Parametric BIM: Energy Performance Analysis Using Dynamo for Revit

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Preface

This thesis aims to encourage university students to explore more about parametric designing and its potential in university levels in Sweden. As there is barely any master thesis-es written about this topic, we took it upon our self to investigate the possibilities of BIM. We would like to Thank our examiner Kjartan Gudmundsson, for supporting and pushing us toward the right path. And we would also like to thank our school, KTH, for the wonderful years and education we received.
Abstract

Due to the rapid development of technology, the AEC industry in Sweden have been struggling to string along it. The demand from authorities to use BIM in the industry are increasing and the respond from companies are minimal. The building process uses to be spanned over several phases and the early design phase is where focus is lied on mostly in this thesis. Here can several actors as architects, engineers etc. be involved. Lack of communication and lack of coordination between the parts have an important impact on the outcome and therefore BIM was developed. In the early designing phase, the project takes it shape and approximated calculations and analysis have to made. Usually the results from the early design phase differ from the analytical analysis that are made later and the costs of projects increases. However, many new tools have come along the way with that development which makes it possible to make energy optimization an even more efficient practice. Therefore, this thesis has been chosen to investigate the different energy possibilities and outcomes during the early design stage, in the aspect of daylight and energy simulations. A simple test building was constructed in Stockholm, Sweden. The building is formed in a way that allows various material parameters to be altered in order to study the impacts of the annual energy distribution. This thesis will shed more light on why it is important to develop the methods of energy simulations in the early design phase, and it’s done by using the latest state of the art tools. A newly developed VPL tool named Dynamo together with the design tool Autodesk Revit and Green Building Studio is used in the simulation process. A script will be coded in the Dynamo tool that will determine and allow the parameter variations of the building model in Revit. A comparison of 4 different case studies is graphically presented at the end. Even though the result was quite expected, the aim of this thesis was rather to serve as an example of how the tools of Dynamo and Revit can successfully coop-orate.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>i</td>
</tr>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Nomenclature</td>
<td>iii</td>
</tr>
<tr>
<td>Glossary</td>
<td>iii</td>
</tr>
<tr>
<td><strong>1 Introduction</strong></td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>1</td>
</tr>
<tr>
<td>1.1.1 Building Construction Phases</td>
<td>1</td>
</tr>
<tr>
<td>1.1.2 Early Design Phase</td>
<td>5</td>
</tr>
<tr>
<td>1.2 Problem Formulation</td>
<td>5</td>
</tr>
<tr>
<td>1.3 Purpose</td>
<td>6</td>
</tr>
<tr>
<td>1.4 Limitations</td>
<td>6</td>
</tr>
<tr>
<td><strong>2 Theory</strong></td>
<td>8</td>
</tr>
<tr>
<td>2.1 General about BIM</td>
<td>8</td>
</tr>
<tr>
<td>2.1.1 BIM-model</td>
<td>11</td>
</tr>
<tr>
<td>2.1.2 Benefits of BIM</td>
<td>11</td>
</tr>
<tr>
<td>2.2 Parametric Modeling</td>
<td>14</td>
</tr>
<tr>
<td>2.2.1 A Brief History</td>
<td>14</td>
</tr>
<tr>
<td>2.2.2 Parametric Design of Buildings</td>
<td>15</td>
</tr>
<tr>
<td>2.2.3 Parametric Modeling for Energy Analysis</td>
<td>16</td>
</tr>
<tr>
<td>2.2.4 Visual Programming</td>
<td>17</td>
</tr>
<tr>
<td>2.3 Design Tools</td>
<td>18</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Autodesk Revit</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Dynamo</td>
</tr>
<tr>
<td>2.3.3</td>
<td>The Anatomy of Dynamo</td>
</tr>
<tr>
<td>2.4</td>
<td>Green Building Studio</td>
</tr>
<tr>
<td>3</td>
<td>Methodology</td>
</tr>
<tr>
<td>3.1</td>
<td>Model Geometry</td>
</tr>
<tr>
<td>3.2</td>
<td>Work process</td>
</tr>
<tr>
<td>3.3</td>
<td>Dynamo</td>
</tr>
<tr>
<td>3.4</td>
<td>Green Building Studio</td>
</tr>
<tr>
<td>4</td>
<td>Results</td>
</tr>
<tr>
<td>4.1</td>
<td>Model of Procedure</td>
</tr>
<tr>
<td>4.1.1</td>
<td>Height Parametrisation</td>
</tr>
<tr>
<td>4.1.2</td>
<td>Width Parametrisation</td>
</tr>
<tr>
<td>4.1.3</td>
<td>House Orientation Parametrisation</td>
</tr>
<tr>
<td>4.1.4</td>
<td>Amount of Window panels Parametrisation</td>
</tr>
<tr>
<td>5</td>
<td>Conclusions and Discussion</td>
</tr>
<tr>
<td>6</td>
<td>Future Work</td>
</tr>
<tr>
<td></td>
<td>References</td>
</tr>
<tr>
<td></td>
<td>Appendices</td>
</tr>
<tr>
<td>A</td>
<td>Appendix</td>
</tr>
</tbody>
</table>
List of Figures

1.1 Energy usage of the building sector of Sweden 1971-2013, TWh (Energimyndigheten 2015) ........................................ 2
1.2 The planning stage (Cpu.net 2013) ........................................ 2
1.3 Sharing the BIM model through IFC (Graphisoft 2016) .............. 4

