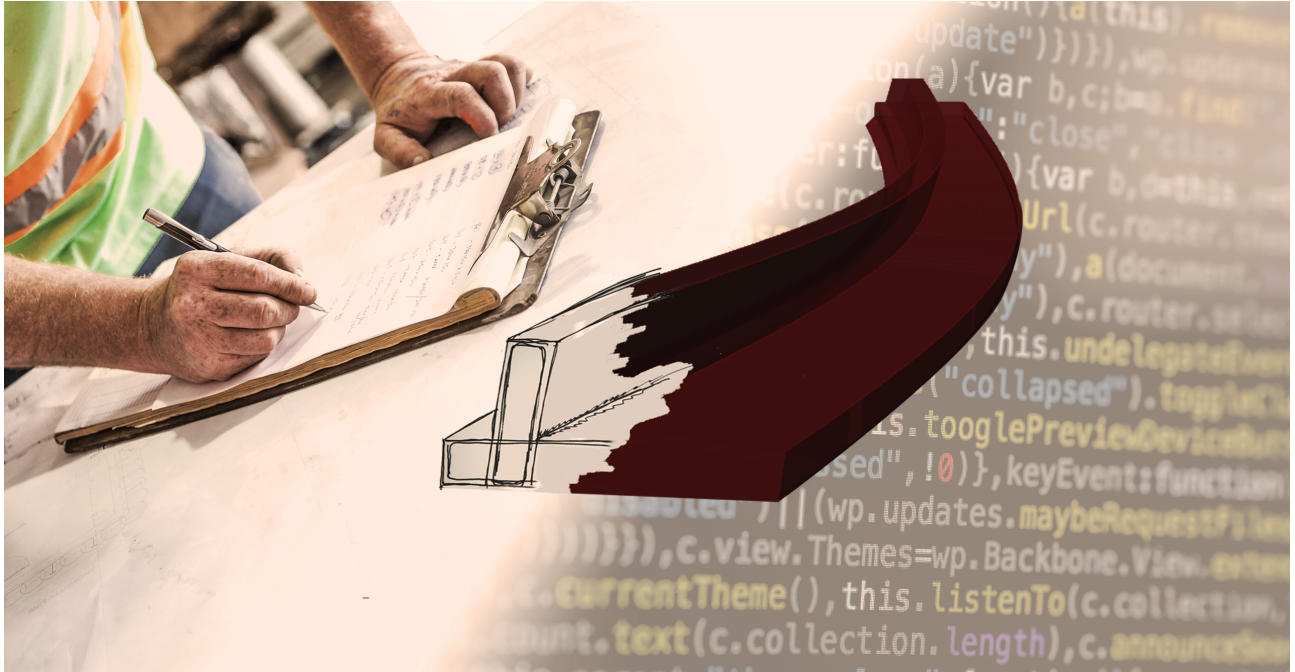




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Creating 3D Models through Parametric Coding

Master Thesis in Design and Construction Project Management

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CREATING 3D MODELS
THROUGH PARAMETRIC CODING

Preface

This thesis is made as a final moment of the master program *Design and Construction Management* at the Department of Architecture and Civil Engineering, Chalmers University of Technology. It corresponds to 30 ECTS and was carried out through the spring of 2020.

We would like to express our gratitude through this preface to Gustav Walleij at Skanska's Technological Bridge Department in Gothenburg, as well as Marcus Davidsson, for the possibility and encouragement to perform this work at their arena. Ahmad Alomran at Skanska, for many valuable insights of the Design Process as well as thoughts about how to further develop the Construction Process. Daniel Olsson, at Skanska for pushing the design process forward, allowing designers to develop further than only making drawings. Daniel Jonsson who helped us through times where the motivation lacked due to software struggles.

More, many thanks to interviewees generously providing us with empirical data, pushing the thesis to its current state. A special thanks to our examiner Mikael Johansson, always bringing new ways as well as positive thinking to the table, and taking time to evaluate the report during a stressful period.

Finally, thanks to our family and loved ones for encouraging us during our years on Chalmers.

