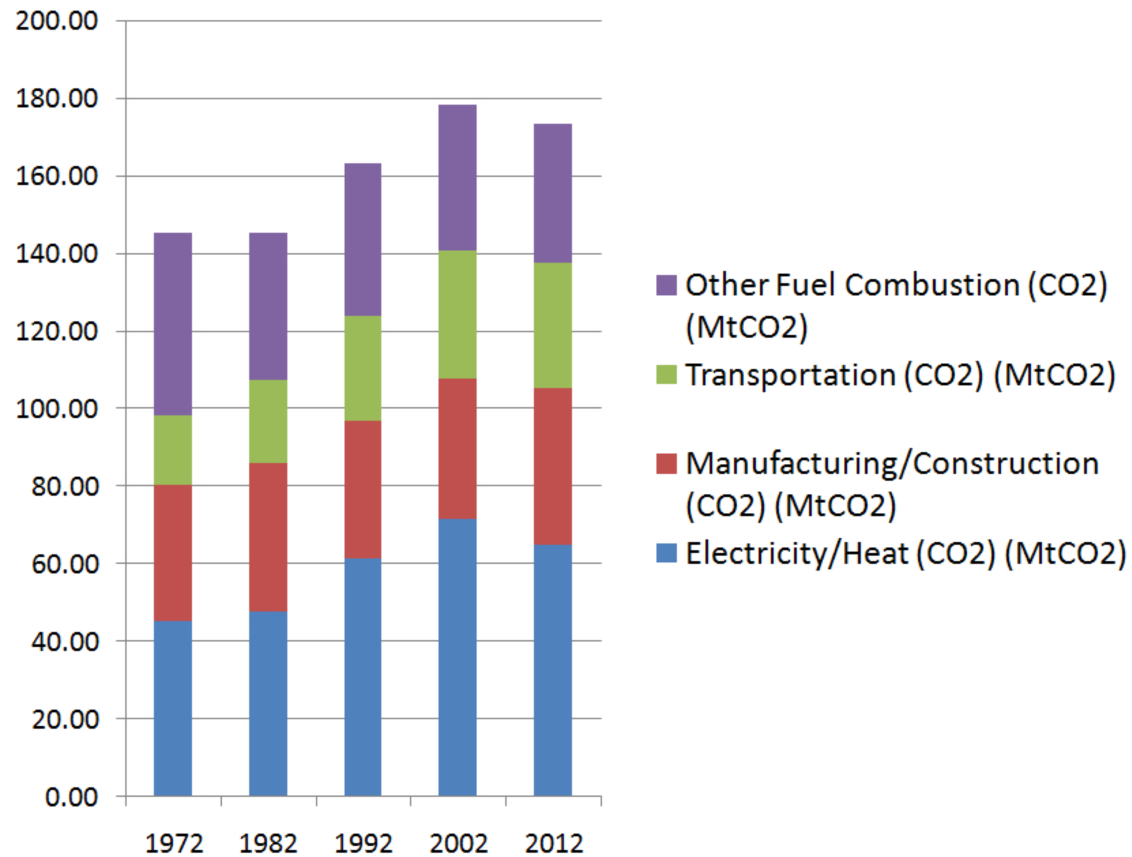


Figure 2.1.b: Green House Gas emission: trend in the Netherlands (source: World Research Institute) Illustration by self

the Figure2.1.a that Increase in CO2 and greenhouse gases significantly increases the feedback from water vapour and clouds (indicated by dotted line and vice versa (indicated by Dashed line)

According to the World Research Institute, Washington, EU ranks 3rd in the countries producing most greenhouse gases (GHG's), after China and United States. In fact, as recent as 24th June 2015, the Dutch government was sued by Urgenda supporters- a group of Dutch citizens- for increasing efforts to reduce carbon emissions. Three judges ruled that government plans to cut emissions by just 14-17% compared to 1990 levels by 2020 were unlawful, given the scale of the threat posed by climate change. The Court has now ordered the Government to cut its emissions by at least 25% within the next 5 years (A.Nelson, 2015). This urges the government to take stringent actions in reducing the carbon emissions. In the World Research Institute database for energy consumption in the Netherlands measured from 1971 to 2012 (Figure 2.1.b) the steady rise in manufacturing and construction and heating and electricity is noticable, although between 2002 and 2012, there has been developments on power-useage for heatng and electricity.

2.2. SUSTAINABILITY IN THE BUILT ENVIRONMENT

The building industry in responsible for about 40% of the CO_2 emissions worldwide (Pelsmakers, 2012) which is shown in Figure 2.1.c. According to ECN report in 2012, the energy saving potential in The Netherlands is highest in the Built Environment, as indicated in figure 2.1.d. This is logical considering the constant energy required in heating, cooling, mechanical ventillation inaddition to the energy required in production and transporting of the systems.

The operation energy is the largest part of the

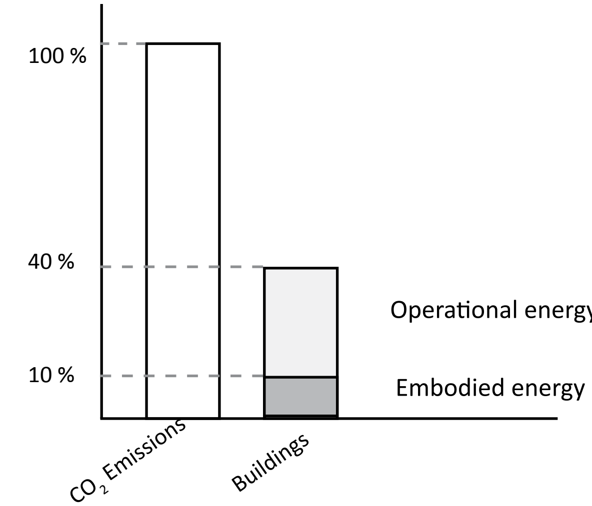


Figure 2.1.c : Breakdown of CO2 emissions and Building Industry (Pelsmakers, 2012)

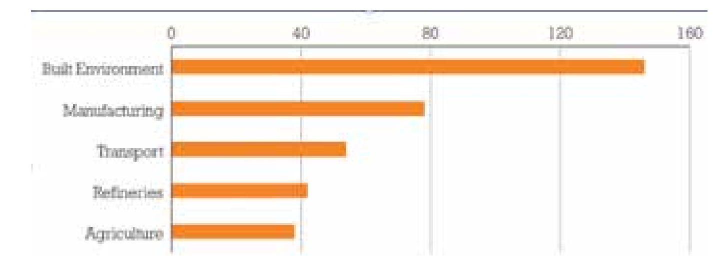


Figure 2.1.d: Energy saving Potential in different sectors in the Netherlands (source: Agriculture Ministry)

energy use in a building, the embodied energy often only accounts for 10-15% in most cases (Thormark, 2002). This is also reflected in a study for sustainable offices in the Netherlands (A. van den Dobbelsteen, 2004) and a study for Norwegian row house by Winther & Hestnes (1999). according to the study by A. van den Dobbelsteen, the environmental costs in an office can be divided into 3 parts: Energy performance cost (77.5%), Material costs (19.5%) and water use (3%). the Study by Winther & Hestnes was performed for a very energy efficient house and the results can be broken down as indicated in figure 2.1.e

thus, To define the meaning of sustanability, it an be divided into two parts: Operational energy and Embodied Energy

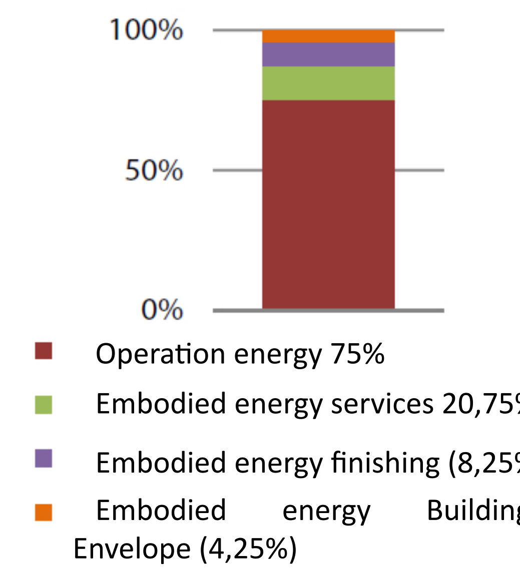


Figure 2.1.e: difference between operational energy and embodied energy as indicated in very energy efficient houes in Norway (Winther& Hestnes, 1999)

2.2.1. EMBODIED ENERGY

2.2.1.1. CRADLE TO GATE

Cradle to gate is a boundary condition associated with embodied carbon, carbon footprint and LCA studies. A study to these boundaries considers all activities starting with the extraction of materials from the earth (the cradle), their transportation, refining, processing and fabrication activities until the material or product is ready to leave the factory gate (Circular ecology, online cited: Aug 2015)

2.2.2. CRADLE TO SITE

A cradle-to-site study favours defining the embodied energy of individual building components. This includes the energy required to extract the raw materials, process them, assemble them into usable products and transport them to site. (Circular Ecology Online cited: Aug 2015; ICE, Aug 2015)

2.2.2.1. CRADLE TO GRAVE (LCA)

A cradle-to-grave approach defines embodied energy as that "consumed" by a building throughout its life. This definition is a far more useful one when looking at a building or project holistically, though admittedly much more complex to estimate. to understand this at a deeper level, Yojanis & Norton (2002) have broken down energy consumption further into the following 3 categories:

A. Initial embodied energy is the energy required to initially produce the building. It is the energy required as described in the process for cradle to site

B. Recurring embodied energy is the energy needed to refurbish and maintain the building over its lifetime.

C. Demolition energy is the energy necessary to demolish and dispose of the building at the end of its life.

This method is also called as LCA or Life Cycle Assessment. This will be discussed in detail in later chapter.

2.2.2.2. CRADLE TO CRADLE

'Cradle to cradle' goes beyond 'cradle to grave' and conforms more to the model of the circular economy. In a cradle to cradle model products would be designed in a way so that at the end of their initial life they can be readily reused, or recycled, and

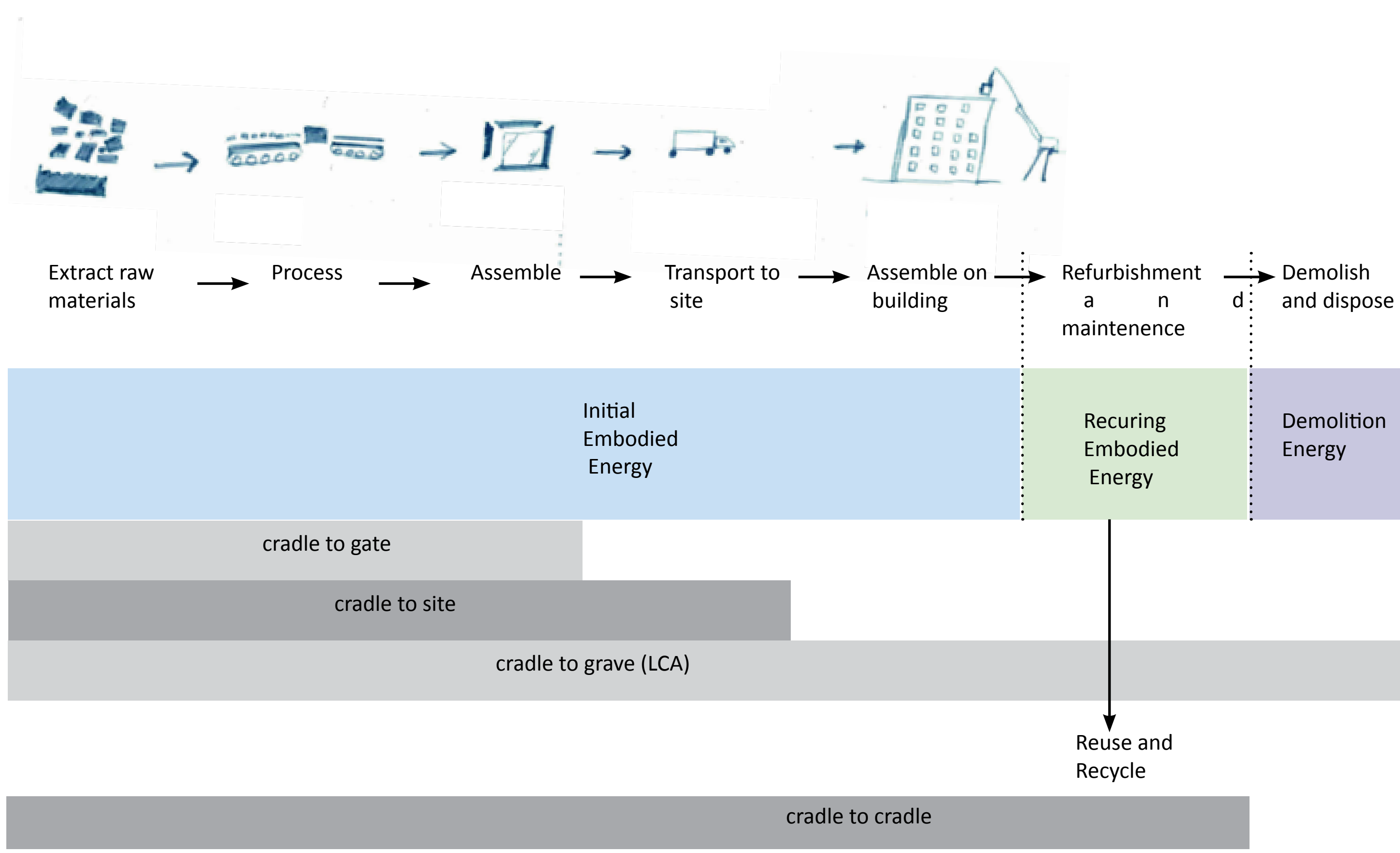


Figure 2.2.1a: Difference Between Cradle to gate/ site/ grave/ cradle. (Illustration by self)

therefore avoid landfill altogether. The steps followed by a C2C Principle is similar to steps in cradle to site principle with the addition of the end of use of the product where it is recycled into another product or re-used in another building. (C2C, 2013)

2.2.2.3. CONCLUSIONS

For windows, cradle to gate and cradle to site are incompete to define the embodied energy within the material for a correct comparision. Ideally, Cradle to Cradle would be the best way of comparing the products, as all materials/ products do not need to be destroyed after its use.However, its rules are much more complex to define the product on than cradle to grave. Also, for windows, considering the life time is between 20-50 years, depending on the choice of materials and maintenence*, it is difficult to define the end of life of the products. Hence, for common practice of comparing embodied eergy, cradle to grave, also called Life Cycle Analysis is used widely in The Netherlands.

For the Purpose of the thesis therefore, LCA Method will be considered to compare embodied energy between materials for window systems. The Situation of LCA in The Netherlands is described in the next sub- chapter.

2.2.3. OPERATING ENERGY :

Operating energy or operational energy is the energy consumed to operate or run the building. this can be in the form of heating, cooling, lighting, ventilation,equipment and appliances. Natural energy sources such as wind, sulight, building material and water help in passive systems such as lighting and ventillation and thermal mass. However, Active systems might also be required such as mechanical and electrical. Occupants of buildings can also contribute to the heating of buildings by virtue of the heat produced through metabolic processes. Operational Energy is a significant measure of sustainability which enables straightforward comparisons between alternative building technologies.

2.3. GREEN BUILDING STANDARDS AND RATING

There are a number of Green Building Rating Systems available, depending on the country and the developer of the system. In core of the rating system is to measure the Environmental impact by the building. Worldwide, many systems are available such as BREEAM (UK), CASBEE (Japan), Ecoeffect (Sweden), Ecoprofile (Norway), EDGE (South Africa), Envest (UK), Escale (France), Green Globes (USA) Green Star (Australia),GRIHA (India), LEED (USA), and many more. In addition to the rating systems, standards such as EPC, Passivhaus and EnerPHit and Zero Carbon Dwellings assist in designing a sustainable building by providing a sustainability label. EPC is the most widely recognised standard in the Netherlands.

The Netherlands mainly recognizes BREEAM-NL, which is developed by Dutch Green Building Council alongside LEED, which is adopted from US. BREEAM developed by BRE, UK is basis for BREEAM-NL as well as LEED. Apart from the internationally recognised BREEAM and LEED tools, the Dutch designers also refer to GPR Gebouw and EPC standards. Eco-Quantum is another rating system developed by IVAM which is based on new standards and refined ratings. The ratings used in The Netherlands are discussed in the sub-chapter.

2.3.1. EPC - EPA

The Energy Performance Certificate (EPC) is a European Energy Performance of Buildings Directive (EPBD), initiative as part of the drive to improve energy efficiency across the EU member countries. Elements of this reinforcement are as follows: an energy label on completion of new buildings, efficiency standards for installation systems and a cost optimisation standard for insulation of external

* Considering weathering of products, average life-time for wooden windows is assumed 20 years and for aluminium is 50 years.

walls during renovation. The government wishes to improve the energy performance of new homes in stages by tightening up the Energy Performance Coefficient (EPC) system in the period up to 2020, with the ultimate aim that new homes should be energy-neutral from 2020 onwards. (IEAA, last updated online on 2013 Apr; MEAAI, 2011). It is based on the Dutch norm NE 7120.

The Energy Performance Coefficient (EPC) is developed by Netherlands Normalisation Institute (NNI) and is an instrument used by the Dutch government to reduce CO 2 -emissions. This instrument consists of minimum norms for new to-be-built buildings. (MEAAI, 2011)The process of calculating the EPC of a building is called EPA or Energy Performance Assessment. The norm is in force since 2006 (IEAA, 2013) and the latest improvements are proposed on 1st January 2010, i.e. to achieve EPC of 0.4. These norms are applicable from January 01, 2015. (RVO-NL1, Cited online on 2015)

The energy index is given by the following formula (ISSOI, 2007) :

$$EI_{new} = \frac{Q_{total;EI\,new}}{C_6 \times A_{gs;EI\,new} + C_7 \times A_{ts;EI\,new} + C_8}$$

In which:

EI_{new}: Energy Index calculated to comply with the EPBD
$Q_{total;EI\,new}$: characteristic yearly energy use of a house based on ISSO 82 [12] (MJ)
$A_{gs;EI\,new}$ tal ground surface (m^2)
$A_{ts;EI\,new}$: total thermal transmission surface (m^2)
C_6, C_7, C_8: numerical correction factors 155 (MJ/m^2), 106 (MJ/m^2) and 9560 (MJ).

EP Check (version 4) is the EPC compliant software, developed by RVO-NL and is designed to check calculations made according to the standard BS 7120: 2011 Energy performance of buildings - Determination method (RVO-NL2, cited online on Sept., 2015)

2.3.2. ZEB

Directive 2010/31/EU(EPBD recast) Article 9 requires that "Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings".

A nearly zero-energy building is defined in Article 2of the EPBD recast as "a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". (Concerted Action EPBD, Sept, 2014)

At the heart of the ZEB concept is the idea that buildings can meet all their energy requirements from low-cost, locally available, nonpolluting, renewable sources. At the strictest level, a ZEB generates enough renewable energy on site to equal or exceed its annual energy use.

The US Depratment of Energy with its research on Zero Energy Buildings: critical look at definition (Torcellini, Pless, Deru, 2006) Helps us understand this concept by further dividing as:

Net Zero Site Energy: A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site.

- Net Zero Source Energy: A source ZEB produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.
- Net Zero Energy Costs: In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.
- Net Zero Energy Emissions: A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

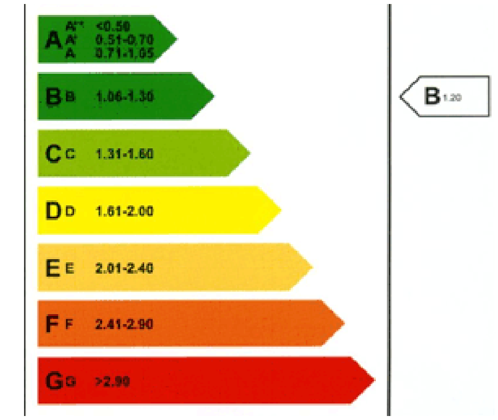


Figure 2.3.a: EPC Grading from G to A+. This mark is used to identify the Energy Performance Coefficient of the building

GPR GEBOUW

Figure 2.3.b: GPR Logo

BREEAM BREEAM NL EXPERT NIEUWBOUW

Figure 2.3.c: (L-R)BREEAM Logo, BREEAM-NL Logo for new construction

Figure 2.3.c: LEED Logo (as per rating): Certified, Silver, Gold, Platinum

2.3.3. PASSIVEHUIS AND ENERPHIT

The Passivhaus standard originated from a conversation in May 1988 between Bo Adamson of Lund University, Sweden, and Wolfgang Feist of the Institut für Wohnen und Umwelt (Institute for Housing and the Environment, Germany. As an independent authority, the Passive House Institute tests and certifies products in respect of their suitability for use in Passive Houses. A similar standard, MINERGIE-P, is used inSwitzerland.(www.minergie.ch) A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post heating or post cooling of the fresh air mass, which is required to fulfil sufficient indoor air quality conditions (DIN 1946) - without a need for re-circulated air." (Feist, 2006).

Adherence to the strict Passive House criteria result in buildings with superior air quality and comfortable indoor temperatures year round that use up to 90% less energy than typical building stock, or less than 1.5 litres of oil or 1.5 cubic meters of gas to heat one square meter of living space for an entire year. Products that carry the Certified Passive House Component seal have been tested according to uniform criteria; they are comparable in terms of their specific values, and are of excellent quality regarding energy efficiency (Passive House Institute1, Cited on Sept. 2015). It is not a compulsory standard. The Criteria and Algorithms for certified Passive House Components for Transparent components (Windows etc) can be found online on Passive House Institute Website (Passive House Institute2, Feb, 2015)

Achieving the Passive House Standard in refurbishments of existing buildings is not always a realistic goal, due in large part to unavoidable thermal bridges in the existing structure. Renovations according to Passive House principles are made possible by retrofitting to the EnerPHit Standard

Criteria	Passivhaus	EnerPHit
Specific Heat Demand	≤ 15 kWh/ m^2.yr	≤ 25 kWh/ m^2.yr
Specific Heat Demand	≤ 120 kWh/ m^2.yr	≤ 120 kWh/ m^2.yr *
Limiting Value	n50 ≤0.6-1	n50 ≤1.0-1

* PE ≤ 120 kWh/m^2.yr + ((SHD - 15 kWh/ m^2.yr) x1.2)

Table 2.3.3.a, Showing difference in values of EnerPHit ad Passivehaus (Passivehaus BRE, online: 2015)

Setting the EnerPHit Standard as the target ensures that both the energy demand as well as the quality is future-proof. 9Europhit, online 2015) If energy retrofits of an existing building meets Passive House criteria (for new builds), it, too, can be certified as a Certified Passive House. The standard has slightly relaxed certification criteria as indicated table 2.3.3.a

2.3.4. GPR GEBOUW

GPR Stands for Green Performance of Real Estate and GPR Gebouw is a software developed by Municipality of Tilburg and W / E consultants together with several at profit and not for profit partners. GPR software assesses and rates the environmental impact, energy performance and design quality of buildings and Urban Developments.

The software is used by public Authorities and building professionals for design, benchmarking and green procurement. (GPR Software, online: Sept 2015)

GPR methodology:

Essential for the GPR software methodology is the assessment of a broad range of sustainability and design quality criteria. These criteria are allocated into five key performance indicators: Energy, Environment, Health, Quality of Use and Future Value.

The GPR software is complementary to the National building regulations: when available, it uses national standards, guidelines or definitions to determining an indicator.

For every performance indicator, the building or urban development is rated on a scale from 1 to 10. The higher the rating, higher is sustainability. The Dutch National Building Act 2006 is used as a benchmark: when a building is rated a six on every indicator, it meets the requirements of the Building Act.

2.3.5. ECO QUANTUM

Eco-Quantum (EQ) was developed by IVAM (Environmental Research and W / E Consultants Sustainable Building Launched in 1999. IVAM originates from the Environmental Science Department (IVAM) of the University of Amsterdam and the 'Chemiewinkel Amsterdam'. .EQ calculates the environmental performance of all buildings based on the methodology of Life Cycle Assessment (LCA).

There are two versions: Eco-Quantum Domestic and Eco-Quantum Research. EQ Research is based on the LCA calculation program SimaPro and designed for in-depth analyzes of the environmental performance of buildings. EQ Domestic is a simplified version of EQ Research and intended for architects who can see quickly with the program, the environmental impact of the materials, water and energy consumption of their design.

For the reference lifetime of the house hold EQ standard 50 years. Calculations are based on a standard life span of 75 years old per building component, but it can be adjusted by the architect. (www.IVAM.uva.nl1, 2015) In addition, weighting factors and normalization factors may be adjusted. (www.kiesuwlabel.nl, 2015)

2.3.6. GREENCALC+

GreenCalc was developed by Sureac, a Dutch foundation of companies working in the area of sustainability, and the Dutch consulting company DGMR. The development was initiated and supported by the Dutch Government Buildings Agency (van den Dobbelsteen, 2004). GreenCalc evolved to a new version GreenCalc+ which is free to use and BREEAM-NL compliant for new projects and Material choices can be used for BREEAM-NL. GreenCalc + examines sustainability in three areas: materials, water and energy consumption. These themes are translated into a clear score to the environmental index. The outcomes are displayed in euros. On the environmental index is recently attached a G- to A-label, as with the EPBD.

In June 2011 there is a cooperation agreement between the Foundation Sureac (administrator GreenCalc +) and the Dutch Green Building Council (administrator BREEAM-NL), with the aim to integrate both methods. This is the intention to create a single common language for evaluating sustainable buildings and areas in the Netherlands come a big step closer. Greencalc can be used within the BREEAM method to calculate to the environmental load of materials (Mat 1 credit). (www.greencalc.com, www.Kiesulabel.nl)

2.3.7. LEED

LEED, or Leadership in Energy & Environmental Design, is a green building certification program that recognizes best-in-class building strategies and practices. LEED Green Building Rating System represents the U.S. Green Building Council's effort to provide a national standard for what consistitutes a "green building." (LEED-NC, 2002)

To receive LEED certification, building projects satisfy prerequisites and earn points to achieve different levels of certification. According to the Latest V4 version, the certification can be divided further into the following 5 types: Building design and construction, Operation and Maintenance, Interior Design and Construction, Home and Multi-family mid-rise and Neighbourhood development. (USGBC1, 2015)

The certification regulated by Green Building Certification Institute (GBCI) according to ISO Standard. 17021. Each rating system is made up of a combination of credit categories.

Within each of the credit categories, there are specific prerequisites projects must satisfy and a variety of credits projects can pursue to earn points. The number of points the project earns determines its level of LEED certification.

Earlier these credits were divided into 5 categories (LEED-NC, 2002) namely Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR) and Indoor Environment Quality (IEQ)The New credits as per version 4 are divided into 9 categories and can be gives as:

Integrative Process (1credit), Location and Transport (16 Credits), Materials and Resources (13 credits), Water Efficiency (11credits), Energy and Atmosphere (33credits), Sustainable Sites (11 credits), Indoor Environmental Quality (16 credits), Innovation (6credits), and finally, Regional Priority (4credits). Thus, a total of 110 credits are possible.

There are four levels of certifications: 40-49: Certified, 50-59: Silver, 60-79: Gold and finally 80+ : Platinum, In the Netherlands, recently the highest certification for sustainability (LEED Platinum) awarded to Transavia's new headquarters at Schiphol-Oost. It is suggested that these criteria should be taken into consideration during the planning stage as success in earning LEED certificates for a project starts at the initial planning stage, where stakeholders make a commitment to pursue it. (Kubba, 2012)

2.3.8. BREEAM

The Centre for Sustainable Construction of the British BRE (Building Research Establishment) developed BREEAM.BREEAM stands for Building Research Establishment Environmental Assessment Methodology and was launched in 1990. (BREEAM ®, 2010-2015). Assessments using the basis of BREEAM are only allowed to parties certified by the BRE.

Code for a Sustainable Built Environment

In 2010, BRE Global positioned BREEAM within an overall framework for the environmental, social and economic assessment of the built environment known as the Code for a Sustainable Built Environment. The international Code for a Sustainable Built Environment is a strategic framework for sustainability assessment. At the highest level, the Code itself forms a vision statement for a sustainable built environment. The Code is then interpreted through a Core Technical Standard and a Core Process Standard, both supported by Core Science (see diagram below).

The measures used represent a broad range of categories and criteria from energy to ecology. They include aspects related to energy and water use,

Figure2.3.8.a : BREEAM Acceptance in the world. (Illustrations by BREEAM, 2010-2015)

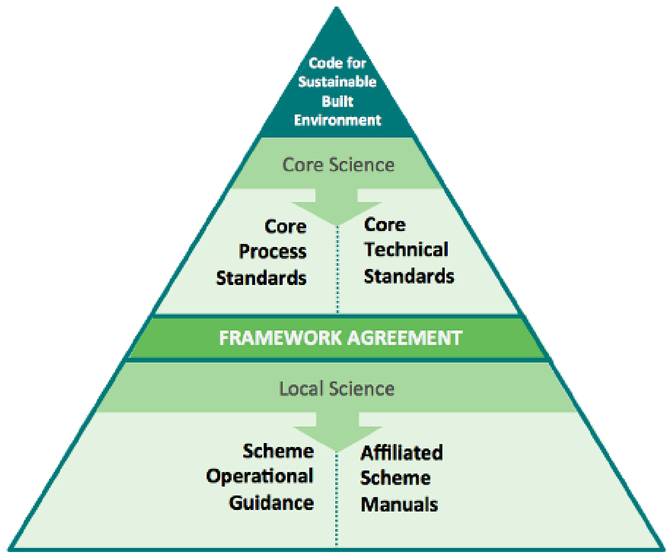


Figure2.3.8.c: the BREEAM Pyramid concept for different countries/ Regions who sign an agreement framework agreement (Illustrations by BREEAM, 2010-2015)

Score		%
★	Pass	≥ 30%
★★	Good	≥ 45%
★★★	Very Good	≥ 55%
★★★★	Excellent	≥ 70%
★★★★★	Outstanding	≥ 85%

Figure2.3.8.b : BREEAM-nl Score star rating for New construction and renovation: . (Illustrations by BREEAM-NL, 2010-2015)

the internal environment (health and well-being), pollution, transport, materials, waste, ecology and management processes. BREEAM to their local context (Example BREEAM -NL) and affiliate their processes, products and tools with BREEAM across all life cycle stages of buildings and infrastructure. On weighing all the aspects, project can be certified as a pass, good, very good or excellent.

2.3.8.1. BREEAM-NL

BRE is a prominent Founding Member of the UK Green Building Council. BREEAM is the preferred scheme for a number of the national Green Building Councils across Europe, including the Netherlands. The Dutch Green Building Council is the scheme operator for BREEAM NL by signing a framework agreement. (BREEAM, 2010-2015)

BREEAM has four labels: New construction, renovation, In-Use and demolition/disassembly. A preliminary assessment can be done by users themselves by an online assessment tool (Nieuwbouw, cited online: Sept 2015). The score is made up of sub-scores for the different categories of sustainability. These categories have their own weighting. For example, for New construction and Renovation (which is the most interesting category in the purview of the thesis), the categories are given as management (12%), health (15%), energy (19%), transport (8%), water (6%), materials (12.5%), waste (7, 5%), land use & Ecology (10%), pollution (10%). This leads to an overall score expressed in stars and has a rating from Pass, Good, Very Good or Excellent. However, the ratings are ambiguous and there is no clarity in the initial stage about how to exactly rate the criteria as per the building. This is done by a certified BRE-assessor and the rating can only be given according to the BRE-assessor's approval

2.4. CONCLUSION:

Total Primary Energy:

It is clear that the operational energy and Embodied energy together constitute the energy consumption of the building. therefore, only looking at embodied energy or operational energy will not give a true analysis criteria for the selected system(s). thus, for the product comparision possibility in the library, the total primary energy should be calculated considering the service life or the intended life span of the element. Holberg, A. and Ruth, J. (2013) calculated total Primary energy by the following formula:

$PET_{LC} = PET_{o}$ / year x Service life + PET_{E} ....(eq. 1)

PET- Primar energy total,

O- operational energy

E- Embodied energy.

PET_{E} can be derived by LCA databases like NIBE SIMApro etc. Yearly operational energy can be calculated by energy analysis softwares. Since Green House Gases is the Major impact to the Enviroment, the calculation for comparision must be performed in term of the GHG's emitted and

convert to CO_2 value for a standard comparative Value. The BIM compliances of these softwares should be taken into consideration. This is covered in the chapter 4.6: role of BIM in sustainability.

Standards and Regultions:

EPC is an important minimum standard that needs to be followed in the Netherlands. It is expected that by 2020, the Netherlands will accept the Zero Energy Design (ZED) standards, although the exact regulations are still under-construction. This is expected to reflect in EPC norms by 2020.

With the progress of Greencalc+ incorporating the BREEAM - NL standards and EPC not providing any ratings to compare products on its own, it is observed that BREEAM-NL is currently the major factor providing the Green Building Rating standards in the Netherlands. However, Globally, LEED and BREEAM rating standards are accepted, and to compare Dutch projects with the world projects, these rating methods are useful. Thus, the Parameters for useful for facade in the Purview of BREEAM-NL, LEED and EPC needs to be studied and is covered in the Facade chapter.

Softwares and GBR:

Kiesulabel.nl website gives a Preview of how can eco-quantum be used. According to the summary, if energy material and water analysis are required, it is good to refer GreenCalc+, GPR Gebouw and Eco Quantum. If only Energy calculations are desired, it's good to refer EPC or EPA. the BIM compliance of these standards and other softwares that associate in acessing the standards needs a further look and is considered in the chapter 4.6 Role of BIM in Sustainability.

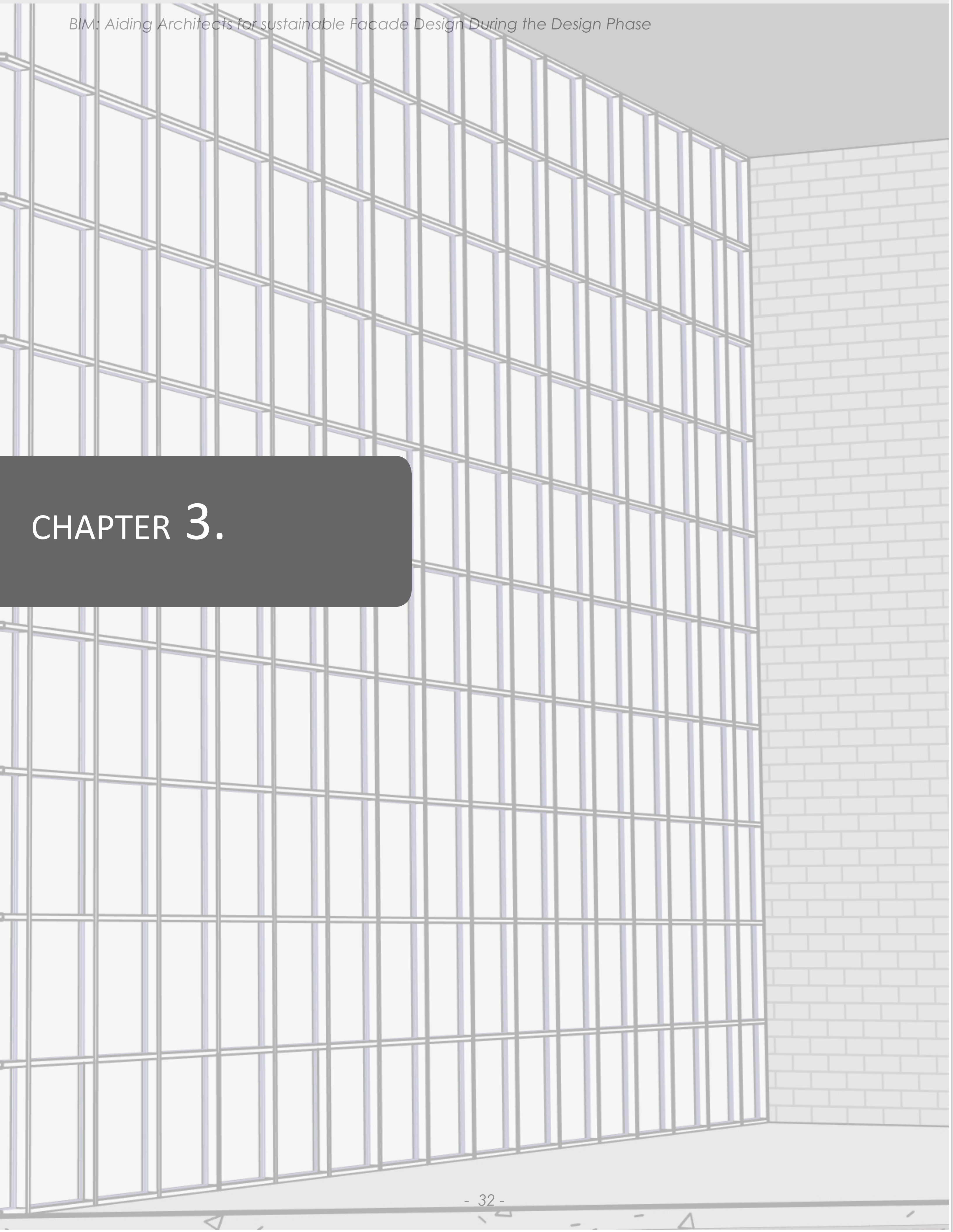
Problems with GBR Ratings:

Sustainability is a concept which is very difficult to quantify and measure. GBR systems, under most categories, are prescriptive-based (for example, the material category of LEED), in which credits are given if certain prescribed values are achieved in the design; and under a few categories, are performance-based, in which the performance of the building for such categories have to be proved to offer certain improvement over a benchmark. . (Lee, Trcka, Hensen, 2011) THe BREEAM Method is measured via criteria scoring, which is a subjective method that is open to skewed results. Due to this mix of prescriptive and performance based scoring methods, together with the difference in weighting assigned to different categories and the rule-of-thumb values used in the rating of each category; the resulting GBR scores might be highly distorted.

The research by S. Aspinall, et al (2012) included 3 accessing methods, including BREEAM and LEED and Interviews with BREEAM assessors reveals more insights on the accuracy of these rating systems. The report revealed that although the criteria set in each method were very similar and concentrating on the same categories, the tendency that a BREEAM certification was much more demanding and difficult to achieve than the other methods compared, thus generating a much more sustainable building stock.

It should be noted that alhough it concluded that BREEAM is an efficient tool in establishing the environmental performance of buildings through design and procurement, it is difficult to rate it. At the time of the research conducted by S. Aspinall et. al. , LEED V4 was not yet launched. LEED on the other hand, with its Version 4 provided much more clarity on the criteria required for design, although it is based on rule of thumb.

it can be concluded that Buildings sustainability can be measured via criteria scoring, which is a subjective method that is open to skewed results. Environmental assessments have been developed in a worldwide context and are being used by many industry and sustainability experts. however, it does guide the clients and architect towards a sustainable goal and it is highly recommended to follow the guidelines, depending on the project type and requirements.



CHAPTER 3.

3. BACKGROUND OF FACADE

3.1. CURTAIN WALL FACADE OVERVIEW

The facade is a selective and permeable membrane that allows, rejects and/or filters any external environment from the interior climate. Rain, air, heat, light, and sound can be dissipated or allowed to come inside the building in order to provide the user a comfortable environment. When facade fails to provide a sufficiently comfortable indoor climate, additional mechanical systems are required to improve the performance. (Knaack, et al. 2007) (Murray 2009). Facade is also regarded sometimes as a part of the exterior envelope (exterior envelope also includes roof) and sometimes also as the exterior skin of the building. Just as he skin regulates the comfort of the body, the facade regulates comfort of the people inside the building.

The facade is one of the most important factors influencing the energy demands and comfort levels inside a building. It is directly related with the possible necessity of mechanical systems for cooling, heating, ventilation, etc. (Knaack, et al. 2007) For example, the more the glazing, the more light and heat permeates and hence, less heating and lighting is required in the interior space. Depending on the local climatic conditions and the internal gains, some active systems can be even avoided, but this may also incur glare issues and overheating.

The concept of windows, which is the focus of this thesis is similar to the certain wall facade in terms of designing- non-load bearing, capability of ventilation, protection against outside atmosphere while also providing acoustic comfort and complying with fire regulations. in terms of energy performance analysis, it has similar characteristics as curtain wall facade. However, the manufacturing, sizes, assembly and maintenance are different from the curtain-wall facade. Thus, the Thermal requirements, Visual requirements,Air-permeability, Acoustic and fire requirements will be similar to curtain wall facade and can be referred for regulations and energy performance analysis calculations and also for LEED and BREEAM. These are given in the sub-chapters below. The types of windows are studied in a separate sub chapter.

3.2. TYPES OF WINDOWS BASED ON FUNCTIONS

Awning Windows:

These Pivot at the top and open inside/ outside, although the most common is the outward swing. Awning windows are usually operated with a roto-gear or push-out lever so that the window can be adjusted to keep out rain but let in fresh air. This window type provides up to 50% ventilation area, as the hardware does not allow them to be fully opened Casement Windows

Casement windows

These swing outward on side hinges. These windows can be hinged left or hinged right (as viewed from the outside) and are operated with a roto-gear and crank. Casement windows provide almost 100% ventilation area, because they can be fully opened and the out-swinging sash can direct plenty of air into the building.

Picture Windows

Picture windows are fixed windows that do not open. They are used to let in a lot of light and to take advantage of a view. Picture windows are often used in combination with operating windows. Casement Windows

Horizontal Sliders

These windows have sash that slide horizontally. Single sliders have one fixed sash, while double sliders have two movable sash. Most horizontal sliders have at least one removable sash.

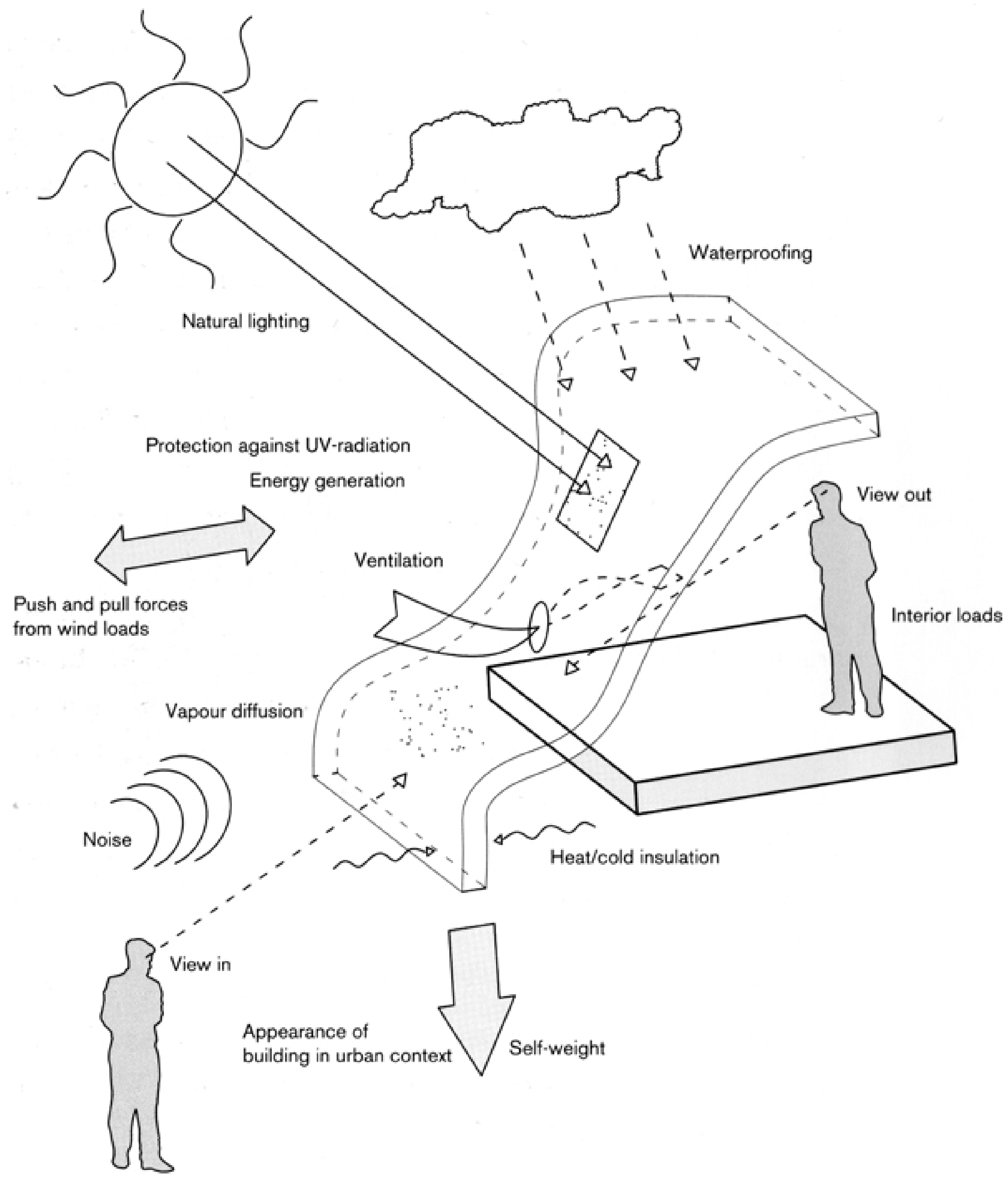


Figure 3.1.a : Functions of Curtain wall facade. (Knaak, et. al., 2007)

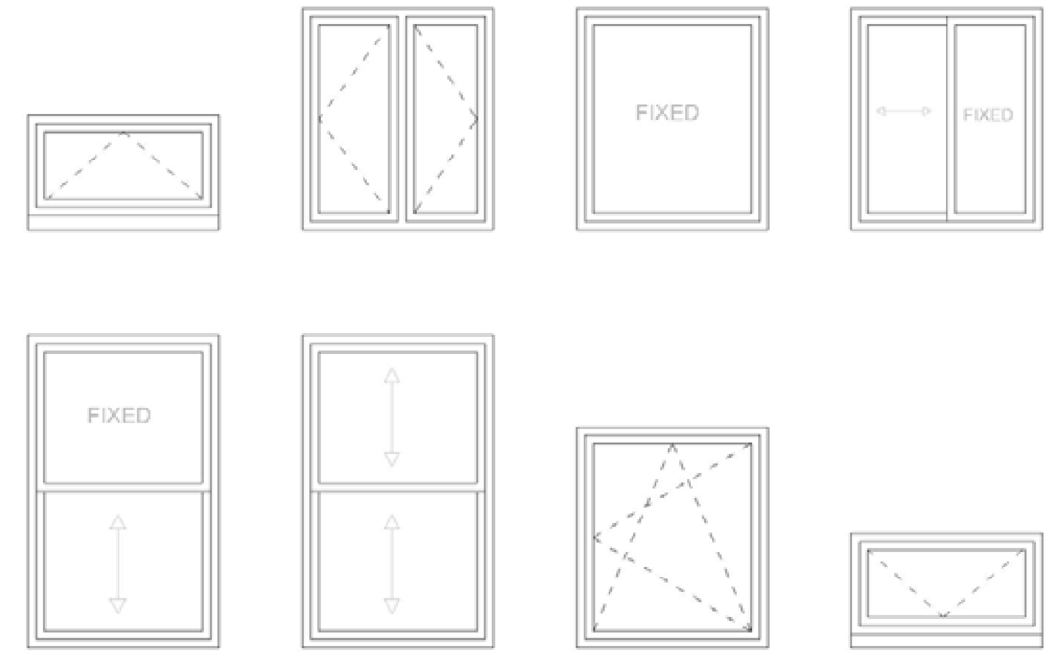


Figure 3.2.a : Window types- (l-r, t-b,) awning, casement, Fixed, Horizontal sliders, Single Hung, Double Hung, Tilt and Turn, Hopper. (illustration by self)

Single Hung Windows

A single hung window is a vertical slider in which the top pane of glass is fixed and the bottom sash moves. In some designs, the sash tilts in for ease of cleaning.