2.1 The linear work flow in the building process (House 2015a) ....... 9
2.2 The ability to impact the building process (House 2015a) ........... 9
2.3 Earlier work-flow building process (House 2015a) .................... 10
2.4 The ability to impact the work proces with BIM (House 2015b) .... 11
2.5 Some of the Benefits of BIM (Calvert 2013) ......................... 13
2.6 Leaning building in Abu Dhabi designed with parametric modeling tool. (Evob 2015) .................................................. 14
2.7 The movie Tron from 1982. (Tested 2015) .............................. 15
2.8 One way a wall can look like (Grasshopper 2012) ................... 16
2.9 Program flow in Dynamo .................................................. 19
2.10 Anatomy of the Nodes .................................................... 20

3.1 The first Revit model ...................................................... 24
3.2 Average surface of the Revit model ................................... 25
3.3 Revit model specifications .............................................. 25
3.4 Dynamo and Revit collaboration ....................................... 26
3.5 Dynamo script code ..................................................... 28
3.6 Dynamo nodes ........................................................... 29
3.7 Dynamo nodes ........................................................... 30
3.8 Dynamo nodes in-depth .................................................. 30
3.9 The Building Performances Factors in Dynamo Revit ............... 31
3.10 Heating Load Charts in Dynamo Revit .................................. 32
3.11 Building simulation list in GBS .......................... 32
4.1 Dynamo parametrization work-flow ......................... 34
4.2 Window Height ............................................. 35
4.3 Window Width .............................................. 36
4.4 Window Orientation ....................................... 37
4.5 Window Panels .............................................. 38
A.1 Orientering ................................................. 45
A.2 Window Panels Parametrization .............................. 45
A.3 Fönsterbredd ............................................... 46
A.4 Fönsterhöjd ................................................. 46
1. Introduction

This introduction chapter will present the background to the research as well as to present the research question, the purpose and the definitions.

1.1 Background

1.1.1 Building Construction Phases

There is no construction project similar to another, but they all share some common characteristic traits. These traits together construct the building process and generally include planning, development and a implementation of the project. These can further be divided into different stages regarding the whole lifetime of the building that is to be constructed. According to statistics, the building environment accounts for a large portion (about 1/3 part) of the country’s total energy consumption. The building electricity production in 2015 was the second highest annual production of all times in Sweden (Energimyndigheten 2016).
Due to these concerns, there have been increased demands in regards of energy- and environmental aspects in construction planning in Sweden that have been developed in the past late years. Resources and costs have to be reduced in order to accomplish the requirements that needs to be met. The demands for a sustainable society comes from both the owners, authorities, companies and the society itself (Regeringskansliet 2014).

During the building process and in the planning stage, the authorities of a landscape are responsible to take decisions if they consider that the landscape have possibilities
to be exploited. Authorities creates a layout plan that works as a guidance for their
decision making when contractors seek permission to perform a project. A layout
plan sets in a rough way the rules of how to exploit the land, and its description
governs how and where the buildings can be constructed. A zoning plan is later
created in parts of the layout plan where exploiting possibilities exist. When decision
is taken to build in accordance to the zoning plan, the project gets its first shape in
the idea and baseline phase. The actors in this early phase are working with each
other in order to please both the authorities demand and the landscape owners.
The important part in this phase is that it works as a spine for the entire project
where a lot of simple analysis can be done. This thesis will work on investigating on
some of these analysis, like for example the optimal orientation of the building, the
size of the windows. These studies will take place in the later sections. When all
the studies needed are finished, they are assembled in a building program with all
conditions and requirement for the construction. As a final step in this phase the
architect makes some preliminary sketches for different alternatives.

After the first ideas and sketches are made, everything has to be designed in more
details. This is governed in the design phase where architects, engineers and project
managers are all involved in the processing of the system documents. These doc-
ument contains of drawings from all parts and technical descriptions which shows
and describes the construction. Further on, everything has to be designed in a
stricter detailing, such as the positioning of windows, which types they are, how
much lighting they produce, what nail dimensions is needed and so forth. In this
way all participants in the ongoing building process takes information from the con-
struction in a more detailed level. Moreover, in this phase the management planning
is made before continuing to the next phase to sustain budget for the project and
to tackle some quality and environmental goals.

From the documentation that is produced in the design phase the client makes an
enquiry to contractors with information about what needs to be performed by each
contractor. The enquiry that is turned over to the contractors should consist of a
technical part that describes how the building have to look like when it is finished
and an administration part that describes how the work have to be performed and
the conditions that is valid during that process. The contractor then makes a cost
calculation for the work and leaves a proposal to the client in which he choose the
most appropriate proposal or the one with lowest price. In the decision making
for the most appropriate proposal the clients usually take decisions regarding to quality, environment price for building and operation of the facilities. The client has the possibility to have one or several contractors. Something that is more common today is that the clients choose only one contractor before the design phase that manages all work. The contractor may in some cases engage other contractors to manage parts that the general contractor is not fit to take care of in the project.

When the client and the contractors comes to an agreement the building schedule can begin. In this phase many different participants are involved such as the project managers, electricians, constructions workers and all the actors involved. The workers need information on how the building will look like and how everything should be constructed. This is usually extracted from a CAD model that is created through a IFC bridge to all the other software.