Gothenburg, June 2020

Tobias Ekelöv

Lukas Olszaniec-Kozakiewicz

Abstract

While the grade of innovation in a variety of industries has been on a steady rise, the construction industry have been criticized for failing to keep pace, pushing the need for new innovative ways of working. In regards to the design phase, Skanska applies different techniques and practices in order to develop models and drawings, and changes made to the design have a major impact on the aspect of both cost and time.

In reinforced structures, even the simplest of changes, such as adjustment of width, lead to a necessity of additional complex revisions of reinforcement. The Current way of working, require remodelling major parts when these changes occur. In the desire to streamline this process, new software that enables parametric design, is challenging the status quo by linking elements to each other, and as a result, creating the dynamic environment needed in current time.

Through studying theory and collection of empirical data, a script prototype was created through Grasshopper, enabling the creation of a reinforced parametric retaining wall following a double-curved road line. This study showed that parametric design has potential to be included into current work flow at Skanska. Initially requiring a higher investment in form of time and money compared to traditional modelling, scripts and parametric models can be re-used, leading to fast returns once another similar project is completed.

Concluding, the undisputed edge that comes with parametric modelling over the classical design process, has an opportunity to revolutionize industry in the similar manner to BIM at the beginning of the decade. Overseeing the future, designers and engineer would take on more managerial role, coordinating the software and develop new scripts.

Keywords: Parametric Design, Parametric Modelling, BIM, Tekla, Grasshopper, retaining wall, change management

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List of Abbreviations

2D Model	Model with two dimensional geometry
3D Model	Model with three dimensional gemoetry
Add-on	Additional small program installed above a software, further enhancing it
As-built document	Drawings of a finished construction
BAT File	Batch File. A file type used to create scripts and commands within Microsoft Windows environment
BIM	Building Information Model
CAD	Computer-aided Drawfting
c/c	Center Distance
Cloud	Clouds are used on revisioned drawings to indicate change
DWG	A standard file type used by CAD programs
3D DWG	A standard file type used by CAD programs, when the model is in 3D
GUID	Globally Unique Identifier. Element inside a model all have unique GUID identification numbers
IFC	A neutral file format used to enable information exchange between 3D modelling and BIM softwares
Parametric Design	A process aimed to create models based on functions and algorithms
Parametric Modelling	Models created through parametric inputs
XLS	A file format used by Microsoft Excel

Chapter 1

Introduction

1.1 Introduction

This thesis is made as a final step in the MSc program “Design and Construction Process Management” at the University of Chalmers, together with the division of Architecture and Civil Engineering and in collaboration with the Structural Bridge Department at Skanska, Gothenburg, Sweden.

1.2 Background

The construction industry has previously been targeted to criticism regarding lack of innovation Ingemansson (2012), leading to a desire to change them in order to be more efficient and to use lesser resources to create more. While change can appear in different shapes and forms, either as a carrot or a stick, Change Management to some degree in order to improve is required. This thesis aims to challenge the design phase and discuss how to implement new ways of working, especially within the field of Parametric Design. Parametric Design is a tool used to automate the modeling of different structures, but can also be used in the future to use other inputs such as environmental regulations as a boundary when designing.

At the time of writing, Skanska uses different techniques and processes in the design phase of a building/construction to develop drawings. In some projects, the 3D models are required while in others, 2D drawings are enough. The use of BIM is more or less limited to the construction phase and only used when 3D models are produced.

Typically, designers work together with structural designers to create models and drawings. While the drawings and models produced are made through different processes, they are all made manually. To semi- or fully automate this process would benefit the process both regarding time and money.

When conducting an initial interview with the supervisor of the thesis, a concern regarding changes during the design phase was expressed. One example of a design change could be to change the width

of a bridge. This lead to additional work in the model where rebars and other details would also have to be adapted. By using parametric design, it would mitigate this problem if objects and instances in the model are dependent on each other. Furthermore, it could also work as a tool to iterative test a construction model, optimizing it in different aspects.

1.3 Aim

The aim of this study is to research the possibility of a parametric design of structures through external software. Furthermore, to investigate how to implement the solution in the most effective way. At the end of this report, the following research questions will be answered:

- Is it possible to include parametric design into the current workflow?
- Does parametric design lead to savings regarding time and money?
- Can the design process include different structures, e.g. bridges and retaining walls?
- Is it possible to provide the model with class structures in order to use BIM in an efficient way during the building process?