Double Hung Windows

Double hung windows are similar to single hung windows, except that both sash move and are controlled by a balancing mechanism so the sash do not fall down when raised

Tilt & Turn Windows

These windows first appeared in Europe but are now used in North America. Special hardware allows tilt & turn windows to tilt inwards for ventilation, or to pivot from the side like a casement window.

Hopper Windows

A hopper window is the reverse of an awning window in that it pivots at the bottom and opens inward.

3.3. TYPES OF WINDOWS BASED ON MATERIALS

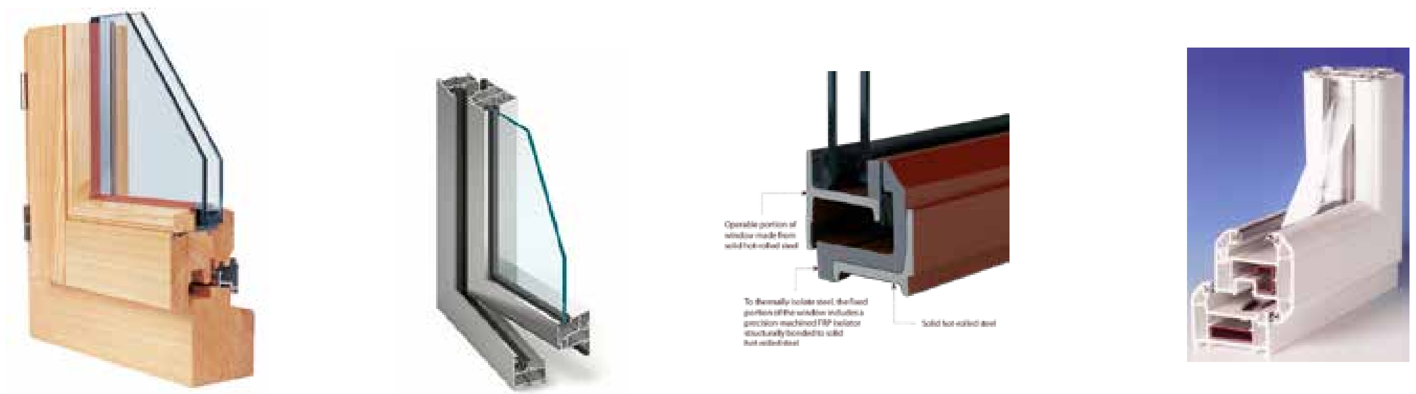
The window in the Netherlands are usually made from wood, metal, PVC, or from a combination of these materials.

Wood Windows

Wood windows are warm, traditional and aesthetically pleasing. Because it is a good insulator, wood does not become cold like metal and glass. Wood is treated with preservatives to prevent rotting. Wood windows can be painted on the exterior, or clad with aluminum or PVC profiles for better weathering and reduced maintenance.

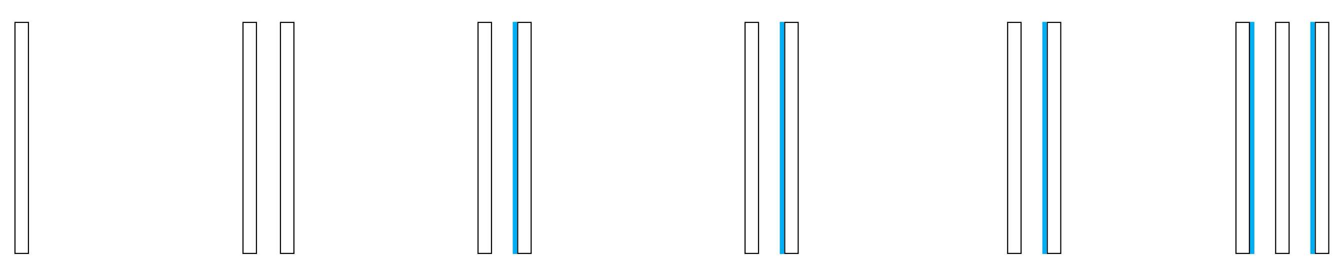
Metal Windows

Metal windows are more durable than wood, and are thinner, lighter, and easier to handle. But metal is a poor insulator and in cold weather, and loses more heat to the exterior than wood. Most recent metal windows are manufactured with a thermal



Wood Aluminium Steel PVC

Figure 3.3.a : Types of windows based on material



Single Glass	Double Glass	HR Glass	HR+ Glass	HR++ Glass	HR+++ Glass
U value: >5.4-3,0 W/m² K	U value: 2,8 - 2,2 W/m² K	U value: 2,0- 1,8 W/m² K	U value: 1,6 - 1,4 W/m² K	U value: 1,2 - 0,9 W/m² K	U value: 0,7 - 0,5 W/m² K
	65 €/m²	70 €/m²	75 €/m²	80 €/m²	120 €/m²

Figure 3.3.a : Types of windows based on glass types : Dutch EPC based standards for Window type.

break, a vinyl or rubber strip that separates the exterior and interior metal parts of the window. The thermal break reduces the movement of cold from the outside to the inside of the building. Most commercial applications still specify metal windows.

The most common metals used are Aluminium and Steel. Steel windows and doors are stronger than any alternative material. By direct comparison, they are three times stronger than aluminum. however, due to he higher density of steel than aluminium, steel windows are also heavier and using them may increase the load on the bearing elements.

PVC Windows

PVC windows are relatively new, having only been introduced during the last 25 years. These windows are extruded from high impact resistant polyvinyl chloride (PVC). PVC windows have excellent weathering characteristics, are almost maintenance-free and have excellent resistance to heat loss. Originally used primarily in renovation because PVC lends itself to non-standard size production, PVC windows are rapidly increasing in the new construction market as well. PVC is available in several extruded colours. Special painted coatings have been developed to expand the range of colours available.

3.4. TYPES OF GLAZING:

The Dutch Widow industry recognises the 5 window glazing types given by the code BS EN 1279-5: 2005 + A2: 2010 (Glass in building - Insulating glass units - Part 5: Evaluation of conformity) table 3.4.a decribes the 5 types according to the u-values. The indicative price related to the glazing type given in the table is refered from Dubbelglas-weetjes, a price related website refered in the netherlands. This price data is used as the company is associated with manufacturers and gives realistic quotes from the manufacturers based in the Netherlands.

The u-value of only glass is 5.8 w/m² K. This is above the Permissable value according to EPC. The NEN 7120 states the permissible limit is 4.2 W/m²K. Hence, single glazing will not be included in this thesis and is also not incuded in the table.

	Prijs (excl. Labour cost)	U-value	Energy savings per house with 20 sq.m of glass
Dubbel glas	€ 65 per m²	2,7	€ 140 per year
HR	€ 70 per m²	1,7 - 2,0	€ 180 per year
HR+	€ 75 per m²	1,3 - 1,6	€ 220 per year
HR++	€ 80 per m²	1,2	€ 260 per year
HR+++	€ 120 per m²	0,5 - 0,9	€ 280 per year

Image 3.4.a indicated the difference between Single glass, Double glass, HR++ Glass and HR+++ Glass.

Double Glass:

Double glass or Standard insulating glass consists of two non-coated glass air-tight panes with a with dry air-filled interspace. When build up of 4-12-5 (inside size, cavity thickness and outer size) is a U-value of +/- 2.8 W / m ² K achieved.

HR Glass:

HR glass, High Performance coated glass consists of a Double Glass where the outer glass is Low e-coated, inner glass is uncoated and cavity filled with dry air. By varying the cavity, the u value of 2.0 to 1.6 W / m ² K can be obtained. the build up in mm is given by 4-cavity-4

HR+ GLass

HR+ Glass is similar to HR glass: double glass with low-e coating on the outer glass. The difference is the cavity is filled with inert gases like argon etc. HR + glass has a U-value of 1.6 to 1.2 W / m 2 K at a build-up of 4 - cavity - 4.

HR++ GLass

HR++ Glass is similar is double glass with low-e coating on the outer glass and cavity is filled with inert gases like argon etc. HR ++ glass has a U-value of 1.6 to 1.2 W / m 2 K at a build-up of 4 - cavity - 4.

HR+++ Glass

HR+++ or HR triple glass or HR3 glass consists of three layers of glass, coated or uncoated. The cavity may be air or gas filled. HR3 glass can achieve a U-value of up to 0.4 W / m 2 K.

3.5. TYPES OF WINDOW SHADING

A varied of shading configurations have been invented and put in the market, such as fixed, manual and automatic movable, internal and external shading device. The location with respect to gazing (interior, integrated between two glazing, exterior) can influence the energy parameter inside the room. Besides, it can also influence glare comfort. The location and type of shading can influence the aesthetics and external appearance. In many cases, only after the building is constructed, the problem of glare s found, at which point, it is either aesthetically disapproving or too expensive to install an external shading, although it might be the ideal one. (Passive Solar Design, 2015; Ander, 2014). A good selection of shading type and operating device affects visual comfort by providing sufficient views to the outside, while cutting glare at the same time. Apart from glare, Sunshading has huge potential in reducing the heating loads specially during hot months, thereby, helping in reducing the energy demands for the thermal comfort of the interior space.

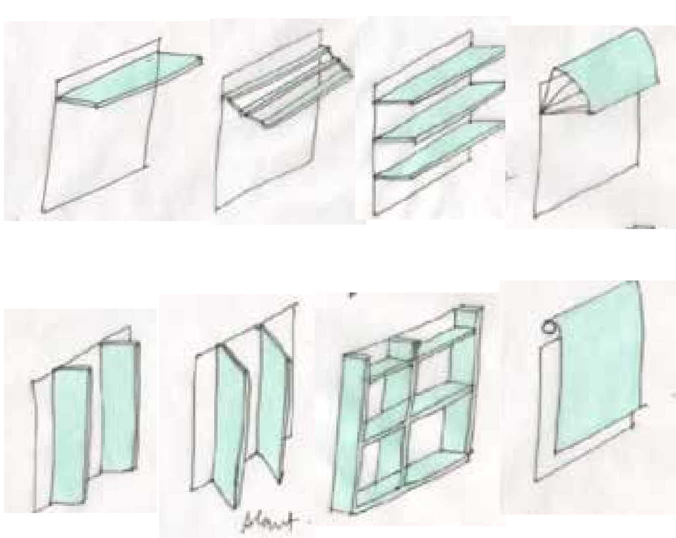


Figure 3.4.a indicating the different types of shading systems. (clockwise from top): Fixed external or ext, Fixed with Slats ext, Horizontal finsInternal or int/ext, Retractable ext , Retractable int/ ext, eggcrate (int/ext), Vertical slanted fins (ext/ int), Vertical Straight Fins (ext/ int) . (illustration by self)

It should be noted that this study required an in-depth research with is not in the boundary conditions of the research of the thesis. Although it is an important consideration and it s strongly recommended that this should be used in the design stage by the designer. however, in the purview of the library for Windows, this is an additional part.

3.6. WINDOW PARAMETERS

Windows and metal & glass curtain walls generally represent as much as 50% to 100% of the exterior cladding of large buildings and are determining elements in the performance of the vertical building envelope. They are often an important architectural feature of a building and represent a significant portion of the overall cost of a building construction or renovation project.

As a determining element in the performance of the vertical building envelope, they must be air and water tight, prevent condensation from occurring on the interior surfaces and resist wind load and other exterior forces acting on the building envelope. Given the ever growing complexity and variety of modern building envelopes, the evaluation of their performance in the pre-construction and construction phase is essential in order to avoid undesirable and costly problems during the service life of the building. (Goncalves, Jutra, 2010)

The parameters required to define a window (and subsequently make a decision) can be listed into five main categories below:

1. Defence against weather (sun/ wind/ rain). This affects thermal comfort and visual comfort. Acoustics also falls under this category.
2. Non- load bearing (Structure related). The curtain wall systems transfer load not to each other linearly, but rather horizontally, to structural members such as floor, beams and columns.
3. Practical matters: this includes parameters such as producability of profiles, maintenance of system and price- both of system and of installing the system. Safety of the system also needs consideration. Legilations also fall into this category.
4. Architectural value: this has to do with parameters that matter to the designer. Appearance, finish and proportion fall into this category.
5. Sustainability: for designer to start thinking in terms of sustainability right from the start, it is important to consider the product that has minimal environmental impact- in terms of production process to transport of material to its use phase and its contribution to reducing energy demands. the next sub-chapter scope of window in sustainability describes this further by analysing LEED, EPC and BREEAM-NL standards conclude from the previous chapter.

3.6.1. DEFENCE AGAINST WEATHER : SUN

The Sunlight consists of 2 parts: Heat and Light. the incoming sunlight from the window , therefore affects the thermal comfort as well as the visual comfort. This is dependent on the transmittance, reflectance, absorption and emittance of the window glazing and frame.

Transmittance refers to the percentage of radiation that can pass through glazing. Transmittance can be defined for different types of light or energy, e.g., visible transmittance, UV transmittance, or total solar energy transmittance.

This Helps to define Visual light transmittance **(VLT) and Solar Heat Gain Coefficient (SHGC).** VLT is the factor that quantifies the amount of visible light that passes through glazing. It varies from 0.9 for very clear glass to less than 0.1 for highly tinted glass. (SHGC), is defined as that fraction of incident solar radiation that actually enters a building through the entire window assembly as heat gain. This is a factor that quantifies the total solar radiation (visible and solar infrared) that passes through glazing. SHGC refers to a part of the light spectrum that is invisible to the naked eye (infrared) while VLT refers to the vsible part of the light spectrum.

Using VLT and SHGC, one can determine LSG or Light to solar gain ratio, which helps to determine the coolness of light.

Just as some light reflects off of the surface of water, some light will always be reflected at every glass surface. A specular reflection from a smooth glass surface is a mirror-like reflection similar to the image of yourself you see reflected in a store window. The natural reflectivity of glass is dependent on the type of glazing material, the quality of the glass surface, the presence of coatings, and the angle of incidence of the light

Energy that is not transmitted through the glass or reflected off its surfaces is absorbed. Once glass has absorbed any radiant energy, the energy is transformed into heat, raising the glass temperature.

When solar energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface. This ability of a material to radiate energy is called its emissivity. Window glass, along with all other objects, typically emit, or radiate, heat in the form of long-wave far-infrared energy. The wavelength of the long-wave far-infrared energy varies with the temperature of the surface. This emission of radiant heat is one of the important heat transfer pathways for a window. Thus, reducing the window's emission of heat can greatly improve its insulating properties.

Insulation factor is given by u- value and is the common measure EPC, EN and ISO stadards for window.u-value measures how well a product prevents heat from escaping a home or building. U-factor ratings generally fall between 0.15 and 1.20. The lower the U-factor, the better a product is at keeping heat inside the building.

3.6.2. DEFENCE AGAINST WEATHER: RAIN & WIND

Other influences of weather are Rain and Air resulting in tight needs for water-tightness, condensation resistance and protection from air infiltration.

Watertight by rain:

This has no value because in the absence of proper water tightness, leakage is observed in the interior of the building. Furthermore, it is important to channelize the rainwater on the exterior surface. This ensures that the rainwater does not result in stains and deterioration of cladding materials.

Condensation Resistance

Condensation resistance measures how well a product resists the formation of condensation. Condensation resistance is expressed as a number between 1 and 100. The higher the number, the better a product is able to resist condensation

Air Leakage (Infiltration)

Whenever there is a pressure difference between the inside and outside (driven by wind or temperature difference), air will flow through cracks between window assembly components. Air Leakage measures how much outside air comes into a home or building through a product. Air leakage rates typically fall in a range between 0.1 and 0.3. The lower the air leakage, the better a product is at keeping air outThe air leakage properties of window systems contribute to the overall building air infiltration. Infiltration leads to increased heating or cooling loads when the outdoor air entering the building needs to be heated or cooled. Air leakage also contributes to summer cooling loads by raising the interior humidity level. Operable windows can be responsible for air leakage between sash and frame elements as well as at the window/wall joint. Tight sealing and weather-stripping of windows, sashes, and frames is of paramount importance in controlling air leakage.

The use of fixed windows helps to reduce air leakage because these windows are easier to seal and keep tight. Operable windows, which are also more susceptible to air leakage, are not necessary for ventilation in most commercial buildings but are desired by occupants for control. Operable window units with low air-leakage rates feature mechanical closures that positively clamp the window shut against the wind. For this reason, compression-seal windows such as awning, hopper, and casement designs are generally more effectively weatherstripped than are sliding-seal windows. Sliding windows rely on wiper-type weatherstripping, which is more subject to wear over time.

3.6.3. PRACTICAL MATTERS

Acoustics:

If the site is located near highway, a higher degree of sound insulation is required. The table lists below the noise tolerance levels. It is observed that 30db is excellent. However, it should not increase 60 db for a comfortable indoor environment. The measurement of sound is given in annex .. it should be noted that naturally ventilated systems can affect acoustics and calculated sound levels may not work

The Dutch regulation ISO 16283-3:2014 specifies procedures to determine the airborne sound insulation of facade elements (element methods) and whole facades (global methods) using sound pressure measurements. These procedures are intended for room volumes in the range from 10 m3 to 250 m3 in the frequency range from 50 Hz to 5000 Hz

Natural Ventillation

Natural ventilation directly drawn into the building though facade an help in reducing the cooling loads on the room. Furthermore, it helps in bringing in the fresh air. however, these, if not operated properly, can result in increased heating loads due to increased air-leakage.

To determine amount of natural ventilation, it is important to know following 3 things:

o Ventilation rate: the amount of outdoor air that is provided to the indoo space

o Airflow direction: the hot air rises up and cold ar is at the bottom. thus providing ventilation at both positions will ensure cooling of the space.

o Air- distribution or airflow pattern: the external air should ideally be made to flow through the room. this will ensure equal temperature through-out the room and also influence the uniform fresh air quality. cross ventilation is the most effective method.

Fire Resistance

This relates to the current regulations as given by the Dutch government in relation to materials and façade. The basic important values in a curtain wall façade that should be considered is: the spread of fire and release of smoke. These are the two main cause of casualties. However the following few guidelines must be followed:

1. That the separation function between fire cells is maintained.
2. That the spread of flame within the wall is limited.
3. The risk of spread of flame along the surface of the facade is limited.
4. The risk of injuries to persons resulting from materials falling from the facade is limited

The Dutch fire resistance test standards can be obtained from NEN-EN 1364-3. it is recommended to read this in conjunction with EN 1363-1,2 and is applicable to curtain walling with fire resistant glazing outside the spandrel area - fully fire resistant curtain walling

3.7. LEGISLATIONS IN THE NETHERLANDS RELATING TO WINDOWS

3.7.1. ISO

ISO (International Organization for Standardization) is an independent, non-governmental membership organization and the world's largest developer of voluntary International Standards.

ISO began in 1946 when delegates from 25 countries met at the Institute of Civil Engineers in London and decided to create a new international organization 'to facilitate the international coordination and unification of industrial standards'. ISo is operational as an organisation starting from February 1947. ISO has 162 member country as of today ad has published over 19.500 international standards. ISO employs over 150 people at its Central Secretariat in Geneva, Switzerland. Window manufacturers may refer to ISO 9000 (quality management) and ISO 14000 (environmental management).

3.7.2. NEN ISO

The Netherlands Standardization Institute (NEN) is a private, non-profit organization, founded in 1916 by the Netherlands Society for Industry and Trade, in cooperation with the Royal Institute of Engineers. The headquarters is in Delft and the organisation has about 300 employees. NEN is a member organisation of ISO. NEN functions as an intermediary between standardization and certification.

3.7.3. EPC

EPC or Energy Performance coefficient (Energie Prestatie Coëfficiënt in Dutch) is the minimum value that the building has to reach in terms of performance. Envelope influences a large part of the EPC like the Insulation, daylight and natural ventilation. Following EPBD, EPC's are widely accepted across Europe. However it should be noted that there are variations in EPC calculation methods depending on the country. For example, in Britain, the EPC are divided into 2 types: energy efficiency rating (running costs of building) and Environmental impact rating (CO2 Emissions) and are rated from 1-100, where 100 is the better score. The EPC in The Netherlands are rated from 0-1 and the goal is to reach as close to 0 as possible. However, in the purview of this thesis, only the Dutch EPC's are considered.

The calculations that lead to EPC in The Netherlands are registered in the Nederlandse Norm (NEN) 7120 they are included in the national "Bouwbesluit" (Building Resolution), which regulates all building activities in The Netherlands (www.nen.nl, cited on September 2015).The change in EPc over the years is noted as below (www.iea.org, Cited online on September 2015; www.milieucentraal.nl, Cited online on September 2015) :

Energy Performance Coefficient (EPC)
15 December 1995 > 1,4
1 January 1998 > 1,2
1 January 2000 > 1,0
1 January 2006 > 0,8
1 January 2011 > 0,6
1 January 2015 > 0,4
Per 2020 > (target) 0

0.4. For non-residential buildings the current EPC-requirement varies between 1.1 and 2.6, depending on the main function of the building.

NEN7120 also helps in providing Energy performance certificates. These rate the building from A+ to G, A rating for buildings with high Performance, and low energy consumption and G rating for buildings with poor performance and high energy consumption. In the Netherlands, it is mandatory for sold or rented existing dwellings to be EPC certified. The certificates are issued by certified Energy Prformance Advisors

3.8. SCOPE OF WINDOW IN SUSTAINABILITY

Window has potentials in terms of Reducing the heating / cooling loads. furtehr, choosing the Right material suited for the building purpose can help further. Window elements can influence also LEED and BREEAM Rating. The potential is discussed below:

LEED

If we look at LEED Version 4, Facade has a potential to influence about 13 criteria constituting to a part

Function of building	EPC requirement	
	2014	2015
Meeting function	2.0	1.1
Cell function	1.8	1.0
Healthcare function with bed zone	2.6	1.8
Healthcare function differently than with bed zone	1.0	0.8
Office Function	1.1	0.8
Logies Function in accommodation building	1.8	1.0
Education Function	1.3	0.7
Sports Function	1.8	0.9
Shop Function	2.6	1.7
Homes and Residential Buildings	0.6	0.4

Table 3.7.3.a : EPC requirements for different building typology (www.rvo.nl, cited on september, 2015)

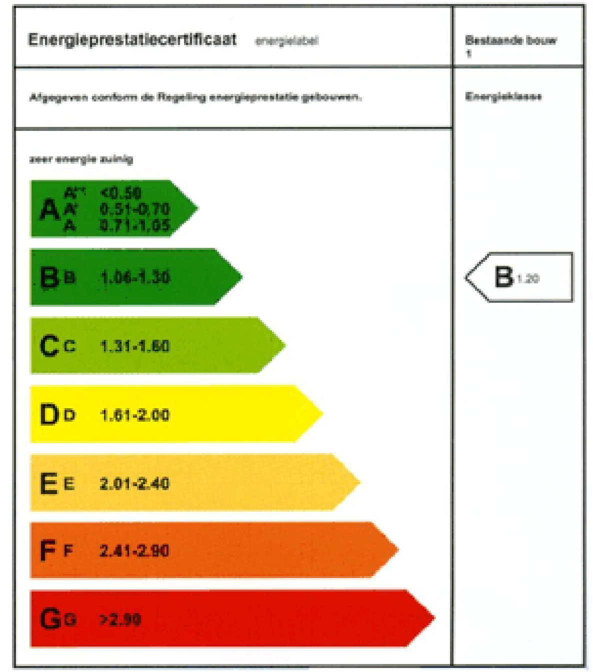


Figure 3.7.3.a : EPC Label example (image by bouwkundigadviesbureau)

		residential		non-residential	
		minimum	EPC	minimum	EPC
Heating	U-Value (Roof, Walls, Ground)	R_c =2,5 m^2K/W	x	R_c =2,5 m^2K/W	x
	U-Value (Windows, Doors)	4,2 W/m^2K	x	4,2 W/m^2K	x
	Air tightness	0,2 dm^3/s	x		x
	Passive solar gains		x		x
	System efficiencies		x		x
Cooling	Area of transparent elements		x		x
	Overheating (time, Δtemp)		x		x
	Solar Gains		x		x
	Shading of windows		x		x
	System efficiencies		x		x
Ventilation	Air change	0,9 dm^3/s per m^2 floor	x	function related	x
	IAQ requirements	Minimum requirements from the Building Decree	x	Minimum requirements from the Building Decree	x
	Heat recovery		x		x
Lighting	Installed power (W/m^2)		x		x
	Daylighting	m^2 of windows > 10% of floor area	x	m^2 of windows > 2,5 - 7 % of floor area Function related	x

In the column "EPC" the "X" mark means that this aspect is part of the calculation of the Energy Performance Coefficient (EPC).

Table 3.7.3.b : EPC requirements for different parameters relating to facade.
Data based on EPBD Buildings Platform > p131_en_Netherlands_june08, as indicated in report by van Ekerschot & Heinemans, (2008)

Figure 3.8.a : Parameters of Facade

of 25 credit points out of the 110 possible and 3 pre-requisites. These criteria can be divided into 3 parts for our reference as: Material based, Performance based and Social aspect. the criteria based on their division are as follows:

Material Based: Building life-cycle impact reduction, Building product disclosure and optimization - environmental product declarations, Building product disclosure and optimization - sourcing of raw materials, Building product disclosure and optimization - material ingredients

Performance Based: minimum energy performance ,Thermal comfort, Interior lighting, Daylight, Acoustic performance,

Social: Integrative Process, Minimum indoor air quality performance required, Quality views , Innovation

BREEAM- NL

BREEAM-NL Criteria are quiet subjective unlike LEED where it is a standard Rule to be followed and Simulations to be performed. however it also leave a large area free for innovative points, as every project is different. Even though a standard window is used, its use in strategic designing can help gain BREEAM-NL points. The categories for Window include Management, Health and comfort, Energy, Material. by using the Quick scan online tool available by BREEAM-NL, it is observed that window elements assist in a part of roughly 20% out of the total 100%. However, it is essential to also excell in all categories to attain the BREEAM star rating.

3.9. CONCLUSIONS:

Parameters for facade :

The Parameters that define a facade are based on many factors such as Thermal and vsual comfort, Legislations and sustainability value. they can be summarized in the figure 3.8.a. However, Since the research of the thesis is targeted on the design stage, what parameters are relevant at the design stage are still unclear. A round of Questionnaires needs to be circulated and conclusions can be made about what the designers think they need. this conclusion needs to be weighed against what is possible in BIM library, and if there is some part that the architects think unimportant, but may rather be useful at the design stage.

Parameters complimenting BREEAM and LEED Categories

From the LEED and BREEAM-NL Study in this chapter, It can be concluded that maerial property and Energy performance categories are important. from this, we can conclude that Material environmental data such as LCA and Environmental Product Declaration (EPD) can be of value. LCA is especially useful if only material is known, not the exact product. the number, type and material of window helps to also define performance of the windows, Although the importance of each criteria is further seen in case study of Orange hall. (annex- to be added)

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CHAPTER 4.

4. BACKGROUND OF BIM

4.1. INTRODUCTION TO BIM

The principal difference between BIM technology and conventional 3D CAD is that the latter describes a building by independent 3D views such as plans, sections and elevations. Editing one of these views requires that all other views must be checked and updated, an error-prone process that is one of the major causes of poor documentation. In addition, data in these 3D drawings are graphical entities only, such as lines, arcs and circles, in contrast to the intelligent contextual semantic of BIM models, where objects are defined in terms of building elements and systems such as spaces, walls, beams and columns.

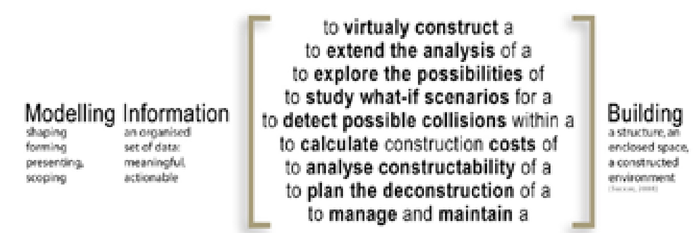


Figure 4.1.a : Some common connotations of multiple BIM Terms. Image Courtesy: Change agents AEC

Differences between the definitions:

Some researchers have opted to differentiate between the many available terms (Lee et. al., 2005) but the extensively overlapping boundaries render the uniqueness of each term questionable. From conceptual to descriptive in nature, these terms can be associated to design process or technology in terms of research or industry bodies or both. Some of the more widely used terms in both research and industry literature are described in able 5.1.a, while Figure 4.1.a presents some common connotations of the BIM term.

Boundaries of BIM:

The boundaries of Building Information Modelling as a term-definition, set of technologies and group of processes is fast changing even before being widely adopted by the industry. As a term, BIM seems to have somehow stabilised now but as a set of technologies/ processes, its boundaries are rapidly expanding (Succar, B., 2008). The topic of BIM, therefore, is divided into 2 categories: BIM in relation to technology and BIM in relation to Management.

This chapter, we will overview BIM and a part of its technological applications, while the chapter 5.7 (Role of BIM in design Process) describes BIM in relation to management.

Sample terms	Organisation or Researcher
Asset Lifecycle Information System	Fully Integrated & Automated Technology
Building Information Modelling	Autodesk, Bentley Systems and others
Building Product Models	Charles Eastman
BuildingSMART™	International Alliance for Interoperability
Integrated Design Systems	International Council for Research and Innovation in Building and Construction (CIB)
Integrated Project Delivery	American Institute of Architects
nD Modelling	University of Salford – School of the Built Environment
Virtual Building™	Graphisoft
Virtual Design and Construction & 4D Product Models	Stanford University– Centre for Integrated Facility Engineering

Other terms: Integrated Model, Object Oriented Building Model, Single Building Model etc.

Table 5.1.a : Widely used terms relating to BIM. Adapted from Succar (2008)

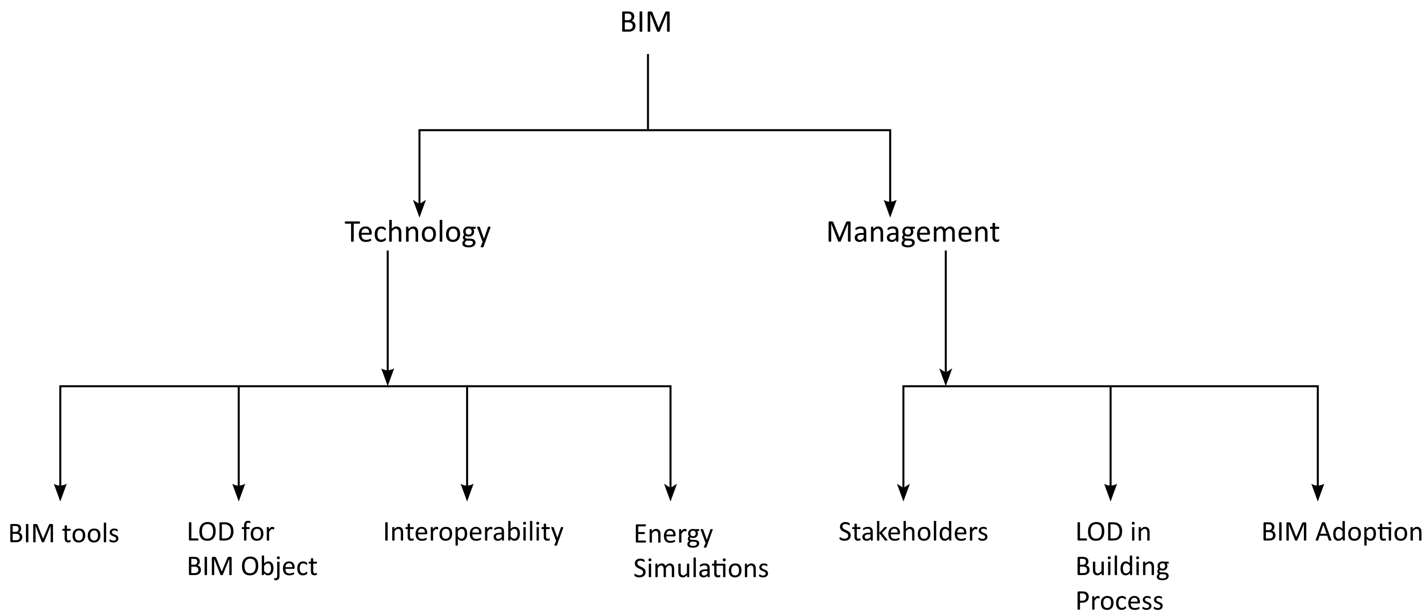


Figure : 4.1.b: Tree diagram of BIM and its scope in the thesis. (illustrations by: Self)

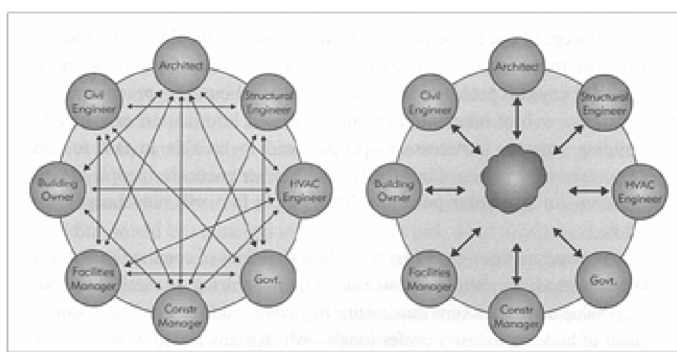


Figure : 4.1.c: Traditional Method (left) versus BIM Method (Right)

4.2. BIM FOR FACADE

Although this thesis is focused on window elements n facade, it should be noted that it is still dependent on the use of BIM for the entire building. BIM assists in optimisation process. In design, manufacturing, and installation, the architect's tireless artistic pursuit and the continuing emergence of urban complexes and super high-rise buildings give facade design technology plenty of space to play its role, and the advent of BIM brings good opportunities for the development of facade design engineering. (Dassault Systems, White Paper 2015) Since it is parametric, it I possible to use BIM and change the elements and see its effect in simulations. This is essential at the design stage, where the effect of light can be seen on the interior of the building elements. Rainfall and Wind-direction are essential to understand ventilation as well as condensation. BIM therefore, should be used with accurate weather data to understand the placement of the geometries.

BIM is especially useful in the complex geometries of the facade. Since it is 3d, and has the ability to attach phase-wise information, it can be used to communicate with manufacturers and foresee the structural implications. However, it is also prone to errors in exchange of data between softwares used by different consultants. Also this necessitates that the consultants use BIM compliant software. The problems with interoperability between different softwares are coverd in the next sub-chapter.

4.3. INTEROPERABILITY

No single computer application can support all of the tasks associated with building design and production. Interoperability depicts the need to pass data between applications, allowing multiple types of experts and applications to contribute to the work at hand. (Redmond, West, 2012) Interoperability has traditionally relied on file -based exchange formats, such as DXF (Drawing eXchange Format) and IGES that exchange only geometry.

Interoperability eliminates the need to replicate data input that has already been generated, and facilitates smooth workflows and automation. In the same way that architecture and construction are collaborative activities, so too are the tools that support them. (Eastman,C.)

Data exchanges between two applications are typically carried out in one of the four main ways listed below:

1. Direct, proprietary links between specific BIM tools
2. Proprietary file exchange formats, primarily dealing with geometry
3. Public product data model exchange formats
4. Extensible Markup Language (XML) - based exchange formats

The common exchange format between BIM applications is IFC (Industry Foundation Classes) For energy related simulations, Xml is used., . However it should be noted that some designing softwares do not provide the options of exporting to IFC files or xml files. These softwares are used mainly for the exchange of geometric data. The data format for exchange should be checked for interoperability before developing the detail levels in information while using the model for BIM.

4.4. BIM TOOLS FOR STAKEHOLDERS

Each BIM building design platform is introduced in terms of its heritage, corporate organization, the family of products it is a part of, whether it uses a single file or multiple files per project, support for concurrent usage, interfaces supported, extent

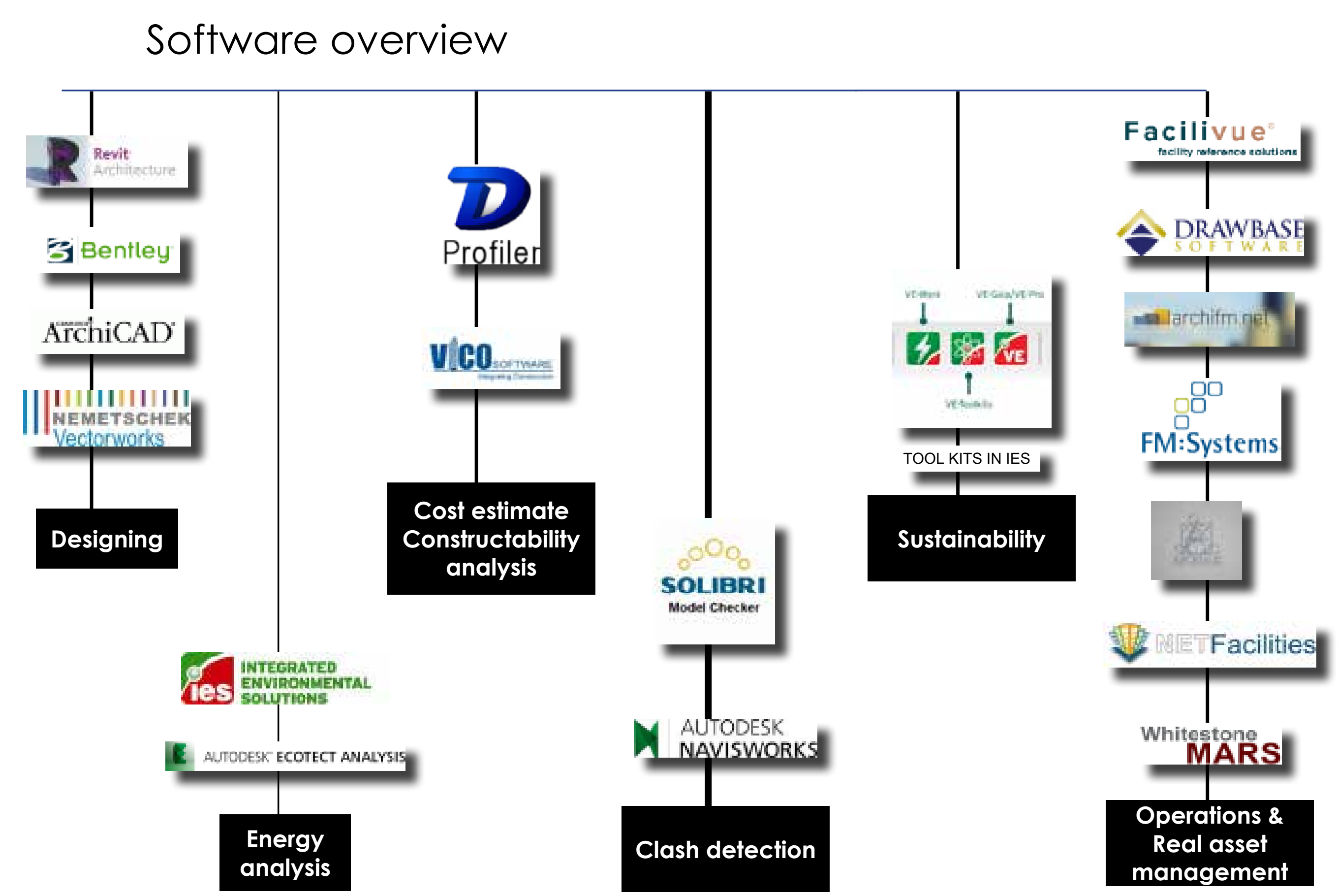


Figure 4.4.a: Overview of different softwares available for different consultants. BAsed on text from Smith, Tardiff (2009) and Eastman et al (2008). (illustration by self)

of the object library, general price class, building classification system supported, scalability, ease of drawing generation, support for 2D drawn sections, types of objects and derived attributes, and ease of use. There are plenty of software packages available today that support BIM Modeling environment. In this chapter few are listed, but many more software companies are taking lead. Also, many software companies are developing their existing products that can be collaborated with other softwares. These are available in the form of upgrades of existing softwares and/or plug-in as a different downloadable package. Figure gives an overview for different softwares that are available for different consultants, depending on the task to be performed, as certain software packages assist some tasks better than the others. for example, Ecotect assists Energy Analysis better than providing Accurate Phasing or cost analysis.

4.5. LOD FOR BIM OBJECT

Like definitions of BIM, there are many solutions given to define LOD. LOD is commonly taken as Level of Detail or Level of Development. For the Clarification of terms, this thesis refers LOD to Level of Development as Detail has a connotation implying only geometric information, whereas Development gives a sense of Geometric and non-geometric definition which is parallel to BIM definition.