![Figure 1.3: Sharing the BIM model through IFC (Graphisoft 2016)](image-url)
1.1.2 Early Design Phase

Significant amount of the society’s energy consumption is due to buildings and to tackle the environmental demands the EU and Swedish authorities have set goals to reduce building’s energy demands. The goal is to reduce the energy consumption by 20 percent until year 2020 and by 50 percent until year 2050 Boverket 2015. The vision is to converge towards near zero energy consuming housing. During a building’s whole lifespan, the proportions for energy consumption are divided not only in the period of the building service time but also on the construction stage. The production of material, the transportation and so forth make a big part of costs. In the early design phase designers are facing critical decisions and often have lack of intuition about the right decisions that have great impact on the buildings in later stages. Numerous researchers have shown that the earlier right decisions are made in the design process, the fewer the changes to these decisions will be at later stages. By this potential for reducing the building’s environmental impact is greater. This could be achieved by choosing material on a smarter way or by optimizing the shape and orientation of the building for example.

1.2 Problem Formulation

The development of technology in the building construction sector have been going fast forward in the latest years. This has forced many of the older programs to develop in order to satisfy the new required demands. The designers been forced to work with 2D drawings, but as the digital world has kept progressing forward, 3D modelling have slowly been taking over with an availability to 4D or 5D models where cost and time can be considered. In addition to this, new tools have also been created to be used as third party programs for optimization purposes. The architects, project managers, installation and construction consultants all work in different software and have their own models. Afterwards changes in the model often creates several issues and errors that can lead to prolonging the project time or increasing the costs. These issues in the early design phase are counteracted by using conceptual modeling tools such as in Revit or in Rhino. The conceptual modeling software often makes simpler and more general simulations that gives an approximation of the outcome later in the process. For example, the buildings sun
energy distribution during a whole year or an approximation of the most optimal window glazing. Lastly, the latest addition among all modeling tools is the VPL (Virtual Programming Language) software. VPL software exists as a plug in or as a third party tool to the modeling software and creates the possibilities to take the modeling to a next level. The Architects can use a lot of programming and scripting to create more complex models that normally is not possible in the already existing tools. This allows more flexibility to the other actors in the project by allowing them to adjust more parameters in order optimize the model even further.

1.3 Purpose

Research on optimized parametrization in other countries has reached a much further stage than here in Sweden. Despite Sweden’s good potential in digitalization and computing development, it has not yet managed to achieve as rapid advances in energy-smart solutions in comparison to countries like the US or China. The lack of researches on this has paved the way for more thesis on this subject. The aim of this work has been to investigate the advantages of using Revit as a single design tool platform while having the possibility of optimizing building models using plug-in extensions such as Dynamo and Green Building Studio. By using Revit as the central design tool, the results and benefits of BIM can in an early stage be evaluated. The hard line goal is to illustrate the feasibility of implementing these middle ware plugins during the early stages of the building and to also present the enhanced benefits when it comes to team collaboration and time saving aspects. The goal is also to evaluate the practicability for people with little to no knowledge to use these tools by presenting some examples of energy analysis later in thesis. The research of this subject also paves the way for more studies that can develop this branch even further. This will be discussed more on the later chapters.

1.4 Limitations

Due to the lack of research done on this topic, a lot of time have been spent on familiarizing with the third party tool that has been paired with the Revit application. VPL is still on its early development and has yet to be fully explored and the
full functionality of dynamo is limited since the program is still in its beta stage. Only architects have used these programs as aid to design complex shapes and no studies have been found in optimization purpose for the designers.

Therefore, this study can be seen as a groundbreaking research to assist students or employees in the building industry. The complexity of the models has been limited in order to prevent an extensive calculation time when optimizing for higher equality models. And lastly, the aim of the study is restricted to research analysis done in the early design phase.
2. Theory

The Terminology chapter will reflect the theory used.

2.1 General about BIM

BIM which stands for Building Information Modeling is a new, modern and revolutionizing approach of design and documentation of building projects. With BIM-technology one can create one or several accurate geometrical models and assign information that will support the construction and management activities during all project phases. The most impressive about BIM though, is the coordination between all participators of the project. These can be the client, the architect, the engineer, the contractor, consultants, fabricators and operators. With BIM there is a transparency in the project that makes it possible to all participants to take part of results or insight on the different processes during all project phases. The key goals of this method is to create wider flexibility and to accommodate more rapid changes during the process. The question is, what is so special about BIM compared to a traditional work flow? A common headache for the consultant is when trying to find clashes. Engineers, architects and builders are all gathered together with their respective drawings and have by overlaying the drawings to find where object are intersecting and where they shouldn’t. This is very common in the construction processes and the occasion for this is the linear work flow that is used.
When using BIM, the entire project can be designed, managed and executed all in one central model. The biggest flaw in the traditional process is the lack of communication from the contributing parts in the project. The result of this may cause conflicts and problems later on the project leading to changes that needs to be changed, which is a costly procedure.

However, these changes can be avoided by adapting an integrated design approach where all the coordinates are started during the initial phase of the design process. This is achieved by front loading the project and allowing all the parties to be on the same page from the very start. This creates opportunities to be much more efficient with time planning, create coupled systems that work together and ultimately reduce
the need for costly changes later down the road. All this is achieved by using a building information model, which is a 3D model that incorporates all the essential components that makes up for a building. It is like a cloud-stored text document that allows multiple users to edit, but through a 3D model that every actor works through. It’s called an integrative design process that is comparable to the traditional process and allows all the participants to contribute to the project from start.

Figure 2.3: Earlier work-flow building process (House 2015a)
2.1.1 BIM-model

The main CAD tools used until some years ago have all been plotted 2D drawings. With the introduction of the 3D models, a lot more complex surfacing tools have been added to allow more advanced geometries. Today’s BIM tools are able to present the plot drawing in multiple angles or view intersections by converting the 2D model into a 3D model. An important detail in the process is as mentioned before that when the model is created, all involved parties are involved in the creating process. The BIM model is a virtual image of the real case scenario and all the information about the life cycle of the building are therefore included in it. The information is both the physical part, the logical composition of the objects and the building itself.

2.1.2 Benefits of BIM

There is plenty of benefits when using BIM in a project, but the most important aspect of BIM comes during the early design stage where many important decisions are being taken. The early stages of every building process is seen as the foundation of the whole project. A more planned and a well thought beginning often results in less errors during the whole building work development. The biggest proportion
of benefits are actually related to the design of the model. Instead of generating the model from multiple 2D views the 3D model is generated by designing directly with BIM software. The design may in that way be visualized earlier and more accurate. At any stage of the design, accurate and consistent 2D drawings can be extracted for any set of objects or a specified view of the project. This lead to a reduction of time and number of errors associated to the generation of the drawings for all disciplines. If changes on the model are required, new and fully consistent drawings can be produced as soon as the model is modified. The errors due to lack of communication can also be reduced by the possibility of earlier collaboration of multiple design disciplines. The collaboration with drawings is more inherent and difficult than using one or several coordinated 3D models where changes can be managed more controlled. Also with earlier collaboration, insight to design problems is given and the designer has the possibilities to improve the model. With the earlier 3D visualizations, it is also possible to make better cost estimations due to the better quantification of areas and material. An example to this is the cost reduction due to energy analyses that can be executed in early stages thanks to the possibility to link the BIM model to the simulation tools. Usually with 2D design one have to wait until the end of the design stage to make an energy evaluation only as a check or a regulatory requirement. This reduces the possibilities to modify the models and improve the energy performance of the building. By linking the model to the simulation tools, modifications and improvements are made early in the process and therefore the outcome is a better building quality is obtained.
Figure 2.5: Some of the Benefits of BIM (Calvert 2013)
2.2 Parametric Modeling

Parametric modeling is not something new and was originally developed in the 80’s for manufacturing. The objects that are represented have not fixed geometry and properties. Instead the geometry and non-geometric properties are represented with parameters and rules that determine the geometries and properties. The parameters and rules can be expressed in terms of other geometries and properties so that when these changes from the user the parameters change in their turn. Now complex geometries that were simply impractical or non-possible in the past, can be modeled thanks to parametric objects. In architecture and construction, BIM software companies e.g. Autodesk, have decided to create a set of base building object classes that the users may modify, add feature or extend before using them.

Figure 2.6: Leaning building in Abu Dhabi designed with parametric modeling tool. (Evob 2015)

2.2.1 A Brief History

In 1960 the research about modeling 3D geometry gained big importance because of its potential in different areas such as movies, architectural and engineering design, games and so forth. The first computer graphic film, Tron (1982) was an accomplishment thanks to the ability of representing compositions of polyhedral forms for
viewing that was developed in late 1960s. The design of pictures with these polyhedrons were limited and it was possible to produce practical 3D models with solid element first after 1973. Different approaches had been developed by scientist and BIM architectural design tools today, all grew up from the object-based parametric capabilities that was developed.

![Figure 2.7: The movie Tron from 1982. (Tested 2015)](image)

### 2.2.2 Parametric Design of Buildings

In parametric design, instead of designing an instance of a building element like a particular wall or door, a designer first defines an element class or family which defines some mixture of fixed and parametric geometry, a set of relations and rules to control the parameters by which element instances can be generated. As an example one element class or family is windows. Fixed geometry or parametric geometry are such as width, height, duct space and so on. An instance is a way to realize an object and by the rules and relations different realizations of a window are possible. These rules and relations may be such as attached to, parallel to, offset from and so forth. With these relations an instance may vary according to its own parameters or the contextual conditions of a related object, for example an adjacent wall that the window is connected with. By changing the parameters of the wall also the window may adopt to its geometry and so forth. The rules may also be set as requirements during the modeling work. Parameters that were mentioned above can have a requirement of a minimum of maximum value and the program
will check these all the time during the modeling and the user will be warned if these requirements are not fulfilled.