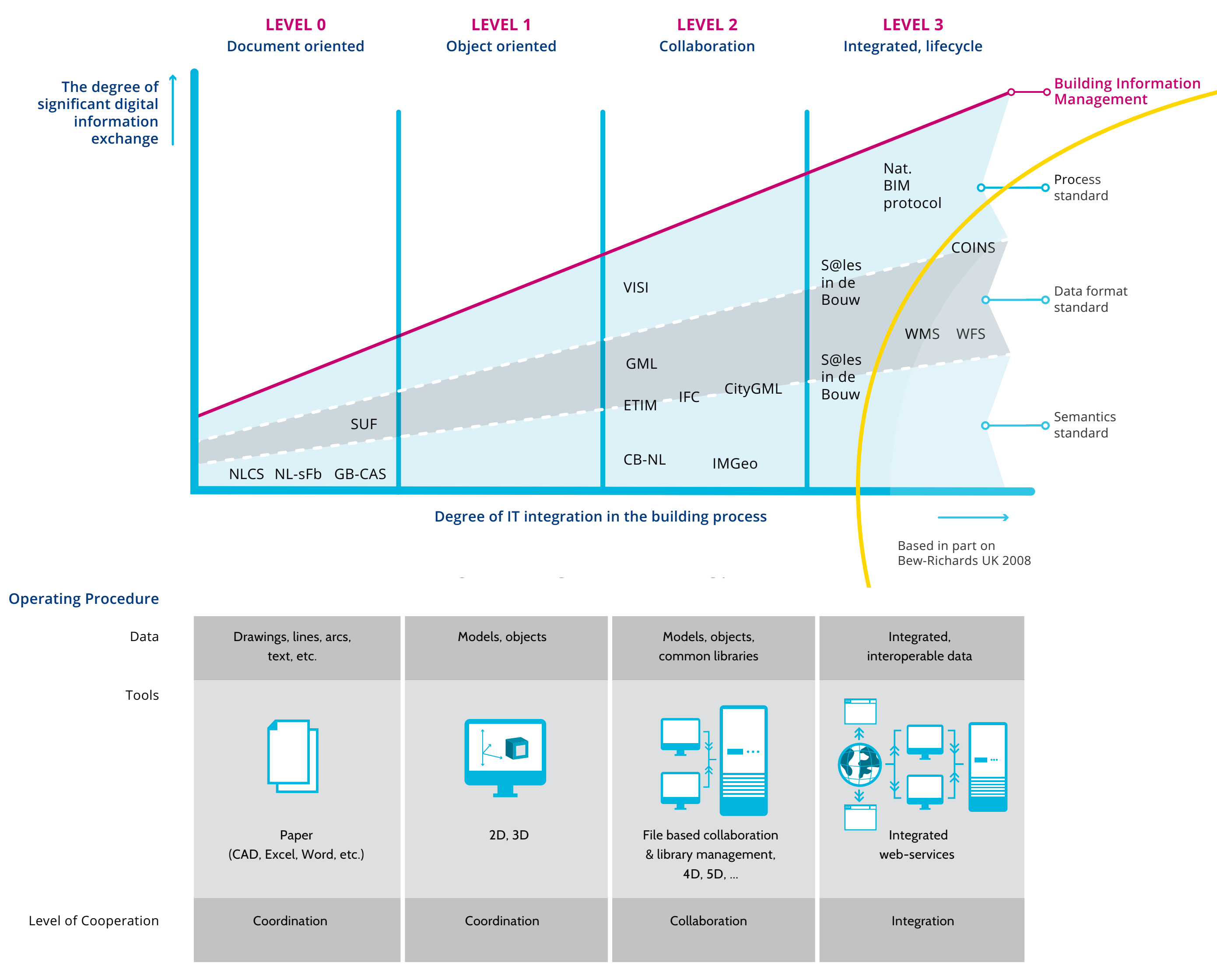


Figure: 4.5.b: Dutch BIM Levels Given by BIR. (illustrations as draw on BIR Leaflet)

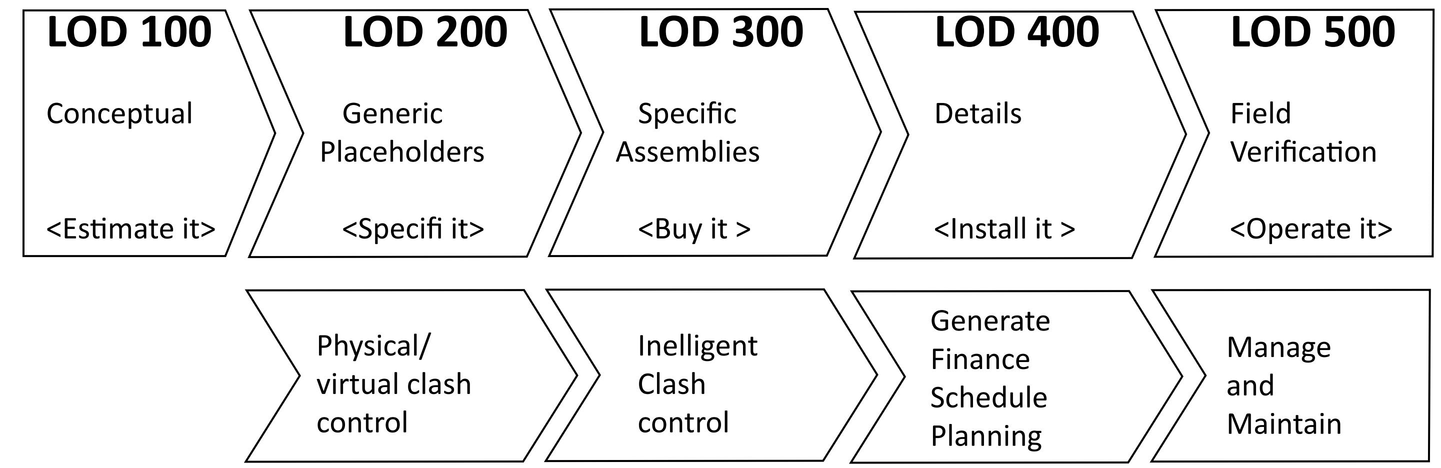


Figure4.5.c : LOD Levels basic overview. adapted from Thermatech Issue 28, (April 2013) and Bedrick, J., & Vandezande, J., BIMForum: cited online on 2015 September

LOD in Netherlands:

According to the Dutch buildng Information Council (Bouw Informatie Raad) or BIR(online: cited on September 2015), the Dutch BIM levels can be defined in 4 levels:

Level 0 or Pre-BIM, 2d document oriented coordination level

Level 1 or Object oriented Coordinaion level

Level 2 or Collaboration level and finally

Level 3 or Integrated lifecycle. These Levels reflect the BIM maturity of the project, and although they do not make use of the term LOD, the Level of BIM maturity is comparable to Level of Development.

Level 1 Object oriented

This is the first step towards implementing BIM: working with 2D or 3D objects in a virtual environment with associated non-geometric description. At this level, there is o question of integration, thus the 3d model does not have to link to simulation or financial planning softwares

Level 2 Collaboration: BIM little

At this level it is possible to share the object models built in level one as they have enough information for data exchange. Schemes like planning (4D) and cost calculations (5D) are to be linked to the model. At this stage, the consultants work together on a collection of autonomous databases, meaning each has their own databases. Planning (4D) and Cost calcuations (5D) are also possible. The parties sharing information are often within a controllable or manageable organizational unit.

Level 3 Integrated, lifecycle: Big BIM. This is the level where BIM information between different (un) known parties - not only within a single organizational unit - is shared through interoperable, open BIM standards. This can, for example, integrated in a web service environment. The construction process is fully integrated into the chain. At the end of level 3 information is shared across the lifecycle in the integrated environment.

However, Ministry of Interior and Kingdom Relations (Rijksbouwendienst) has in its BIM Norm version 1.0.1 (Rgd BIM Standard, July, 2012) has identified BIM LOD levels to be in accordance to the AIA E202 - 2008 Protocol Exhibit. The LOD Definitions Can be found below. Whereas Table 4.5.a Describes the scope of different LOD for model content as well as its authorized use.

AIA Definition

Fundamental LOD Definitions (AIA E202 - 2008)

The descriptions of the LOD Definitions are given below:

Level of Detail ->	100	200	300	400	500
Model Content					
Design & Coordination (function / form / behavior)	Non-geometric data or line work, areas, volumes zones, etc.	Generic elements shown in three dimensions - maximum size - purpose	Specific elements Confirmed 3D Object Geometry - dimensions - capacities - connections	Shop drawing/ fabrication - purchase - manufacture - install - specified	As-built - actual
Authorized uses					
4D Scheduling	total project construction duration phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.)	
Cost Estimating	Conceptual cost allowance Example $/sf of floor area, $/hospital bed, $/parking stall, etc. assumptions on future content	Estimated cost based on measurement of generic element. E.g., generic interior wall.	Estimated cost based on measurement of specific assembly. E.g., specific wall type.	Committed purchase price of specific assembly at Buyout.	Record costs
Program Compliance	Gross departmental areas	Specific room requirements	FF&E, casework, utility connections		
Sustainable Materials	LEED strategies	Approximate quantities of materials by LEED categories	Precise quantities of materials with percentages of recycled/locally purchased materials	Specific manufacturer selections	Purchase documentation
Environmental: Lighting, Energy use, air movement Analysis/Simulation	Strategy and performance criteria based on volumes and areas	Conceptual design based on geometry and assumed system types	Approximate simulation based on specific building assemblies and engineered systems	Precise simulation based on specific manufacturer and detailed system components	Commissioning and recording of measured performance

Table 4.5.a : Level of Detail Definition Adapted from Jim Bedrick, 2008

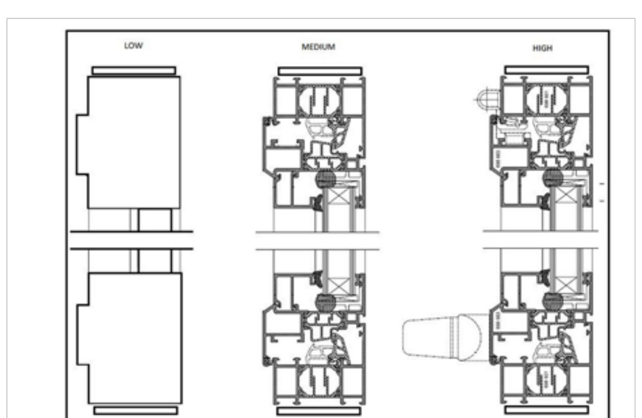


Figure 4.5.d : Geometric Level of Detail example for a Til-Turn Window

- LOD 100: 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.

- LOD 200: 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.

- LOD 300: 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.

- LOD 350: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.

- LOD 400: 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.

- LOD 500 : 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

4.6. ROLE OF BIM IN SUSTAINABILITY

The Current tools in BIM to assist in Embodied energy or LCA calculations are stll limited. It is possible to export material schedule and import to SIMApro and work around it however, this process is still very time consuming and complex to understand and less motivational to use within the professional world. The automation of calculating the embodied energy within the BIM environment still needs development. In the current situation, BIM assists sustainability by way of accessing building performance analysis in virtual simulated environment. This is also commonly termed as BEM or Building Energy Modeling, which is adapted from BIM.

The term building performance analyses (or sustainability analyses), refers to various assessments and evaluations (e.g. building orientation, day lighting analysis, building massing, energy analysis, etc) and is typically conducted to determine a building's environmental performance.

Krygiel and Nies (2008) indicated that BIM can aid in the following aspects of sustainable design.

- Building orientation (to select the best building orientation that results in minimum energy costs)
- Building massing (to analyze building form and optimize the building envelope)
- Day lighting analysis
- Energy modeling (to reduce energy needs and analyze renewable energy options such as solar energy)
- Water harvesting (to reduce water needs in a building)
- Sustainable materials (to reduce material needs and to use recycled materials)

The combination of sustainable design strategies and BIM technology has the potential to change the traditional design practices and produce a high-performance facility design. One such effort in the Columbia campus of the University of South Carolina resulted in approximately $900,000 savings over the next ten years at current energy costs (Gleeson, 2008)

In addition to software analysis, LEED and BREEAM-NL need drawings that require certification. Although these drawings can also be produced by conventional 2-d Cad BIM software produces these drawings more efficiently as part of the building information model and have the added advantage of parametric change technology, which coordinates changes and maintains consistency at all times. Thus, user does not have to intervene to update drawings or links. In simple words, the 2d drawings are updated with the 3d editing of the model. This helps also in getting accurate drawings for Approvals as per Dutch

Legislations.

In a case study by Azhar, Brown & Sattineni (2010), energy simulations were performed for feasibility of BIM through a case study of DPR Construction Inc. headquarters building which is a 52,300 ft2 LEED(R) Gold certified facility located in Sacramento, California, USA.

It was found that the results from the energy analysis clearly indicate that their building is performing within 10 percent of the actual energy usage. This means that the results confirm that the building is performing in accord with the original design intent as well as the simulations. It was therefore concluded that their current BIM-based building performance analyses methods are, in fact, close to accurate and effective

Thus currently, it can be concluded that BIM can be used in operational energy analysis. The embodied energy comparison in BIM still needs software development. The analysis in the simulation can be used to compare results. Comparisons may be done at different levels. Cole (1999) points out four types of "comparison":

- comparing a specific performance criterion relative to a declared benchmark
- comparing performance scores of one criterion with the others within the same building
- comparing a specific performance criterion with the same criterion in another building
- comparing the overall performance profile

For this thesis, we will focus on comparing a comparing a specific performance criterion (performance of window elements) relative to a declared benchmark (Minimum EPC Standards).

Problems with the tools:

However, it should be noted that, the field of building environmental assessment tool is vast. This means that not one single tool is developed such that it can be used for any kind of assessing and for all building types. Another issue is the algorithm used in calculation of the fuel usage for the operation of the building. In a study shown by Stadel et al (2011) Green Building Studio was compared with IES-VE using the same building and simulation conditions. Estimates from the GBS tool are 36% greater than the IESVE results. The difficulty with relating each tool's estimate is ensuring

That they account for the same building components (i.e., they provide an apples-to-apples comparison). This is because the tools' output estimates aggregate the emissions and do not necessarily translate the precise sources of emissions or energy (e.g., electrical, thermal).

Thus to make comparisons between Facade elements, the same software should be used. Hence, this way, the simulation conditions are the same, and so are the algorithm and the source of energy for heating/ cooling.

Stadel, A., Eboli, J., Ryberg, A, Mitchell J., Spatari, S., (April, 2011), Intelligent Sustainable Design: Integration of Carbon Accounting and Building Information Modeling

4.7. CONCLUSIONS:

4.7.1. LOD CRITERIA FOR LIBRARY:

The BIM levels defined by BIR are insufficient for defining an LOD level for object for the BIM library. The library is oriented towards 3d objects that has file exchange possible so Level 3 would be desired. however, this level defines also exact details for cost and scheduling, which is relatively of less importance during the conceptual design stage. hence, the Library would have to be defined between level 2 and 3, which brings ambiguity in defining the BIM object LOD Level.

The AIA Definition for BIM Object has a wider scope and more specific definitions for each LOD stage for BIM object. the Rgd BIM Norm version 1.0.1(July, 2012) in section 2.2.6.1, defines LOD 300 as a minimum standard for governmental projects for both 'As designed' (definitief ontwerp/bestek) and 'As built, as maintained' (revisiemodel). As Designed model is the model tender/ construction begins while AS built/ maintained model is for the operations phase. The question, therefore, remains, what would be a good LOD level for the conceptual design phase, where flexibility is desired, yet preliminary analysis and interoperability is possible?

To analyse this, we can divide the requirement into: Geometric information and non- geometric information:

Geometric information:

A TNO research conducted by van Berlo et. al. (2014) reviewed 9 Dutch SME companies during an R&D project to focused on the levels needed in the Dutch AEC industry. There are 2 conclusions that are important for this thesis: Level 250 and 350 needs to be added and that the level of detail of the geometry of a model was not important at all.

This is also true for windows. the exact geometry of the profile is not important while conceptualising. This is confirmed by drawings shared by INBO, A Dutch architecture firm and can be viewed in Appendix. The drawings clearly indicate that during the design stage, he geometric details of the windows are not used. thus, thi information for the profile, can be reduced to a four-planed close volume object. an approximate volume is required to place it with respect to the wall element.

Non- Geometric Information:

For simulations and interoperability, Location, Type of Window, approximate Quantity, Basic 3d Object geometry, estimated cost based on generic elements, Specific room requirements, and approximate simulation based on specific building assemblies and engineered systems. on referring to LOD definitions and referring to table 4.5.a, the requirements fall between LOD 200 and LOD 300. Thus ***LOD 250*** should be referred (also confirming to the van Berlo et al research) with the following requirements:

model content: Generic elements shown in 3-D, dimensions of window , Type of window, Maximum size

4D Scheduling Time-scaled, ordered appearance of major activities

Cost Estimating Estimated cost based on measurement of generic element. E.g., generic interior wall.

Program Compliance Specific room requirements, utility connections

Sustainable Materials Approximate quantities of materials for LCA calculations

Environmental: Lighting, Energy use, air movement Analysis/Simulation Approximate simulation based on specific building assemblies and engineered systems

4.7.2. INTEROPERABILITY CRITERIA FOR LIBRARY

Before starting a project, the consultants are advices to get togather and decide the fle exchange formats possible between BM applicatios. As each project is different and consultants usually change, the interoperability criteria between consultants need to be mutually decided. Table 4.7.2.a can be used as a reference of exchange formats and what it means to conver a file to that formate. It should be noted that files of the same format type should be echanged with each other. For example oftware that produce XML format files should no tbe changed into 3ds format. Since 3ds format is based on surface and shapes, it will dis-attach the non- geometric building data associated in the xml format.

Image (raster) formats	
JPG, GIF, TIF, BMP, PIC, PNG, RAW, TGA, RLE	Raster formats vary in terms of compactness, number of possible colors per pixel, some compress with some data loss.
2D Vector formats	
DXF, DWG, AI, CGM, EMF, IGS, WMF, DGN	Vector formats vary regarding compactness, line widths and pattern control, color, layering and types of curves supported.
3D Surface and Shape formats	
3DS, WRL, STL, IGS, SAT, DXF, DWG, OBJ, DGN, PDF(3D), XGL, DWF, U3D, IPT, PTS	3D surface and shape formats vary according to the types of surfaces and edges represented, whether they represent surfaces and/or solids, any material properties of the shape (color, image bitmap, texture map) or viewpoint information.
3D Object Exchange formats	
STP, EXP, CIS/2	Product data model formats represent geometry according to the 2D or 3D types represented. They also carry object properties and relations between objects.
Game formats	
RWQ, X, GOF, FACT	Game file formats vary according to the types of surfaces, whether they carry hierarchical structure, types of material properties, texture and bump map parameters, animation and skinning.
GIS formats	
SHP, SHX, DBF, DEM, NED	Geographical information system formats
XML formats	
AecXML, Obix, AEX, bcXML, AGCxml	XML schemas developed for the exchange of building data. They vary according to the information exchanged and the workflows supported.

Table 4.7.2.a: Interoperability Criteria

CHAPTER 5.

5. PROJECT DELIVERY METHODS

5.1. PROJECT DELIVERY METHODS

There are a number of models for the process of designing and constructing facilities. in the netherlands, the common methods used are 1. Design-bid-build (DBB) 2. Design-build (DB) 3. Engineer-procure-construct (EPC) 4. Design-CM contracts 5. Design-agency CM contracts. This chapter discusses the 2 widely used methods(Forbes, 2010) Design-Bid-Build and Design- Build: Another emerging project design method is IPD (Integrated Project Development) which has a similar process to BIM and hence is also included in the discussion and a comparative graph is shown at the end.

5.1.1. DESIGN-BID-BUILD (DBB)

Design-bid-build contracts represent the most frequently used type of project delivery systems for most construction projects, and are considered to be the "traditional" delivery method. DBB projects (Forbes et. al., 2010). The Process is shown in Figure 5.1.1a and the actors's involvement is repreented by figure 5.1.1b. Some important characterics are listed below:

The project is conceptualised by the owner, who hires architect. the architect develops the drawings and draws up the tender in association with the client. the tender of Request for Proposals (RFP) are issues and contractor is selected by architect and client. Bid analysis is carried out and a legally binding contract is then awarded. The drawings, specifications, and signed documents then become construction documents. (forbes et al., 2010)From this point, the contractor's role becomes more important for a timely construction delivery while architect's role is to overlook the project. The communication is directed through the architect to the owner. (Prieto, 2012)

5.1.2. DESIGN-BUILD (DB)

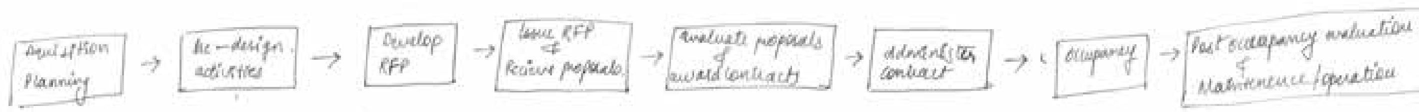
Design-build (DB) projects accelerate delivery through concurrent design and construction activities. As is typical of all types of projects, a DB project is conceptualized by the owner; planning is carried out based on the objectives to be met, and on the economic and technical feasibility of the project.. Planning and schematic design are carried out by the owner's design professional, while the design builder continues the preliminary design to obtain a final design. Typically, their design professional develops a preliminary design and cost and schedule proposals for the overall project. In some DB projects the owner may review proposals from a number of design builders before hiring them.

the important aspect of DB as against DBB is that the DB organization initiates construction while finalizing the detailed design and at intermediate checkpoints, verification is done by the parties to the project. The design culminates in the preparation of completed drawings and specifications that are used to complete the project. The owner or agents, such as architects/engineers or construction managers, monitor the progress of the construction, ensuring that approvals for interim payments match the progress of the construction work. the process is indicated by Figure 5.1.2.a while figure 5.1.2.b describes the role of actors.

5.1.3. INTEGRATED PROJECT DESIGN (IPD)

Integrated Project Delivery (IPD) is a project delivery method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction. (Building Green, 2008; AIA CC 2014)

The critical difference between IPD and DB is that in IPD, the design from concept stage is developed by all stakeholders, which gives them equal sense



Fg 5.1.1.a: Design - Bid- Build project delivery phases. Adapted from Forbes, 2010. (Illusration by self)

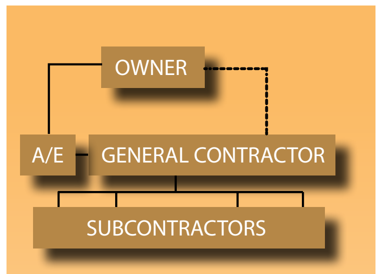
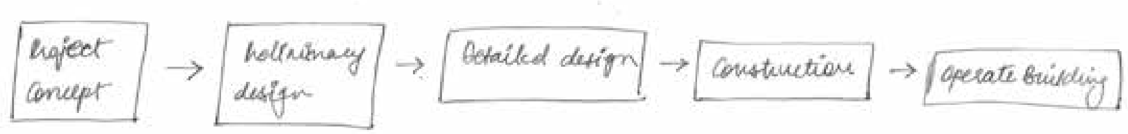
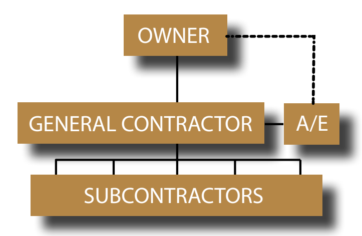


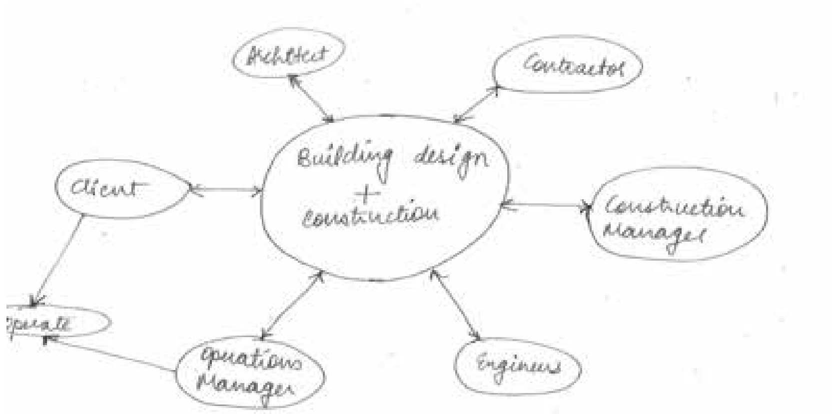
Figure 5.1.1.b: Indicating the role of actors in Design - bid-build project delivery method (illustration by www.findorf.com)



Fg 5.1.2.a: Design -Build project delivery phases. Based on text from (Cushman et al, 2001). (Illusration by self)

Figure 5.1.2.b: Indicating the role of actors in Design -build project delivery method (illustration by www.findorf.com)





Fg 5.1.3.a: Integrated Project Delivery method. Based on text from (Building Green, 2008; AIA CC 2014). (Illusration by self)

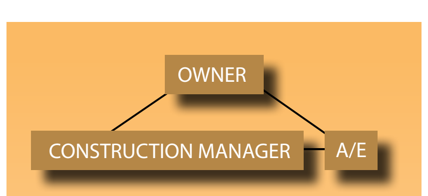


Figure 5.1.3.b: Indicating the role of actors in Integrated project delivery method (illustration by www.findorf.com)

of participation and involvement. With IPD, owners have greater participation during the Design and Construction phases and less risk for change orders related to design errors. Moreover, designers and builders are incentivized to collaborate to find innovative solutions, as their profits are tied to meeting the owner's goals. (Wilson, 2014)From figure 5.1.3.a, it can be seen that the process is similar to the process of BIM. this is further explained in chapter 5.5: role of BIM in facade design process.

The Integrated Project Delivery method contains, at a minimum, all of the following elements(lean construction institute, 2008; AIA CC 2014) :

- Continuous involvement of owner and key designers and builders from early design through project completion
- Business interests aligned through shared risk/reward, including financial gain at risk that is dependent upon project outcomes
- Joint project control by owner and key designers and builders
- A multi-party agreement or equal interlocking agreements
- Limited liability among owner and key designers and builders

Figure 5.1.3.b describes the role of actors in IPD.

5.1.4. CONCLUSIONS

A design process selected by the client has influence over the achievement of Sustainability goals and the implementation of BIM. as mentioned in chapter 5.1.3, IPD process has a strikingly similar working method as BIM. Therefore, in theory, to use BIM most efficiently, IPD would be the ideal process. However, the selection of design process is more complicated and depends on Size and type of project. A construction manager may be of more value and necessary involvement, depending on the size of the project. the possbilities of Sustainable design and BIM Project phases is discussed in detail in chapters 5.4 and 5.5 respectively.

two delft university researchers in 2013 studied the main project deliery methods that are used for renovation of social housing in Europe. They presented 5 case studies, 14 interviews of energy

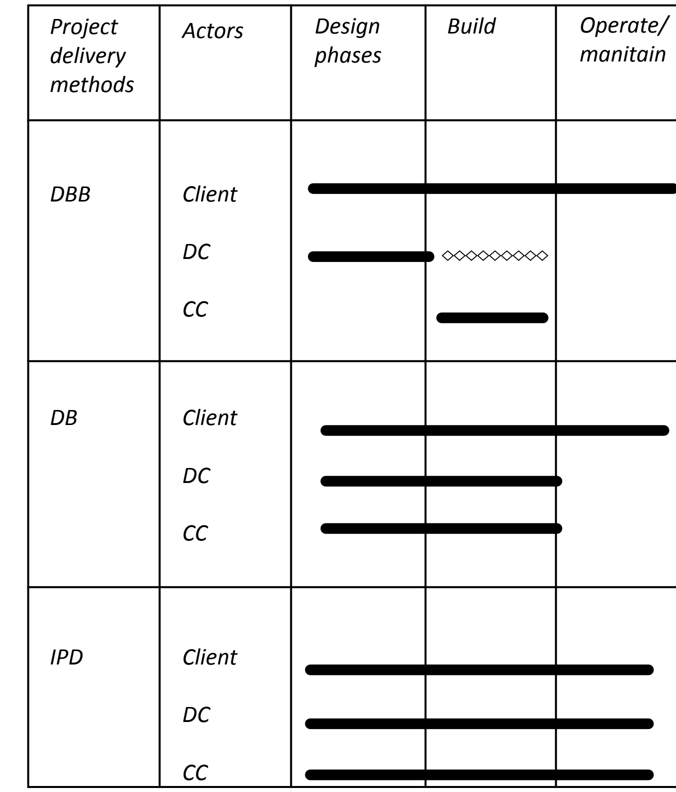


Figure 5.1.4.a: Adapted from (Salcedo Rahola et. al, 2013)

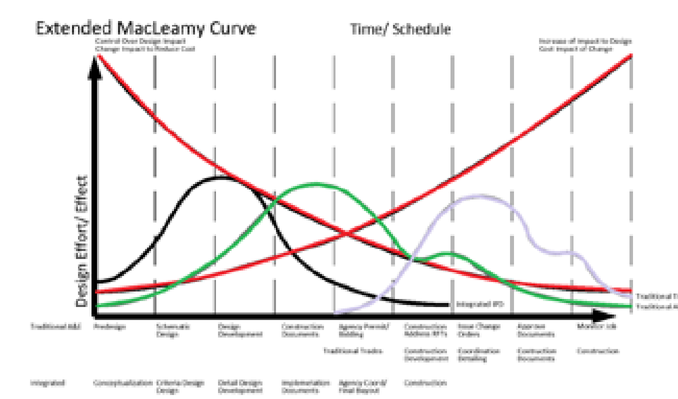


Figure 5.1.4.2 : Difference between traditional design proces and integrated design process in social housing sector. Adapted from Macleamy Curve. (MSA Integrated Project Delivery. Aug 2004).

renovators and 36 questionnaires with housing organisation and and concluded that Architects role is much more important in IPD, than in DB and least in DBB. However, it should be noted that this is not general representative date for all the EU countries, and the same could be true for all building types . Figure 5.1.4.a shows the representative data for DB, DBB and projected situation for IPD based building construction process

Comparision between DDB, DB and IPD:

The difference between the 3 processes is the control client has over the deign development. the more integrated the process, the more client is directl involve. Furthermore, the three processes have Influence on the project as the Project time and cost has a direct relation with the stakeholders involved and the design stage the building is at.

This is clearly indicated by Figure 5.1.4.2.a The Chart of Effort and effect against time line of building design and construction. The arced lines in red represent the impact of changes made in design and its influence on cost. The first red line starting from the upper left to the lower right shows the opportunity or positive impact to a project. (Changes made earlier in the project have the greatest opportunity to take design into consideration, with less effort and less cost at the beginning, with the opportunity decreasing over the lifespan of construction). The second red line starting from the upper right to the lower left shows the missed opportunity or negative impact to a project. (Changes made later in the project have the greatest negative impact with less design consideration and an increase in effort and cost towards the end of the construction lifespan). What this means, it's cheaper and better to make changes earlier, as they are worse and more expensive later.

Traditional A&E. The green line represents the amount of effort A&E teams put into a project over the lifespan of construction. Most of the time A&E's put into a project tends to fall between (design) and (permitting/bidding).

Traditional Trades. The purple line represents the amount of time and effort trades put into developing construction documents and/or models. As seen in the chart, most of the trade's effort tends to fall between being awarded a project (bidding), and (construction).

IPD. The black line represents how IPD can combine the A&E and the MEPF trades to shorten the build cycle time.

5.2. FACADE DESIGN PROCESS

An integral part of the construction and facade industries is the construction process needed for designing and constructing buildings and facades. A general sequence can be defined for both the construction process of buildings and facades (BNA, 2014; RIBA 2013; Klein, 2013). This chapter briefly describes every construction phase. It should be noted that the following chapters describe the construction chain in its traditional process and related to the DBB Process.

5.2.1. SYSTEM DESIGN PHASE

Before the building or facade projects starts the facade systems are designed project independent by facade system suppliers, such as Schüco and Alcoa. Systems suppliers design, develop and sell profile systems for different facade products with a range of shapes, colours and surface treatments. These ensure a large degree of freedom in the following design and construction process. In addition to system suppliers, some of the larger facade builders also developed their own facade systems, e.g. Scheldebouw and De Groot enVisser. Systems developed by facade builders can either be based on profile systems from system suppliers (e.g. All in one facade of De Groot enVisser) or on profile systems developed by individual facade builders (e.g. Thin Environmental Cladding of Permasteelisa).

5.2.2. PREPARATION AND BRIEFING PHASE

In this stage a project is strategically appraised and defined. The phase starts with a review of a number of alternative options, such as renting or buying and existing or new building. A feasibility study is then conducted and an alternative is chosen. During briefing the financial, legal, technical and urban planning aspects of the building are being developed. The combination of these aspects leads to a first definition of the functional requirements for the building and facades.

5.2.3. CONCEPT, DEVELOPED AND TECHNICAL DESIGN PHASE

During the architectural design the spatial,

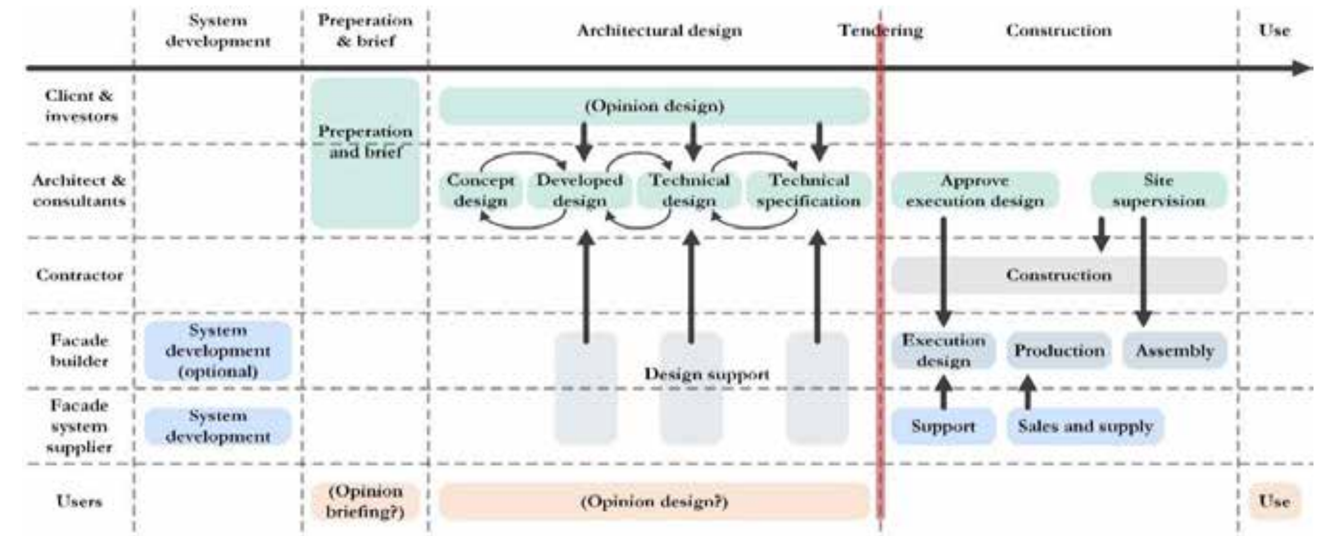


Figure 5.2.a : Different phases in the facade design and construction process with activities. (adapted from Klein, 2013, Illustration by Cleton, 2015)

functional, financial, technical and organisational plans are being developed. The phase first starts with a preliminary (concept) design and finally this design is further developed into a definite design. At the end of this phase the design will be detailed in such a way that the official intuitions can give their approval. Finally, all details of the building are specified and the tender documents are created. Depending on the regional procedures or the type of the tender, a specialised facade builder might or might not be involved in the architectural design.

5.2.4. CONSTRUCTION PHASE

In the construction phase the building will be constructed. Before the actual construction can begin the technical design has to be further developed into production and construction drawings. The construction system and logistical process will be further elaborated in budgets and planning. The main contracts will start gathering materials and equipment and start contracting subcontractors. When the preparations are finished the construction of the building starts. This phase is finally with the handover of the building to the client and conclusion the building contract.

5.2.5. EXECUTION DESIGN PHASE

In the execution design phase, the facade builder has to execute a number of internal design steps. First, the basic project design is developed based on the final documents of the architect from the previous design phases. In the beginning of the execution design certain decisions have to be made due to required delivery times of certain products. Next the design is elaborated and completed which has to be approved by the architect or other consultants which may take additional time. Finally, the production and assembly design starts which it very complex and time consuming which requires a lot of knowledge and experience. To a large extent, facades are standardized building products. This is largely because the performance of the facade has to be guaranteed, which can only be achieved by testing the facade system.

5.2.6. PRODUCTION PHASE

During the production phase the facade builder receives profiles and fitting from the system provider which are cut, milled and coated. At this point of the process the design is 'frozen' because changes at this point are virtually impossible and if done cause tremendous logistical effort and costs. Depending on the facilities of the facade builder the facade is manufactured and pre-assembled in the factory as much as possible. The quality is easier to monitor and the factory offers dry, clean and controllable working conditions.

5.2.7. ASSEMBLY PHASE

The final assembly phase is an important step in the overall construction process of buildings. After the facade has been installed all interior work can be executed independently of weather conditions. The complexity of the facade is that it is connected to all the other components of the building, such as the structure, roof, services and infill. All the parameters concerning the assembly of the facade have to be taken into account in the preceding phases.

5.2.8. USE PHASE

During the use phase the building will be used, maintained and operated. Although the changing needs of users will generally mean requirements will increase throughout time, the performance of buildings and facades will remain the same or will start to deteriorate due to aging and degradation of products. Although this deterioration will always occur, the start and rate of this deterioration are controllable. This means it is important to decide the desired performance of buildings and facades at the start of the use phase and which measures are to be taken during the use phase to return to a higher performance. These measures, e.g. maintenance, cleaning and replacement are considerable costs issues that must be taken into account in the preceding design phases. In addition, the respon¬sibilities in case of failure have to be clearly stated. Depending on the regional procedures or the type of the tender, a specialised facade company might or might not be involved during the use phase.

5.2.9. END OF LIFE PHASE

There will come a time the building will no longer be able to deliver the required performance making it necessary to make decisions regarding the future of the building. There are a number of possibilities ranging from a simple or significant renovation, changing its use or demolishing the building.

5.3. STAKEHOLDERS

Many stakeholders are involved in the construction process of both buildings and facades. As all of them often have their own agenda, conflicts will likely occur at some point. Because of this it is important to understand the different perspectives and their impact in the various phases

5.3.1. OWNER AND INVESTOR

The owner and investor of a construction project can be divided in private and public parties. Private parties normally focus on the financial aspects and the economic returns on a project, while public parties will also need to consider the interests of the public [1]. As mentioned before in the short to medium term, sustainable building will likely achieve a price premium when sold in the open market making them attractive to owners and investors. In the medium to long term conventional buildings will depreciate much faster and will depreciate much faster and will arguably have to accept reduction in price when sold in the open market making them unattractive and risky for owners and investors.

5.3.2. ARCHITECT AND CONSULTANTS

Specific consultants such as architects mainly contribute their professional knowledge to the project throughout the design, tendering and construction stages [1]. The architect is the one to integrate the input of the different stakeholders in order to design and develop the building as a whole. Although the architect has been a central figure in the construction process and has influence on most decisions, complexity of projects are continuously increasing and because he has to increasingly rely on the expertise of other consultants he is in danger of losing control of the process. Currently, architects are mostly generalists with limited knowledge and expertise of individual technical aspects, such as in the case of facades (Klein, 2013)

5.3.3. CONTRACTOR

Both the main and sub-contractors have to make sure that the construction project is completed within the time and cost, and according to the quality specified in the contract documents (Chinyio et al, 2010) . A contractor's main resource is his ability to organise and take on risk for his clients. His profit potential also lies in the difference between the agreed price and the actual construction costs. Because, in most cases, he will try to translate the given specifications into the lowest construction costs, this can lead to conflicts with the other stakeholders (Klein, 2013)

5.3.4. FACADE BUILDER

The facade builder translates the architectural design into facade design and construction and has to guarantee the performance of the facades as a whole. The complex nature of facades and the integra¬tion of numerous subcomponents require a considerable amount of design, planning and logistical effort. The facade builder tries to establish a relationship with the architect and general contractor, but although depending on the contracting strategy to a large decisions are made based on price. Generally the facade builder does not have the capacity for innovation, with the exception of a few large facade builder who tend to focus on project specific innovation instead of strategic and funda¬mental innovation (Klein, 2013)

5.3.5. FACADE SYSTEM SUPPLIER

The supplier needs to provide reliable material and equipment for carrying out the construction on site (Chinyio et al, 2010). A facade system supplier's main focus is towards the architect, who makes decisions regarding the application of his products, and the facade builder who actually buys his products and further processes and assembles it onto buildings. To a large extent, the facade systems are standardized building products. This is largely because the performance of the facade has to be guaranteed, which can only be achieved by testing the facade system. Facade systems are tested for wind, water and air tightness as well as sound and thermal insulation, blast and burglar resistance and structural integrity (Klein, 2013).

5.3.6. USERS

End-users of a construction project normally focus on the function of the building. The end-users of a building could include residents, tenants, operators, visitors and customers. End-users require¬ments and satisfaction are vital factors for the investment strategy of the owner or investor, because they put the project in effective use and provide the revenue streams that provide the return on investment of the project. Since each group of end-users have their own particular objectives for the building the construction stakeholders should take into consideration the need of every group of users, and when necessary incorporate their opinions in the building (Chinyio et al, 2010).

5.3.7. SOCIETY

Society has a vested interest in projects which are both privately or publicly owned. There are a number of groups working to protect the interest of society, e.g. government authorities, labour unions, trade associations, community groups and social activists. Their effort is mostly focussed on achieving sustainability in social, economic and environmental terms (Chinyio et al, 2010). Society also has a passive and perhaps rather unconscious role in the process of facade design and construction, but their interest are rather high due to the impact of facades on the environmental, social and cultural value of buildings.

5.3.8. CUSTOMERS

Customers can be divided into two main groups, consumers and organisa¬tions. Consumers purchase on the consumer market and buy products or services for their own use. Organisations can be further divided into the industrial market, reseller market and government market. First, the industrial market comprises of those companies that buy products or services to enable them to produce other goods and services. Second, the reseller market consists of companies that buy products and services to resell them to consumers. Third, the government market concerns government agencies that purchase products or services to enable them to carry out their activities (Jobber et al, 2009)

5.4. ROLE OF SUSTAINABILITY IN FACADE DESIGN

A secondary effect that can be considered is the energy flows- possibility of rainwater harvesting, air-purifier, natural ventilation, and climatic functions. Apart from these, possibility of energy generation- Building Integrated Photovoltaic (PV systems that form façade elements) can also be looked at. These need a careful look in the initial design stages. These also have structural implications, thus, making it difficult to implement in the later phases of the design.

Unlike BIM levels, there are no definitive rules on the sustainability process. However, there are ways to include sustainable goals for a building within the building design process.It is observed that there are two methods of including sustainability in the design process. The first one is when sustainability comes as an afterthought, after the design has been conceptualized. At this stage, it is difficult to make changes to the façade as is influences the interior spaces. The requirement for sustainable standards comes from client, who is the decision maker for the level of sustainable solutions. Client also appoints the sustainable engineer, sometimes on the advice of the architect.

However, sometimes the client is motivated from the beginning to have sustainable building, either to pursue EPC A+ rated building or to reach BREEAM-NL excellent standards. This makes it easier to incorporate the sustainable strategies from the beginning of the design process. This means that the structural implications can be foreseen as well as the reduction in the building services that can be influenced by a high performance façade and passive strategies. Thus, it is suggested to use this method to ensure a good engineered building that is optimized to provide good performance.

In the purview of this thesis, window element is concentrated within the façade element. While this is a small element, it does determine the amount of transparent element within the façade. Windows also influences the u-value as they provide openings, therefore a thermal break within the insulated exterior wall. While the wall can be super insulated, the window can be a thermal bridge between the exterior and the interior environment, thereby, affecting the net heating gains/losses to/from the interior space. To assure a perfectly insulated building, ideally there should be no windows. However, this is not possible as daylight and exterior are essential for psychological well-being. Thus, window is in fact a crucial element within the sustainable façade element.

5.5. ROLE OF BIM IN FACADE DESIGN PROCESS

BIM usually thought of using in the phase after contractor is selected who then selects the sub contractor who then selects the system suppliers. At this stage, the initial 3d model by architect from design phase is redrawn by the architect as per contractor's quote which is then redrawn by the façade builder as per specifications from façade builder and then (if required) by architect again, to suit minor design changes. This is further reflected in consequent consultants (climate/ structure/ lighting etc as per project requirement)

If BIM is already in use with library specifications and required tolerances, the architect can already use it at the design phase. This will help in a faster decision making of the real feel, whilst analysing the options available at the table with a larger, long term picture of sustainability. Furthermore, the need to completely discard the model for the further stage of design development is no necessary. This means that the architects can add more information to the existing model element in the construction and post construction stages, where more information is needed/ changed. this will result in saving time specially towards the final stages, as a completely new model is not necessary and the schedules and relevant data like product procurement, product life cycle and maintenance requirement is already generated by the model when it is complex enough.

The Figure 5.5.b helps us understand the scope of BIM in different Sages of Design-Bid-Buid based contract. By connecting the underlying character of the two stages (shown in triangular brackets < >) We can connect the LOD stages with the design process stage. The LOD 250 suggested in the previous chapter, thus fits well between the schematic design and tender docment production stage. After this stage, it is easy to replace the Library data with the manufacturer's BIM object satisfying the required Performance specifications thus, the post tender stage can be directly uppgraded to LOD 400/ 500, Depending on the constructor/ operator/ client request.

5.6. CONCLUSIONS

From the diagram of IPD and BIM definitions, it can be concluded that BIM is Ideal in the IPD design Process. however, BIM can also beused in DB or DBB process.

The need and goals for sustainability if set in the initial design stage would be ideal. This would give the consultants guidelines to work towards the goal from the begining stage. Using BIM simulations, the possibility of gaining High Performance facades can be evaluated during the design phase. At this stage, the optimisation of facade can be generally seen in terms of % of glazing as well as orientation of the

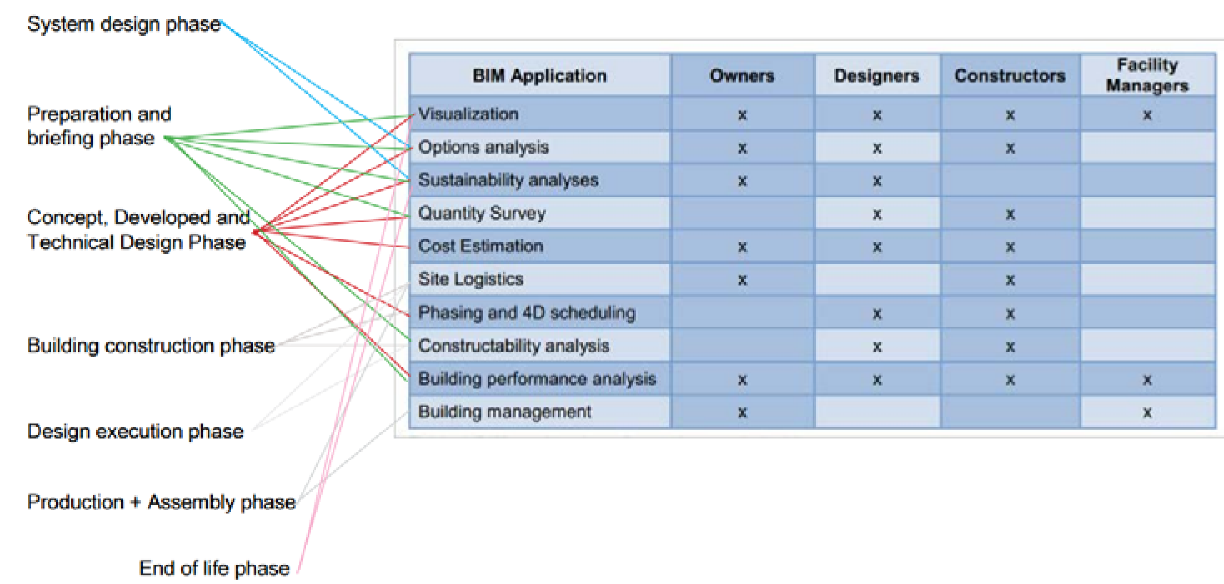


Figure 5.5.a: Figure indicating the inter- relation between Building Phase, BIM Application and actors. (Adapted from Azhar et. al, 2012).