![Image](image.jpg)

Figure 2.8: One way a wall can look like (Grasshopper 2012)

### 2.2.3 Parametric Modeling for Energy Analysis

Due to the substantial impact to the environment that buildings energy consumes and it is important that designers pinpoint where improvements can be made in an early design phase and in order to optimize its energy performance. This is in the other hand a very complex assignment due to the large amount of parameters that are involved in the energy performance of the buildings. Such parameters may be material properties, geometry, weather data, user behaviors and so forth. In this stage there is a lack of easy-to-handle tools that can be used by architects and engineers to explore the design alternatives that exists. By testing different alternatives, the designers can investigate the outcome of changes such as the profit margin by alternating the isolation thickness or influencing between different window types. Other examples on design alternative studies can be on energy gains of heat-flux from daylight distribution, orientating the house positioning or by storing the heat...
gains gathered by renewable energy. Due to the lack of such tools, designer decides to either not consider the energy performance in their design but instead use general rules-of-thumbs, which may result in an inefficient building design. Another alternative would be to hire energy experts in the early design phase to simulate between different building design alternatives which would be a costly method. Another issue with the hiring of energy experts for simulations is the transferring of an architectural model to an energy model which is not only time consuming but also error-prone. Because of these named issues designers may choose to just simulate only few design alternatives that would result in an optimized design solution. With BIM and by integrating parametric modeling into it the designers get great benefits to create sustainable building designs. The possibilities to variate parameters and their relations are great with parametric modeling and BIM. With the central model method that is used in BIM the methods and tools provided makes it possible to manage building project and a more efficient way, looking at time and cost aspects. A BIM model may contain most of the data needed to run energy simulations and the risk of errors and time consumption are reduced since no preparation for transferring of data is needed.

2.2.4 Visual Programming

The intent of a designer has always been to thrive after more sophisticated building geometries. A progressing and a developing computer aided design helps to remove the restrictions that a designer is faces and allows of what the Computer programming have until today been a restrictor to be used for implementing designers sophisticated intents, e.g. through the use of loops or conditional statements in parametric BIM. Visual programming enables a simplified and user-friendly way to replace the conventional elaborate coding with a visual metaphor of connecting small blocks of independent functionalities into a whole system or procedure. With visual programming computer programs can be manipulated graphically rather than textually (Mohammad Rahmani Asl 2015).

Several survey shows that non-programmers or novice programmers have easier to understand visual programing language instead of conventional programing language (Mohammad Rahmani Asl 2015).

Grasshopper and dynamo are based on visual programing language (Python) and
create many opportunities for designers using Rhino or Revit. This study is based on Revit and Dynamo that have some differences from Grassshopper, which have been known for designer’s longer time than Dynamo. Example of benefits of Dynamo are (Dynamoprimer 2016):

- **Customize Revit**: Up front, Dynamo lets users build automation routines for Revit without the need to learn the Revit API, which is not easy. This opens up numerous opportunities for users of Revit to customize their workflow with a significantly reduced learning curve.

- **Control Model Information**: As Building Information Modeler, the real power of Revit is not in pure geometry creation, but in how you can track and control model information. Dynamo lets users design systematic relationships for manipulating model elements and parameters that would be otherwise impossible with conventional Revit tools.

- **Design with BIM**: BIM is often put in the box of being only for ‘production’... not for designing. Dynamo has the potential to turn this preconception on its head and allow designers to explore iterative frameworks in the context of a BIM tool.

### 2.3 Design Tools

#### 2.3.1 Autodesk Revit

Revit is the only complete parametric Building Information Modeling tool available today. It was originally created by individuals from the U.S. based company PTC (Parametric Technology Corporation) which is also known for their popular software FEM tool, Mathcad, that is widely used in the engineering field. The creation of Revit was only in architectural purpose, i.e. it was built by architects for architects. The majority of the people behind its development are architects or come from a design and construction background (Arkin 2007).
2.3.2 Dynamo

Dynamo is an application that can be downloaded as free software and run alone or as plug-in to Revit. It is a visual programming tool that aims to be accessible to both non-programmers and programmers alike. It gives users the ability to visually script behavior, define custom pieces of logic, and script using various textual programming languages.

Once Dynamo is installed it enables users to use Virtual Programming to process data and compose custom algorithms. Users can create geometries, manipulate models in Revit or within Dynamo itself very easily by coupling code blocks which are programmed to execute a task assigned to them. Figure 2.6 illustrates a typical workflow in Dynamo. Usually, what is known from Grasshopper is that the workflow goes from left to right but in Dynamo it can go both ways.

![Program Flow in Dynamo](image)

Figure 2.9: Program flow in Dynamo
2.3.3 The Anatomy of Dynamo

As mentioned early in this chapter, Dynamo is a VPL tool and the operation of data is executed via nodes and wires in the Dynamo workspace. The nodes consist a script which are assigned a task. It can be a very simple operation as storing a number in a list or creating complex geometry. The language in which the codes are scripted is Python. With some exceptions, the majority of nodes are composed of five parts:

- 1. Name of the node.
- 2. Main body. Right-clicking here presents options at the level of the whole Node.
- 3. In- and out ports where wires are connected
- 4. Data preview where primary results executed from the node can be previewed.
- 5. Lacing Icon that indicates the Lacing option specified for matching list.

![Figure 2.10: Anatomy of the Nodes](image)

Connecting nodes with each other is very simple and can be done by just clicking on the out-port from a node and connect to the in-port on another port. The in- and output is depended on the type of nodes and the work flow direction. The wires
that connect the nodes transports data from a node to another like electrical wires that transfers power.

2.4 Green Building Studio

Green Building Studio is a flexible cloud-based service that allows you to run building performance simulations to optimize energy efficiency and to work toward carbon neutrality in the early conceptual phase of the design process. This software is a whole model energy analysis tool. GBS will help extend your ability to design high performance buildings at a fraction of the time and cost of conventional methods.