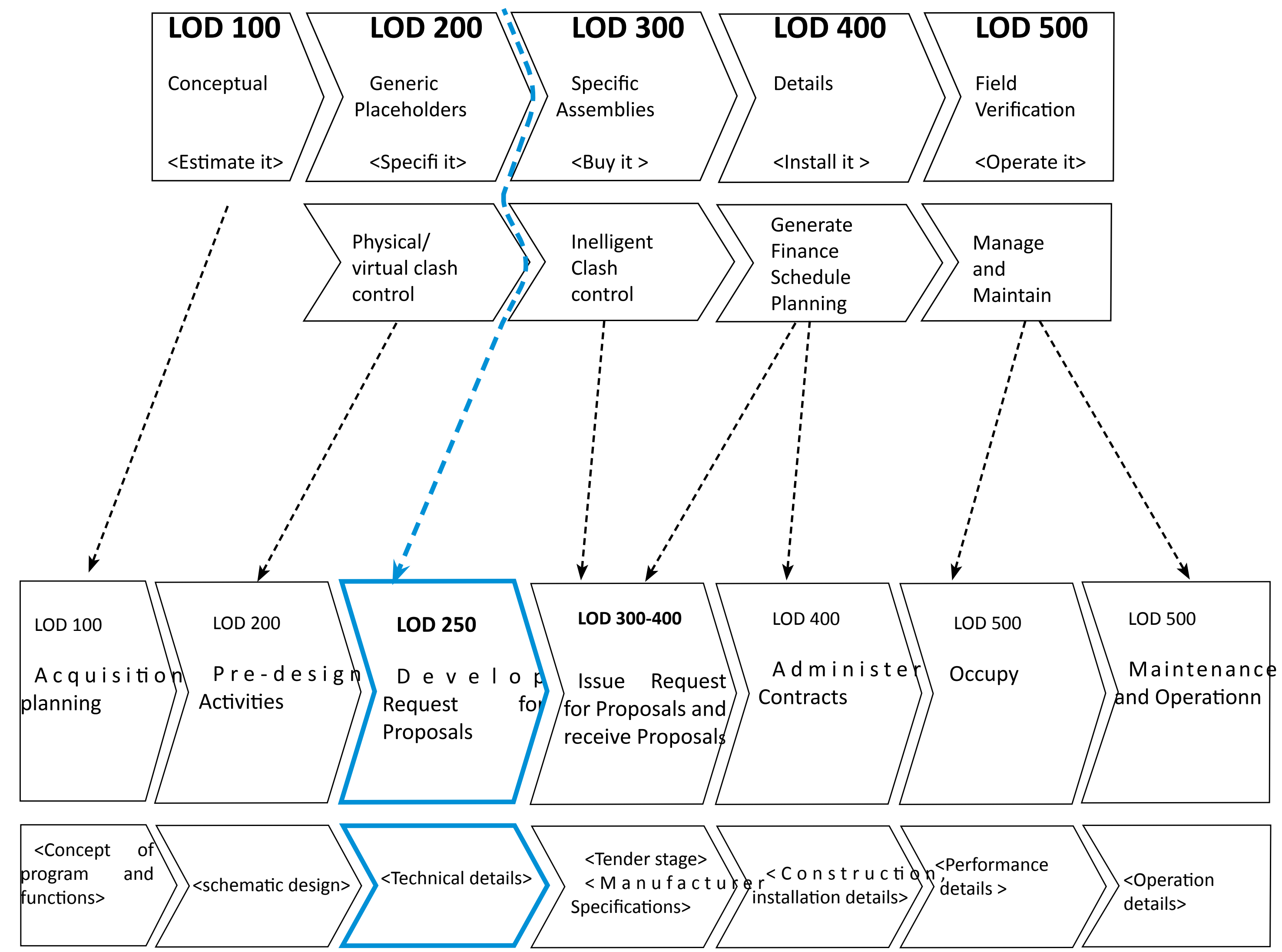


Figure 5.5.B: Figure indicating the relation between BIM levels and Design-Bid-Build building design process: specific to the Window element. The Blue line indicated the scope of the proposed BIM library

building. However, the role of library is to optimise the use of the materials according to the design. Thus, the Library can be intstrumental as it requires the designer to think in terms of performance of the facade.

However, BIM is too advance to be used in conceptual design. Many designers like Mensinga,P from Arup and Leon, S. from Inbo have suggested in ther interviews (ANNEX) that in the initial design phase, they prefer using 2d tools. When they are more clear about the basic design concept like initial idea of form, they move to 3D model in virtual model. Lack of knowledge of capability of mass mdels in BIM envronment pushes them away from using them. Thus, it is suggested that the BIM library at LOD 250 should be used at the end of schematic design phase and beginning of technical details phase when performance based details need to be specified.

Thus, after the conceptual model is developed, it is ideal to start using BIM and Library elements to check for energy calculations and LCA value. This will help in understanding not only the material and window type, but also the space requirements in terms of thermal and visual comfort.

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CHAPTER 6.

6. INTEGRATION OF FACADE + BIM + SUSTAIN-ABILITY

6.1. HYPOTHESIS: BIM LIBRARY FOR SUSTAINABLE FACADE DESIGN

As explained in the introduction, Seeing the difference in the BIM model provided by the manufacturers and the BIM models used by architects, a Library for facade cladding was suggested in one of the VMRG meetings.

Thus, after a backround understanding of topics, it was also important to study the existing Libraries available in BIM.

Most architecture firms refer to the 2d data from the catalouges and insert this data to their individual models. This results in a lot of waste of redrawing the elements by every firm. Thus, it is relevant to understand the 4 existing libraries: 2d Library(not BIM), Libraries from arhitecture companies(not open source), FAB window by Itannex and the fore-runner: BIM object.

6.2. EXISTING LIBRARIES

Apart from the inbuilt object library that some softwares such as Revit and Archicad provide, some Architecture firms like Arons en Gelauff prefer to also have their own object library (Figure 6.2.a). Some manufacturers such as Reynaers also provide an extensive library which is free to download via their website (see reference: Reynaers BIM model, Online, cited: august 2015).

Besides the individual manufacturers, there are 2 platforms in the Netherlands that provide a range of information available from the manufacturers that are BIM compliant and available for designers. they are listed below, along with the traditional 2d libraries that can be used as reference to build BIM model.

6.2.1. FAB WINDOW BY ITANNEX:

This is a object library compatible with Revit developed by Itannex, a software company in the Netherlands. The file containing objects is freely available on the internet with simple registration at Itannex website (Online: Itannex, cited 10 august, 2015). (http://www.itannex.com/item/fabwindow/). the File is available in Revit 2014, 2015 and 2016 format. This essentially means that the users of lower versions than Revit 2014 will not be able to work with the objects.

These objects work as Revit families which means, change to one object instance affects change in all the instances. however the information in a single file, which means, to have the object in the model, first the file has to be opened, unlike the built-in Revit families available in the toolbar.

Pros:

- All objects defined to the same level of detail
- All objects are editable
- Comes with a user manual
- Good for visual design, additional information can be inserted manually
- 2d details available

Cons:

- Editing the objects can result in unattaching the object to walls
- Limited data, cannot be used for energy analysis
- Only works with Revit 2014 and higher versions.
- Available 2d details are very basic.
- Needs to be updated via manual download.

Figure 6.2.a

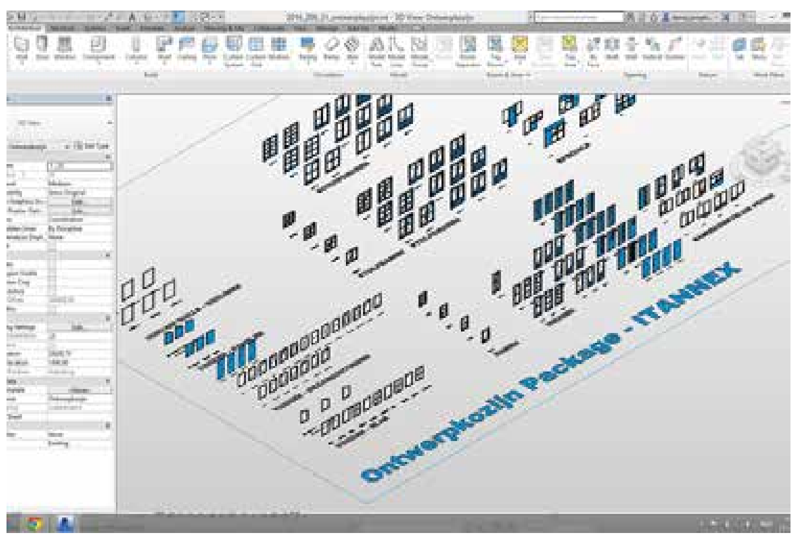


Figure 6.2.b

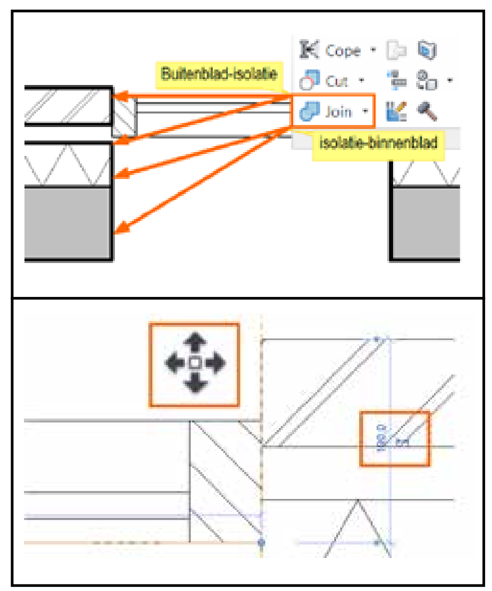


Figure 6.2.d

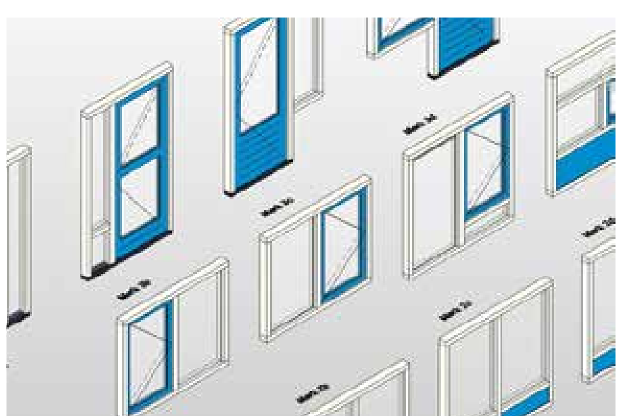


Figure 6.2.c

Anti-clockwise, from top:
Figure 6.2.a : In-house doors and Windows library by Arons en Gelauff Architecten (www.Arons en Gelauff Architecten.nl, online cited: 2015
Figure6.2.b/c, : Fab-window bim objects: as seen in revit Interface. (Screenshot illustration by self)
Figue 6.2.d: Details available in Revit interface (Illustration as represented in user manual that comes with the download, appendix).

- BIM software compliant, not fully BIM object as it lacks non-geomeric data.
- data available only for wood.

6.2.2. BIMOBJECT:

BIMobject is a Swedish company that operates via an online portal. BIM object is digital content management portal and facilitate development, hosting, maintenance, syndication and publication of the digital replicas of the manufactured products (www.BIMobjects.com cited : Aug 2015)

The Product Portal contains a range of products divided into 5 main categories like Brands, BIMobject categories , Materials, Building Types and Functional spaces.

They claim to be working in close coordination with the manufacturers and the discontinued items are not shown (www.BIMobjects.com cited : Aug 2015), which means that the information is regularly updated and hence more reliable than Itannex. This is managed by the BIMobject® Cloud portal. However, it should be noted that the change is reflected only on the website and not on the downloaded items.

Another drawback is that even though this is managed by a privately owned organisation, the input amount of information in the categories may not be complete in the selected BIM model. also they information from one object to another may not be comparable, as they show different categories for non-geometric information.

Pros:

- BIM objects from manufacturers- gives information from the manufacturers directly to the user without any 3rd parties.
- Information on the website is updated regularly and monitored by private party.
- The categories to compare the objects are present although may be incomplete
- (most) BIM objects are not dependent on a singular BIM software.

Cons:

- Editing the objects does not take into account
- Limited data, cannot be used for energy analysis
- Only works with Revit 2014 and higher versions.
- Available 2d details are very basic.
- Needs to be updated via manual download.
- BIM software compliant, not fully BIM object as it lacks non-geomeric data.
- data available only for wood.

6.2.3. 2D LIBRARIES:

In the traditional way of designing buildings, these libraries are only used in detail during the technical design phase. However, basic generic information such as span, profile material, glass type, window type and u-values may be considered in the initial phases. Obviously, it is out of scope of the architect to go through data from every manufacturer to make an initial decision for design and Hence, a sales representatives generally required to provide the initial information required for the design (Klien, 2013 Interview: Saxxon Appendix_).

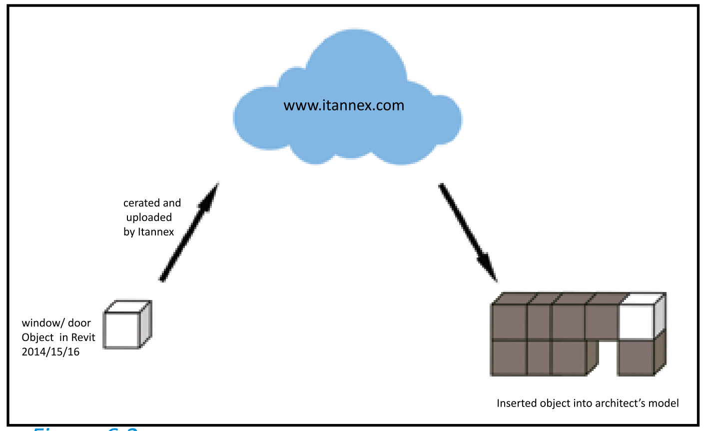


Figure 6.2.e

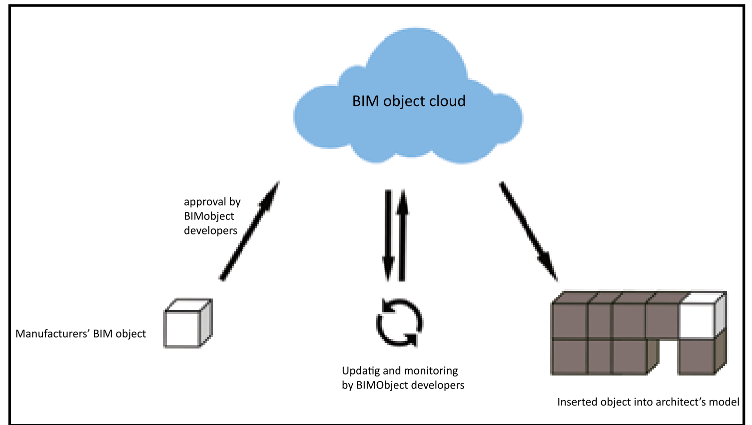


Figure 6.2.f

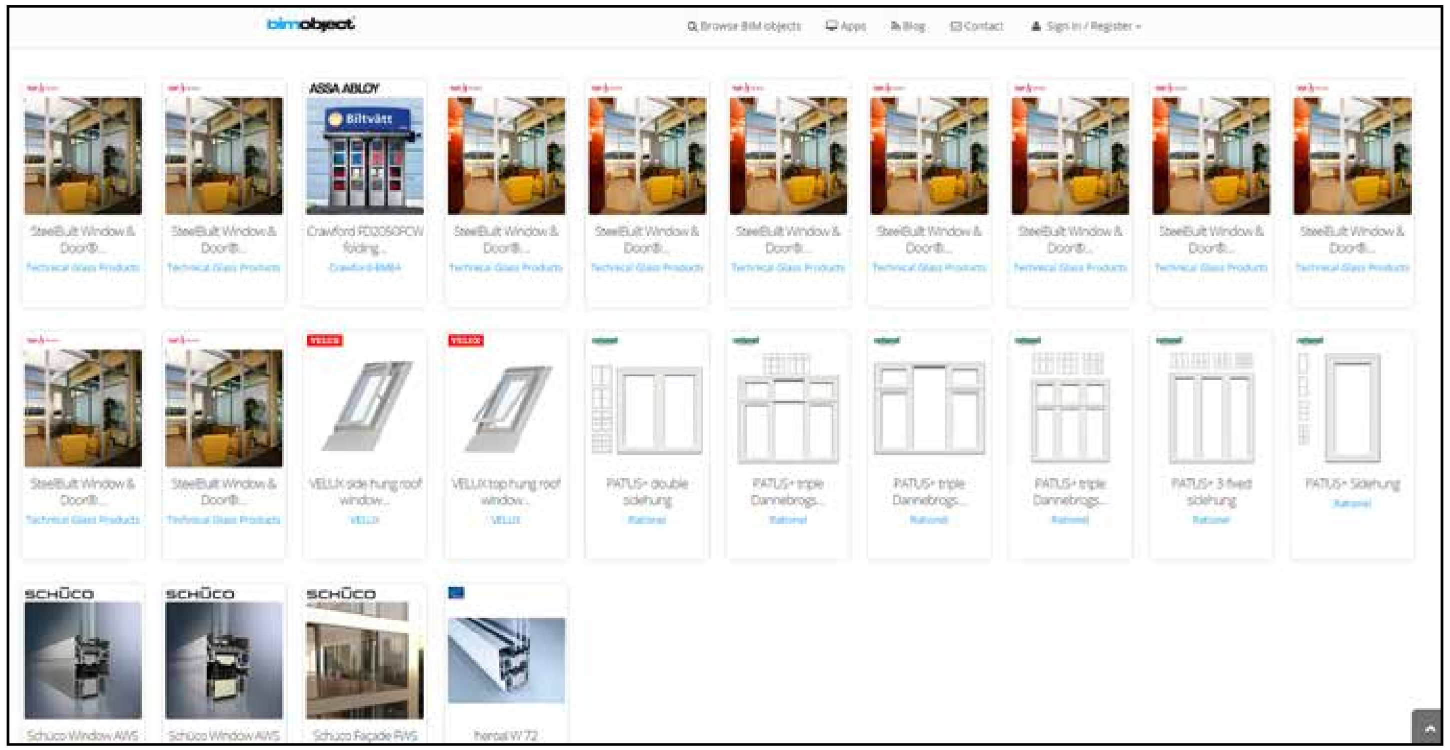


Figure 6.2.g

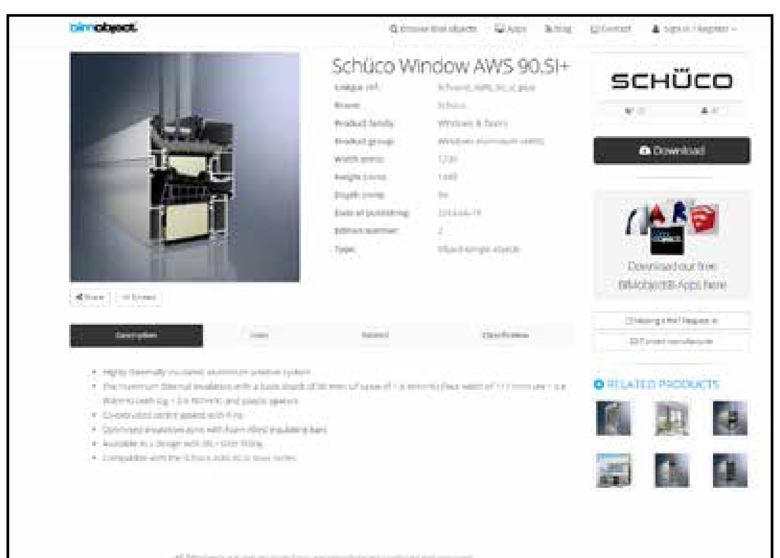


Figure 6.2.h

Top-bottom, Left- Right:
Figure 6.2.e/f : Schematic difference between working of Fab-window and BIM object (illustration by self)
Figure 6.2.g : BIMobject website screenshot: indicating objects available when searched for "Window". (Screenshot illustration by self)
Figure 6.2.h :

Oppoite page:
Figure 6.2.g: Example of Shuco window product with triple glazing, image indiating the tabs and categories available from manufacturers.

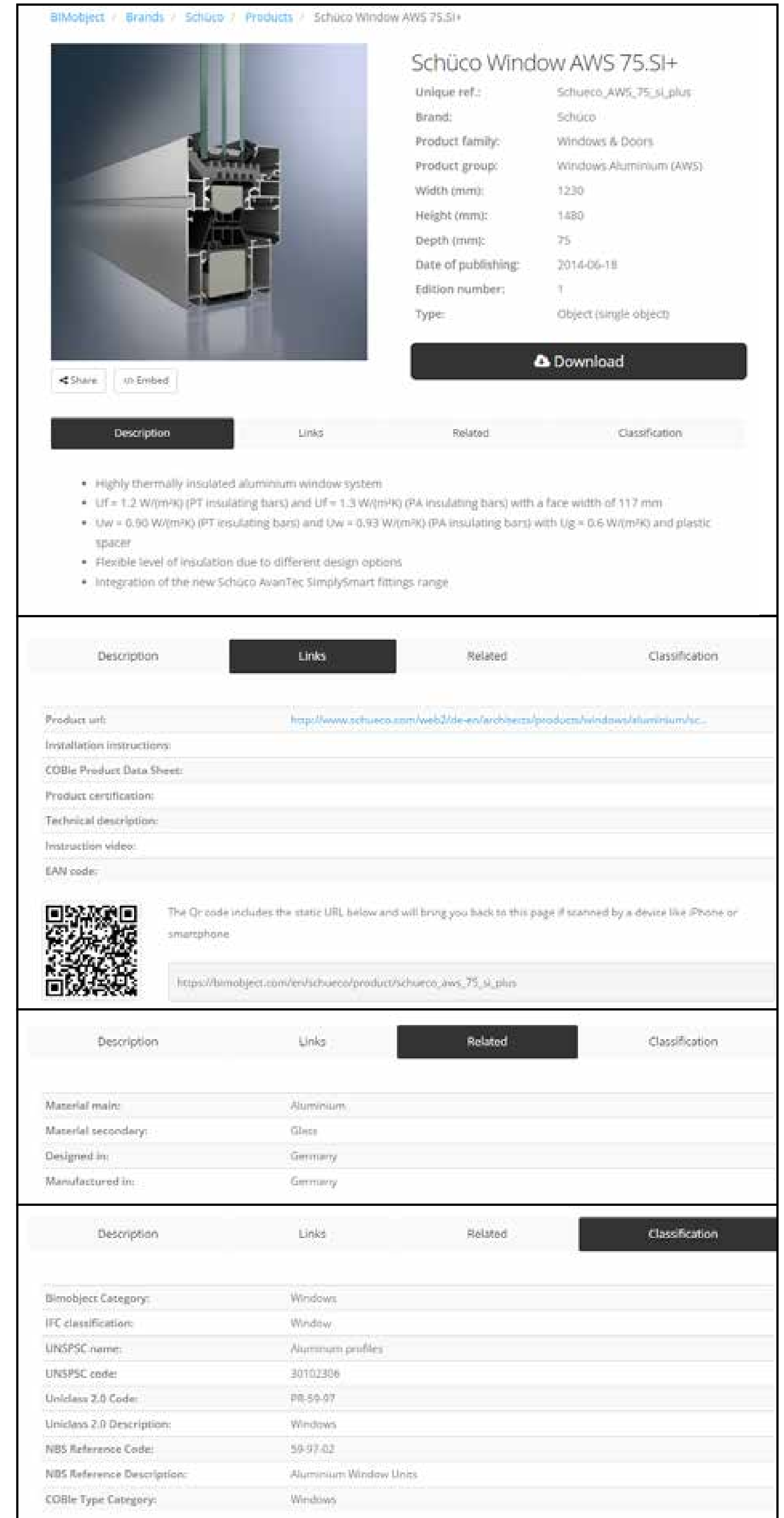


Figure 6.2.g.: Example of a Shuco Window as available in BM object web-platform.

	Fab window	BIM object	2d libraries
3d object on BIM complaint software	Only directly compatible with Revit2014,15 and 16. can be taken to other versions or softwares by converting file format.	Revit/ Archicad compatibility depends on manufacturer.	3d object unavailable
Level of detail	LOD 200 (geometry)	Depends on manufacturer	Not applicable
Kinds of information	Sizes, window opening type, material type (standard information from Revit material database)	Manufacturers can choose from the following:	
User interface	Comes with a manual for users. Helps users to apply object to project, change any plane material and add comments.	No standard manual,	Paper based information. easy to read manual
Application in design stage	Yes. More object information can be manually added	Maybe. As there is no standardisation in the information, objects can be too detailed or not enough detailed depending on the manufacturer. However, since manufacturer information is available, it can ideally be applied to the stage where the manufacturers are known.	Yes. Although the information can be too complex to compare products, basic information can be extracted
Sustainability value: embodied energy	No information given. Users have to manually type in the information	No comparative information. The users have to calculate the embodied energy as no standardised value is available.	Comparative information available from the same manufacturer for different products. Other information like LCA have to be manually calculated
Manufacturer's specification	Generic model, Manufacturer's specifications can be added by user	Manufacturer's specs added by manufacturer	Information from manufacturer
Easy of comparison	Relatively easy to compare	Relatively complex to compare, information in different tabs and data might be missing	Very complex to compare, information might be missing updates and comparison to be done by expert or 3rd party (like sale's person)

Table 6.2.4.a: difference between Fab-window, BIMobject and traditional 2d library (Illustration by self).

6.2.4. CONCLUSIONS

Table 6.2.4.a gives a brief deail about the differences btween the 3 open source libraries available. the fact that BIM object works in close coordination with manufacturers helps in getting the exact and up to date information. however, it is observed that this could be not ideal for an architect to use it as it is confusing to go through thousands of manufacturer data. Fab window provides simplified geometrical inputs. however, criterias mentioned in the facade chapter are missing.

It would be ideal if a secondary library is present that connects the manufacturer data at a later stage, but has only the basic information required for the design estimates. This means that a range is allowed instead of exact values like LCA for material data and U-values etc for performance data.

Figure series 6.2.4 a-e represents the evolution of the library and the scope of the proposed library. the idea is to use the ease of selection based on geometry as seen in Itannex and still being connected with real manufacturer data.

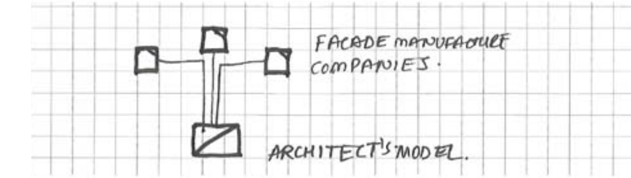


Figure 6.2.4.a Traditional method in accordance with 2d libraries

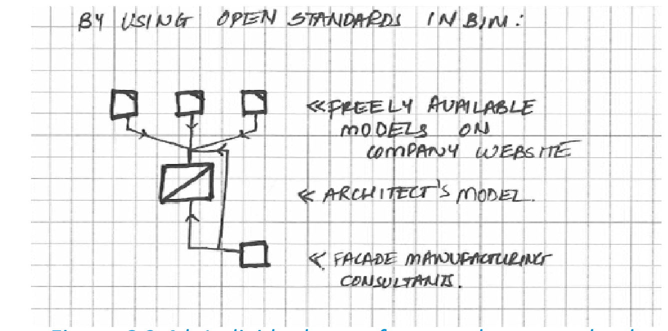


Figure 6.2.4.b Individual manufacturer data, translaed from 2d libraried into BIM environment

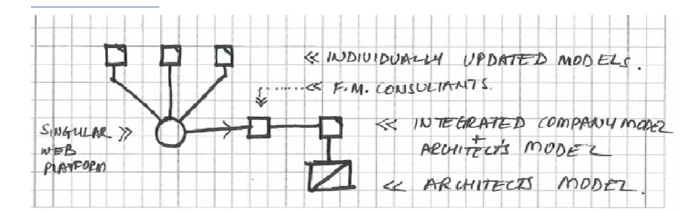


Figure 6.2.4.c: Influence of Itannex (circle represents Itannex platform). it is observed that afer using Itannex, Facade manufacturers are required to fill in the detals using company data from BIM an input this in Architect's model

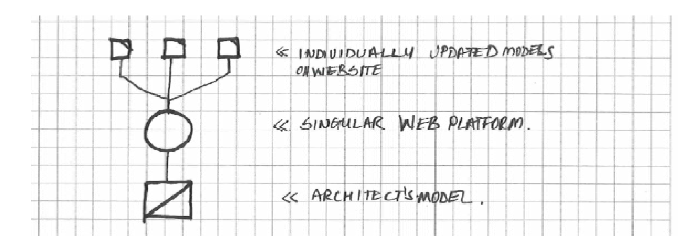


Figure 6.2.4.d: Influence of BIM object Platform (circle represents BIMobject platform), Providing ease of chosing manufacturer wthout going through the hassel of extra steps.

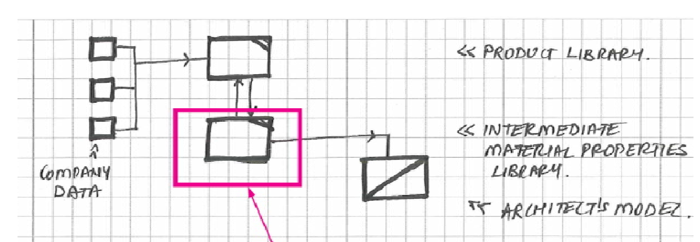
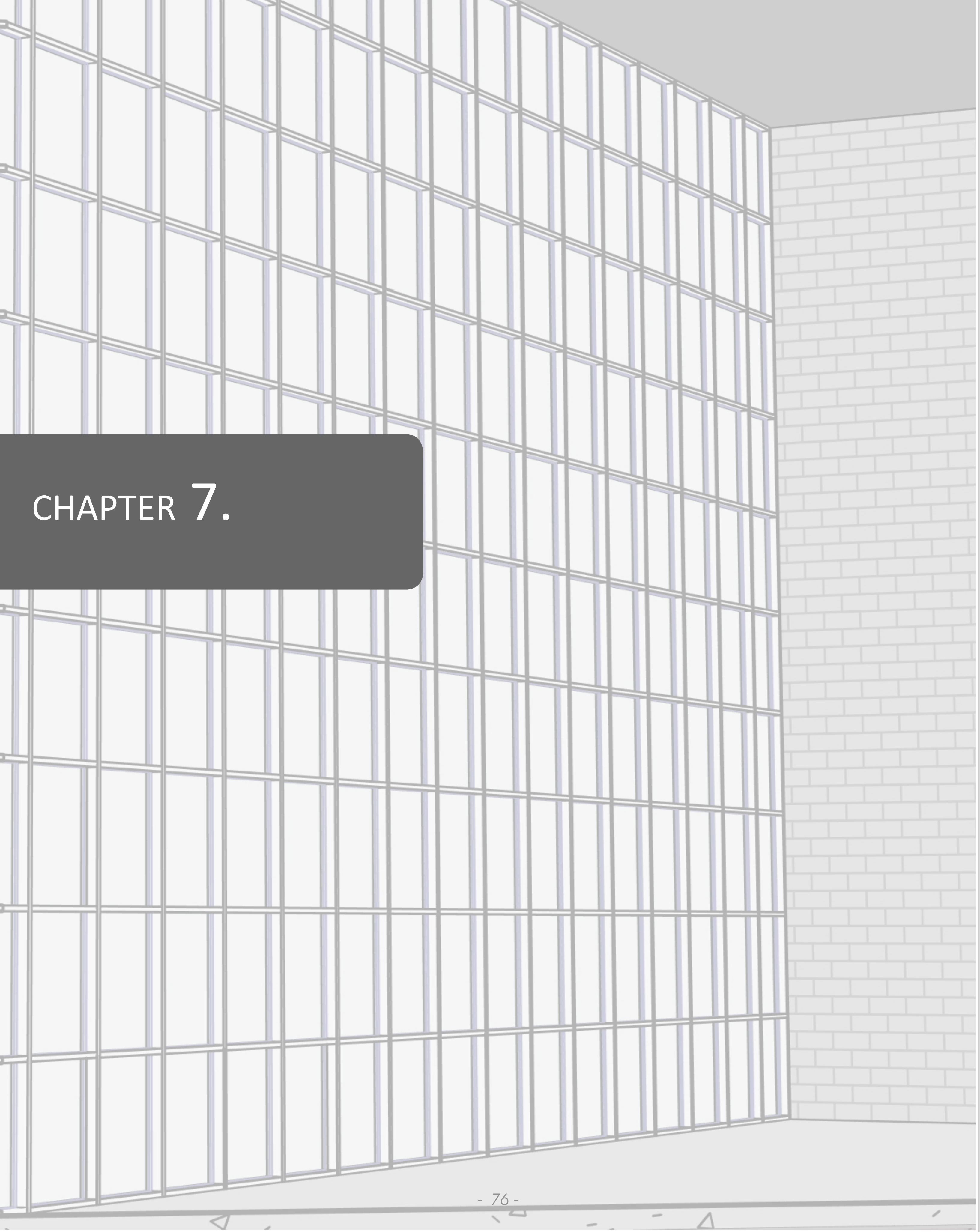


Figure 6.2.4.e :Proposed Library: Adapted from c and d modules mentioned above: a secondary Library with geometric details and range of value for parameters connected to the actual manufacturers, ready to extract when information is necessary.



CHAPTER 7.

7. GUIDELINES FOR THE LIBRARY

According to the conclusions drawn from the literature research and the predefined goals of the research, a set of guidelines can be listed to design the BIM library. These guidelines are the underlining criteria for the library and help to establish the following for the library:

- The non geometric parameters that needs to be provided by the manufacturer,
- To define a working method to use the parameters and
- Suggest a suitable BIM platform to develop these elements.

Pre-defined Guidelines:

(pre-defined goals for the research direction)

In order to define the content of the library, it is relevant to define the guidelines for defining the content. The predefine goals defined during the onset of the research are summarised below:

- Non-load bearing window elements are to be considered for developing the library
- Different materials for common window types to be considered
- Design stage should be considered
- The library aims at assisting architects involved in sustainable design.

Sustainability:

- Calculations should take into consideration the Green House Gases (GHG) Emission. This should be measures in CO2 value. The Gas and electric consumption should be converted to CO2 value.
- **Embodied energy:** LCA value is chosen for comparison. IVAM (Interfacultaire Vakgroep Milieukunde) , NIBE (Nederlands Instituut voor Bouwbiologie en Ecology) and SIMApro are the databases available for The Dutch Regulations. NIBE is chosen along with ICE (Inventory of Carbon & Energy) as these data are freely accessible and closely relate o the Dutch standards.
- **Operational energy:** The window has a huge impact on the operational energy, as it is the first defence against the external environment. Parameters relating to these should be according to the data required in the simulations.
- **Certifications:** EPCs are mandatory in the Netherlands thus they should be necessarily be a part of the parameters. . NEN 7120 gives guidelines for EPC ad selected values for facade are taken into account.
- LEED and BREEAM are also selected for certification as these are international standards. However, on a further investigation, these are excluded from the parameter list as many decisions are related to management and cannot be included into the technical parameters. The technical decisions are partly accommodated by EPC.
- **Product comparison**: For a proper product comparison, a total of operational energy and embodied energy should be compared. The Durability of materials should also be included in this.

LOD

- Both LOD definition terms are considered: Level of Detail (geometry related) and Development (non-geometric information).
- LOD 100, 200, 300, 400 and 500 are considered (according to the AIA document of BIM LOD Standard). LOD 250 is suggested to be included with the following criteria:
  - Approximate energy simulation,
  - Cost based on measurements,

- Simple geomtery,
- Type of window based on material and opening,
- Dimensions of window.

Intermediate, generic library.

- On observing the current libraries, an intermediate library is suggested with generic information and approximate geometric profile.
- The generic library should have sufficient information to be linked to the manufacturer data.

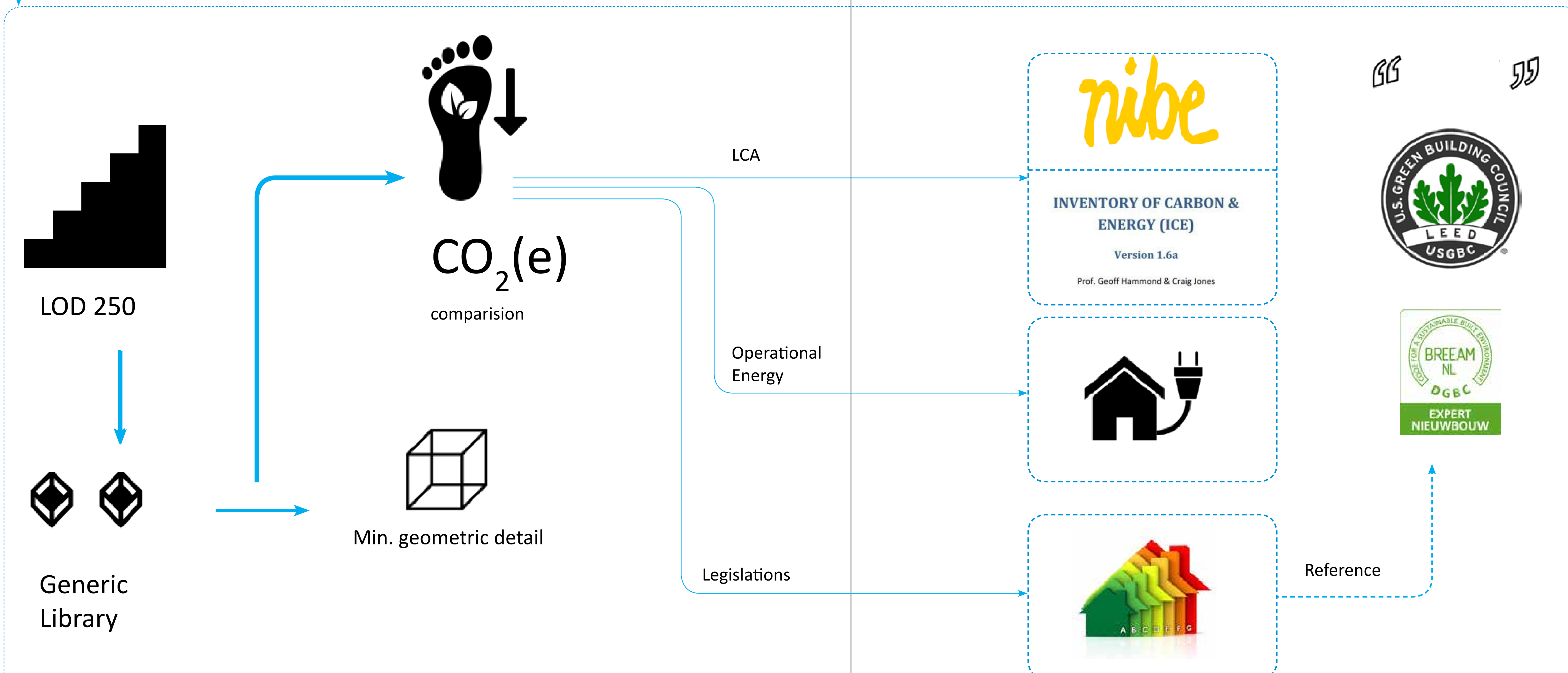
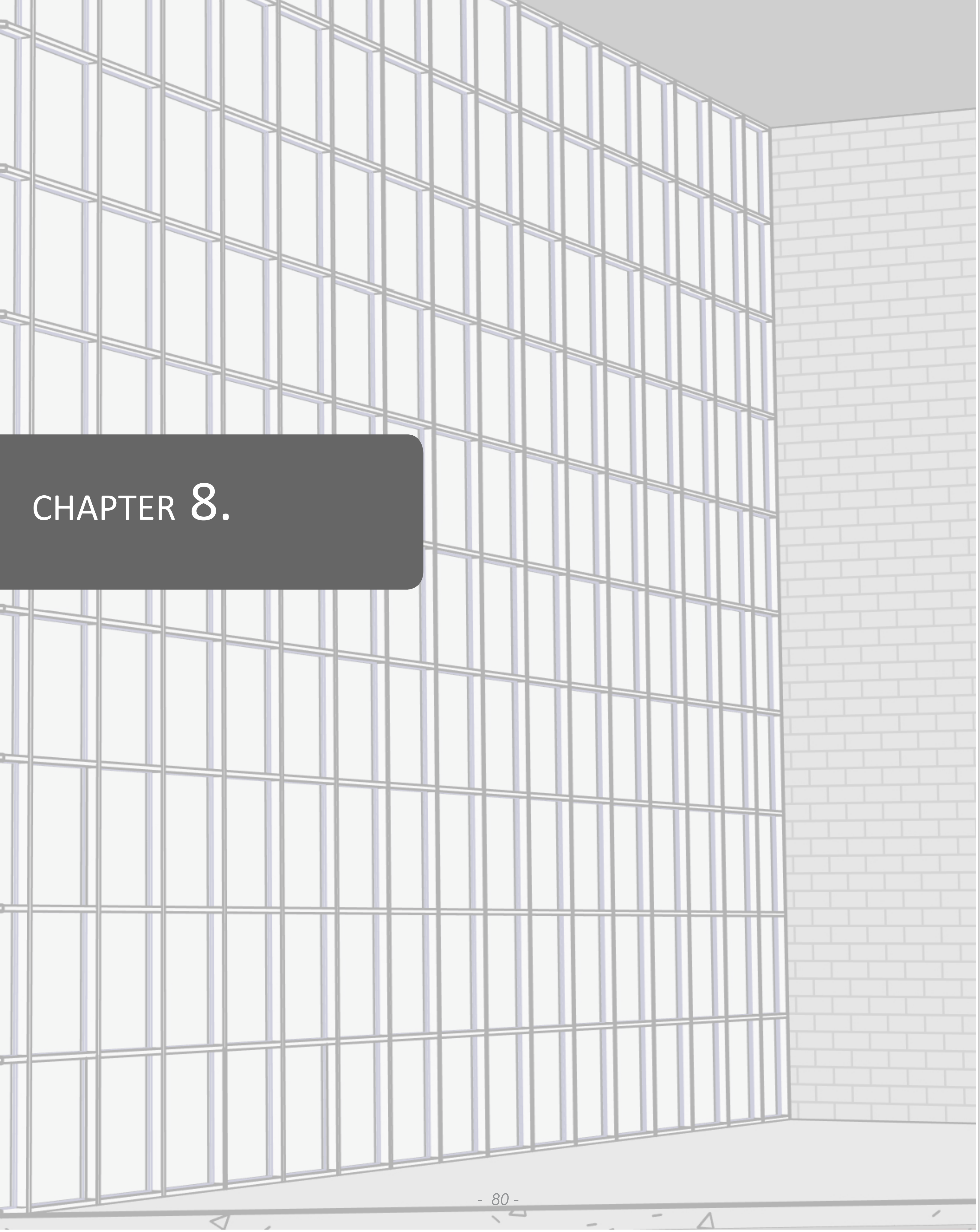


Fig 7.a: Schematic Represenation of the guidelines of the library



CHAPTER 8.

8. LIBRARY DEVELOPMENT

The design deveopment is divided into 2 parts:

Non-geometric information (parameters of library) related and user interface related. 7.1 defined the parameters related design options and 7.2 validates them by using BIM applications by applying to a case study. The outcome of this is also the user interface avalable within the BIM envronments which leads to the user interface related design options in chapter 7.3.

8.1. DESIGN OPTIONS: PARAMETERS

The parameters in the library can be calculated using 3 options: embodied energy related parameters, Operational energy related parameters and EPC related parameters

In order to come to details of the parameters BIM applications need to be reviewed using these parameters. These will be studied as a case study in chapter 7.2. The importance or relevance of these options need to be validated are architects are interviewed to gain more insights.

8.1.1. OPTION 1: EMBODIED ENERGY

This design option considers the parameters required to make the material choice relating to embodied energy. The lowest embodied energy ideally is prefered. NIBE Database is considered as IVAM database depends on SIMApro and SIMApro software is more complex and difficult to comprehend in the limited time span. For some values such as glass and inert gas, ICE (Inventory of carbon and energy) database is used. ICE database is developed by Bath university. This database is also considered for researches for The netherlands (Loussos et al, 2015; Ritzen et al, 2013), and hence, is used for glass and inert gases where NIBE database is not available.

Since no BIM applications automate this process, this method is partly deeloped in excel file. The idea is that the values are available square meters. By using BIM, running meters can be obtained and the final CO_2 value can be calclated.

8.1.2. OPTION 2: OPERATIONAL ENERGY

This design option considers the parameters required for window selection in terms of simulations required in the BIM applications. The BIM energy simulation softwares such as ecotect are pre-dominantly focused on providing the operatioal energy data. This design option therefore, studies the softwares and lists the Parameters that should be included in the non-geometrc data associated with the library.

8.1.3. OPTION 3: PARAMETERS BASED ON EPC

These are parameters relating to energy peformance coefficient (EPC) which as explained in the earlier chapter, forms the basis for approval of buildings. These parameters are mentioned in the table 3.7.3.a of Sub chapter : Legislations in the Netherlands realting to windows

8.2. BIM FOR SUSTAINABLE FACADES:

Inorder to understand the impact of the Material, performance and social aspects of sustainability, a case study was performed on the virtual environment of Orange Hall (Oost Serrie) of the Architecture Faculty, Delft University. The user iterface of the virtual environment as well as the data required for performing the simulations were studied in sub chapters 7.1.1 & 7.1.2.

In addition, a series of interview were performed to find the importance of criteria suggested in the conclusions of the facade chapter. These criteria were places along side the criteria found in EPC, LEED and BREEAM. These are noted in chapter 7.1.3 as conclusions which help to define the Design Tool in sub-chapter 7.1.3

User interface as design options are noted in sub-chapter 7.2

8.2.1. CASE STUDY PART 1

AIM:

To test the possibility of Embodied energy calculations within the BIM environment.

Method:

NIBE Database was selected for obtaining the LCA values in CO2. NIBE is based on SIMApro and a TWIN model Greenhouse gas emissions was considered as the comparison value. The window frame calculations do not consider the glass and Inert gas fitting. For the calculations of Glass and Inert gases, the ICE (Inventory of Carbon and Energy) database is considered. ICE is a database developed by researchers from University of Bath. It is observed that researches in Netherlands (Loussos et al, May 2015; Ritzen et al, Nov. 2013) also accept ICE Database as it closely relates to the Dutch standards.

The NIBE database gives 14 options for frame in materials: wood, aluminium, steel and PVC. The method also gives value for the number of years it can be used.

The ICE database gives the values for kg CO_2/ kg of Glass as well as inert gas such as krypton and xenon.

The model in Revit gives the approximate running meters for the frame (681 meters). The section is given by NIBE database. Thus the co2 value must be multiplied by the running meter to get the co value according to the amount of material used. Glazing is excluded from the database and hence needs to be calculated separately.

Described 5 types of glass used in the Dutch window industry: double glass, HR Glass, HR++ Glass , HR++ glass and triple Glass, as indicated in the façade sub-chapter 3.4 However, the embodied energy of these are not clearly indicated and can be simplified as:

Double glass, HR glass: 2 Glass panes
HR+ and HR++ Glass: 2 glass panes + Inert gas
HR+++ Glass: 3 glass panes + inert gas

A standard cavity of 12 mm is considered for volume of the inert gas.

The sq.meter of the glass and volume of the cavity can be obtained by the Revit model. This must be multiplied by the ICE database and the final value can be obtained for comparison. Thus a combination of 14 frame options by 3 glass types is possible.

Analysis:

The 6 parameters are selected from those indicated in NIBE database. They are Embodied energy related as wel as parameters required for the building construdion and Finance indication. the embodied energy related parameters include: Environmental classification, Green House Gas Emissions (Kg CO_2) given per m^2, End of use. The extra parameters related to structural load and cost indications inclide Mass, Price in Euros and Life Span. There are 16 materials from 4 material types that are window frame related as given by Nibe. The Embodied energy is Lowest for materials hat are rater high on the environmental classification and the value inclreases b ya multiple of the running length, as per the calculation mentioned in the methodology.

HR3 glass gives highest Embodied energy and Double Glass and HR Glass is the lowest in the comparision. The calculations are available in the annexure.

Conclusions:

There is no BIM software to analyze this directly. Besides, it is to be noted that since the running length for the frames is the same, the CO2 value obtained will be also comparable to the multiple of the embodied energy value. However, the calculated method is still useful when making an embodied energy + operational energy calculations. The parameters related to embodied are obtained from the NIBE Database and is indicated in the Analysis diagram indicated by Figure 8.2.1.a

The type of glazing depends on the performance chosen. The embodied energy alone gives a biased opinion of choosing the glazing type. This calculation s therefore rejected from the conclusions.

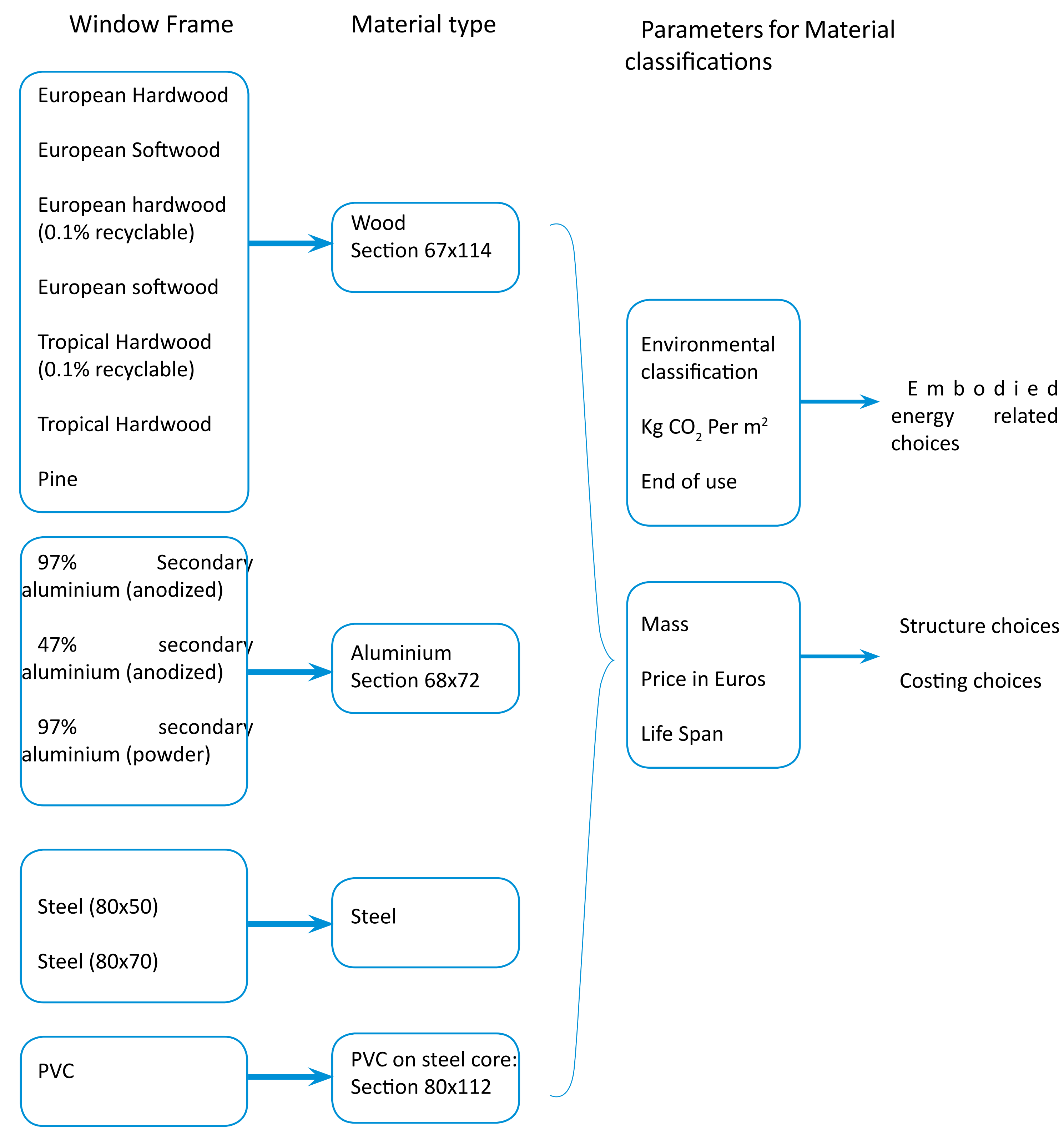


Figure 8.2.1.a : Analysis of the Parameters and material types as indicated by NIBE (see annexure 12.4 for the details).

8.2.2. CASE STUDY PART 2

Aim:

To test the possibility of operational energy calculations within the BIM environment.

Method:

A model for the Orange hall with the Location and climate data according to its coordinated was designer. The realistic data o number of occupants was and type of useage was inserted. Curtain wall family type from revit was selected and 1200x1200 standard frames were used.

The u-value of material type and glass type and the Visual Light Transmittance (VLT) and Solar Heat Gain Corfficient (SHGC) values are obtained from he EPC database. (NEN 7120). 3 frame types (wood or PVC, Metal with thermal break and metal without thermal breal were consdered and of the 16 u-vales available, the highest u value of each glass type was considered. Thus 4 glass values were obtained and 12 material options were generated.

At the time the analysis was made, Revit was not fully integrated for Energy simulations. Hence a gbXML export was performed. This was preferred as the export file is coded to retain the green building simulation related data. This data is the imported to energy simulation software Ecotect. It is observed that from June 2015, Ecotect will be replaced by Green Building Studio (GBS) and hence, GBS is also used for energy simulation. Gbxml file from Revit was also uploaded to GBS.

Analysis:

Revit:

The families in Revit are object related, i.e., changes in one object reflects changes in all the objects of the same family name. It is easy to input parameters as required according to phase. The scheduling shows the phase wise data, as generated in Revit. This process is not yet automated but need to be made manually.

Ecotect:

The entry in this was Material based; meaning the change in non-geometric information was done by changing the applied material to the object. It was far easier to change the non-geometric parameters and run the energy simulations. There was also flexibility in updating the material library. Selection of object was not automatic due to errors from exporting the revit model. Each element needed to be manually updated with material, which is time consuming. Modeling in Ecotect took more time as the model was already available in Revit, but selection of materials was relatively easy.

Green Building Studio

Unlike in Ecotect where weather data for Architecture faculty was not available, green building studio provided weather data from the nearest weather station according to the location coordinates. However, the HVAC values were not constant ecotect as many options mandatory in ecotect were missing. Water calculation was also mandatory and this was added to the final score.

The calculation was cloud based and much iteration could be run simultaneously, however, there was not enough flexibility to input the data according to the parameters suggested by the material library used in Ecotect.

General.

The facade alone could not be calculated as HVAC values were needed for the model to function. Apart from the HVAC values, the schedule of useage, weather data and number of perople and occupancy was also required. Green building studio also was highly dependent on water useage, as that is one of the main criteria of LEED and Green building studio assists in criteria for LEED, as advertised by Autodesk. The input-output work flow I indicated in the figure 8.2.2.a.

Conclusions:

For an almost accurate analysis of the operational energy, more parameters are required than the facade. These are contect related, space useage, innovation (energy production) and HVAC ystems. The CO_2 emissions requrired for heating/cooling and lighting the space is considered as gas and electricity useage. These are based on assumes values, but are useful as the same measurement system is used and

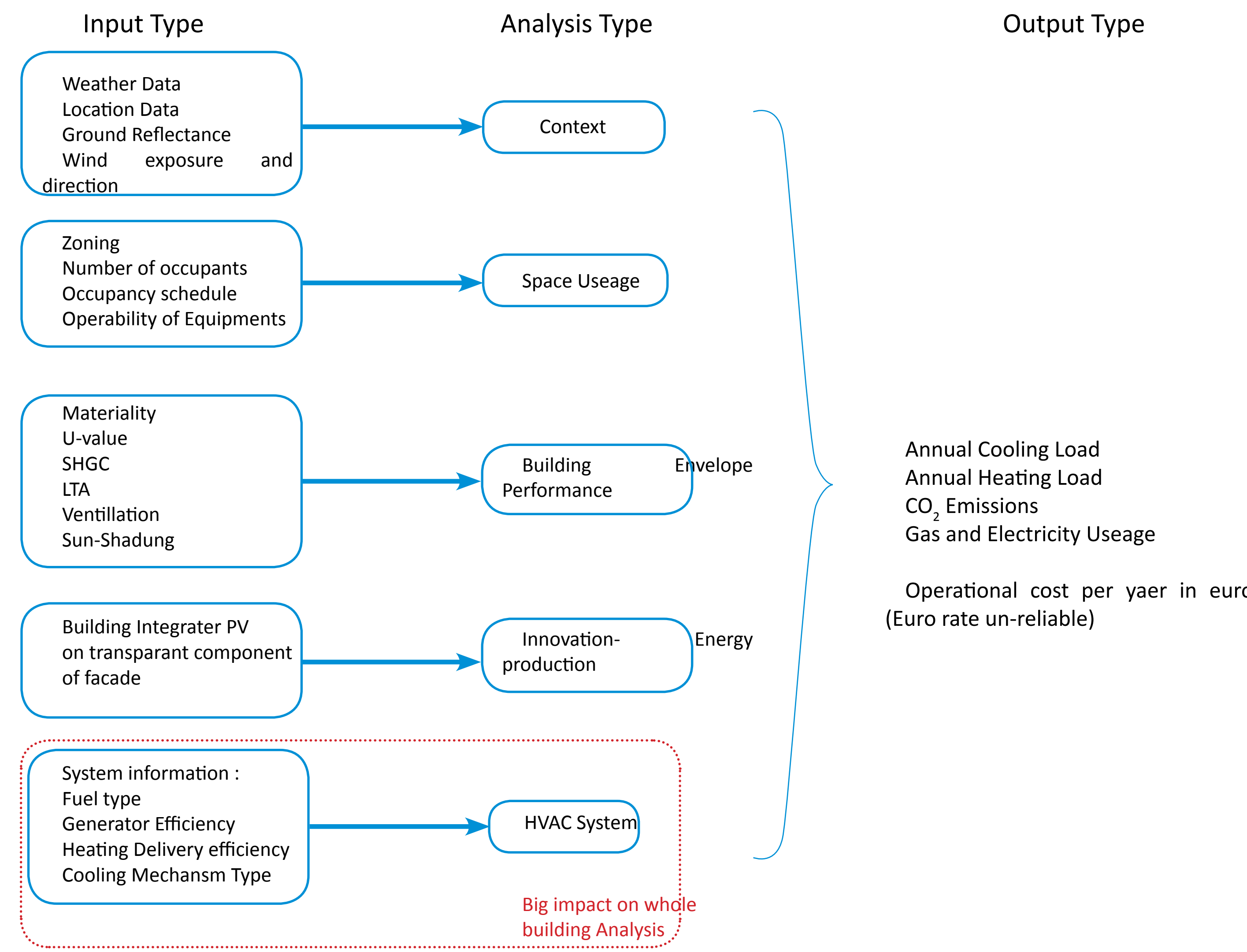


Figure 8.2.1.a : Input - output dataflow , as observed from BIM applications for Energy Simulations.

the optimisation of design/ selection of materials can be done effectively.

Furthermore, from the case studies of the BIM applications, 3 types of user interfaces can be observed. These are discussed in the chapter 8.3: Design Options for User Interface. This is important because the kind of user interface also influences whether the designers would prefer to use these tools.

8.2.3. CONCLUSIONS:

Limitations of the Calculation method of NIBE:

NIBE classifies most wood profiles at high environmental classification since the released GHG's (and other environmental impacts) during their production is lower than metal. However, the durability is also lower. For example, 1b classified product, European softwood (35 years) has an impact of 8,95 kg CO_2 /m^2 whereas 97 % secondary aluminium frame lasts 75 years, more than twice the durability of softwood is classified 2c: 4 spots lower than softwood. This data does not consider replacement. Thus if the soft wood window needs to be replaced, it will cost 8,95 kg CO_2 /m^2 extra. Thus, bringing the total comparable embodied energy for 75 years is:

European Softwood: 17, 9 kg CO_2 /m^2

97 % Secondary aluminium: 17, 5 kg CO_2 /m^2

The above comparison indicates that aluminium has a better embodied energy compared to wood.

The second drawback of NIBE calculation is that it is based on LCA and recyclability is not taken into consideration. Thus, after the use of the material, the metals and some PVC have ability to recycle and save extra material. However, wood frames have near zero recyclability. Thus to produce a new wood window, all of the Embodied energy is required, whereas to produce the metal and PVC windows, a part of the Embodied energy can be preserved from the previous metal or PVS window elements who have reached the end of their life time.

Thus the equation 1 stated in the chatper 2.4 needs to be rephrased. The embodied energy needs to be divided by the service life of the elements to get the per year comparison. Also the operational energy needs to be calculated per year. This will give a comparative CO_2 value of all materials.

The new equation looks like:

$$PET_{LC} = PET_O / \text{year} + PET_E / \text{Service life} \quad \text{....(eq. 2)}$$

PET- Primary energy total,

O- Operational energy

E- Embodied energy.

Combined Parameters for comparision:

As explained in conclusion of chapter sustainability, choosing the parameters based on embodied energy or operational energy alone gives a biased answer about the selection of materials. Moreover EPC parameters satisfy the legal requirements but do not give insight on the performance value of the building. Thus all these 3 design options are essential and needs to be provided in a singular tool. Since there is no existing BIM application where this can be performed, ideally the software needs modifications to accommodate these parameters that help to distinguish precisely which parameters relate to EPC, Embodied energy and Operational energy, while at the same time, providing these parameters in a singular platform.

Thus, to explain the final design, Excel tool is selected. This is because the IFC data can be extrapolated to an Excel File, and hence, the data from Excel can be used directly.

The Next chapter describes the tool required in a BIM environment.

8.3. FINAL DESIGN

The final list of parameters is listed in the next page in figure 8.3.a. These parameters are derived from the case study from the previous chapter. On developing the list of parameters defined for different materials for windows, the designer is still not able to compare the material to see which one is sustainable over the other. Thus, a separate framework is made using excel. The list of Parameters is meant to be open source and hence is made available through a web-portal (http://bim-curtain-wall-windows.blogspot.nl/)

How to use the tool and frame work:

Figure 8.3.a:

1. The architects may choose the material of frame and type of glass to begin.
2. The values in yellow will be updated according to the database (shown in the next page)
3. The total value of CO2 is calculated by the formula in equation 2, which is shown in the figure 8.3.b
4. Along with the parameters, some general data is pre-requisite for the BIM applications to function. As well as for EPC
5. Thus Figure 8.4.b defines a whole picture: the extra parameters relating to building that should be included.

Figure 8.3.b

6. This indicated the overall tool in BIM. The categories are generally in different tabs/ steps.
7. By inputting the values of figure 8.4.a, and 8.4.b, Total Primary energy for comparision is available. HVAC data is not added as this has to be inputted with an expert. For window comparision, a constat HVAC value may be considered.

How to use the parameters within the BIM environment:

Since no such tool actually exists within the BIM environment, this needs to be created within the BIM environment. However this required coding and modification of the software and it was not possible to do within the time frame of the thesis. Therefore, it is suggested that using material libraries within the BIM environment, these parameters can be updated for running the simulations and after that, for adding the specifications for generating scheduling. It is suggested that once the performance based criteria is known, the geometric detailing that is required for tender documents can be produced by using suggestions from the manufacturers or updated file from BIM object. Figure 8.3.c gives an example of the geometric detail drawings that can be produced for different scales.

Embodied energy based parameters	
Window Frame	Select from drop down
KG CO2 value (frame)	value
Glass type	Select from drop down
KG CO2 value (glass)	value
Fill type (between glass)	Select from drop down
KG CO2 value (infill)	value
Service Life	value (years)
Recyclability	value (%)
Operational energy based parameters	
VLT	value
SHGC	value
U-value glass	value
U-value frame	value
U- total	value
General data:	
thickness-profile	value
Colour frame	Select from drop down
Coating frame	Select from drop down
BIPV	Select from drop down
thickness glass	Select from drop down
Spacers Between Glass	Select from drop down
Profile placement	In model
Acoustic	Select from drop down
price (per unit)	value
EPC based Parameters:	
u- value	Max =4.2 W/m.sq K
air tightness	0,2 cubic decimeters/second
Solar heat gain	requirement
daylighting	depending on interior function
Ventilation	requirement
Sushading	provision
area of transparent elements	depending on residential/ non residential

Figure 8.3.a- Parameters selected

Kg CO_2 of frame, Glass is already divided with the service life

WINDOW FRAME PER M²	Service Life (years)	KG CO_2	KG CO_2 Per year	Recyclability	PRICE IN EURO
European hardwood (67x114) acrylic painted	50	8,95	0,179	0,0%	1,20
European softwood (67x114); painted, acrylic	35	10,8	0,309	0,2 %	1,44
European hardwood (67x114); painted, acrylic	50	9,23	0,185	0,1 %	1,48
European softwood (67x114); painted, acrylic	35	10,8	0,308	0,2 %	1,65
Tropical hardwood (67x114); painted, acrylic	50	15,7	0,314	0,1%	2,36
Pine (67x114); acetylated modified	50	17,6	0,352	0%	2,42
97% secondary aluminum (68x72), anodized	75	17,5	0,233	63,0%	2,92
Steel (80x50); Powder	100	31,8	0,318	62,6%	3,39
Steel (80x70); Powder	100	33,1	0,331	65,6%	3,59
47% secondary aluminum (68x72), anodized	75	17,6	0,234	63,0%	3,69
97% secondary aluminum (68x72), powder	75	15,6	0,208	65,7%	3,70
47% secondary aluminum (68x72), powder	75	14,7	0,196	65,7%	4,47
PVC on steel core (80x112), 0% Secondary	40	36,5	0,9125	73,4%	6,80
Tropical hardwood (67x114); painted, acrylic;	50	15,7	0,314	0,0%	19,90

Table 8.3.a: Data from NIBE

	U_{glass}	wood or plastic U_{fr} = 2,4	metal with thermal break U_{fr} = 3,8	Metal without thermal break U_{fr} = 7,0	VLT	SHGC
single glass	3,3	3,3	3,6	4,5	0,95	0,85
	3,2	3,2	3,6	4,4		
	3,0	3,0	3,4	4,2		
double glass	2,8	2,9	3,3	4,1	0,9	0,75
	2,6	2,8	3,2	4,0		
	2,4	2,6	3,1	3,9		
	2,2	2,5	2,9	3,7		
HR glass	2,0	2,3	2,8	3,6	0,8	0,75
	1,8	2,2	2,6	3,5		
HR+ glass	1,6	2,0	2,5	3,3	0,79	0,65
	1,4	1,9	2,4	3,2		
HR++	1,2	1,8	2,2	3,0	0,75	0,60
	1,0	1,6	2,0	2,9		
	0,9	1,5	2,1	2,8		
HR3	0,7	1,4	1,9	2,7	0,65	0,60
	0,5	1,3	1,7	2,5		

Values in red indicate that it is advised to not use it as minimum u value is 4.2

Table 8.3.b: Data from EPC

Building typology	Select from dropdown list	EPC value	
Green Building Standard(GBS)	Select from drop down list	Criteria to fulfill	points(LEED) % (BREEAM-NL)
	(LEED/ BREEAM-NL) refer figure 8.4.c	Extra Criterias	points(LEED) % (BREEAM-NL)
Contextual analysis		**Tool**	
Weather data	Terrain Type	Predefined weather/ location data (drop down menu)	
Location data	Wind exposure rating		
	Ground Reflectance rating		
Space useage		Tool	
Number of building occupants		client brief	
Lighting Types		client brief	
Equipment types		client brief	
Occupancy schedules		client brief	
Building envelope Performance (only windows)		**Figure 8.4.a**	
Building Envelope Initial embodied energy		**Figure 8.4.a**	
Primary total Energy :	operational energy per year	+ embodied energy value ÷ service life of material	
Resultant value =	value from simulation	+ precalculated value for figure 8.4.a	
Cost estimation	data from figure 8.4.a	X nr. Of unis from model	

Figure 8.3.b: Tool to compare the carbon footprint of the materials

Building typology	EPC requirement 2015
Meeting function	1.1
Cell function	1
Healthcare function with bed zone	1.8
Healthcare function differently than with bed zone	0.8
Office Function	0.8
Logies Function in accommodation building	1
Education Function	0.7
Sports Function	0.9
Shop Function	1.7
Homes and Residential Buildings	0.4

Table 3.4.c: EPC value according to Building typology: used for reference

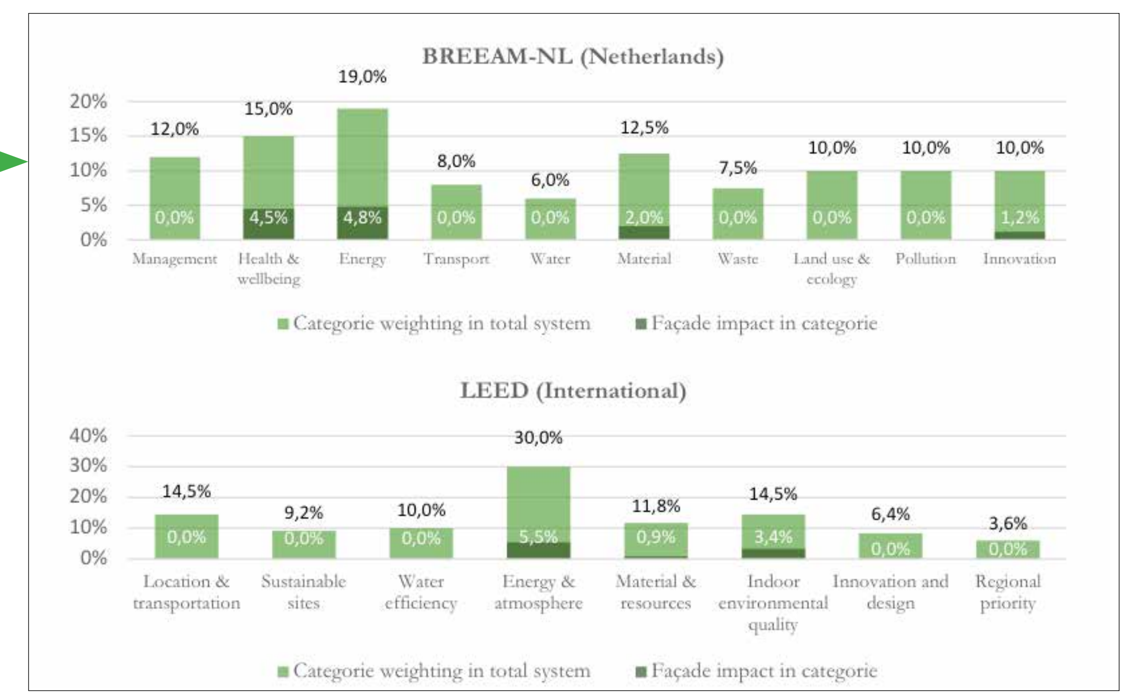


Figure 8.4.c: BREEAM-NL and LEED Characteristics, Image from Cleton , I. (2015, Apr)

8.4. USER INTERFACE

From the case study of using BIM platforms, the following 3 types of Platforms can be used for the library:

8.4.1. PRE- DRAWN OBJECT:

These are pre drawn objects like in FAB-window and BIMobject. These are pre-drawn models shown as families in BIM environment, Families for BIM are comparable to Blocks in CAD: Editing one edits all. With the parameters in it that can be extracted by siulation softwares. Scheduling gives the approximate costing. Update to the Higher LOD detailed model means replacing the family type.

The main **advantage** is that the BIM infrastructure is already present.

However, while updating or changing model, complications with softwares can occure such as dis-joining of the element to the wall. This can lead to mis-calculations for simulations as well more time spent in correcting the error caused. Another **disadvantage** is that the change in data of the generic library will not be automatically updated and this can result in architects using old data.

8.4.2. DATA PLUG-IN ON IN-MODEL BIM OBJECTS

This can be related to the material library in Ecotect. A plug-in provides data that can be added to BIM objects and families. By easy click, the values can be changed. This option is also available in designing softwares like Revit and Archicad, where the material of the family types can be changed.

This has an **advantage** over the previous option that the families are not disjoined when the library parameters are updated. This can prove to be a huge advantage in the time factor. It is also supported by architects such as Bjorn (DP6) and BIM manager such as Mark Maas (Paul de Ruiter Architecten) that plug -ins help.

However, the **draw back** of this system is that the concept of plug-ins work against the concept of making things easy if all system developers start making their own plug-ins. The computers have limited data space and processing speed. It has the similar problem of update as the pre-drawn object based library.

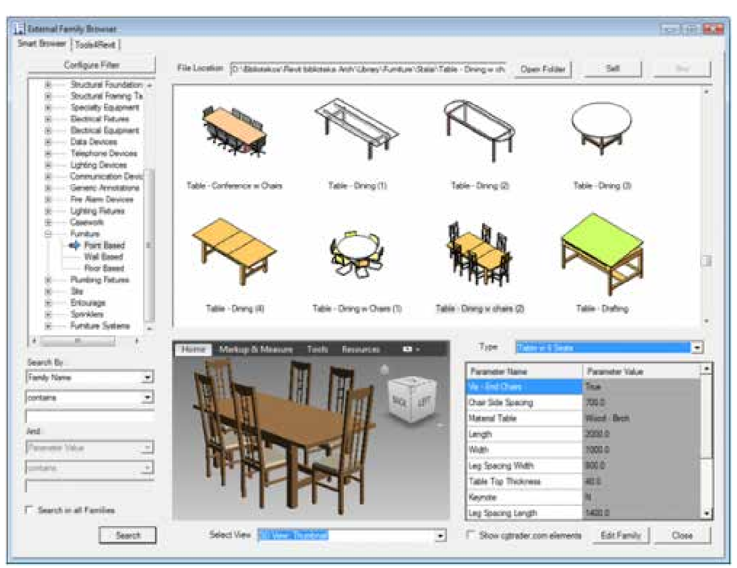


Figure 8.4.1.a: Object Library in revit

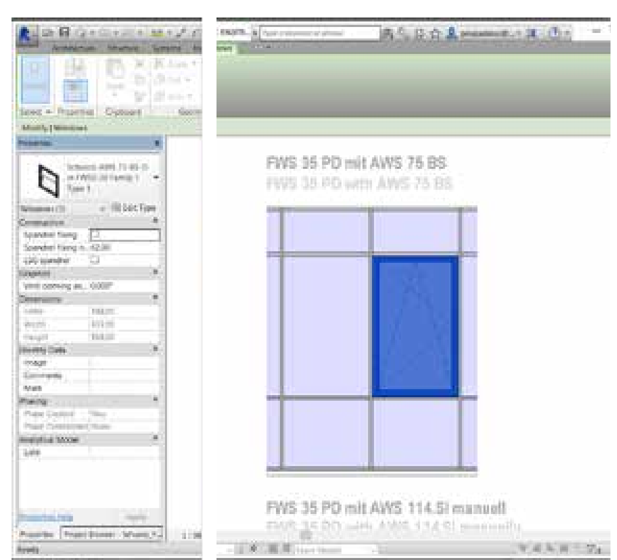


Figure 8.4.1.b example of family in revit

Figure 8.4.2.c: material library in ecotect

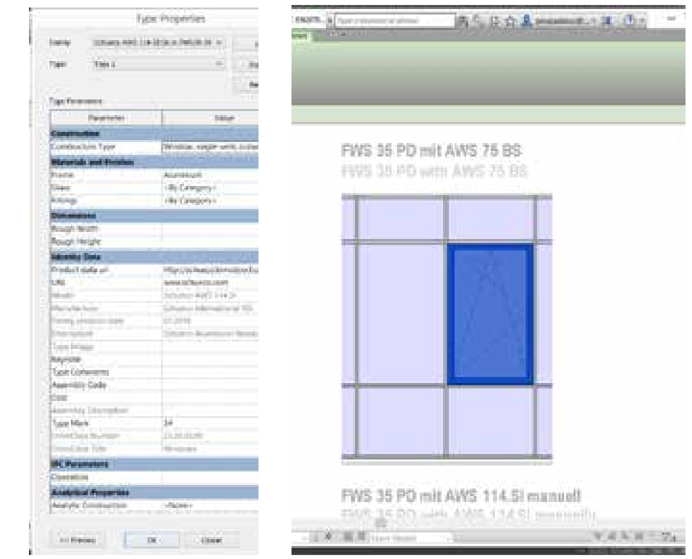


Figure 8.4.2.c: Parameter data based on maeri in Revit.

8.4.3. CLOUD BASED COMPUTATION

This is still an emerging concept in the digital world. The computation is carried out by remote servers. This solves the problem of the disk space and processign speed on individual computers. .

The controller is a trusted company with high performance servers and computing machines. One example learn through the case study is the Green Building Studio. In this case the trusted company is Autodesk. Since it is a old company, and assures before using the services whether the data is shared or not, dependng on the user's choice. User is allowed to tick a box that says share my files to stake holders, to everyone or to me.

This could be an ideal solution since the data can be directly updated by manufacturer and the update appears in the model of the designer. Computations also can be easily performed.

However, the major disadvantage is the trust that the service provider sticks to the choice you make in the project. Also, there is a possibility that the user can share a confedential document with an error in making the choice. Thus options should be available

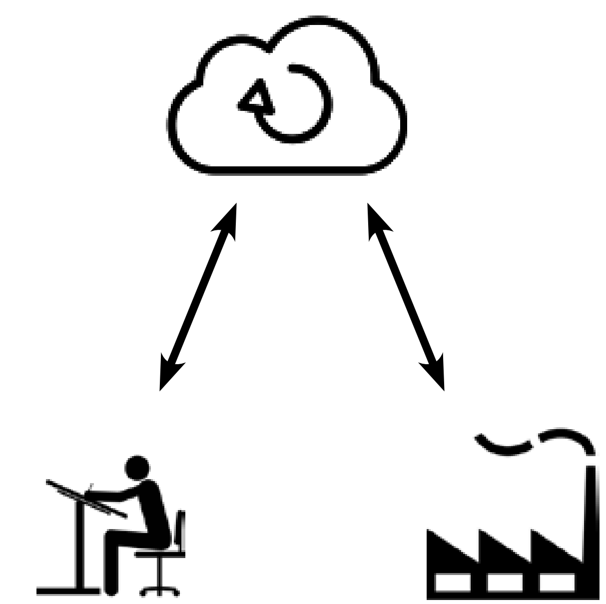


Figure 8.4.2.d: Representation of a cloud based BIM object- the manufacturer data is inported to architects drawing through a cloud based service

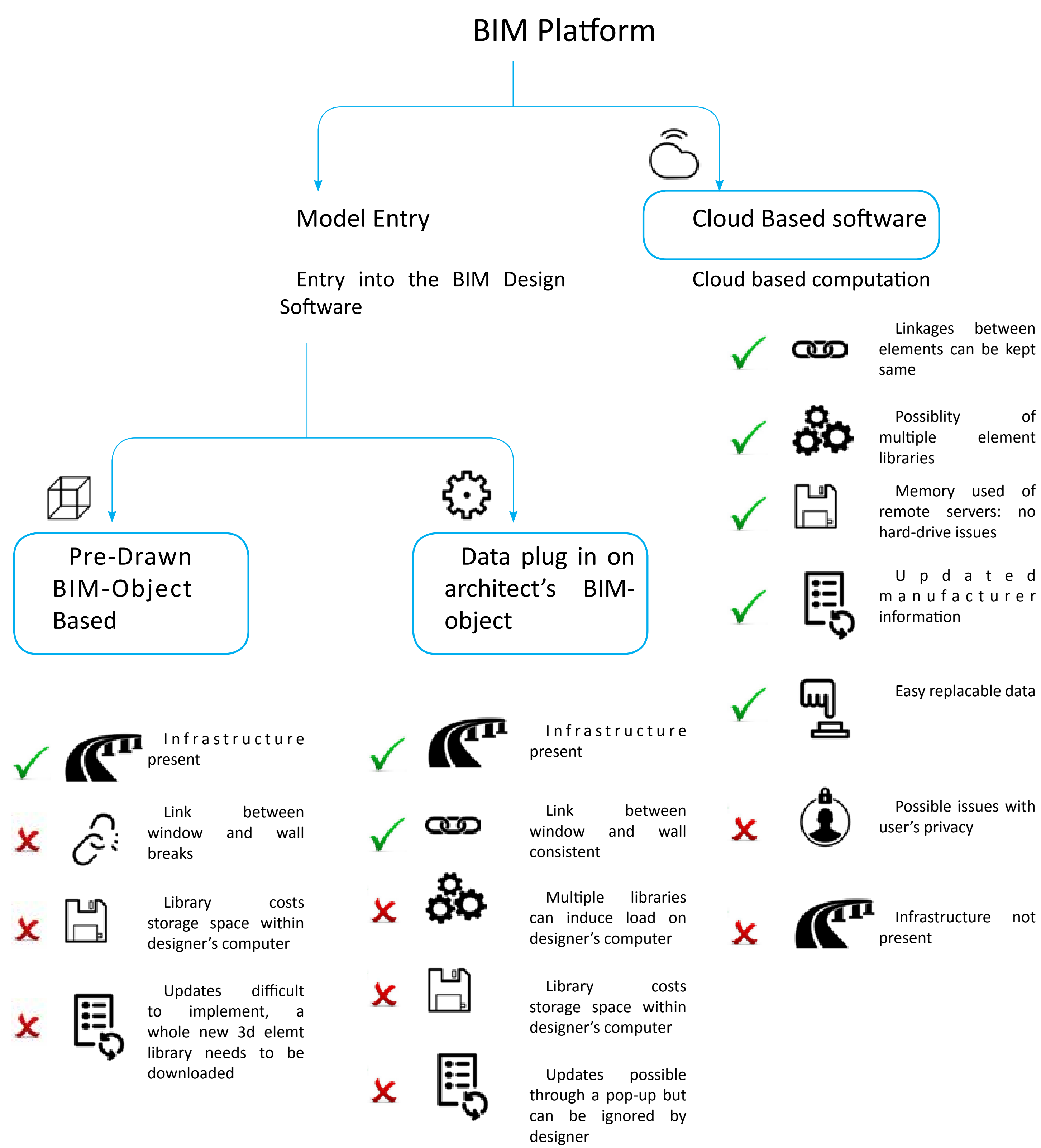


Figure 8.4.2.e: Flow chart explaining the 3 concepts of user interfaces with pros and cons.

to change the choice at a later stage and a reminder should be given with every log-in about the choice made.

The other draw back is that if the main server breaks down, all he files are stuck in the system. These technical issues are only the ones that are easily identifiable, and the details should be discussed with IT developers.

8.4.4. CONCLUSIONS

Although it seems that the cloud computation is the most promising, the technical details still needs to be worked out. If the library has to be imediately rolled out, it should be in the form of a Plug-in. The reason is that this prevents the re-drawing/ re-attaching the families with wall element.

It is also accepted by 3 of 4 experts interview. The fourth one being a software developer, and not a designer.

However, if there is a trusted party that is investing time and resources for cloud comuptation, this can be a good base for the dutch architects, although, a lot of training would be required to get all (or atleast most of) the architects on board.

8.5. TESTING THE FRAMEWORK DEVELOPED IN FINAL DESIGN

The framework developed in the chapter 8.3: final design needs to be tested to get an overview of the possible outcomes. For this, all three materials for frame: wood, Aluminium and Steel are considered. PVC is discarded from comparison as it shows very high embodied energy compared to the other materials. Since our goal is to achieve as low carbon foot print as possible, the materials from the table '8.3.a: Data from NIBE' regarding frame material is selected. Table 8.4.a shows a comprehensive list of selected materials. This gives us 5 frame options: 3 materials and 2 options for metals with/ without thermal break and 4 glazing options, thereby giving us 20 comparative results. These results are analysed through lenses of asumptions made and the material choices by using the tool.

This chapter covers the assumptions made and the simulation conditions that are common for all the material types. For analysis, these are put togather within one tabulated results and conclusions are drawn through the observations made

8.5.1. SIMULATION CONDITIONS:

Model information:

The proposal is not to optimise the design, but rather use one design and optimise the material used. Thus, the design conditions are similar to those considered in chapter '8.8.8: Case Study 2' where orange hall was considered.

A room size of approximately the orange hall used in chapter '8.8.8: Case Study 2' is considered. The dimensions of the room are: 24x25m base and height of 10 meters. Standard window sizes of 1.2x1.2 are considered. The location considered is Mekelpark, Delft. This is within the TU Delft Campus, opposite the sports and culture centre. The glazed area is considered to be south facing.

WINDOW FRAME PER M^2	Service Life (years)	KG CO_2	KG CO_2 Per year	Recyclability	PRICE IN EURO
European hardwood (67x114); painted, acrylic	50	9,23	0,185	0,1 %	1,48
Steel (80x50); Powder	100	31,8	0,318	62,6%	3,39
47% secondary aluminum (68x72), powder	75	14,7	0,196	65,7%	4,47

	U_{glass}	wood or plastic	metal with thermal break	Metal without thermal break	VLT	SHGC
		U_{fr} = 2,4	U_{fr} = 3,8	U_{fr} = 7,0		
single glass	3,0	3,0	3,4	4,2	0,95	0,85
double glass	2,2	2,5	2,9	3,7	0,9	0,75
HR+ glass	1,4	1,9	2,4	3,2	0,79	0,65
HR3	0,5	1,3	1,7	2,5	0,65	0,60

Table : 8.5.a: selected materials and their properties: based on low embodied energy and high performance

Figure: 8.5.a & b: (left and right): Location of the project: delft, south holland. Location of the project: Mekelpark, TU Delft.

Figure: 8.5.c: Location of project in 3d view.

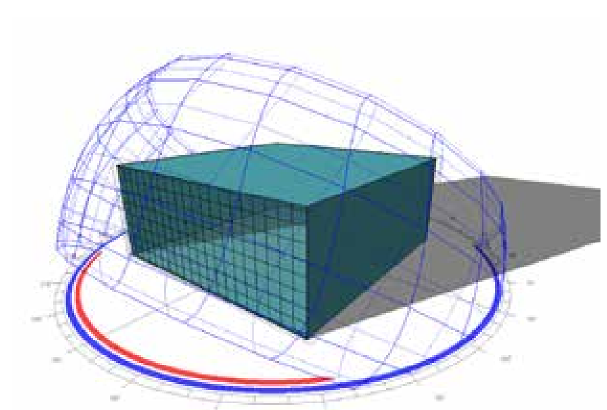


Figure: 8.5.d: Model in ecotect showing sun path diagram. The curtain wall faces the south direction

Ecotect is used for simulations as it allows easy plug-in based material library wihin the simulion environment.

The weather data is obtained from software Meteonorm 7. Amsterdam, Rotterdam and Delft weather files are obtained, however, errors are observed in the delft weather data and hence, the next closest location: Rotterdam is used and loaded to Ecotect.

The material library is made in Ecotect and the material is replaced for each simulation. Thus a plug-in method is used here.

The assumptions used are as follows:

- 100 people occupancy, occupancy schedule available in appendix
- Weekends no usage
- Summer months 15% usage,
- Mixed mode HVAC system is used
- No heat pumps
- The wall containing curtain wall faces the south direction.
- Remaining 3 walls are brick wall with standard software provided u- value of 6,0W/m2 K, SHGC of 0.56
- Carpeted concrete slab on ground with values same as brick wall.
- No added insulation is considered.

The analysis are displayed in the table 8.3.b below

8.5.2. ANALYSIS :

Table 8.3.b displays the results as indicated in the frame work described in chapter final design. By using th eframe work, a comparative GHG value is achieved. to get the comparative final CO2 value, equation 2 is used which is the addition of operational energy per year (recieved from simulation) and the embodied energy divided by service life.

Difference in operational energy of different materials:

The operational energy for the given building with the assumed simulation conditions can vary between 40 MWh to 51 MWh* by changing the material. This is about 24.2% change in the energy consumption. The corresponding GHG emissions vary between 22.9- 29.6 T Co2 that is about 25.5 % difference in the GHG emission. The percentage difference between Mwh and GHG emissions indicate the minor error during rounding off during conversion from MWh to kg CO2 emission.

	Timber				Aluminium with thermal break				Aluminium without thermal break				Steel with thermal break				Steel without thermal break			
	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed
GHG operational	25707	24549.3	24056.28	22906.02	26992.92	25854.63	25425.42	24303.66	29608.65	28501.7	28207.59	27167.34	26992.9	25854.63	25425.42	24303.7	29608.7	28501.7	28207.59	27167.34
GHG embodied FRAME	71.78				76.048				76.048				123.384				123.384			
GHG embodied glass[1]	47.94	63.92	70.63	102.59	31.96	42.61	47.08	68.39	31.96	42.61	47.08	68.39	23.97	31.96	35.31	51.29	23.97	31.96	35.31	51.29
total embodied energy	119.72	135.7	142.41	174.37	108.008	118.658	123.128	144.438	108.008	118.658	123.128	144.438	147.354	155.344	158.694	174.674	147.354	155.344	158.694	174.674
total primary energy	25826.72	24685	24198.69	23080.39	27100.93	25973.29	25548.55	24448.1	29716.66	28620.4	28330.72	27311.78	27140.3	26009.97	25584.11	24478.3	29756	28657.1	28366.28	27342.01

[1] Value of glass as well as gas infil. For calculations, refer appendix.
All values displayed are in kg CO2 unless otherwise specified.

Table 8.5.b: Comparative results of 20 values in terms of operational energy, embodied energy and total. Green indicated least value (best choice), blue indicates highest value (worst choice) within the selected frame of materials. For details, refer annexure 13.9

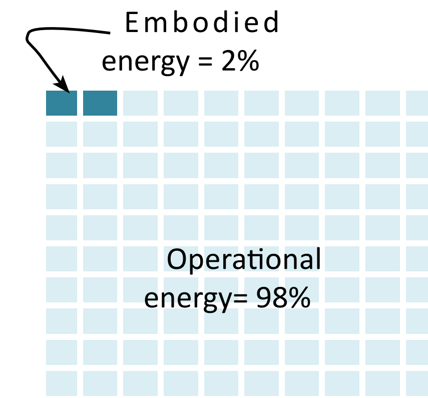


Figure 8.5.e: Diagram indicating average percentages GHG emission by impact from embodied energy of curtain wall facade and operational energy as obtained from the simulations

Embodied energy:

The difference in embodied energy is highly dominated by the amount of glass used. Thus, windows with same material for frame show that using triple glass has a higher embodied energy impact than single glass. However, the operational energy is much higher: on an average about 187 times higher than the embodied energy of material if only the curtain wall is considered. In other words, the curtain wall constitutes about 2% of the operational energy. However, it should be noted that if the embodied energy of all the elements of the building: exterior wall, roof, floor and beam and column are considered, the embodied energy is significantly higher than the one indicated. The operational cannot be divided for facade separate from the building; therefore, it will remain same when all the elements of the building are considered. In such a case, the embodied energy should not be eliminated from the calculations.

Continuation of table 8.3.b from the page on left.