Green Building Studio uses the DOE-2.2 simulation engine to calculate energy performance and also creates geometrically accurate input files for EnergyPlus. Key to the integrated interoperability is exhibited through the gbXML format, an open IT bridge that allows information to pass through the Green building studio and the Revit application.

Energy Settings Defaults Allow Reasonable Energy Results with Minimal Inputs

If a parameter has not been defined in your model, GBS uses a default value in order to generate an energy model with the minimum information needed for a simulation. These intelligent values are appropriate to the building type, size, and location. These defaults are primarily based upon the ASHRAE 90.1, ASHRAE 90.2, ASHRAE 62.1 and CBECS data, and vary with building type, location, size, and number of floors.

A typical whole building energy analysis looks at over 50 variations of different parameter alternatives in a building, and that can take considerable time to conduct. Green Building Studio tests a variety of building features automatically and, with the Potential Energy Savings chart, provides straightforward guidance on which variations will have the largest impact on energy use. All of these runs are completed in the cloud in about the same amount of time it takes to do one manually.

Green Building Studio’s tight integration with the Revit modeling environment makes analysis accessible in the tool most architects and engineers use to design new and retrofitted buildings. In Autodesk Revit 2014 and beyond, Revit Energy Analysis seamlessly creates a valid Energy Analytical Models from detailed architectural models, and includes the thermal properties of building elements. Once the
simulation is finished you can view and compare the energy and carbon results in the “Results and Compare” window within your model in Revit or Vasari. Based upon the results, you can revise energy settings and parameters within your model, or within the GBS website, and submit additional analyses for your project to move toward a better and more energy efficient design.

Moreover, Green Building Studio has analyses capabilities, beyond the Whole Building Energy Analysis, using the DOE-2 simulation engine, such as “Carbon Data”, “LEED Daylight”, “Water Use”, “Renewable Energy”, and “Natural Ventilation Potential” to help you move your project toward sustainability.
3. Methodology

This chapter, including its sub-chapters, is intended to clarify how the research has been conducted and also to describe the research methods that have been used. In order to get the full idea of how the case study is going to be conducted, it is necessary to begin by describing the model geometry and its purpose in this thesis. The following sections will also describe the working process, show how Dynamo and Green Building Studio can be implemented on a Revit model. The obtained results will later be investigated in terms of both reliability and validity in the Results chapter.

3.1 Model Geometry

The geometry of the Revit model is a simple one-room single family house building with a single windows and door. Each iteration requires a lot of computer power and has been greatly simplified in order to save time. Different parts of the building will become fixed and as other parts will dynamically change depending on which analysis that will be conducted.
The orientation of the window is set in a path along the West of the building, which means that sun energy can only be reached throughout the western side of the house. The location of the building will be set to Sweden, Stockholm, with the standard sun settings corresponding to Sweden sun data values.
The area of the single family house will have an approximate area of 26 sqm, and as shown in the figure above, the building shell will consist of Standard-Revit light weight construction types.
The room will not consider any type of heating distributor and a more detailed specification list of the used climate shell is given in the figure above.

3.2 Work process

Revit Architecture is one of the best 3D modeling tool known today. With the extended side-tools, the software is capable of utilizing all form of complex geometries as it is continuously evolving throughout the years. By coupling Revit with the add-on called Dynamo, it is possible to calculate generative algorithms that paves the way for endless possibilities. Together with the GBS, the algorithms can be analyzed in a 3D way, showing an energy analysis that can determine the model in the early phase of BIM.

The simulations were performed in a collaboration mode, which allowed for smooth integration between the model and the simulation tools. The whole study was followed out by the use of one single platform design tool and the model could therefore be manipulated using middle-ware plug-ins allowing the use of parametric modelling. The outcome of the assessment was later evaluated and attached to the appendix front.

Figure 3.4: Dynamo and Revit collaboration
What’s seen in the picture 3.4 above is the Revit model interacting with the Dynamo code going back and forth, assigning the latest given parameter to the material that is being investigated and calculating the current energy use of the house. For every iteration there is a calculation at the same time as their results are getting passed over to Green Building Studio platform, continuously storing the latest data until the analysis process is finally complete.

### 3.3 Dynamo

Dynamo is available as a free state of the art open source tool and is developed by the Autodesk team. It is developed as a platform for computational designing, and is best known for its feature to work with Autodesk Revit files by running Dynamo as a Add-in program. The main use of this tool in this thesis has been to send calculated Revit data to the GBS. In order to parametrize the height of the house windows, the model data needs to be saved as a GBXML file through scripting, and later saved on the computer. A python code is scripted to recognize the current results of the Revit model according to figure 3.5. The code allows the current model to be saved every time a new iteration takes place, and overwrites the previous GBXML data for every new changed parameter.
Figure 3.5: Dynamo script code

The Dynamo package used to calculate the model data is called "Energy analysis for Dynamo", and the set-up nodes are according to the figure below. The concept of the package is to give the model a unique project ID which later returns a run-ID. The run-ID is used to extract the results analysis from the GBMXL file and forward on to the cloud storage of GBS. The data shown in the figure is given for the current run of the model and is overwritten for each iteration run. The model nodes are according to Figure 3.6.
The Dynamo nodes is used to perform iterations that consists of a basic programing understanding, using a simple set of rules in order to allow the parametrization to take place. As shown in the figure 3.7, a "Code-block" was created to define the interval of the allowed changes to be made. As earlier mentioned, the amount of runs is limited in GBS for those using a licensed student version which only allows a maximum of three runs. The list map node was used to gather all different results gathered from the different changes in parametrisation, and is later on sent to a CSV excel file in order to complete the loop. The project ID is gathered from the Revit UI and is patched to RunEnergyAnalysis node. The scripted code from the figure 3.5 is also connected to the RunEnergyAnalaysis, which will prompt us a specific Run ID for the project. This Run ID will gather information the GetAnalysisResults node and allows us to gather the information we seek. The Boolean nodes are used as a programing language term to allow us perform the iteration.