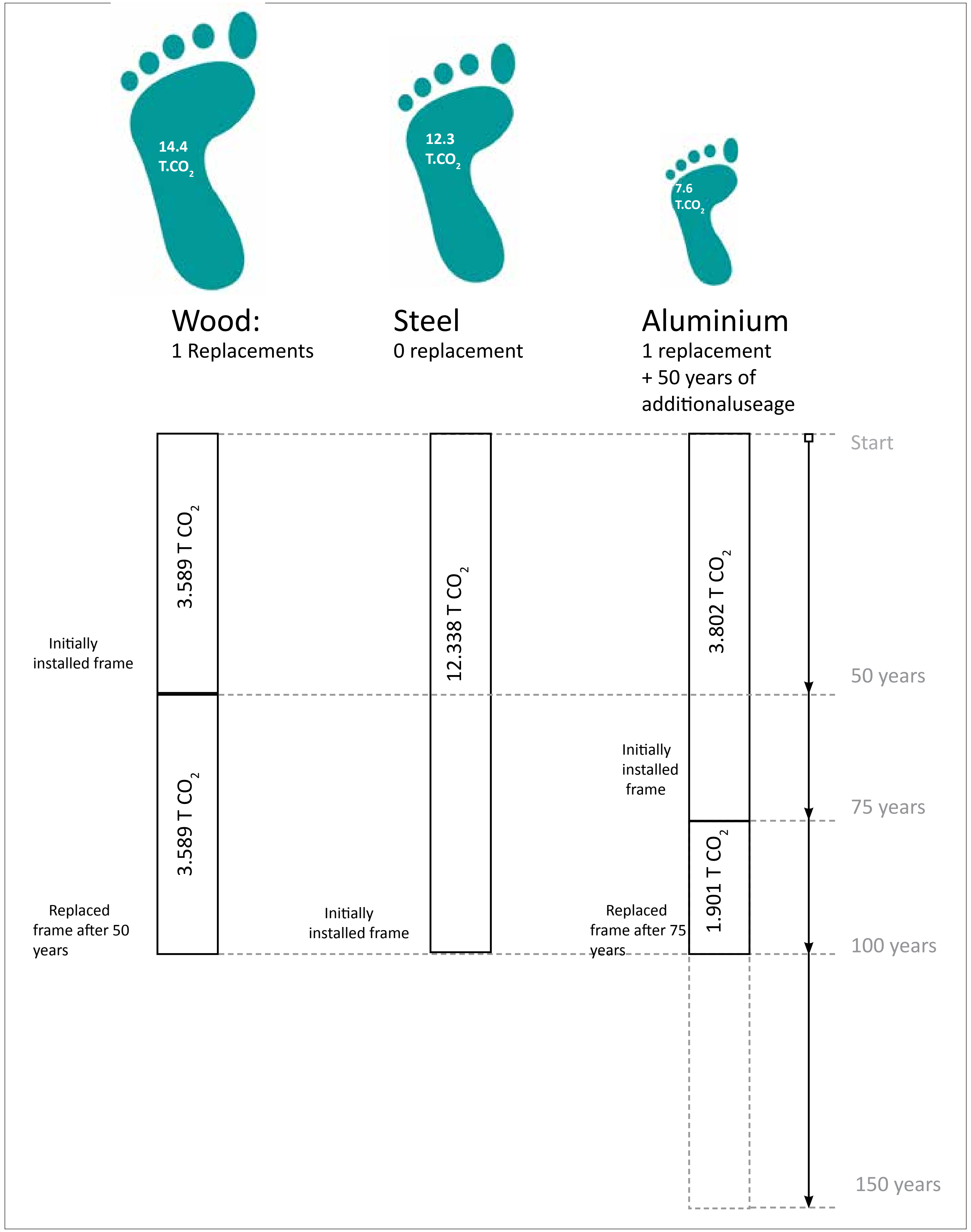


Figure: 8.5.f:
Comparing carbon value in terms of durability between materials: considering a time frame of 100 years. The image only considers GHG impact of embodied energy.

Recyclability:

The energy calculations consider the materials usage only for the first application of the material. However, for the second application, recyclability plays a very important factor. By using recyclable materials, as seen in the case of metals, about more than half of the embodied energy can be re-used in the next cycle.

This means that although triple glazed glass with timber frame shows better total CO_2 impact, for its replacement, the same amount of CO_2 will have to be spent which is 23,08 T.CO_2 **. Whereas for the production of HR+ glass with aluminium frame of 65% recyclability***, about 15,89 T. CO_2 of the 24,45 T.CO_2 is already available. Thus for the replacement additional 8.56 T.CO_2 will be required, which is one third of that required for production of wooden windows frames.

Durability:

Another aspect is the durability. A steel frame lasts for 100 years whereas the wooden frame lasts for 50 years. By using the embodied GHG frame value from the table, we can get a comparable per year value of the material within the project. Thus, for a 100 year time span, a steel frame would consume 12.338 T.CO_2 (multiplying the per year kgCO_2 value with 100 for 100 years), whereas a wooden window would require 14.356 Tco2. The aluminium equivalent (without recyclability factor) for 100 years is 7.605 T.CO_2. This concludes that wooden windows are a bad choice if durability and recyclability are the priority.

Figure 8.4.f gives a broad understanding of comparing materials by recyclability and durability.

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*1 MWh or 1 Megawatt hour= 1000 kWh
**1 T. CO2 or 1 Tonne CO2 = 1000 kg CO2,
*** Recyclability considers the recycling of window and not just the material. This includes the gaskets, frame material, glass material, and all the component materials associated with window. Therefore, the recycling value of material is different than the recycling value of the window. Moreover, recyclability values are with the assumption that all the materials of the window needs to be recycled, including glass

8.6. CONCLUSIONS:

This chapter analyzed the 3 aspects of defining parameter of the BIM based library and consolidated them within one working tool kit or a framework. Ideally this framework should be developed within BIM environment. However, developing the BIM library within BIM environment needs Programming knowledge, which is out of the scope of this thesis. Thus excel was used, as it allows automatic change in data when the corresponding input changes.

The result of the analysis of the parameters also gave the possible types of user interfaces in which this tool can be developed. 3 types of options were discovered: object based BIM library, Plug-in Based BIM library and cloud based BIM library. Plug-in based bim library was selected for immediate application of the tool.

Plug-in based material library was generated in Ecotect to test the library gave comparable results for materials used.

It is observed that the operational energy of the building is much higher (98%) than the embodied energy (2%) of the curtain wall. However, the embodied energy should consider all the materials used in the building elements: exterior walls, columns and beams, roof and floor. Altogether, the embodied energy is much higher but the operational energy remains the same. Thus calculating only the embodied energy as suggested in the tool is not enough to define the GHG emissions of whole building. However, the tool does help in making sustainable choices about the curtain wall material by providing comparison especially when looking at it in long term as recyclability and durability. When we look at the recyclability as well as the durability, the material choices are different, as seen in the example of comparison of materials for 100 years. Although it can be argued that 100 years is a long duration and the way the material will be used is questionable, it should be noted that it is a factor that needs to be considered by the clients as an after-material-use asset. Thi can, to some extent be regulate by green Building Standards and the legislations.

CHAPTER 9.

9. CONNECTION TO RESEARCH QUESTIONS

1. How to measure sustainability for the built environment in general and for window in specific?

Sustainability is an important issue to address but to compare if one product is more sustainable over the other; it is difficult process, involving People-Planet-Profit (social impact, environmental Impact and Economic Impact). One way is to compare its environmental impact of producing the building elements and operating building. The environmental impact addresses many aspects such as toxicity, waste, green house gas emissions, energy use, land-use, soil use etc. In the purview of this thesis, we are focusing on embodied energy, operational energy and service life that are typically responsible for the Green House Gases. Commonly as Green House Gases such as Chlorofluoro carbons, Methane, Propane, etc are converted to CO_2 kg equivalent a.k.a. CO_2(e) kg value for comparative value to measure products.

Chapter 2 helps us conclude that the aspect of measuring environmental impact in built environment is through measuring the greenhouse gas emissions. This can be concluded via the amount of CO_2 and CO_2(e) released in the environment through the production of the building material (embodied energy) and the amount of CO_2 kg released by fuels to operate the building (operational energy).

For the window, the embodied energy is stored in the frame as well as the glass. The LCA or cradle to grave method is used for embodied energy. By using NIBE (for frames) and ICE databases (glass and infill inert gas), the comparable CO_2 values for production, can be obtained. However it should be noted that comparing different windows using only embodied energy creates an incomplete picture, because the recycle value of the product should also be included. Although at the moment this is still difficult due the absence of definitive values within the NIBE and ICE databases.

The influences of choices made regarding the window build up on the operational energy are obtained from the case study in the chapter 8. The influence is seen in reducing the heating and cooling load and subsequently reducing the fuel usage. These include U value, solar heat gain coefficient (SHGC), Light Transmittance and indirectly influencing characteristics include Sunshading and Ventilation.

2. What are the Dutch and international norms and tools to calculate sustainability?

Globally, many Green Building Standards are available, depending on the country such as BREEAM (UK), CASBEE (Japan), Ecoeffect (Sweden), Ecoprofile (Norway), EDGE (South Africa), Envest (UK), Escale (France), Green Globes (USA) Green Star (Australia),GRIHA (India), LEED (USA), and many more.

In the Netherlands, the Green building Rating system suitable is BREEAM-NL developed by DGBC (Dutch Green Building Council). LEED is also used for comparing green buildings at an international level. Apart from these, a minimum EPC (Energy Performance Coefficient) should be met to get building permits in the Netherlands. The calculation methods are described in NEN 7120.

Apart from EPC, Zero Energy Build (ZEB), Passivhaus and EnerPHit can also be referred for a more energy efficient house. These two standards are developed outside the Netherlands. GPR Gebouw, GreenCalc+ and EPcheck are tools that can be used to calculate the EPC of the building.

3. What parameters relate to sustainable facade design?

As explained earlier, sustainability can be defied on 3 pillars: People, Planet and Profit or Social impact, Environmental impact and social impact. The entire facade design is a huge topic to be covered within the purview of the thesis. Thus, beginning with that small part in facade- a window- as a starting point for defining these impacts is the option that is looked here. Environmental impact of windows in terms of GHG emissions is discussed in further detail to outline the parameters.

These parameters can be divided into 2 categories: Embodied Energy related and Operational Energy related. The Embodied energy related parameters are those that directly relate to the production, transportation, assembly and end of life of the window element. The fuel released in this process is converted to GHG emissions. The durability of the materials should be also considered as some wood are more durable than the others. The NIBE gives us a comparable standard for Frame materials, while ICE gives comparison for glass and infill gases in the cavity between the window panes. These values are divided by the service life and a comparable value of GHG emissions in embodied energy per year is obtained. For the operational energy related parameters, EPC gives perspective on the impact of the parameters such as u-value, VLT (visual Light Transmittance), SHGC (solar Heat Gain Coefficient) and other parameters such as sun shading and ventilation. These are the parameters that relate to the reduction of Fuel in Heating/ cooling the interior space adn are calculated as per fuel usage per year. This fuel value is converted to kg CO2 per year data. And the final score of embodied energy and kg CO2 is compared. Thus, factor such as Air and water permeability also affect the operational energy. These factors should be checked during manufacturing and construction of the elements into the building.

Embodied energy related parameters:

Parameters as observed from the NIBE and ICE database that are relevant according to the GHG emisions: kgCO2 (per kg material), Kg material used in design, Service Life (years), Price in Euros.

Operational Energy Related Parameters:

Parameters as observed in simulation softwares as well as EPC: U- value (frame and Glass), Visual Light Transmittance, Solar Heat Gain Coefficient, air Tightness, area of transparent elements, ventilation.

4. Types of facade systems?

Curtain wall, Double skin load bearing: brick and stone.

In the purview of this thesis, the focus is defined in the window systems. Windows can be defined in the following systems according to the opening types:

Awning, casement, fixed, Horizontal sliders, Single hung, Double hung, tilt and urn and hoper. These are explained further in chapter 3.2: types of windows based on functions.

Apart from the above mentioned opening types, the windows can also be divided according to the type of material for frame and type of glazing. These are shown below. The detail for these are given in chapters 3.3 and3.4 respectively.

Type of window based on frame material: Wood, Aluminium, Steel and PVC.

Type of window based on glazing: single Glazing, Double Glazing, HR+ glazing, HR++ glazing, and HR3+ glazing or triple glazing

5. Parameters to define facade at design stage?

This question is answered by the chapter: Design options. The parameters for facade at design stage can be defined into 3 categories: EPC based, Embodied Energy based and Operational Energy based. These categories help make an informed decision about the CO2 footprint based on approximate and estimated values, and are covered in Question 3 of this chapter. Apart from these three categories, it is observed that there are some general parameters that can sometimes be used to make a decision to architecture and cost. The details of category-wise parameters are listed in the figure 8.4.a of chapter 8.4 Final Design. It should be noted that some parameters are repeated in two categories. This only indicates that the parameters are relevant to both categories. The general categories that are relevant are: profile thickness, Colour and coating of frame, Profile placement, Acoustic value, Price per unit.

6. Role of sustainability in facade design?

Chapter 5.4 describes the ways in which façade design can be instrumental in making the building more sustainable. The major implications are integrated functions and amount of glass. This can help in reduction of mechanical support systems that are required to maintain a comfortable atmosphere inside the building. Sometimes, these are also termed as high performance facades.

However, there is no set rule to when these systems should be used. However, in general 2 methods of using sustainable solutions can be described: the first one is when sustainability comes as an afterthought, after the design has been conceptualized while the second one is when the client and the design team is motivated right from the start to pursue high Green-BIM standards. Using BIM, the sustainable solutions can be applied from the beginning of the project and major changes such as reduction in transparent part of façade or changing the orientation can be noticed here already.

7. How does BIM help in sustainable design?

The Current BIM tools help in calculating the Operational energy. These are outputs are in the form of Heating Load, Cooling Load and Carbon emissions. The change of design can be implemented into an energy simulating environment like Ecotect, IES-Ve and Green Building Studio. The software gives the feedback depending on the location and orientation of openings. An estimate weather data from the nearest weather location can be used. The softwares use the inbuilt algorithm depending on the standards it is built on. The possibility renewable like photovoltaic can also be incorporated. By comparing the output of heating and cooling loads, using the building more efficiently during those periods can be possible.

Besides, BIM has the potential to collaborate with the consultants at an early stage. With the use of the BIM based window library proposed in this thesis, the information from the manufacturers can be brought to the designers at an early stage, thus helping them make an informed decision. This gives the architects a better decision making position where he is informed about the consequences of choosing materials, and also has knowledge about where the transparent members should be placed and to what size. Thus BIM has potentials in influencing both Environmental impact as well as the Social impact.

8. What are the Green-BIM tools available globally and in the Netherlands?

Green BIM tools are those that process gbXML based files- those for energy related calculations. Globally, many softwares are available that allow this some of them being: AECOsim- Bentley, ISE-VE, Revit (recently Ecotect was discontinued from March 20, 2015 and features are merged with Revit) .EcoDesign STAR - Graphisoftis ad Green Building Studio (GBS)- Autodesk the latest addition. Generally, the exchange flow between the softwares of the same company is smooth compared to softwares developed from separate companies. However, in theory, these are comparable as long as the common exchange file is present. It s observed that in the Netherlands, Ecotect is the most polar software (all the architects interviewed use Revit). However, the green BIM tools differ from company to company. Some general differences between these are: the standards they follow for their calculations. GBS for example, uses standards that assist to achieve LEED goals. Some of these standards are based n ASHRAE standards and calculation methods especially for thermal comfort. GBS also gives water usage as this is one of the important criteria for LEED credits. However, it is observed that there is no specific green BIM Software that helps in assisting EPC or BREEAM-NL calculations. The existing tools are Green Calc+, EP check which are not BIM compliant but are effective in EPC calculations.

9. Where do Green-BIM tools still need development?

The problem is the existing disconnect between the BIM softwares and the softwares that help to access sustainable standards like BREEAM, LEED and

EPC. Although there are individual softwares like GPR Gebouw, EPcheck and GreenCalc+, the feedback from the building is not directly integrated into the design softwares. This means that the designers are heavily reliant on the experience of the sustainability advisors, and on a longer process of changing design, and analysing in separate softwares and repeating the process.

Due to time limitations in a project, these are sometimes not optimised to the extent that they can be, thus leading to not most energy efficient option. The most important change that needs to be incorporated within these softwares is the inclusion of embodied energy. Since the embodied energy is given less importance, the parameters relating to sustainability are also the parameters relating to the operational energy, within the BIM environment.

Another problem observed in the conclusions of the questionnaire (annexure) is educating the client in both considering the use of BIM and in giving importance to embodied energy. The designer is restricted with the initial budget and the operational costs. These are the short sighted goals which define the immediate returns, the aspects that the client is most interested in. However, if shown that in the longer run, the end of building materials plays also an important role, architects and sustainable designers are inclined to consider the material data, but the final decision is still taken by the client.

This can be, to a certain extent, be regulated by the legislations. If the government gives more incentives to re-useable recyclable materials, there is more motivation to consider the end of life of materials in the initial design process. Furthermore, the EPC only regulates parameters relating to the operational energy, and gives no consideration to the materials

Level of detail	200	250	300
Model content			
Design & Coordination	Generic elements shown in 3-dimensions - maximum size, -Purpose	Generic elements shown in 3d - maximum size - Purpose - capacity	Specific elements confirmed 3d object geometry - dimensions - capacities - connections
Authorized users			
4d Scheduling	Time-scaled, ordered appearance of major activities	Time-scaled: ordered appearance of major assemblies, depending on the generic geometric detailing	Time scaled. Ordered appearance of detailed assemblies
Cost estimating	Estimated costs based on measurement of generic element Example: generic window frame and glass	Estimated costs based on measurements of generic elements but of specified performance, Example: generic window with Hr glass/ HR+++ Glass, etc.	Estimated costs based on measurement of Specific assembly Example: specific window and glass with exact cavity distance and filling
Program compliance	Specific room requirements	Specific room requirements, occupancy.	Furniture, fixtures and equipments, utility connection etc
Sustainable materials	Approximate quantities of materials	Approximate quantities of materials with percentages of recycled/ reused materials and their approximate GHG emission value	Precise quantities of materials with percentages of recycled/ reused materials and exact GHG emission values
Environmental: Lighting, Energy use, Air movement analysis/ Simulation	Conceptual design based on geometry and assumed system types	Approximate simulation based on geometry of elements and EPC based generic system types	Approximate simulation based on specific building assemblies and engineered systems

Table 10.10.a: difference between LOD 200 and 300 and introduction for LOD 250

used. Thus, the operational energy of the material could be good, but the embodied energy service life and re-useability/ recyclability of the material could be having a high impact on the carbon emissions. But at the moment this information is not brought forward.

10. What BIM Design stage is appropriate for the BIM Library?

BIM Design Stages are commonly called as BIM LOD (Level of Development) Stages.

In the Netherlands, According to the Bouwinformatie Raad, 3 LOD levels are possible: LOD1-3. However there are no definitive boundaries to define this level of details, thus leaving a lot of room for confusion and miscommunication. The AIA E202 - 2008 Protocol Exhibit clearly defines the boundaries of each BIM level and also provides example. This is also adapted by the Dutch Ministry of Interior and Kingdom Relations (Rijksgebouwendienst) and can be found in the BIM norms published in July 2012. The details about the LOD are explained in chapter 4.5: LOD for BIM Object. Furthermore, LOD is differentiated from LOD 100-500. LOD 200 Defines generic Place holders that help to specify the BIM object. LOD 300 contains enough information that purchases can be made.

Following the AIA E202 standard, LOD 250 is chosen for the library. This LOD category falls between 200- Physical/ virtual clash control (data relating to Specifying it) and LOD 300- Intelligent clash control (data relating to Purchases). The reason for defning LOD 250 was because the generic library that was required could not be defined fully based on LOD 200 or LOD 300. It was one step higher than LOD 200, yet a step lower than LOD 300. Thus a new LOD needed to be defined. The Boundary conditions of this LOD 250 are shown in the table 10.10.a side by side of LOD 200 and LOD 300,

11. What are current project delivery methods based design stages in the Netherlands?

The most traditional project delivery method in the Netherlands is DBB or Design-Bid-Build. In the recent years DB or Design Build has also taken importance. Integrated Project Delivery is the most recent method that is implemented in few projects in the Netherlands. The main difference between all three is the level of integration of each consultant in the project. These methods are discussed in detail in the chapter 4.1: Project delivery methods. The design-Bid-Build method is selected for a detailed analysis

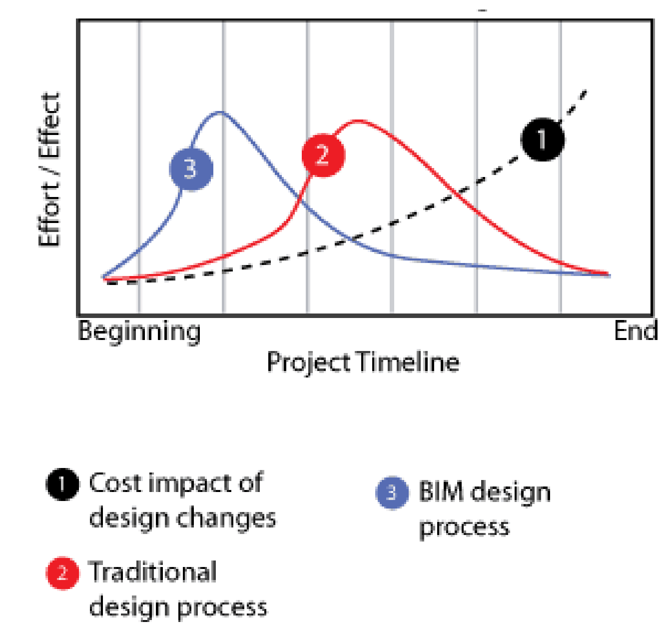

Figure 10.12.a : Conceptual BIM process shifts the design curve. (source: Welland, 2009)

of the facade design and construction. The Dutch Building method is based on the traditional Design-Bid-Build and is based on the Model Building Team Agreement 1992 (Bruggeman et al, 2008). The key aspect of this method is that the contractor is involved in the design stage as an advisor to the project owner and the design team. The design team, consisting of architects and technical designers, depend on the contractor for construction techniques, logistics and actual cost calculations to produce design details and technical specification for tendering.

12. How does BIM assist the project delivery method?

If we look at the current facade design process, we observe that the System supplier has a role in providing the information to the architect during the preliminary design stages. During the preliminary design stage, using BIM currently does more harm than good as a lot of detail is required by the software already during the preliminary design stage. The architects use the details from the system supplier directly into the model. These details are not required for design, since when the contractor is known the details are changed again, depending on the systems supplier.

By the presence of a BIM library, the design team is not dependent fully on the knowledge and experience of the constructor in the design stage for advice. The design team can therefore; take inputs from the database provided by the manufacturers and use it in their simulations. This database is expected to be up-to-date with the manufacturer information, therefore, the design team gets the latest changes, directly into his model, thus fast forwarding a few steps and making the process of design faster.`

As seen n Diagram 12.a, BIM allows changes in the early design stages with low cost impact on the design process. This is because the engineering information from the contractor can already be inserted in the in the BIM model during the design stage.

13. What are current window libraries in The Netherlands?

The current window libraries are of 4 types, in-house libraries of companies, 2d libraries of windows, Fab-window by Itannex and BIM object. The comparison between these libraries is explained in further detail in chapter 6.2: Existing libraries.

It can be noted taht these are incomplete and not efficietly described for architects use. The main disadvantage of Fab window is that it does nto cotin the non-geometric data relevant for the the designer. While this problem is solved by the BIM-object, the data provided in BIM object website is not only too detailed for architect to use in overall BIM model, but also difficult to compare the products as they are presented in different files, and user needs to go through each product to compare it. The problem of comparison is nonexistent in Fab window as the all the possible objects are preset in one file and loading the file automatically loads all the family types.

Thus there is still need for an intermediate library that talks the laguage of the architect but displays information from the manufacturer.

14. What are the available platforms for BIM library?

On making case study 2, there are 3 kinds of platforms that can be developed for BIM library. These are object based library, Plug-in based library and cloud based library. These are further explained in chapter 8.4: User Interface. The pros and cons are studied of each of these. It is recommended that a Cloud based library would be the best option for the designer. However, the infrastructure of remote cloud based servers and the platform developed by a neutral company (a company that does not propagate a particular company or companies) does not yet exist. Thus, for an immediate implementation, a plug-in is suggested. This helps fast change of information without un-attaching the element from its neighbouring elements like wall.

15. What would the new library look like? Who should use it? When should they use it? On which platform should it be developed? How it is supposed to help in sustainable facade design? Will architects use it? Are there any benefits for the manufacturer?

The new library should be integrated in the current softwares. The interface should not be difficult to use but rather an interface that is already in use by the architects. This is further analysed in chapter 8.5: user interface, where 3 types of interfaces are discussed: Pre drawn object (BIM object based library), Plug-in into the BIM environment (material library) and a cloud computing service (cloud based library, includes computing). The advantages and disadvantages of each of these are described in the chapter in detail and finally Plug-in based library is chosen for immediate application as the infrastructure is present and plug-in allows changes without much effort. However, if a unbiased company (like Autodesk or government) is willing to invest in cloud computing, this method is better

as many plug-in are possible at the same time, as well as computing power is provided by remote servers,, meaning there is less load on the architect's computer systems. However, for architects to trust this data fully, it is important that the company does not represent or support any particular group of companies within the window manufacturers.

How the proposed solution supposed to help in sustainable facade design?

Question 12 already answers how the BIM library can help in Design-Bid-Build contracts. However in the Netherlands, variants of Design-build are gaining high popularity, Design-Build-Finance-Maintain (DBFM) and Design-Build-Finance-Maintain-Operate (DBFMO). These are especially requested by clients in large and complex projects where function, performance and efficiency are prioritised over owner's subjective architecture style. In this case, the client chooses the contractor who hires architect and other specialists. The same tender-winner is responsible for construction, maintenance and in case of DBFMO, also operations of the building. This assures a higher performance of the building. In such a case, the design team still can use the BIM library (proposed by the thesis) to define the performance of the elements.

Furthermore, it is observed that the embodied energy is not given any importance today. Only the operational energy is given an importance. The proposed solution automatically gives the value of the embodied energy, by selecting the materials. While the architects and clients can chose to ignore it, the final value in kg CO2 is displayed. This gives a motivation to see the total environmental impact of both the phases- embodied energy as well as the operational energy of the material selected.

Users of the Library

It is bserved that all the architects interviewed rejected the idea of using the library. However, the BIM managers intervied confirmed that they would like to use the library as it assists them. This library is also amed at assisting the Sustainability engineers. However, the sustaianblity engineers depend on the BIM managers for developing the drawings and actually integrating the libraries. thi is because the architects are involved with overall planning and looking at legislations. Sustaianble Designers, on the other hand are looking at overall systems for optimisation. The BIM experts actually product the documents. Hence it can be concluded hat BIM experts wil predominantly use this library.

Since there already is no library that has the generic information that connects the performance related information, it is difficult to predict that the Sustainability consultants will use it or not for the simulations, although, the library is aimed at providing the data that is useful for the sustainability analysis. However, both: Peter Mninga(Arup) and Girogio Carella (Paul de Ruiter Architecten), the two sustainability engineers consulted, Confirm that the library proposed in this thesis could be essential to use, although they are still reliant on their BIM-using colleagues to bring he elements into the vrtual model. Thus, there is hope that the future Engineers will use this library for to make optimisations on their designs.

Developers of the Library

As mentioned in the previous chapter, a trusted company should arrange the deelopment of the library. A Plug in is the simplest solution to for starter. VMRG is actively involved in getting sustainability and innovation and is connected to metal cladding companies. VMRG is also a trusted name for CE markings. An initiative by VMRG could help in getting the designers to use the library. However, technical possibilities for VMRG to take initiative for the Window element is questionable.

A Privately owned company such as BIMobject or autodesk could also be a potential developer, as they are neutral entities, not connected to a particular company or group of companies

Benefit for manufacturer:

By using the library, comparable information between different manufacturers is made available to the architect. The architect makes informed decision about the product, instead of using the material choices based on his experience or the availability of relevant details (as observed from Chris de Weijer interview). As many manufacturers are not yet on BIM, there is an information gap between architects and manufacturers. Also, those manufacturers using BIM have their data in overly complicated objects where each line is modeled. It is observed that this library is not useful for the architect. Thus, by having a library that has the performance based information from the architect, the manufacturers can generate their details according to the performance criteria. This simplifies the process and enables a more effective communication between manufacturer and architect.

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CHAPTER 10.

10. CONCLUSIONS

The aim of the thesis is to test the hypothesis of a BIM based window library (henceforth refered to library) which can be used for architects at design stage to make sustainable choices.

It is observed that BIM is emerging as an essential architect's tool but there are gaps in the information provided. At the same time, it is observed that following EPBD directive, sustainability is also an emerging topic. Thus, this thesis was an effort to bring the sustainability-related information to the manufacturer's BIM model.

This thesis focuses on reducing the gap between the architects and manufacturer. For the manufacturers, the shift from 2-D library to BIM based library is not fully evolved. The manufacturers today try to over-detail their BIM model, thus providing as much information possible to the designer. However, upon basic analysis of the existing libraries, it was observed that these over detailed models are inconvenient at the design stage. The literature research confirmed that geometric details are not important for the design stage. However, BIM has the potential of describing a range of non-geometric information.

On the other hand, it was observed that sustainability is a vast topic. Since the European EPBD (Energy Performance Building Directive) focuses on reducing Environmental impacts caused due to Green House Gases, environmental impact was chosen as a study point within the realm of sustainability. Within the environmental impact, the factors causing the Green House Gas Emissions in the building sector are recognised as embodied energy, operational energy and service life of the building elements. Thus it became fundamental to define parameters relating to embodied energy and operational energy that should be included in this library.

Based on literature and case study, Parameters based on EPC, Embodied Energy and Operational energy were formulated. These are expected to be within the BIM platform. A LOD 250 is defined for this level and the design stage where it can be used is after the schematic design and before tender documents. This tool has the data regarding parameters from EPC, Embodied energy and Operational Energy with added information that can help in making aesthetic decisions was concluded and consolidated within a working method in MS-Excel. This method is proposed to be incorporated within the BIM environment, which required IT related knowledge.

Thus, two main inputs are given by the research: The parameters relating to the making (relatively*) sustainable facade choices and the formula to compare the Total primary energy. The Parameters are described in detail in Chapter 8.3: Final Design.

The formula is given by:

$$\mathbf{PET_{LC} = PET_{o} / year + PET_{E} / Service\ life} \quad \text{....(eq. 2)}$$

PET- Primary energy total,

O- Operational energy

E- Embodied energy.

These two are combined into one tool, and added to the working method in Ms. Excel.

Research Question: developed tool

The above mentioned formula, guidelined of the library chapter and the parameters obtained from the research of literature helps to define an over-all framework of using the BIM library. This tool aids in to compare the materials from the BIM library, Thus answering the main research question: *How to effectively define the contents of a 'BIM library for curtain wall facade window elements' such that it guides architects towards a sustainable facade design during the design stage.*

In order to see how the tool helps in materia comparision, the tool was tested using virtual simulation for building performance, thus giving GHG emissions for energy spent in operating he building. GHG emissions for embodied energy was calculated manually and the formula was used to get the total energy. As observed from testing the tool, it is seen that comparing between operational energy is more important than the embodied energy, as within the

** The term relatively is used to define the environmental impact, as in this hesis only the GHG are considered.*

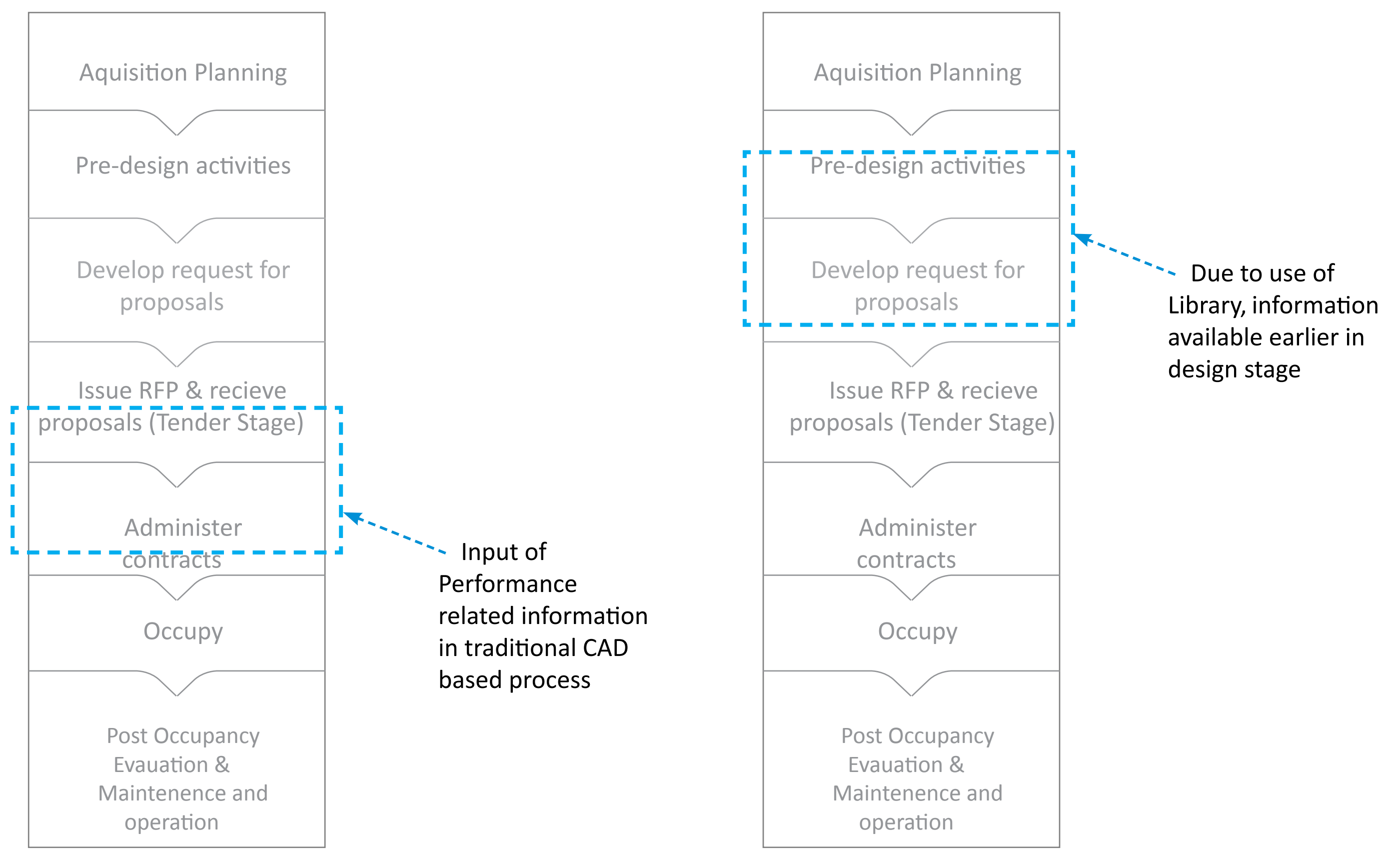

Figure 11.a: Effect of library : shift of information input in the Design-Bid-Build Process.

selected design, the embodied energy of curtain wall facade constitutes to 2% og GHG emissions copared to the total GHG emissions of Curtainw all embodied energy and whole building operational energy combined. However, whe only embodied energy is compared, and durability and recyclability are given priority, then the material choices are differet.

To test if the architects find this a valuable tool, a set of interviews of willingness of architects to use the proposed tool was conducted. Initially, it was found that the architects are reluctant to use the tool the way it is proposed in the thesis. The reason being that they find it complicated and consider window a small element that does not need so much time and effort. However, BIM managers (Mark Maas, Paul de Ruiter Architects; Björn Bleumink, DP6 Archtiects) agreed that this tool will be helpful for them and they would be willing to use it.

Role of the Library in current design process:

In the current design-bid-build design process, the information relating to the windows is provided by the consultant contractor in the initial design phase. However, the details regarding the window selection comes much later. Sometimes, some optimisation possibilities are observed after the tender stage, where it is difficult to make changes.

The Library provides a generic library that can be replaced b the manufacturer's details. Thus, during the design stage, the engineering information is provided to the architect. This provides possibility of optimisation before the tender stage, as compared to the traditional process where it will be after the tender stage. This method is expected to improve the tender, as the performance based criteria are defined. Diagram 11.a describes the shift in the

information provided to the architect in the design stage.

Furthermore, on looking at the design process in the Netherlands, it is observed that most of the engineering related information is already provided by the consultant contractor in the design stage. This means that currently, the information required is provided by the contractor and his knowledge and experience. This could provide a slightly distorted dimension, as options that are beyond the knowledge of contractor are ruled out. However, this library helps is making window choice based on optimisation from the availble comparable options, which is missing from contractor's input. The tool provided helps in calculating the total kg CO2 for the life time of the window element. This information, although is not required by clients at the moment, it is still required at an environmental impact point of view.

Role of research outcomes in sustainability:

Sustainability as a whole can be measured by 3 pillars: People-Planet-Profit or Social impact, Environmental impact and economic impact. The effect of library though these 3 spheres are studied by 2 outcomes of the library: displaying the importance of embodied energy and providing an over-all material comparison.

Social Impact:

The library displays the embodied energy, which is not generally the requirement from the client. However, the tool described in the thesis displays the embodied energy of the selected material. While the clients and designers choose to ignore this value, Embodied energy is essential to consider the total environmental impact of GHG emissions. The tool proposed in the thesis shows the embodied energy impact in the total environmental impact which considers Embodied energy, Operational energy and service life of the element. Thus this has an educative impact on embracing the importance of the embodied energy within the material and using it in the total impact. Thus, this helps in raising awareness of the total impact of the products considered.

However, both, design optimisation and importance to embodied energy needs more push than that given by the library. To some extent, this motivation

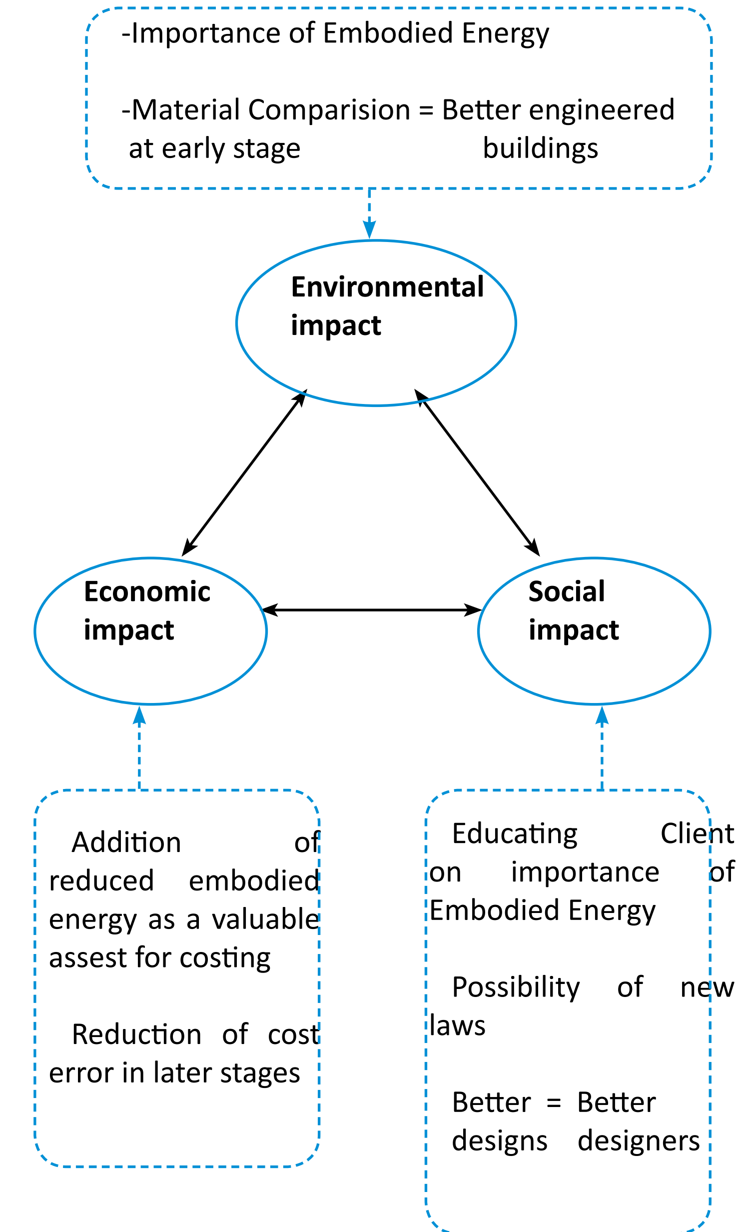

Figure 11.b: Impact of Library in the three spheres of sustainability.

can be provided by the law, if these calculations and simulations are made compulsory to show while approving the buildings. However, many architects and client are still slowly shifting towards BIM and are currently highly dependent on their experience rather than simulations. Thus, the time required for this shift is difficult to tell.

Environmental impact:

This is studied in much detail throughout the thesis. The important aspect that is considered for comparing the products is the Green House Gases emissions. The thesis proposed to calculate these emissions in both: the production to demolition phase (cradle to grave phase) as well as in the operational phase where the energy is consumed by the building in heating, cooling and ventilation. The most important conclusion found in this thesis regarding the calculation of the embodied energy is use of the formula (equation 2) given earlier in this chapter.

Moreover, the BIM library forces the architects to consider optimisation options. As explained in the previous chapter answering the Question 15: "How the proposed solution supposed to help in sustainable facade design?" a lot of relevant information that can influence the optimisation like u-value, Visual light Transmittance value etc are brought much further in the design process. This brings out the better engineered buildings.

Economic impact:

The economic impact of the library is difficult to define. One hand, considering the embodied energy impacts not only the cost of construction but also impact the cost of demolition and savings in re-using materials. Thus the embodied energy can be seen as an asset for the end of life phase. However, the time frame of building and service life of the elements also brings into question- how well it is maintained. This is especially important when we consider re-usable materials- what is the quality if the materials after the end of service life to the materials. These factors make it difficult to quantify into a euro value.

One clear benefit from the library is in avoiding the cost of errors in construction and operation stage. As the library already helps to define the performance of the window, the problems with the performance related windows is already fore-seen in the design stage. This means that there is less errors expected during operations as the performance is optimised. This saves replacement costs and can be especially beneficial in contracts that do not consider the operations and maintenance (contracts that do not consider DBFM or DBFMO) as a good performance is already guaranteed.

Adoption of BIM Library in Dutch AEC industry:

In general, it can be concluded that although many opportunities are seen by using this library, this is still not at a developable stage due to two main shortcomings: architects' uniwillingness or rejection to use this library as some are still against BIM and secondly, the developing authority of the BIM library. One Suggestion is if VMRG takes up the responsibility of creating this platform and at the same time educating the clients and designers about its use can be one step. Another possibility is through law enforcement, however, since the knowledge of using these softwares and tools is still crude, such a law will affect the designers negatively at this stage.

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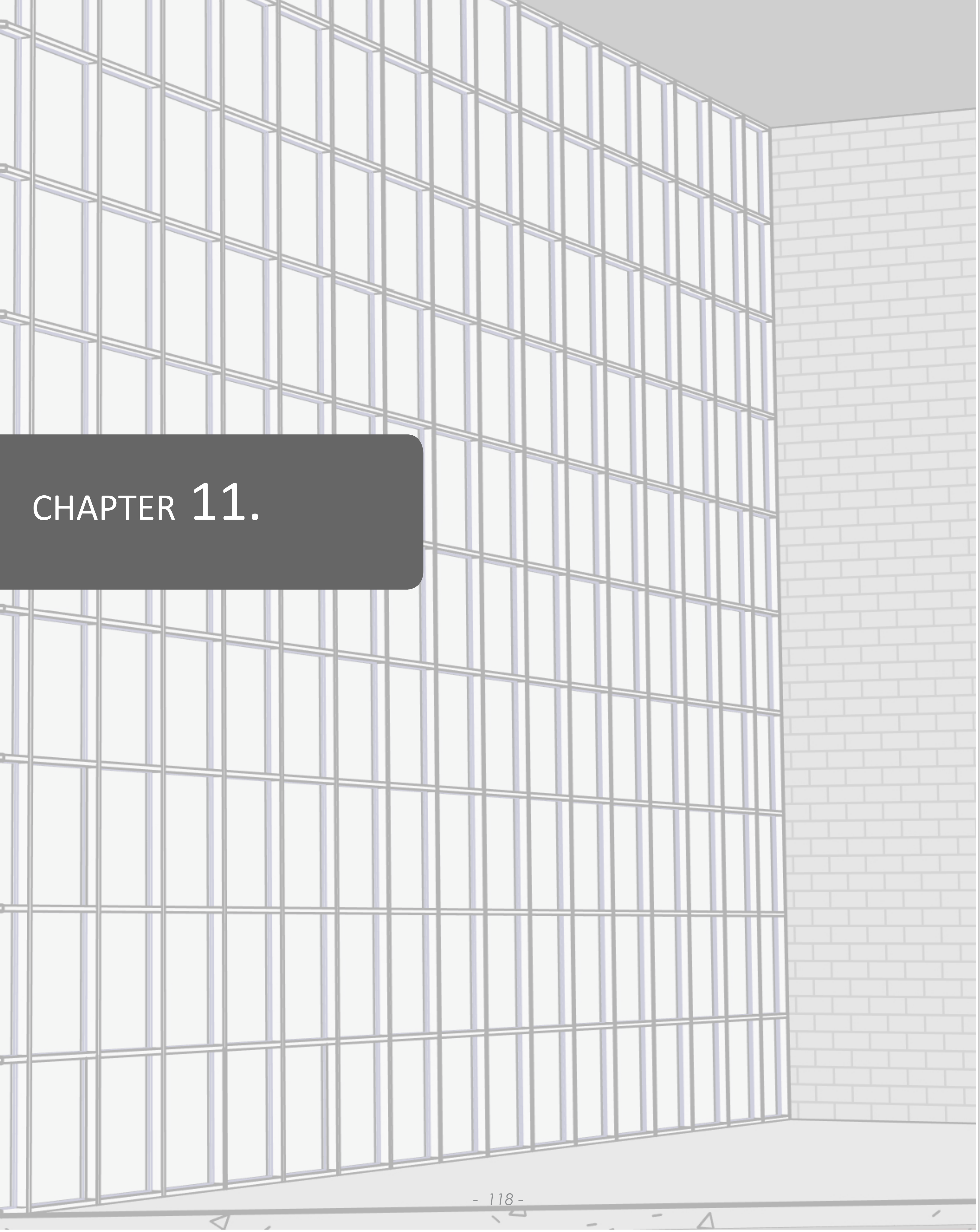

CHAPTER 11.