The picture below explains the construction of a node composition in order to perform iteration runs. First off, a custom node named "Set parameter and write results value.." is created to define the loop details. The custom node inputs are required to be satisfied in order for the parametrization to fully function and retrieve any output results. The first node in the Custom node is defining the element of the
Revit project and needs the project file opened in background in order to work. An initial value, maximum value and increment will be chosen to define the loop. Two file paths are created to save the incoming results and to allow each run to overwrite the latter.

The rules of the loop are carefully noticed in Figure 3.8. Dynamo will use the defined variables using a simple loop equation to satisfy the loop.
3.4 Green Building Studio

The analysis results of the building performance are recognized from the GBMXL file and are plotted in Revit. Figure 3.9 shows the determining factors that are calculated through the data given from the Dynamo codes. The results can also be viewed as charts through the different energy resources which makes it easier to differentiate, according to figure 3.10.

![Energy Analysis Result](image)

### Building Performance Factors

<table>
<thead>
<tr>
<th>Location:</th>
<th>Stockholm, Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Station:</td>
<td>184930</td>
</tr>
<tr>
<td>Outdoor Temperature:</td>
<td>Max 25°C/Min -14°C</td>
</tr>
<tr>
<td>Floor Area:</td>
<td>26 m²</td>
</tr>
<tr>
<td>Exterior Wall Area:</td>
<td>95 m²</td>
</tr>
<tr>
<td>Average Lighting Power:</td>
<td>4.84 W/m²</td>
</tr>
<tr>
<td>People:</td>
<td>0 people</td>
</tr>
<tr>
<td>Exterior Window Ratio:</td>
<td>0.02</td>
</tr>
<tr>
<td>Electrical Cost:</td>
<td>0.19 $/kWh</td>
</tr>
<tr>
<td>Fuel Cost:</td>
<td>3.78 $/Therm</td>
</tr>
</tbody>
</table>

Figure 3.9: The Building Performances Factors in Dynamo Revit

The bright side with using GBS is that the energy calculation is made in a web-cloud, which makes the iteration run faster as the calculation wont harvest on the computer engine.
It is also possible to view the results from the GBS website browsers if preferred, as more information about the runs are accessed from there. The base-runs represents the amount of iterations with the corresponding energy use and run-id.

Each base-run is overwritten and is shown in date order from down to up, as shown in Figure 3.11. It is also preferable to keep to a minimum amount of iterations due to computer power limitations.
4. Results

In the following sections: results from the various simulations are presented along with a short discussion on each simulation. The results and evaluations consist of the information that was received when conducting the analyzes. Each individual simulation is presented at the start of each section, and the conducted parametrization was performed on the window height, window width, amount of window panels and of the optimized house orientation. The gathered results were expected but satisfying, and proved that the Dynamo script was successful. Each section will include images of the most relevant results, while a complete collection of the results is presented in appendix A.

4.1 Model of Procedure

The following are a generalization of results obtained by the Dynamo iteration process. The run process is straightforward when all the nodes and packages are assembled. As viewed in figure 4.1, shows that Revit only requires the details data of the material parameters. In the case of the figure, one can see that the only data that needs to change is the node "Family types" and the interval body for the loop.
For this case study, we selected 4 different parameters to analyze: Height, Width, House orientation and Amount of window panels used. The results are gathered through the GBS and was later evaluated in graphs where we have chosen to consider the energy performance and energy price in SEK as the main factors.

### 4.1.1 Height Parametrisation

*How will the energy distribution and price be affected by the changes of the window Height?*

Changing the shape or size of a window will affect how the light is reflected within the house. The intention with this simulation was to see how the parametrization of a window can affect the energy cost. Three heights were compared while the width of the window was fixed. The model of the house was constructed in such a way that no other energy sources were considered, such as heating or cooling sources. This was done to ensure that the sun light was supplying source and to not complicate the evaluation of the results. The analyzed window was fixed on a 450 mm width
with the height dynamically changing from 2000 mm, 3000 mm and 4000 mm. The approximate result changes in energy cost can be viewed in the graph figure 4.2.

![Window Height Parameterization](image)

**Figure 4.2: Window Height**

The graph shows a linear increase in energy cost when choosing a higher window due to transmission losses, which was expected and is an indicator that the dynamo script works. What can also be seen in the graph above is that the increase in energy cost is not proportional to the increase of height, i.e. the increase from the 2m-3m height does not give similar energy cost as 3m-4m. This is because the energy balance in the house depends not only on the transmission losses, but also additional energy gathered from the sun. The additional height of the window compensates the energy losses by giving the slope a flatter character. The final evaluation of the results shows that choosing a higher window height is the least favorable in this case.