11. RECOMMENDATIONS

This research was an effort to bring sustainability and BIM in one platform. However, since both the topics are vast within themselves, only the environmental impact and within that, only the Green House Gas emissions were considered. Within BIM also, only BIM LOD 250 is considered. Thus, reconsidering the boundary of the thesis is a good starting point: to look at a broader view in environmental impact: at soil use, land use, toxicity and waste. Furthermore, this thesis focuses on the LCA database from NIBE and ICE. This does not consider the Re-use and Re-cycle potential. According to the European Parliament, 30%reduction in extraction of raw materials is proposed by 2030, by using circular economy: reuse and recycle. Thus this potential can be looked further and the databases used in the research can be defined more accurately.

GHG was selected for comparisons. However, there are many more aspects that define the sustainability of a product. To look into all the aspects of sustainability and a full sustainability analysis could be a good point for future work. Furthermore, many companies define their Environmental Product Declaration. This could be added as a connection to selecting the right product from the generic library. This step could include organising the database and defining the source that gives clearances to these EPD values. This could be a good addition to the library- where depending on the material and window type, available manufacturers can be viewed.

Limitations of NIBE and ICE database: both NIBE as well as ICE were generated few years ago. This means that the information is not always updated. Moreover, the calculation method of both these methods was not possible to look into in depth within the purview of this thesis. Also, it was observed that these databases did not include recycle and re-use capability. These could be important as a value generator- especially with the focus of European Union to focus on a circular economy.

Limitations of EPC database: EPC database gives an average value of the materials available for windows. However, this thesis did not focus on the database from frame manufacturers. This means that, there could be a possibility that the frame materials can achieve high performance values. However, at the moment, this information is unknown as this study needs to be performed. Moreover, the reliability of the softwares for operational energy can be questionable. As a general rule, it is considered that the same software should be used for the simulations for different materials, as the algorithm is the same. However, some studies have shown up to 20% difference between the simulated results and results after building is operational. Thus applying the tool and the Material data to a project as a case study can give more insights.

BIM in other phases of project delivery: it is a general notion that massing studies cannot be performed during the conceptual design stage. However, during this thesis, it was found that massing studies are actually possible and are also useful. However, the shift from massing study to LOD 250 (proposed LOD for the Library) is not a smooth process. Furthermore, after using the tool, the connection to selecting manufacturers should be made possible. BIM can be a useful tool for reducing the onsite waste by indicating delays in the construction schedule. Radio-Frequency Identification (RFIDs) could be useful. It was also found during the interviews that feedback from the user after occupancy is not available for the designers. Making a flow to connect this step can be a good step for future work as the design community has an opportunity to learn from constructed projects.

Two more aspects that I realized while interviewing the architects are: architects do not have feedback of the performance of the building (Peter Mensinga, Arup) and that Facilities managers do not necessarily know the design intent as that information is not present in BIM elements(Jeroene Coenders, White Lioness; Chris de Weijer, DP6). Thus, some information like the intention of design and final performance of the building and elements is lost while in operations. This could be a good research option- to test how to resolve the loss of information during the operations, as the information is partly already available in BIM model.

Comparison of products by price is not given importance in the current thesis. It is observed from the interviews that price is a major decisive factor. However, to make a correct judgement the initial cost should be viewed in relation to the operational energy. Probably, if the results of cost of operational and embodied energy can be compared with the onetime buying and maintaining cost, the clients and architects have a better idea about the cost implications of the chosen product I the long run.

Initially, there were considerations to test the library in an actual environment. However, due to reasons such as no proper possibility to integrate architects within the research and due to time restrains - of architects as well s the thesis, this step could not be performed. However, it is advised that this should be done. By applying the library in a real project involving actual designers and contractors, conclusions not known from this thesis can be obtained. This can help in improving the library.

Finally, the concept of BIM library bringing the sustainability related information to the architects can work to its maximum potential only when there are libraries available of all building elements such as structural systems, heating systems, ventilation systems, roof systems etc. It could be good to research how to bring these library systems together

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CHAPTER 12.

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CHAPTER 13.

13. ANNEXURE

13.1. CASE STUDY FOR LITERATURE REVIEW:

There were 2 case studies made in the begning of the project. The aim was to identify general advantages and ds-advantages in using BIM in the design phase and in contect to The Netherlands

13.1.1. CASE STUDY 1: SOUTHPARK HUB

Location Queen Elisabeth Park, London, UK

Project Size Multi-functional two storey pavilion which includes restaurants, offices, kitchens and shop.

(Relevant) Project details

Method: From the onset, it was decided that:

- The model will be used for coordination and clash detection purposes only
- Approach the design with handover in mind
- Work closely with facility manager to achieve their requirements for the 'as constructed' model

During the construction phase, the drawings were used from model to site.

Tendering stage

The model at tendering stage was LoD 200. at this time, the model in place was for reference only and not coordinated with BIM model. The Lod 200 Specification meant: Similar to design or design development, the model would consist of 'generalised systems or assemblies with appropriate quantities, sizes, shape, location and orientation.' Authorised uses would include analysis of selected systems by application of generalised performance criteria.

These were standard specifications the project was tendered at. however, post tender it was clear that LoD500 was the final requirement for the hand in of model post- construction. after the tender stage, the model was focused to drawing LoD500 model.

Advantages There were added advantages of having the model as a single point of reference:

- Reduction in RFI (Request for information)
- Solves issues in engineering point of view
- Development to as built phase smoother, since the models were updated in realtime. this means that there was no need to back-trace the steps to produce the as built drawings.

Key benefits of BIM (Post tender tage):

Co-ordination:

- Integrated process
- greater accuracy
- faster design resolution

communication:

- design development
- Validation and understanding of ideas and intent

Dis-advantages

It took more time to produce 2d drawings in 1:50 as it would in CAD. 2d drawings were a requirement by client. The 2d drawings needed to have a similar character to the conventional drawings and sometimes a 2d- drafting software was used to match the representation

LOD 500 was used post tender. Therefore the design stage is missing for analysis.

Figure 13.1.a : Image of the Project, showing its location within the complex.

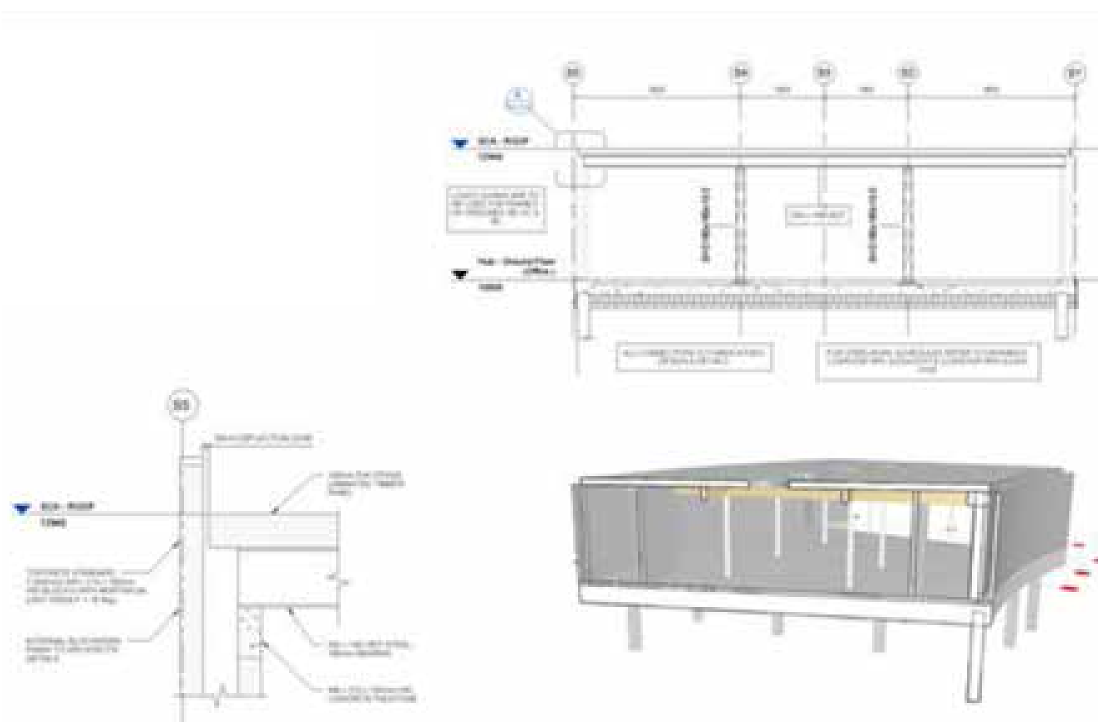


Figure 13.1.b : 2D drawing production from BIM model

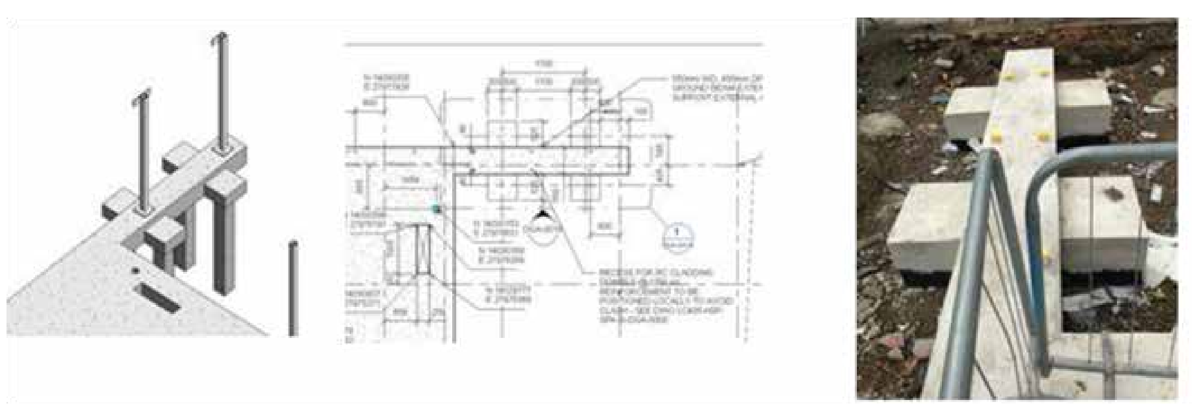


Figure 13.1.b : Transition from BIM model o Drawing to construction

13.1.2. CASE STUDY 2: CHRISTELIJK HOGESCHOOL EDE (C.H.E)

Figre 13.1.2.a : Image of C.H.E. Facade design by Inbo Architects, (image courtesy: Inbo Architects)

Location Ede, The Netherlands

Completition: 2015

(Relevant) Project details

Method:

The design stage progressed from LOD 100 (details relating to finance department) to LOD 200 (details relating to finance and contractor) to LOD 300 (details relating to finance, contractor and supplier of contractor).

In this particular project, each party, namely architect, contractor and engineers made individual models and the data is shared at the end of the week. The architect then updates his model according to inputs from other parties and the new model is shared in the beginning of the next week. Thus, this process is repeated everyweek. This also results in a lot of rework but on the upside the architect does not have to wait for the other parties to update their part in the model, in the case where every party works on one singular model on server.

However, it is important to note that there was also a higher authority called BRINK that was appointed by the client to check if everything in the model was in order. They also used it to control finance.

Regarding details of the geometric data, the façade started to take a definitive shape when the tender phase was approaching. In this phase, it also got more specific about the size and material of the façade. However, drawing doors and windows separately was rather complicated and showed many inaccuracies. Curtain-wall system of drawing tool from Itannex was used. In this tool, there is an extensive library of most components available in the façade market. Editing of the components after installation in terms of changing the frame type and element size was also smooth.

Advantages

In order to avoid re-working of the same components, in the beginning of the project, it was clear that the parties involved in the project had separate roles in model. This avoided any clashes between the working environment and model editing.

Dis-advantages

Important for architects was the material properties that sometimes hinders when rendering or generating real-views for client. However, that has to do with software incapabilities of rendering properties with respect to the near-realistic view required by the clients.

All consultants drew te same model and the elements were put togather every week. This means that some elements were redrawn by the consultants 2 or many times, resulting in wast

13.1.3. CONCLUSIONS

The library from Itannix can be very useful at LOD 100 stage. For LOD 200, however, additional data (mostly non-geometric) is required when talking about façade. These data are mainly the requirement of contractors and the engineers. However, if there was a range to choose from, the decisions could be made faster and more independently. For the data relating to price, the company still prefers to contact the system suppliers as they have the updated data.

Adding the data towards the end is much more difficult

It shoud be noted that the design stage is not explained in either of the case studies. However, a lot of engineering data engineerign data was made available earlier.

It is good to explain the design to sub-contractors together because all the systems work together

It is good to have the operator on-board at the design stage, as designing for maintenance is possible (and important). It is possible to therefore, get feedback from people who do the maintenance work which is an important part of a good design functioning.

Depending on contractual arrangements, the BIM Coordinator should act as the Lead Designer (in this case it was the architect)

Dring the design sage, the architects do not prefer using BIM as it does not give them the creative freedom they need while they are in the initial design phase. BIM should therefor be used when the Form-finding and design concept is clear. howeverm if BIM is used for post tender phase, it could be too late to implement efficiency related solutions. Therefore, BIM should ideally be used after the architectural concept has taken shape, but before the tender stage: Ideally in the beginning of the detailing stage.

13.2. QUESTIONNAIRE PART 1:

13.2.1. ARCHITECT:

Name: Saxon Leer Duckworth

Company: Inbo

Specialisation: *Architect and urban designer. Education building, public building, high density housing.*

1. **Do you use BIM?**

   As an office, yes. Personally, I find difficulty in time and to give precision

2. **(If no to above) If no, would you like yo use BIM, and in how many years?**

   Yes. I would like to implement more BIM methods in my office. But I would keep that as a specialist job n modeling not as a designer's work.

3. **If you already use BIM, do you see/foresee specific problems with its use/ interoperability?**

   Most of other consultants use Revit or Tekla. Revit is modeled based on export for Tekla. We use Clash detection software Solibri and in case of clashes, normally, we communicate with traditional methods like Telephone and emails. This is because, what we see is not easily understood he reason for why it is different from our consultant's model. We use BIM to think and judge if the underlying design concepts are approved.

4. **Do you design with sustainability outlook?**

   We refer to the basic regulations for building codes, but going further in-depth depends on the requirement by client.

5. **How useful do you think is BIM for facades at design stage?**

   Depending on level of design, initially it is framework of design where the exact details are unknown. For us, this starts in 2d, what looks in proportion to human eye. We use sketching tools like sketch up and rhino to visualize and BIM as a system of communication. I do not think of Revit as a tool for this initial conceptual design such as just a skin, and i on find it flexible with older models of Revit. The distinction between floor and walls is rigid. This inhibits fluidity in developing the design of building and restricts freedom of designing the overall building.

6. **How often do you design a curtain wall?**

   A complete glazed curtain - not so often. Although, we do use it for easy way o developing ad then replace by detailed facade with separate walls and window element.

7. ***Whether BIM or not, what information do you think is relevant at design stage for designing a curtain wall facade?***

   (refer chart)

8. **Q. I am working to develop a Library in BIM hat helps designers in early stages of design. How do you think can a library help?**

   Currently, we have an in-house library of elements that we draw as and when it is required. These are basic dimensions that we use to draw the technical drawings till tender stage. The problem with this library is that it is disconnected from any automated system. This means we have to manually update and clean-up many old library data manually which is cumbersome and prone to human error.

   The biggest problem i observe in libraries is the plug in. the companies expect an architect to install their own plug in, which is a separate plug-in from each company. Also, each company has their own libraries which are updated from time to time. I don't find t convenient to store each company's files on my computer as it will make my system low. Also, the libraries will need constant update which will increase inefficiency exponentially.

9. **Any special comment?**

   I have been against libraries from companies, since they add too much data that I cannot work in my architecture model. And this copy will be redundant with the new update in the facade system. Hence, I like to have the human connection of a facade expert who tells me all the prices and systems that I can use, by analysing my design.

However, I do see BIM as a potential to change the problem solving in the design stage as contractors an easily replace architectural elements with their detailed elements. this means that, small discrepancies like window sizes and facade aesthetics can be changes right from the start and there will be lesser re-work of drawings.

13.2.2. SUSTAINABLE ENGINEER:

Name: *Peter Mensinga*

Company: *Arup*

Expertise: *Sustainable engineer*

1. **Do you design with sustainable outlook?**

   Yes

2. **What are the sustainability issues that can be solved by facade? in other words, What is facade's role in helping solve sustainable issues?**

   Between inside and outside, analysis is always outside to inside and a good transition between the two. There are different ways to do this: Space inside the building: is it open building from inside? Can they be semi- conditioned spaces? Regulations also come into picture: material uses and the client needs to know. Furthermore, the facade protects from rain, wind, outside temperature, for which insulation value is essential. Solar irradiation control is also important. The next level of sustainability is to predict how the inside walls act depending on the external wall.

3. **Do you use BIM**

   We are in Transition. BIM is only used to certain extent. We do use the same CAD model that the architect s using. We use BIM for management guide, managing between different disciplines. Mainly we use BIM for the geometric information although we have not adopted full BIM methods.

4. **If no, would you like to use BIM? Give reason if not?**

   We are not yet fully implementing BIM. There are many restrictions associated with it. Questions are unanswered such as who is investing in software and learning? Is it architect, client, engineer, contractor, project manager? Which investment is fulfilled, time and finance?

   Also, (I see) BIM as a difficult tool to implement in the early stages of design, as at this stage, very little use of computer is made. I normally sketch over architects plan based on my experience and forward this to draftsman who completes the digital drawings.

5. **(If yes to using BIM), how would you use BIM for which purposes?**

   We use BIM, only for certain projects and at construction stage. This is because, we draw the buildings to very detailed level and that is useless if it is in the early stages where architect still makes many changes and we have to keep re-drawing all the details.

   We also use BIM for time-management of phases of the project which can be foreseen during the design stage. We also use it to understand technical things like performance, operational energy, and comfort zone for the users.

   The problem with new ideas is that it cannot be understood by users, but BIM can be a very useful tool in making this learning process. What is interesting is if BIM model once handed over can be moderated by users such that after construction, we can get feedback from our designs. This will help us in improving new designs and make the building sector more communicative.

6. **(If yes to using BIM), Do you observe problems associated with it?**

   The largest problem we see is investing time over BIM applications. If is financially feasible only if applied to a large scale, small scale development, I believe, has little potential.

7. **Q. I am working to develop a Library in BIM hat helps designers in early stages of design. How do you think can a library help?**

   I am unsure about this yet. See, how the architects design is first the interaction of facade at ground level and public space. Then upper floors for daylight, openings and the elevation relation to the street. We aid them in influence of openings on energy performance, as a basic guidance or a thumb rule. So yes a library consisting these thumb rules would definitely help the architects.

   However, when you don't know the output, computer models can have drawbacks. Exact calculations like cooling capacity take too much time, which is undesirable in the initial designing process. A basic guideline would help.

   So a library where technical details are available but put in place only at later stage would be useful. The library thus should provide easy calculations in beginning. This should still skip the sketch design. But when the construction companies are brought in, this could help them to get a better product.

8. **Which parameters of facade can be used to reduce operational energy <which parameters are most effective?**

   (Refer chart)

9. **Any special comments?**

   I believe BIM will result in shifting roles, it will bring more knowledge to architect and can influence understanding of decisions which could be helpful in design stage. Things come together as the engineering information can be available to architect.

   The parameters you mentioned in previous questions are the once that normally come in tender stage, but if it is included already in design stage, this can affect in quality but could be time consuming at the design stage, on the other hand, the later stages are (in this case) well defined.

Name: Floris Buijs

Company: JAZO Zevenaar BV.

Expertise: Sustainable engineer

1. **What kind of information (from architect) is relevant at tender stage ?**

   See answer Lion Schreven.

2. **What are the current problems in 2d drawing coordination/construction?**
   One of the biggest problems we encounter with 2d engineering is that you cannot oversee everything you're engineering/ designing. With the increase of complexity in architectural designs you cannot foresee every detail; therefore you are forced to make decisions which can result in additional time and costs.

3. **What are the opportunities you see in BIM projects**

   The experience we have with BIM projects is that we don't need a lot of drawings to set up/ design our models. We are able to retrieve the information directly from the BIM model. When there are questions/ problems we'd like to discuss with our clients or third party Company's, we can call them and walk through the model by phone. As a result of clash detection the chances of additional cost are reduced to a minimum, therefore we are able to give a more accurate delivery time for our products.
   For JAZO a company which specialise in ventilation of transformer & plant rooms we are able to add information to our BIM models such as; ventilation capacity, burglary proof, fire resistance, etc. Also with BIM we are given the chance to be more involved with the designing of the architectural structures of the transformer & plant rooms. This directly gives us the opportunity to be able to advice in an early part of the building process, which can lead to a reduction in cost & time for all the parties

4. **What difficulties do you observe whilst working with 3d models ?**
   Time, especially time!
   As a manufacturer of facades we are specialised in customized products, lots of one kind product. This means we are in the top region, in quality and in price. As a result of this we have to reduce cost wherever we can in order to stay ahead of the competing firms.
   The experience we have with BIM projects we done so far, is that it costs a lot of time, and time is money. We have to retrieve the information we need from the BIM models we receive. Then we can set up our models in drawing software, once this is done we have to export the models in a different format so we can upload them in the BIM model for a reverence check. This goes back and forward until the model ready for approval to our clients. We also still have to include drawings for third parties and utility companies.

13.2.3. FACADE COMPAY:

Name: Lion Schreven

Company: JAZO Zevenaar bv

Specialization: Ass. Architect & Building engineer

1. **What kind of information (from architect) is relevant at tender stage?**

   In the early process we can deliver parametric models, models that the architect could use in his project. Duel the process of designing the architect can make changes to the model; this model is changeable in width, height and depth. When the design is formed we get back our model, the model is than analyzed by our engineers who can then read out the parameters we needed for our manufacturing process.

   But when an architect doesn't use our model, we *would like to get information of the width, height and depth off the desired space. It would be useful to get this information at the beginning of the design process, so we can assist the architect and can easily adept our design.*

2. **What are the current problems in 2d drawing coordination/construction?**

   The environment around us is in 3D, you can easily see when an object fits. In a 2d environment I must consider different sections of a model to see if objects fit. And of course we can manage that; we did this a long time ago. The great thing about 3D modeling is the interference you see when you are moving objects. The object will move in all of the views and sections. Therefore faults will be seen in the early designing and engineering process and not on the construction yard. This saves money.

   As an architect I would say that the 2D drawings will always be around on the construction yard and on the design table. It is important to see joint in a 2D matter. 3D is too complex in a joint; a 2D drawing gives you an overview of the situation. The 3D models give me a great opportunity to make different designs in a short time. Evaluate the design and make changes.

3. **What are the opportunities you see in BIM projects**

   In this early process of BIM (we're using it since 2013) we see that there are opportunities for contractors. They can manage models, see the interference between different components and can add the 4D module of BIM. For a supplier like JAZO there is not really an upside, we use the BIM technology to get projects, we do not benefit from the software. We work in different engineering software that is more precise and can talk with our machines. The BIM software now on the market can't do that. Maybe in the future, when we are talking in the same file standard, the file standard that people and machines can read.

4. **What difficulties do you observe whilst working with 3d models?**

   It can be too complex. Designing in 3D will often affect your detail level. In 2D we draw every alloy window frame with the exact detailing of the manufacturer. If you at this detailing in 3D model (no 2D projection but physical 3D modelling) you will eventually ruin your project model. The extra detailing will slow down your PC, it doesn't react quickly enough on your actions (if you possess a quantum pc… then you're fine). It will drive you mad! So keep it simple, the big things in 3D the small detail things in 2D.

Name: Bram Kotter

Company: Alkondor, Hengelo.

Specialization: *Director, facade systems*

1. **What kind of information (from architect) is relevant at tender stage?**

   The outlines of the aluminium profiles and the architectural connections (between the construction and our façade or frames)

2. **What are the current problems in 2d drawing coordination/construction?**

   No problems

3. **What are the opportunities you see in BIM projects?**

   Working intensively together with all parties to eliminate faults. Being part of the construction process earlier (this is an opportunity for us).

4. **What difficulties do you observe whilst working with 3d models?**

   The level of detail which is demanded by our customers is different while we work with one database (Revit families). Further the export to IFC files has difficulties regarding data loss.

13.3. MODELLING DATA FOR CASE STUDY 1&2

Basic data for orange hall:

Room size: Length width height	30 x 25 x 13 m
Occupants	112
Façade: dimensions: length, height	30x13 m
Opaque façade element	(metal framing is negligible amount)
Transparent façade element:	100%
Shading/type	Yes/ Internal
Shading from other building/ trees	Yes- building
Ventilation situation	Artificially ventilated, ventilation capacity : 117,5 kW
Heating load	21kW (from lighting)
Cooling load	0
Lighting capacity	9000m3/h for 55 units
Acoustic	40dB (inerior)
Facade integrated functions	Shading
Support system	Metal grid supported by vertical metal column.
Location :	Delft, The Netherlands

Revit assumptions and modeling

Number of People:	163 people
Average Lighting Power Density:	10.67 W / m²
Average Equipment Power Density:	10.89 W / m²
Specific Fan Flow:	6.9 LPerSec / m²
Specific Fan Power:	-19,514.338 W / LPerSec
Specific Cooling:	0 m² / kW
Specific Heating:	0 m² / kW
Total Fan Flow:	5,124 LPerSec

Total Cooling Capacity:	-29,208 kW
Total Heating Capacity:	29,527 kW
Domestic hot water for heating	34,318
Floor Area:	741 m²
Fuel source assumed in area:	
Fossil	69 %
Nuclear	25 %
Hydroelectric	0 %
Renewable	6 %

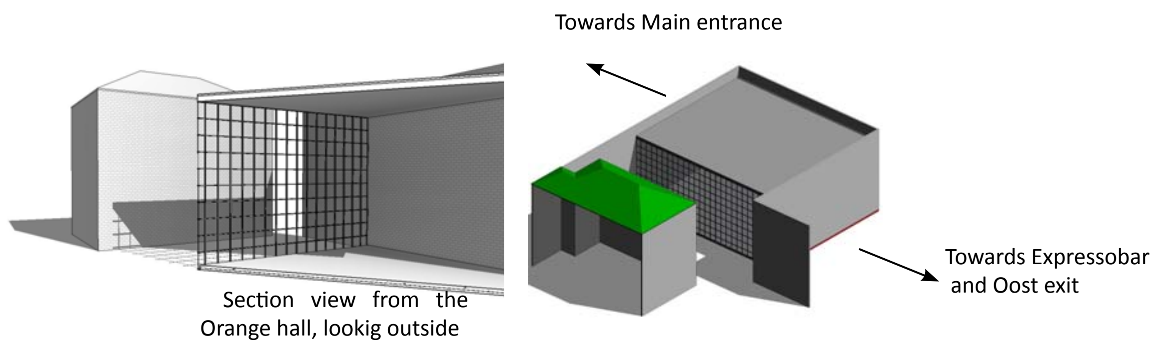


Figure 13.3.a: Images of the revit model

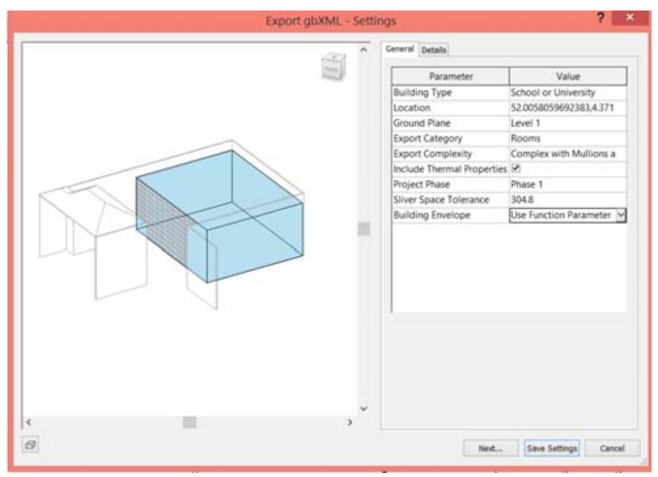


Figure 13.3.b: gbXML export condition from revit model

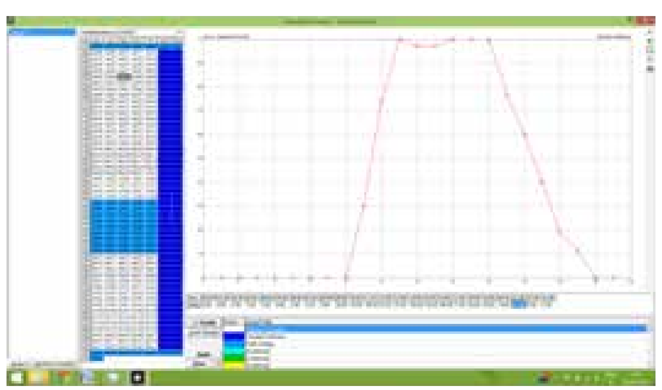


Figure 13.3.a: Scheduling and operational hour

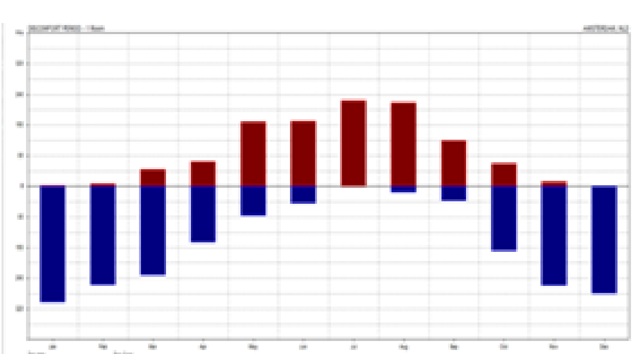
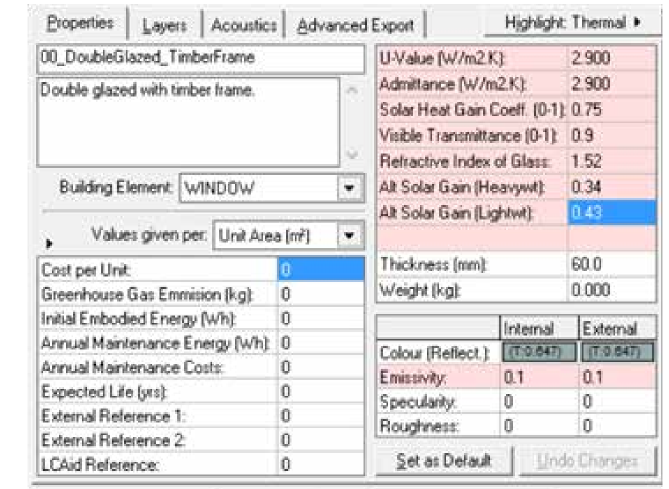
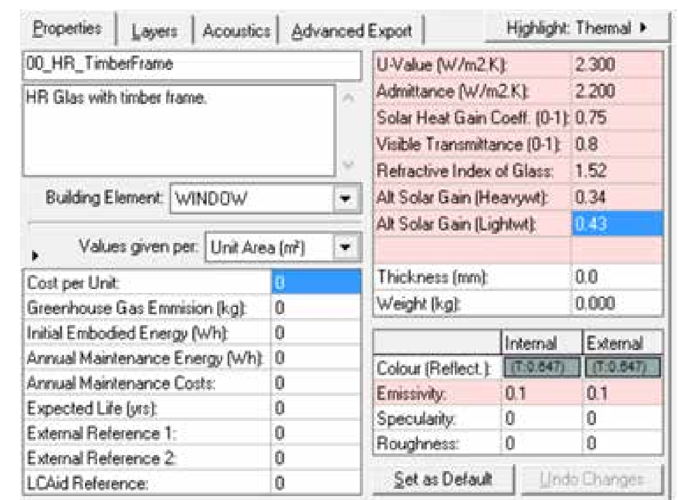
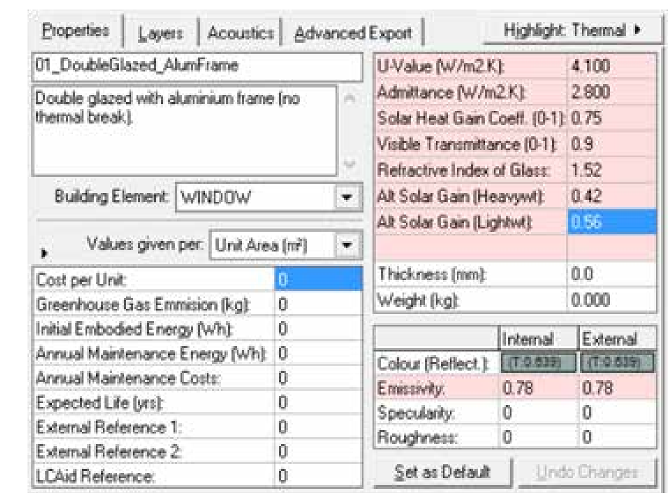


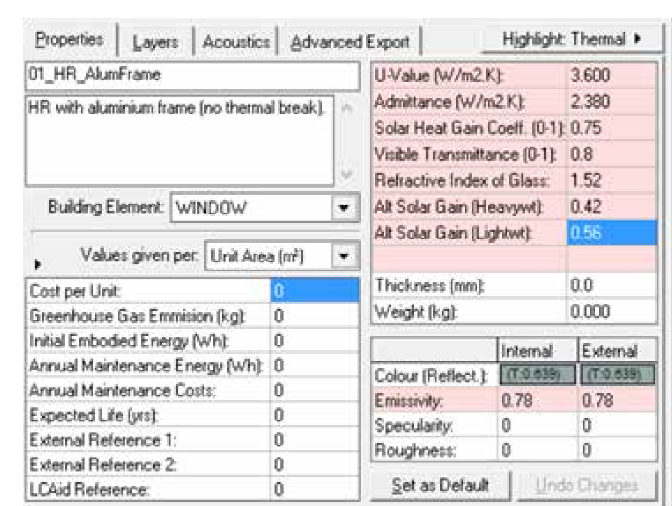
Figure 13.3.a: monthly discomfort

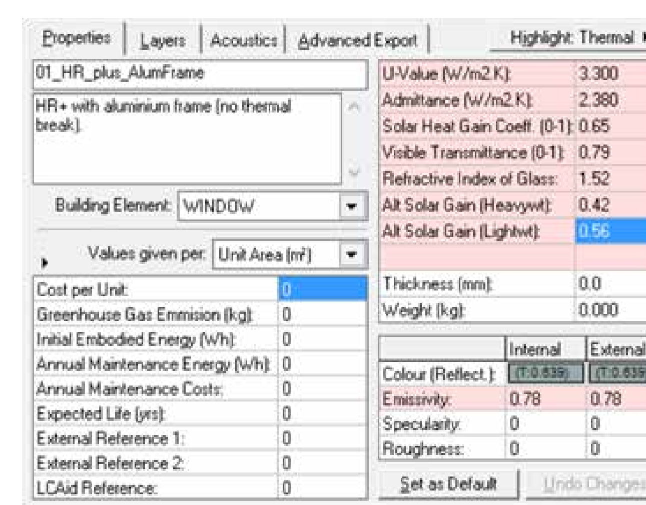
Material Input in Ecotect

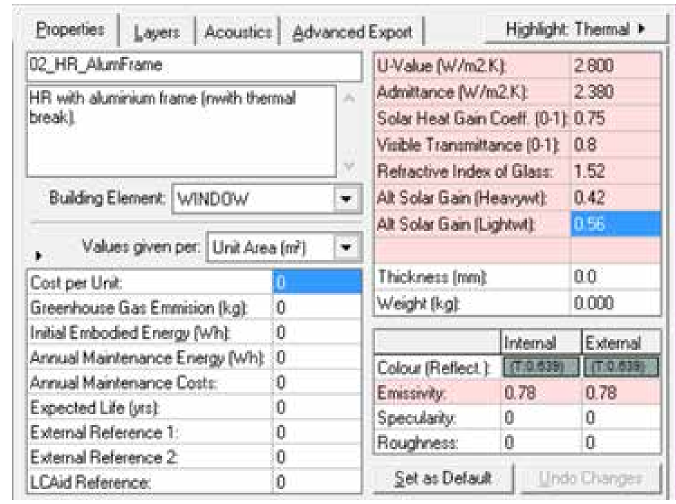


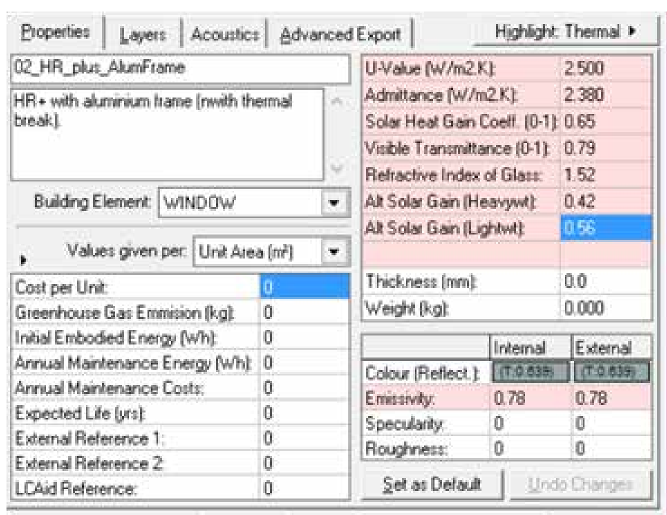


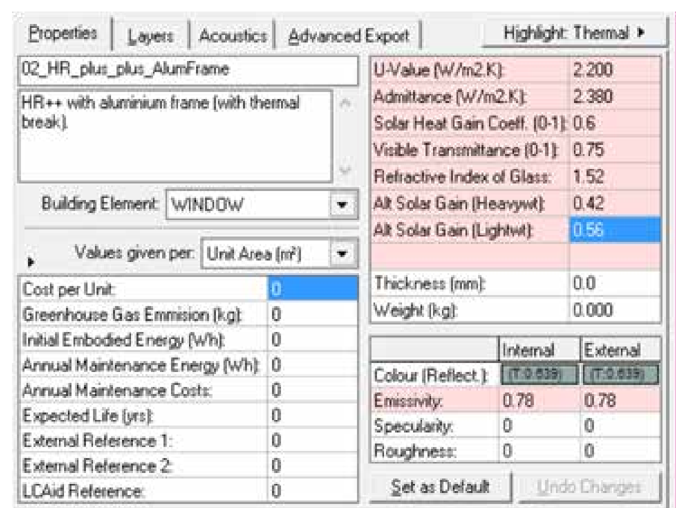












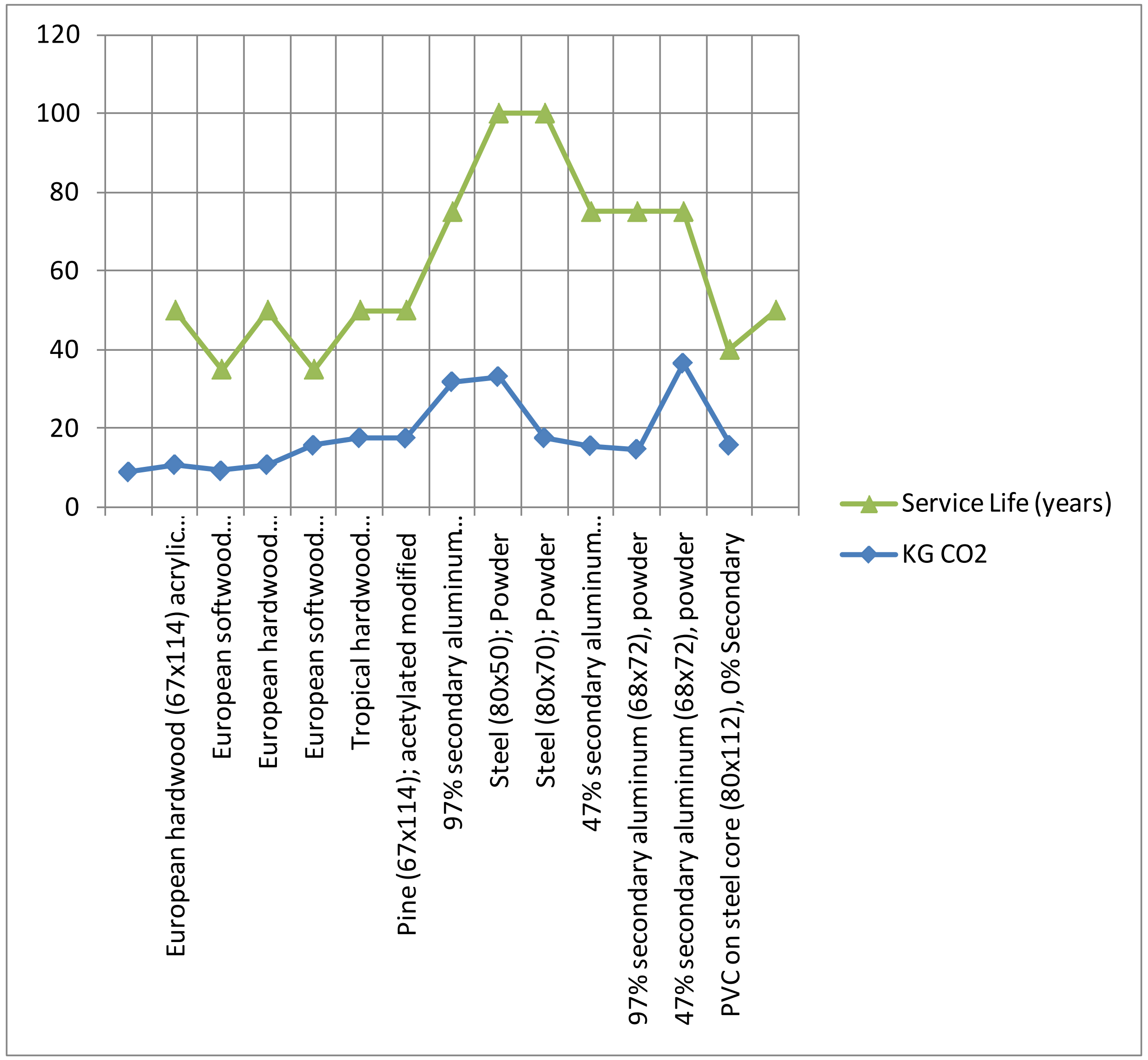
13.4. CHART USED IN CASE STUDY 1: DESIGN DEVELOPMENT

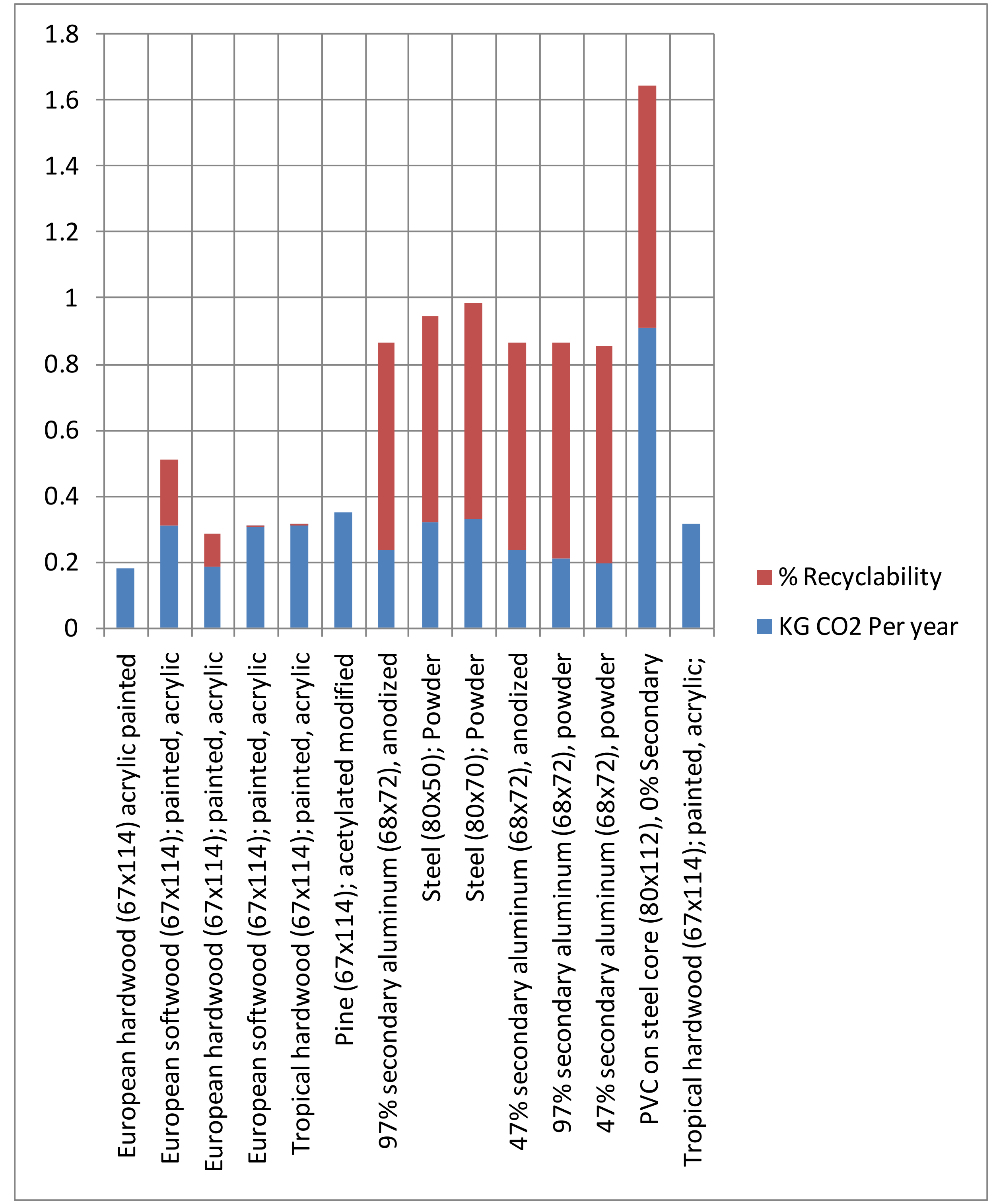
WINDOW FRAME PER M2	ENVIRONMENTAL CLASSIFICATION, DURABILITY	U VALUE KW/M²K	KG CO_2	END OF USE:	MASS	PRICE IN EURO
European hardwood (67x114) acrylic painted	1a, 50 years	2.4	8,95	Dumping ground: 4,7% Combustion: 95.2%	9.1kg	1,20
European softwood (67x114); painted, acrylic	1b, 35 years	2.4	10,8	Dumping ground 4,7 % Combustion 95,1 % Recycling 0,2 %	5.5kg	1,44
European hardwood (67x114); painted, acrylic	1b, 50 years	2.4	9,23	Dumping ground 4,7 % Combustion 95,2 % Recycling 0,1 %	9.1	1,48
European softwood (67x114); painted, acrylic	1c,35years	2.4	10,8	Dumping ground 4,7 % Combustion 95,1 % Recycling 0,2 %	5.5	1,65
Tropical hardwood (67x114); painted, acrylic	2b, 50 years	2.4	15,7	Dumping ground 4,7 % Combustion 95,2 % Recycling 0,1 %	9.1	2,36
Pine (67x114); acetylated modified	2b, 50years	2,4	17,6	Dumping ground 4,6 % Combustion 95,2 %	6,0	2,42
97% secondary aluminum (68x72), anodized	2c, 75 years	1,299	17,5	Dumping ground 4,8 % Combustion 32,2 % Recycling 63,0 %	3,8	2,92
Steel (80x50); Powder	3a, 100 years	1,3	31,8	Dumping ground 5,5 % Combustion 23,7 % Recycling 62,6 % Reuse 8,3 %	8,8	3,39
Steel (80x70); Powder	3a, 100 years	1,3	33,1	Dumping ground 4,9 % Combustion 20,8 % Recycling 65,6 % Reuse 8,7 %	10,1	3,59
47% secondary aluminum (68x72), anodized	3a, 75 years	1,299	17,6	Dumping ground 4,8 % Combustion 32,2 % Recycling 63,0 %	3.8	3,69
97% secondary aluminum (68x72), powder	3a, 75 years	1,299	15,6	Dumping ground 5,0 % Combustion 29,2 % Recycling 65,7 %	3,6	3,70
47% secondary aluminum (68x72), powder	3b, 75 years	1,299	14,7	Dumping ground 5,0 % Combustion 29,2 % Recycling 65,7 %	3,6	4,47
PVC on steel core (80x112), 0% Secondary	4b, 40 years	-	36,5	Dumping ground 6,9 % Combustion 15,5 % Recycling 73,4 % Reuse 4,3 %	7,2	6,80
Tropical hardwood (67x114); painted, acrylic;	6a, 50 years	2,4	15,7	Dumping ground 4,7 % Combustion 95,2 %	9,1	19,90

(A window frame of 1500x3300 mm, which meets the requirements of the Building Act. The frame has a U-value of up to 2.5 W / m²K.Finishes, maintenance, glazing / glass beading and rubbers should be included. The amounts are calculated back to 1 m². Fasteners, glass, mounting frame, locks, soothes closet, sill or weir were not included.)