### 4.1.2 Width Parametrisation

*How will the energy distribution and price be affected by the changes of Width?*

In the case of parametrisation of the window width, the height was now used as a fixed value with a dynamically changed width. As shown in the figure 4.3, as expected, the energy usage was increasing in relation with the window width. It is worth noticing that even though the window area on every iteration is the same as
with case of window height parametrization, the energy usage is not similar. This can be explained by the orientation of the window and the different ways the sunlight is transmitted to the building. Compare for example the energy usage for the cases with 450x200 and 2000x450 window dimensions. Though they are being same the resulting energy usage differs. This is a second indication that the written dynamo code is working and that the Dynamo tool can be suited in these kind of energy simulations.

The analyzed window was fixed on a 450 mm height, with a dynamically changing width from 2000 mm, 3000 mm and 4000 mm. The approximate result changes in energy cost can be viewed in the graph figure 4.3.

**Figure 4.3: Window Width**

4.1.3 House Orientation Parametrisation

*How will the energy distribution and price be affected by the change of house orientation?* To further analyze the capabilities of dynamo, the following case was conducted through a house orientated parametrisation during a summertime period. With the help of a script in Dynamo, the house was able to rotate through different orientations. A simplified equation was being used to estimate the sun rotation in Revit. The starting point of the iteration, the house faces east in equal to the sunrise, and at the end of iteration facing the north equaling sun dawn. The setup
of the code was scripted in a way that allowed the house to move in a 67.5-degree angle at each iteration resulting in a total movement of 270 degrees.

![Window Orientation Parameterization](image)

**Figure 4.4: Window Orientation**

The results show that the orientation of the window on the south result in less energy usage than the other directions. Which can be explained by the amount of solar hours that this side of the house is exposed to.

### 4.1.4 Amount of Window panels Parametrisation

*How will the energy distribution and price be affected by the amount of window glass panels used?*  Three different windows were simulated in order to study the significance of the quantity of window panels. The thickness of the panels was all the same and belongs to the same distributor of Pikington. The Dynamo script will select between the three different window types by dividing them into three computations of iterations and runs.
The three different windows that was used in this case had glass thickness that corresponds to the measurement of: Pikington - Single Glass: 3/8” (9.525 mm), Pikington - Double Glass: 1/4” (6.35 mm) + 3/8” (9.525 mm), Pikington - Triple Glass: 1/4” (6.35 mm) + 1/4” (6.35 mm) + 1/4” (6.35 mm). The dimension of the window is unchanged and equals a dimension of 450x2000 sqm.

As expected, the triple glass window gave the best results in energy usage per year. When comparing the results of all three, the different in energy between the amount of window panels narrows down for each window panel added, meaning that the biggest energy difference is between the double and the single glass window.
5. Conclusions and Discussion

It’s clear that building performance analysis in an early building has great potentials in a project. The designer has a broad variety of approaches to choose between that will lead to a better decision making which will likely pay off later. In the near future, the complexity of the building will become more feasible due to continuous development of computer designing and software tools. There is also a clear growth in popularity of scholars finding different optimization approaches as the requirements of energy-consumption are becoming tougher.

One of the greatest challenges of building optimization is the tedious interoperability among the different software tools. From an energy point of view, it is considered preferable to include tools with a model platform (Revit), an energy simulator (Green Building Studio), a daylight simulator tool (through the Dynamo package or the Revit application) and a direct connection to a virtual programming language (Dynamo).

The programs that was mentioned in the parenthesis was of great use for us when working with this thesis and did not require any extensive computer programming skills to maintain, which was the main reason to why we choose to operate with these in the beginning. An important point to mention is that Dynamo is at its earliest beta stage and did cause quite a bumpy road for us at the start. More than half of the time was spent on the finding answers for the suddenly appeared bugs and glitches, but this also paved the way for the fastest learning. It is also important to note that the yearly updates of Revit caused the python scripts in Dynamo to stop working, which forced us to use the older version of Revit 2015 application. We conducted the analyzes in a student licensed version of Revit which became slightly tedious after a while because it limited our result area.

The access to GBS has been a great asset during this thesis and have provided
great and fast feedback to our energy building simulations. It was one of our most essential tool because of its cloud-based features which could allow multiple runs work in parallel in the cloud for optimization purpose.

This thesis has helped us learn the great differences between using the combination of Dynamo-Revit-GBS or Rhino-Grasshopper.
6. Future Work

The world of digitalizing is wide and offers many new topics for parametric studies, and in the below text are some of the suggestions we propose for the reader to further extend the knowledge about parametrisation in a BIM early stage designing.

One can choose to continue to embroil the script code that determines the most optimized solution for energy. By creating a fitness function, you can customize the output of the result so you get more optimized solutions to the parametrisation, but this requires a working mathematical algorithm and a smart way to implement it in the Dynamo plug-in.

In order to fully exploit the possibilities in further studies, one needs to have the complete versions of the software that is used, i.e. to allow more iterations in green building studio. A powerful computer is also necessary to avoid crashes and to create smoother runs on advanced algorithms.

It can therefore be beneficial to partner up with a programmer who can provide for the algorithms codes or for the fitness functions in order to perform more advanced building simulations.
References


Appendices
A. Appendix

Figure A.1: Orientering

Figure A.2: Window Panels Parametrization
Figure A.3: Fönsterbredd

Figure A.4: Fönsterhöjd