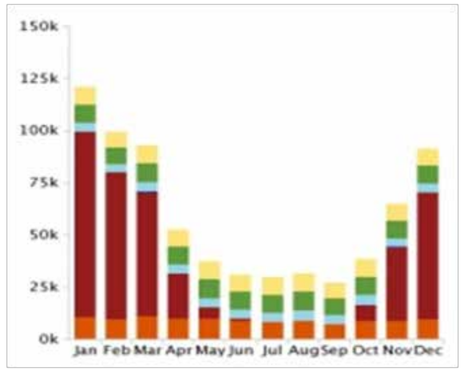
Material	Kg CO2 per kg material
Krypton filled	26
Xenon filled	229
Glass	0.85

13.5. CHARTS FOR CASE STUDY 1

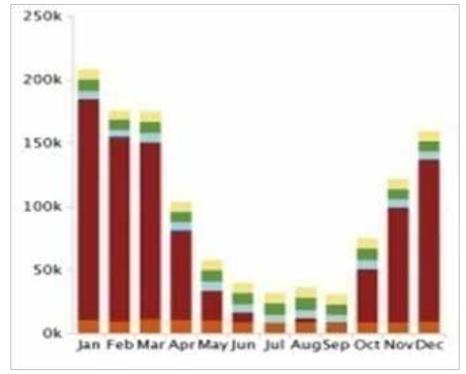




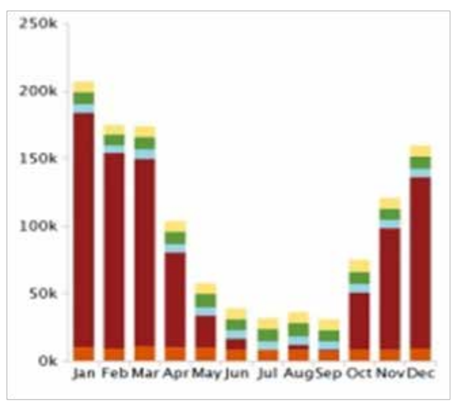
13.6. CHARTS OBTAINED FROM CASE STUDY 2



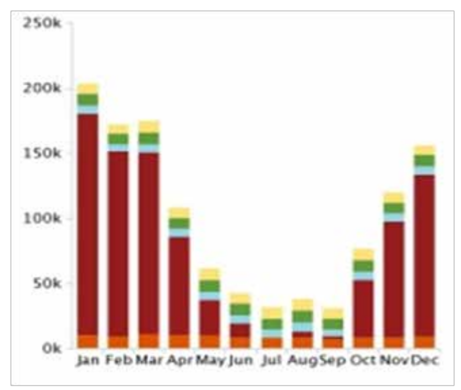
Base Run



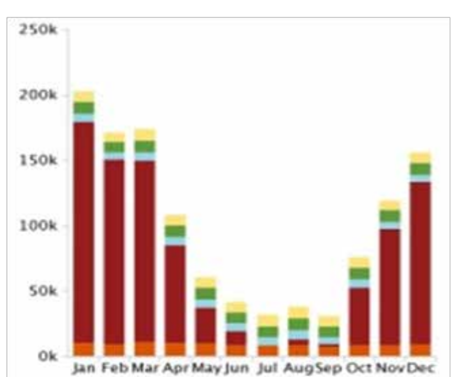
Metal frame with double gllazing



Wood frame with double glazing

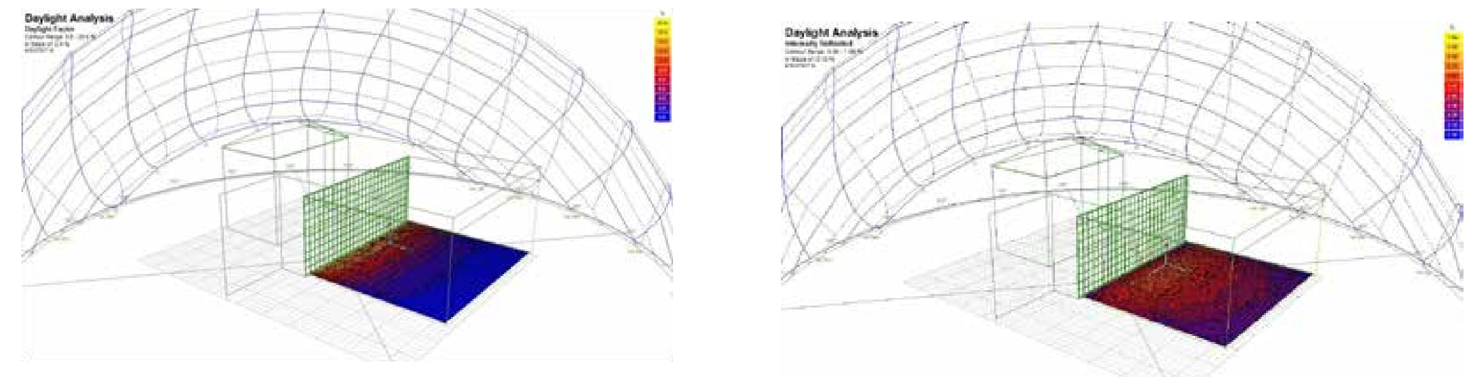


Metal frame with triple glazing



Wood frame with triple glazing

13.6.1. IMAGES AND CHART FROM ECOTECT



Figures indicating daylight levels and internally reflected light respectively

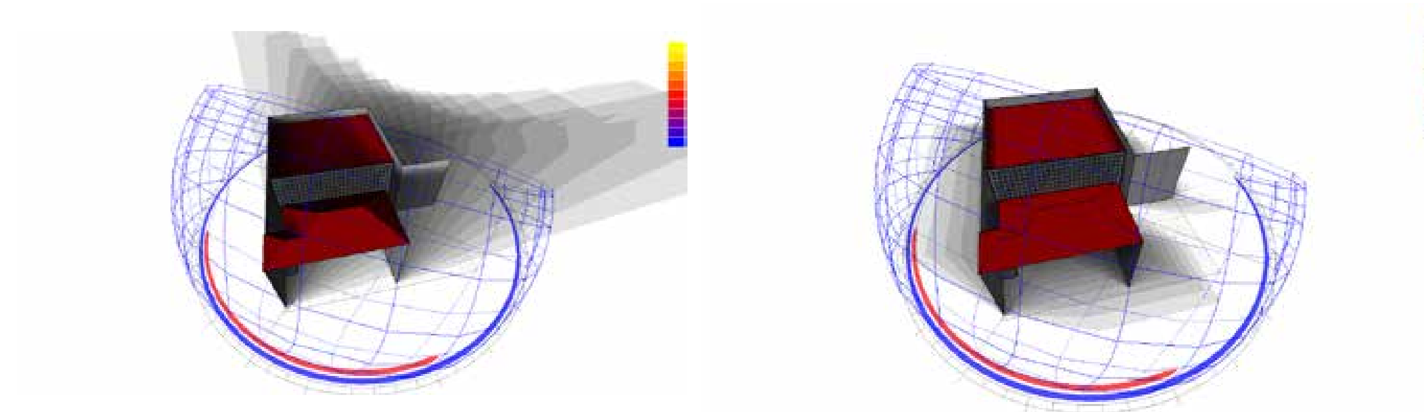
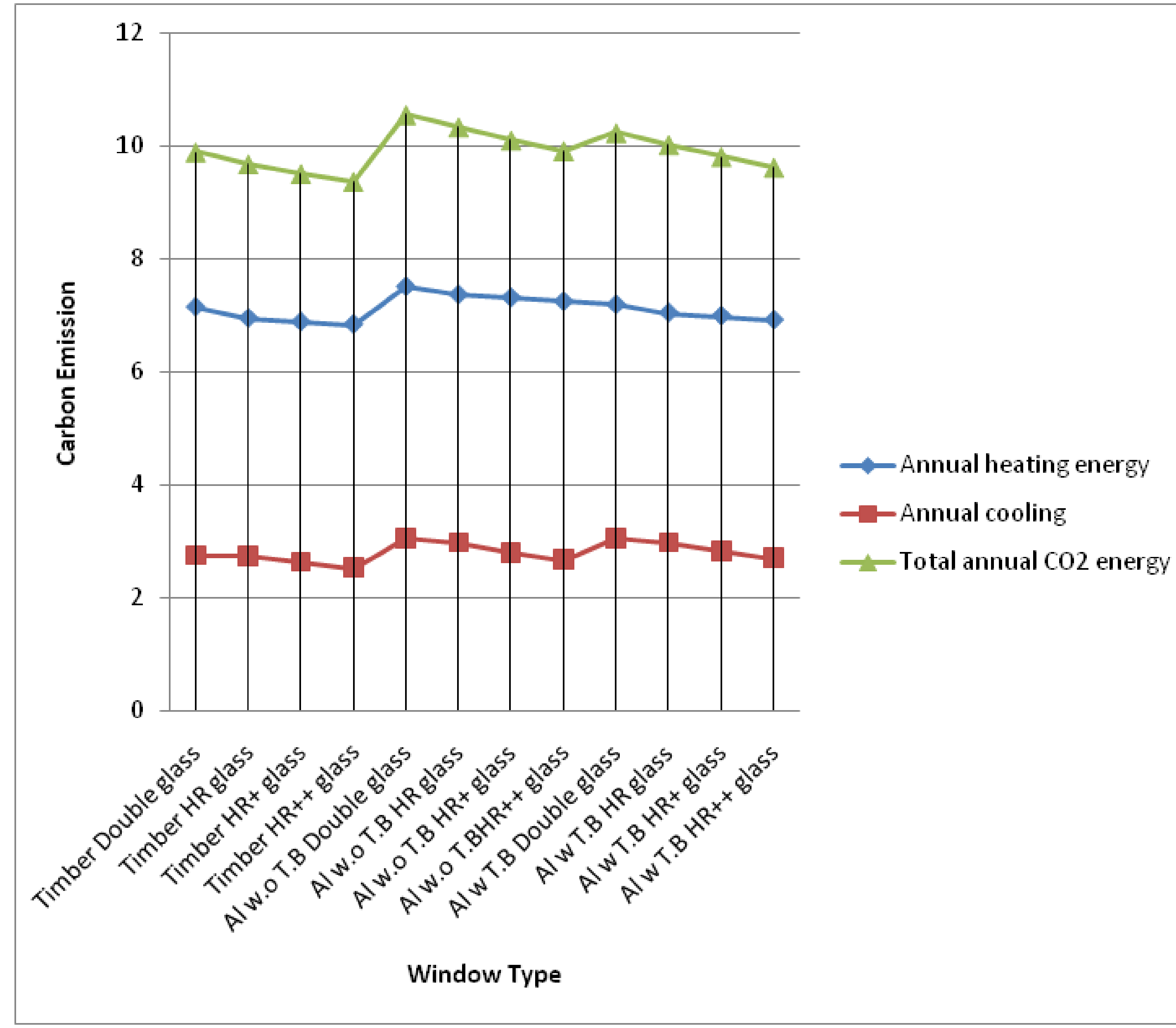


Figure indicating the hourly shadowing of winter and summer solstice, respectively

	Timber				Aluminium without thermal break				Aluminuim with thermal break			
	Double glass	HR glass	HR+ glass	HR++ glass	Double glass	HR glass	HR+ glass	HR++ glass	Double glass	HR glass	HR+ glass	HR++ glass
Max heating (kW)	197.9	193.7	191.6	190.2	206.4	202.9	200.7	198.6	200.7	197.2	195.1	192.9
Max heating on	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec	16:00 in 17 dec
Max cooling (kW)	305.1	297.6	289.8	285.3	324.6	315.4	305.4	298.1	322.7	313.5	303.6	296.2
Max cooling on	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june	12:00 on 7th june
Total heating (kWh)	223770	217593.8	215457.5	214094.8	235075.7	230608.1	228989.8	226775.6	225039.8	220607.578	218879.406	216581.188
Total cooling (kWh)	85968.5	85614.7	82278.5	79163.0	95451.6	92999.4	87448.4	83678.2	95423.7	93153.672	88322.6	84652.3
Total load: (kWh)	309739.1	303208.6	297736.0	293257.8	330527.2	323607.5	316438.2	310453.8	320463.5	313761.250	307202.0	301233.5
Per sq.m heating	298.4	290.125	287.277	285.460	313.434	307.478	305.320	302.368	300.053	294.144	291.839	288.775
Per sq m cooling	114.6	114.153	109.705	105.551	127.269	123.999	116.598	111.571	127.232	124.205	117.764	112.870
Per sq. total energy consumption	412.986	404.278	396.981	391.011	440.703	431.477	421.918	413.939	427.285	418.348	409.603	401.645
Annual heating energy (Kg CO2)	7.148 x10^6	6.950 x10^6	6.883 x10^6	6.839 x10^6	7.509 x10^6	7.367 x10^6	7.315 x10^6	7.244 x10^6	7.189 x10^6	7.047 x x10^6	6.992 x10^6	6.918 x10^6
Annual cooling Energy (Kg CO2)	2.746 x10^6	2.734 x10^6	2.628 x10^6	2.528 x10^6	3.049 x10^6	2.971 x10^6	2.793 x10^6	2.673 x x10^6	3.048 x10^6	2.976 x10^6	2.821 x10^6	2.704 x10^6
Total annual CO2 energy	9.894 x10^6	9.684 x10^6	9.511 x10^6	9.367 x10^6	10.558 x10^6	10.338 x10^6	10.108 x10^6	9.917 x10^6	10.237 x10^6	10.023 x10^6	9.813 x10^6	9.622 x10^6

Summarised results from Ecotect



Analysis as obtained from Ecotect values

13.7. TABLES FOR CHAPTER 8.5: TESTING THE FRAMEWORK

	Timber				Aluminium with thermal break				Aluminium without thermal break				Steel with thermal break				Steel without thermal break			
	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed	single Glazed	double Glazed	HR+ glazed	triple glazed
Single glazing (u value)	3,0	-	-	-	3,4	-	-	-	3,4	-	-	-	3,4	-	-	-	3,4	-	-	-
Double glazing (u value)	-	2,5	-	-	-	2,9	-	-	-	2,9	-	-	-	2,9	-	-	-	2,9	-	-
HR+ glass	-	-	2,0	-	-	-	2,4		-	-	2,4		-	-	2,4		-	-	2,4	
Triple Glazing (u-value)	-	-	-	1,3	-	-	-	1,7	-	-	-	1,7	-	-	-	1,7	-	-	-	1,7
VLT	0,95	0,9	0,65	0,60	0,95	0,9	0,65	0,60	0,95	0,9	0,65	0,60	0,95	0,9	0,65	0,60	0,95	0,9	0,65	0,60
SHGC	0,85	0,75	0,65	0,60	0,85	0,75	0,65	0,60	0,85	0,75	0,65	0,60	0,85	0,75	0,65	0,60	0,85	0,75	0,65	0,60
kgCO2 per year (frame)	0,185				0,196				0,196				0,318							
Recyclability	0.10%				65.70%				65.70%				62.60%				62.60%			
Price in euro (indication)	1,48				4,47								3,39				3,39			
Durability	50 years				75 years				75 years				100 years				100 years			
Heating load (kWh)	42765	41049	40589	38822	45008	43328	42979	41292	49573	47955	47837	46292	45008	43328	42979	41292	49573	47955	47837	46292
Cooling load (kWh)	2334	2019	1614	1364	2347	2031	1626	1346	2371	2048	1650	1369	2347	2031	1626	1346	2371	2048	1650	1369
Total kWh	45100	43069	42204	40186	47356	45359	44606	42638	51945	50003	49487	47662	47356	45359	44606	42638	51945	50003	49487	47662
GHG operational	25707	24549.33	24056.28	22906.02	26992.92	25854.63	25425.42	24303.66	29608.65	28501.7	28207.59	27167.34	26992.9	25854.63	25425.42	24303.7	29608.7	28501.7	28207.59	27167.34
GHG embodied FRAME	71.78				76.048				76.048				123.384				123.384			
GHG embodied glass[1]	47.94	63.92	70.63	102.59	31.96	42.61	47.08	68.39	31.96	42.61	47.08	68.39	23.97	31.96	35.31	51.29	23.97	31.96	35.31	51.29
total embodied energy	119.72	135.7	142.41	174.37	108.008	118.658	123.128	144.438	108.008	118.658	123.128	144.438	147.354	155.344	158.694	174.674	147.354	155.344	158.694	174.674
total primary energy	25826.72	24685.03	24198.69	23080.39	27100.93	25973.29	25548.55	24448.1	29716.66	28620.4	28330.72	27311.78	27140.3	26009.97	25584.11	24478.3	29756	28657.1	28366.28	27342.01

[1] Value of glass as well as gas infil. For calculations, refer appendix

All values displayed are in kg CO_2 unless otherwise specified

Table 13.7.a: Tabulated values of input and results in ecotect. A summary is used in table 8.5.b

13.7.1. CALCULATIONS FOR TABLE 8.5.B

Single Glass :
Weight of 6 mm glass: 15 kg/m2
Mass= 15 kg/m2 X 188 m2 (surface area glazing)
= 2820 kg
Embodied energy of glass= 2820kg x 0.85 kg co2 per kg
= 2397 kg CO2

Double Glass : 4-15-4 (air gap)
Weight of 4 mm glass: 10 kg/m2
Mass= 10 kg/m2 X 188 m2 (surface area glazing)
= 1880 kg
Embodied energy of glass= 1880kg x 0.85 kg co2 per kg
= 1598 kg CO2

HR+ Glass: 4-15-4 (krypton gas)
Embodied energy of glass= 1880kg x 0.85 kg co2 per kg
= 1598 kg CO2

Embodied energy of Krypton:
Volume of krypton= 20m x 9.4m x 0.015m = 3.456m3
Mass= Density x Volume
= 3.733 kg/m3 x 3.456 m3
= 12.901 kg
Embodied energy of Krypton= 12.901 kg x 26 kg CO2 per kg
= 335.426 kg CO2
Total embodied energy = 2x embodied energy of glass + embodied energy of krypton= 3531.426
Since the service life of wood is 50 years, the embodied energy per year is 70.628 kg CO2 per year.

Triple glass: 4-15-4-15-4

Embodied energy of glass= 1880kg x 0.85 kg co2 per kg
= 1598 kg CO2
Embodied energy of Krypton= 12.901 kg x 26 kg CO2 per kg
= 335.426 kg CO2
Total embodied energy = 3x embodied energy of glass + embodied energy of krypton= 5129.426
The durability of glass and filling gas depends on the durability of frame material. The glass and gases last much longer than the frame material, however, when the frame has reached its end of life, the whole window will be replaced to maintain good quality. The below mentioned table gives an overview of the embodied energy per year of glazing type, which directly corresponds to the durability of the frame material.

	Single 2397 kg CO_2	Double 3196 kg CO_2	HR + 3531.426 kg CO_2	Triple glass 5129.426 kg CO_2
Wood 50 years	47.94	63.92	70.63	102.59
Aluminium 75 years	31.96	42.61	47.08	68.39
Steel 100 years	23.97	31.96	35.31	51.29

13.8. INTERVIEWS DURING TOOL DEVELOPMENT PHASE

13.8.1. ARCHITECTS :

13.8.1.1. CHRIS DE WEIJER (DP6 ARCHITECTS)

Specialise in Sustainability and BIM
General background questions:

1. **How many years in BIM / sustainability?**

   As far as I can remember... Somewhere in the early 90's. I guess around 1992-93.

2. **What kind of projects mainly undertaken?**

   We have a wide range of portfolio. Earlier we were mostly into dwellings. Now we have projects ranging from schools, education, cultural centres. We also have some offices, not too many. From the housing sector, we have mostly refurbishments and very few new dwellings.

Sustainability related questions:

3. **In which directions are you interested in sustainability? Do you use Certifications like LEED/ BREEAM/ EPC? Any other?**

   We are mostly interested in the operational energy of the building. Recently we designed the BREEAM Excellent building in Holland. It s called ROC Friese Poort. EPC is the underlying rule, so it has to be used in the design stage. We are recently looking also into innovative materials.

4. **On a scale of 1-10, how important is operational energy for you while at the design stage (before Tender)?**

   Very important. I would rate it about 8 or 9

5. **On a scale of 1 to 10 how important is embodied energy for you while at the design stage (before tender)?**

   Less important than operational energy. It is mostly not required, unless the client requests it.

6. **What is the motivation to design sustainable buildings? What are the obstacles?**

   The motivation in an underlying broader view which is to do with thinking for the future generations and how to save the planet. It is deeper discussion relating to the definition of sustainability.

   The largest obstacle we see in designing using sustainability is the financial constrain from the client. For example, in the ROC Friese Poort Project, if we had a larger budget, we could have done a better job.

7. **What is client's motivation for sustainable buildings?**

   A part of it has to do with the same motivation that we have, that is to make a better world. But a large motivation is that sustainability has monetary value. They expect to sell their buildings for a higher price. The buyers also see that the buildings save energy and this works for selling the finished buildings for a higher value.

BIM:

8. **Could you elaborate your interest in BIM? What is your motivation?**

   We have been interested in BIM since a long time. Our first project was the Cinema in Eden. It was complex geometry, set into the hill, and could only be understood properly only in 3D. Ever since, we use BIM for complex geometries or when client demands BIM use. It is good during the use stage to have as-built model in BIM. We start using BIM during the VO stage. In Holland we have 3 design stages: SO (schematic design), VO Preliminary design, DO (final design). We begin with LOD 100 and move to LOD 400 immediately after the design is finalised and details are required. We use mostly details from Shuco as we have them already. The sectional data of the frames is important before we go to the tender stage. In terms of the non- geometrical data, we normally use U- value. We want to be as precise in our values to be as sure as possible. Apart from that, LTA and fire resistance are also important as they are required for building approvals.*

9. **Where BIM can be in the new design process?**

   I wouldn't want to change it. I find the current method very convenient to work with.

Figure 13.8.1.1.a

Figure 13.8.1.1.b

Figure 13.8.1.1.c

Figure 13.8.1.1 (a-c): ROC Friese Poort, Drachten.
Figure 13.8.1.1 (d-g) : Cinema EC, Eden.

(All Images Image Courtesy: DP6)

Facing Page: Parameter v/s Design stage as suggested by Chris de Weijer.

Figure 13.8.1.1.d

Figure 13.8.1.1.e

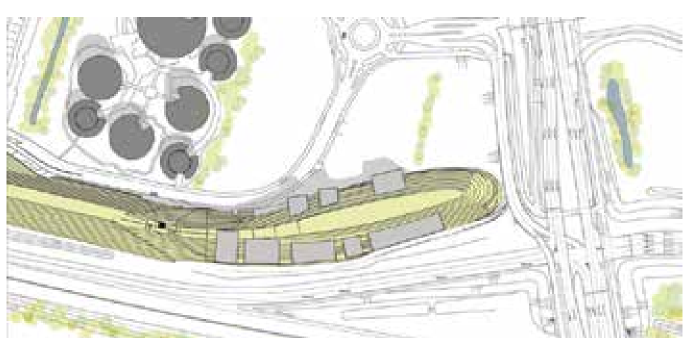


Figure 13.8.1.1.f

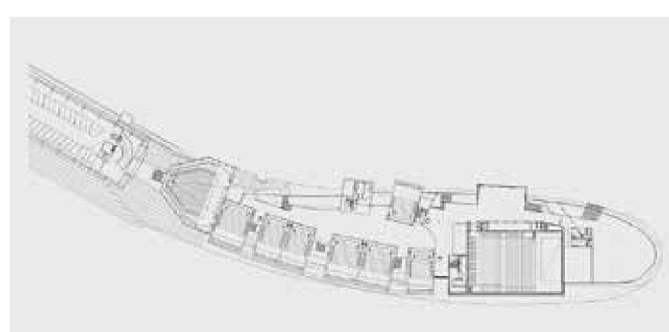


Figure 13.8.1.1.g

10. You use BIM already in the preliminary design stage. What are advantages/ disadvantages?

We use BIM not while schematising, but during the VO stage. At this time we are already in contact with other consultants and we work in close contact with contractors. The advantage are many: the model is prepared according to the use phase, communication is better, less time is required and the quality of buildings are better. The dis-advantages are a difficult question.

11. Where is sustainability in the current design process?

We start thinking and making strategies before the sketch design. This way, our ambitions are clear even before we start designing anything.

12. What are advantages/ disadvantages?

There are hardly any disadvantages of starting early. The earlier we are into sustainability, the less time we waste during the later phases.

13. How much influential is the facade in respect to sustainability?

Facade is important for Loss/ gain of energy. We have advisors who make the simulations and give us an estimation of the operational energy. We usually involve them in the very beginning of the project and work closely with them.

Social:

14. How architects see their role in sustainability?

Architects have a broad role. They are the most important in the design process.

15. BIM/ sustainability in process of design-shortcomings? Future vision?

This is a difficult question. 15 years ago we did not have the possibility of computers. Only 10 years ago we are getting so advanced in this tool. Right now, BIM is already better for calculations: it is faster and more accurate. The shift is incredible and difficult to predict what is next.

16. How should the facade companies improve in providing the information? Which information is more relevant? What kind of preciseness/ range? (Chart useful?)

From the chart, all the data checked in the preliminary design phase should be included.

Proposed solution: short presentation and excel file of proposed design

17. Is this solution convenient at the design stage?

I wouldn't prefer using the tool. We normally want to perform whole building analysis. Just this tool is giving incomplete information. Besides, this tool also has Embodied energy, and we normally focus mainly on operational energy. If the client requests Embodied energy calculations or BREEAM aspirations, we ask our energy advisors to make the LCA calculations. It is not what I would use everyday

18. If this is as a plug in, would it be easy for you to use it?

*Probably. The details of working method can be discussed with my colleague (Björn Bleumink)**.*

19. Should this be readily available from a dropdown menu or prefer putting the range/ number manually in BIM applications?

I wouldn't prefer a range of number. I would want the exact number to be absolutely sure of what information goes in.

20. Would you prefer a standard list of parameters to lead you step by step towards sustainability (like EPC, BREEAM) or would you prefer to demand the parameters as needed by your design?

EPC is required for the approvals. So those parameters should be there. BREEAM aspirations

** It should be noted that the LOD mentioned refers to mainly the geometric detail.*

*** An interview with the colleague is followed by the questionnaire* *should be discussed with special consultants to make sure it is in order.*

21. Additional comments.

Not at the moment.

Discussion with Björn Bleumink.

During discussion with Chris, he mentioned that the details of working with Revit can be better explained by his colleague who actually uses the Itannex database. Chris asked Björn if he had some time to answer some questions and Björn cordially replied to the questions. The following is a transcript of the short discussion, th questions mainly revolved around working method with Families.

P: Chris tells me you also use Itannex library. It is similar to the one I have researched ? how handy is it?

B: Itannex had a workshop where they showed us how we can use BIM Software Revit and the manufacturer's data. The Library has to much info and we cannot use it as we need a bit more general where we can add our information. Therefore, we make our own families with simplified geometries.

P: What kind of simplified of geometries do you work with? And at which design stage?

B: We need simple geometry because when we are printing at 1: 50 or 1: 100 scale, we cannot see anything when the geometry is complex. We use LOD 100 and develop it till LOD 300. (image shows reference)

P: what kind of non-geometric data is also associated with it?

B: the geometry helps to get the quantity such as Sq. Ft of Glass. The dimensions entered match the outer dimension of the manufacturer. Normally, we have cad file links to the model for the details, which we use to generate 1:5 details when required. These are generated from Revit.

P: If you had could based families, would it be easier for you to search your families?

B: Yes, Right now, we do find it difficult to search the revit families. If they are on cloud, it will be easier to search.

P: So I assume you prefer your simplified families to be on the cloud?

B: Yes, but also, we would prefer to use the manufacturer profile in that way as the search will become much easy.

B: Right now we use the 'ICN BIM Werk Methodik'. We select the data manually from the manufacturer's families such as Venelux. So, are you only focusing on the window profile and glass? Because VMRG also is associated with cladding companies.

P: Yes, VMRG is also probably also interested in expanding to cladding companies once BIM library in window systems are clear.

B: Cladding library in BIM would also be very useful, especially for the rendering. Then it will be easier and accurate to show the patterns on the facade as we can get the manufacturer.

Figure 13.8.1.1.h: Top and bottom: Images showing LOD 100 and 200 respecively, as depicted by Björn. He suggests that LOD 300 should have more detail such as atachment to the wall. The Higher LOD's are aken directly from manufacturers.

13.8.1.2. JEROEN COENDERS, WHITE LIONESS

General background questions:

1. **How many years in BIM?**

   15 years, 5 academic and last 10-12 in practice. I have been using BIM as a programming platform in engineering and design since I was 14, that was 23 years ago.

2. **What kind of projects mainly undertaken?**

   Not anymore, I develop softwares now at my software development firm. Previously I was involved in infrastructure as well as buildings. The only project I am currently involved in is information management of 300.000 buildings in the north of Holland. I use BIM here as information or knowledge management. I dont use the existing softwares, I use my own developed softwares.

3. **Could you elaborate your interest in BIM? What is your motivation?**

   I have a vision of BIM that is idealistic, clean solution to many problems. It is possible to optimize designs and use less material that makes the project more sustainable, connected and optimised walls etc. In general, BIM provides ability to avoid many mistakes while construction. It is possible to avoid many accidents. It is possible to have a proper design of infrastructure and management of the same. There are many advantages to using BIM.*

4. **Where BIM can be in the new design process?**

   Currently, BIM is most useful from beginning of engineering to preparing the construction stage. It loses purpose during and after the construction. BIM for facilities managers doesn't work yet. This is due to the integration between the software they use and the software the model is made in. Facilities managers don't know why some materials are there, they don't know the design intent and results in mis-management. On the other hand, during construction, it can be argued that BIM is useful via handy devices such as a, i-pad. However, crashing apps is a common occurrence, rendering it useless to carry it. Apart from that, the other disadvantage is that as it is a construction site we are talking about, i-pad gets dusty, dirty even has a chance of breaking easily. That is why; the concept of BIM doesn't work yet in the construction stage and after the construction.

5. **Can BIM be already in the preliminary design stage? What are advantages/ disadvantages?**

   For the concept design phase, in the current softwares, it is not very useful. It does not explain the design intent of the designer, whether architect or a structure modeller. Revit for example, works in families. You can place the elements irrespective of whether they can belong here. Thus, it does not design the system, but it places individual elements. It does not model you concept, for example, why a space is there. These guidelines should be able to be integrated in the model. Another example of BIM software that works as divided elements not system is when I was designing a dia-grid, I could only Place individual columns and beams, where as I wanted to design a dia-grid as a whole system.

6. **How much influence is a change to facade for structure during the design process?**

   Facade is not the main load bearing element. Generally, it has little influence on the structure. In high rise buildings for example, the load bearing elements are beams, columns, floors. Changing facade has a very small influence on the structural system. There are instances also, where facade has influenced change in structural elements. Arnhem station, a project where I was involved, is one example where the facade influenced the structural design. The facade design was changed hence the structure changed. But these examples are relatively few.

Sustainability related questions:

7. **Where can BIM influence in sustainability?**

   BIM can be used to analyse and simulate to predict the future. Materials can be chosen to determine the performance. Although, material not as elements but as system-the concept I explained earlier-is still not there. Inputting fragments and getting feedback does not give the entire picture. This results in a continuous confrontation with the model. Another aspect where BIM is still improving is suggesting alternatives to use less energy and materials. This process of optimisation is not yet automatic.

   Also the construction industry needs to change. The way we construct has not changed in the past few decades. If we design optimised structures, the constructors don't know how to make it. Hence, the structures end up having more material as the final building should stand and have no mistakes in construction. Car industry on the other hand is far advances. They use machines arms where it is not possible for humans to make it. They design new tools to have the exact form as designed in virtual environment. The construction industry has still to grow.

8. **On a scale of 1-10, how important is operational energy/ Embodied energy for you while at the design stage (before Tender)?**

*I think operational energy is highly important. It seems more dominating in defining he energy consumption and environment influence. Also, it is easy to influence. If it is not according to performance, elements can be changed later. Embodied energy on the other hand cannot be changed***.*

Social:

9. **How willing are architects to adopt BIM?**

Depends. Previously they were quiet reluctant in using BIM, they argued that they don't need it and the current tools (at that time) are sufficient. Now they are more inclined to use it. Partly because it s fashionable to use it, and partly because they see the benefits in using BIM.

Initially there was alot of resistance from architects as well as other disciplines. It seems that soon there will not be a choice of whether to use BIM or not, it will always be used. The younger designers today can already use it. I advice architects to involve younger designers as they are more proficient with BIM. Also, today there is client requirement in many cases to use BIM as hey want it for operational stage, although it is not used for its full potential. However, there are instances where the clients don't require BIM and so they refuse to pay for the added costs. In such cases, the architects use BIM anyway because it is faster and produce the 2d cad drawings from BIM softwares.

*Jeroen is a BIM and Structural expert. His comment related to using materials not in tensile/ compressive elements of the load bearing structure, thus eliminating the materials that have no importance in load bearing capability.

** Jeroen here explained the embodied energy as the structural elements, as they are the mostly the high embodied energy elements in the building. The operational energy can be improved after construction by improving the replaceable systems such as HVAC by adding relatively low embodied energy impact elements such as heating and ventilation.

10. **Would you prefer a standard list of parameters to lead you step by step towards sustainability (like EPC, BREEAM) or would you prefer to demand the parameters as needed by your design?**

I have also written about standardisation in my PhD. I don't believe standardisation is a solution. There is no room left for innovation, hence no standard is the best standard! Options should e available whether standards are to be used or not. The information should directly relate to the manufacture data but not as separate manufacture-wise information. A generic library like you mentioned could be useful. However, only window library is a small thing and there are many things to look in the design of the building.

11. **Additional comments.**

Not at the moment

13.8.1.3. MARK MAAS AND GIORGIO CARELLA (PAUL DE RUITER ARCHITECTEN)

Mark Maas(will be referred as M) and Giorgio Carella (Will be referred as G)

Expertise: BIM Manager, Sustainability

Company: Paul de Ruiter Architecten.

1. **How many years in BIM / sustainability?**

M: 1/ 1.5 years in company

G: 6 years in practice and 4 years in company.

2. **What kind of projects mainly undertaken?**

Villa, housing/ resource centre, hotel, a wide variety of portfolio. We do not take competitions that have only concepts. We take projects that need o be realised.

3. **In which directions are you interested in sustainability? Do you use Certifications like LEED/ BREEAM/ EPC? Any other?**

G: We use all. LEED rating we use mainly for the international projects, BREEAM-NL for the Dutch projects. LEED and BREEAM-NL are used when there is a client request.

4. **On a scale of 1-10, how important is operational and embodied energy for you while at the design stage (before Tender)?**

G: Both are important. Embodied energy is less important. Operational energy is required to perform a preliminary evaluation of energy consumption. But we are not quite there yet. Today, the way sustainability is done, everything is all in hands of consultants. Embodied energy is not given as much importance as it should. Clients do not request that as it does not influence or profit them in the business.

5. **What is the motivation to design sustainable buildings? What are the obstacles?**

M+G: The motivation is to design different than others, to create an image of ourselves in the market. The sustainable movement also has economic reasons and green issues and we would like to address those.

G: There is also a question of ethics, for example a group of Greek researchers identified the effects of heat island effect in terms of who is affected by it. Ultimately, the poor people, the children and old people suffer most out of this. So there are also ecological problems associated with it.

It was different few decades ago when materials and expertise was not available. Today there is no excuse to not use sustainability as new materials are emerging and experience is also available.

6. **What is client's motivation for sustainable buildings?**

G: Money. During construction, everything is slow as things are done the way it was done 20 years ago. The contractors do not use new techniques because they do not have enough expertise on it. The material performance is difficult to prove as there are not enough tools to evaluate it, for example he double glass facade. It is expected that it helps in better performance than the normal curtain wall facades. However, it is difficult to prove the exact number of how much the energy saving will be, and the clients ask for that.

Also the material performance is difficult to know if it is true. A colleague of mine performed a research on the certificated of certain criteria of materials. What she found was extraordinary. Here are loop holes in the criteria as well as in the process of who organises and who checks the claims.

7. **Could you elaborate your interest in BIM? What is your motivation?**

M: mainly it is a client request. Using BIM thus puts us on the fore front. There are also many advantages to using BIM. It is possible to design a good building that uses less energy. This helps in an image formation that we are technically advanced. BIM helps in better designs while working together with companies. Problems can be seen earlier. There is definitely more work for the architect.

8. **Where BIM can be in the new design process?**

G+M: BIM is today at the stage that AutoCAD was 20-30 years ago. BIM is sort of the new trend now, in the past 5-10 years. We use BIM together with all the consultants.

The preliminary design I still prefer that the architect uses basic 3d tools such as sketch up. It gives them more freedom. The BIM tools already ask for alot of data in the initial stages. This is inconvenient for me to work as I have to throw away all the data and start from scratch. Thus, when the consultants are known, the proper value can be inserted into the BIM model.

I believe that BIM is a powerful tool if used right after the concept is finalised. Client doesnt need this yet, but this should be done.

9. **You use BIM already in the preliminary design stage. What are advantages/ disadvantages?**

M: The disadvantage in the early stages is mainly for the architects. It has too many details, because the software asks for it. There is less freedom in thinking and designing. Making changes in Revit takes a lot of time. The 3d model has too much information and it is a bulky model.

The current softwares are not smooth. These are complex programs for the initial stages as it is not user friendly and provides less freedom for designing.

10. **How much influential is the facade in respect to sustainability?**

G: It is very important as the heat exchange is through the envelope- facade, roof and floors. We use Saphire a computer program for analysing the heat exchange. Mostly we use glass curtain walls, no bricks.

11. **How architects see their role in sustainability?**

Architects have an important role. For example I was at a lecture in Rome that was called "energy and Environmental quality in the built environment. The Islamic centre of Renzo Piano was called by the lecturer Mat Santamouris "impulse art". This is true for architects even today. The technology is great but the maintenance of keeping it functioning costs 3 times the operational energy. So the role of architects can be very important.

During that lecture he even asked, to an audience of architecture students: :how do we protect people?" That made me quite think. It still does today, in a time in which we have learn to know an expression like "Environmental refugees"

12. **How should the facade companies improve in providing the information: Which information is more relevant? What kind of preciseness/ range?**

M: By providing elements that are generic, basic and easy to use. Only the information I want, no added information. For example, I had this family of the toilet where I only needed the family of toilet, but it came with wall for wall mounted and with floor for floor mounted when I insert this to my library, it clashes with the floor or wall in my model.

The facade companies should only provide the mullions in thickness, no details. If it a heavy file, I can't do anything with it. 2d drawing in a detail view is alright, I don't require it in 3d. It is hard to manage printing in plan as it shows a black spot with all the lines.

G: I would prefer to use 3 main values: u- value, Visual light transmittance and Solar heat gain Coefficient: how much energy, how much heat and how much cooling. I would prefer to be able to change the values wothout changing the object.

<u>Proposed solution: Library in BIM from Manufacurers:</u>

13. **If this is as a plug in, would it be easy for you to use it? Or would you prefer an object based library?**

G+M: Shüco had a plug in that worked on xml. The profile was designed as the architect wanted and within 6 minutes the file was ready for the machines to use. The plug in showed I think is a good solution. Changing value without changing the object is convenient.

14. **Should this be readily available from a dropdown menu or prefer putting the range/ number manually in BIM applications?**

G: Option should be available. I would like to be able to choose from the drop down menu

M: I prefer a fix number. F I want to choose another value I should be able to do that. The Shüco example I gave you, it showed me if I change the window height, it is not ok if it is located at a high tower in a windy ituation. This kind of plug in I would like to use.

15. **Additional comments.**

M: when I import an object, each company uses their own object styles. In the end I have too many object styles and I don't know where to look the information from. Standardisation is missing. Deep level customisation is good but not useful for making choices.

If you have to trick the software to make it think something else so it shows what you want to see, there is something fundamentally wrong going on here. I should have the possibility to customise what I want.

I strongly think there is a dire need for customisation.

16. **Who should develop the standards?**

M: The government should make these standards. Then can everyone use them. Revit is also involved in making the Standards. Revit standards already exist. There is also BuildingSMART that is involved in standardisation. However, these standards are not suitable for the Dutch market. We are involved together with some experts from other architecture bureaus to help in this process but this has to come from a higher body.

If VMRG develops standards for windows, will it be good to follow them?

This is difficult to tell. Maybe yes, if everyone follows the same standard. The best thing is if it comes from the government. Then it is mandatory to follow one standard and everyone uses the same object styles, naming, parameters etc. I do not prefer to see parameter list from all consultants which have the same information 2 or 3 times in the same list. This is confusing. Right now, we develop these standards in the company with consultants, and this process is repeted with every project.

13.8.2. CONCLUSIONS OF THE INTERVIEWS:

It can be seen that if one manufacturer who produces the standard components is known to the architects, it is easier for them to use that. However, when shown the BIM-Object site, they are adaptive to using more manufacturers who cater to their request. It is also observed that experienced architects find it acceptable to manually browse through every item. From their experience, the can shortlist and select a product easily. However, the designers in BIM are usually different from the main architect. The BIM designers confirm that during the design phase, they prefer a less complex geometrical detailed model and hence, they have their own library of the standard elements, to which they add manufacturer data as and when needed.

When questioned about the workability of the tool created, the architects are reluctant of using it, since it is too much in depth about the facade. However, they did show interest in a library that VMRG can offer, if it is similar to the BIM-Object website. However, they are unsure if the tool is going to be so complex then how they would use it.

In order to show how the tool works, a manual should be available. Easy to update families would be useful to jump to higher LOD stages. The tool should be few steps and not to complicated.

Another Important conclusion that can be drawn is the need for standardisation. The question remains who shold develop it, one private owner should not develop it as they might nt have all the view. It should be discussed with parties togather so that everyones needs and views are covered.

It is observed that plug in is accepted by the architects as it is easy to change values without much effort and re-drawing.