The outcome of this research is to provide Skanska with a basic platform/way of working for a parametric design that can be adapted into many different projects and also to identify possible flaws to prevent unnecessary development of non-working features. Furthermore, this thesis will also discuss the topic of implementing new features into an existing work process through Change Management as well as evaluating it together with designers working with real-life bridge projects in Tekla.

1.4 Scope

In order to limit this study, this thesis will limit the content of the term “structures” to focus on retaining walls. Retaining walls shows many similarities with bridges, which the department at Skanska mainly works with. They both often include piles and reinforced concrete and the structures are constrained to a given road line.

While the use of BIM is an important topic in terms of streamlining the building process, this thesis will briefly touch upon this aspect, in order to include classes, names, materials, and other BIM information.

1.5 Method

This study is compiled based on five main parts; Initial interview with the company, theoretical study, interviews aimed to gather empirical data, development of the prototype, and finally evaluation combined with analysis.

The initial interview was conducted in order to identify and precise the extent of the work as well as the department's thought about parametric modeling. Secondly, a theoretical study in the form of a literature review about key concepts related to the subject combined with tutorials introducing the parametric software in order to lay ground for further study. Thirdly, the collection of empirical data in form of semi-structured interviews aimed at gathering the understanding and knowledge about current state of the company. The collected data combined with theory was used as a foundation in the process of creation of a module inside Grasshopper.

The practical part, the Grasshopper module, was evaluated in terms of usability for Skanska's Bridge department, as well as adaptability to create other forms of structures. Lastly, the result was evaluated and analyzed. Based on these, conclusions were compiled into recommendations for Skanska.

Chapter 2

Theory

The following chapter will present the theoretical framework together with the CAD programs being currently used in order to create models and drawings in the design phase. Moreover, this chapter will also describe the software used to create parametric models.

2.1 Change Management

Change Management is an important aspect of the construction industry. Bilge Erdogan (2005) stated that change can either be business-related, based on technology, people, cultural or related to design. The Swedish construction industry has previously been criticized for being too conservative regarding change and innovation (Nordstrand, 2008; Ingemansson, 2012), and therefore preventing productivity growth, to increase its overall quality and to lower its costs. Ingemansson (2012) argues that calling it "conservative" is to mitigate the industry's problems and that there are more reasons to why, in some cases, the construction industry is not considered innovative. The definition of innovation is one, that innovation is related to product design and not structures, another that many construction companies work are small and cannot compete with large regional companies regarding research and development. To call it conservative can therefore be true in some cases, while in others unfair. This is also supported by an interview conducted by Ingemansson (2012) together with *Sveriges Byggindustrier*. Companies were asked in 2012 if they had increased the number of virtual buildings, e.g. 3D modelling. Only 12 percent of the small companies asked had increased this, while the same number at larger companies was 91 percent. This shows the difference between companies in the construction industry.

Ingemansson (2012) describes further that a majority of construction companies, small and large, argues that the focus on profitability and lack of time acts as a road bump in implementing change in companies.

2.2 Building process

When a need for a new construction occurs, a building process is initialized. A building process can be divided into several phases, mainly; pre-phase/Planning, Designing, Constructing, and managing/using. While all of these phases got their own characteristics, they are also both directly and indirectly linked. The construction process also differs between a process of building or buying a construction (Nordstrand, 2008). Moreover, this thesis is written in collaboration with a construction consulting office and the building process will be described keeping this in mind.

While creating 3D models is typically an activity within the designing phase, the information created is used in phases down the line as well. Therefore, it is crucial to understand all phases, to see how they are connected, in order to improve them.

2.2.1 Planning

The planning phase is where the foundation of the project is laid. Nordstrand (2008) stresses the importance to have a competent project leader that plans and coordinates the project and its different actors in order to mitigate common problems that might occur. During this phase, decisions are very much connected to the scale of the project as well as what is going to be built, where and how. A smaller project, e.g a home to a family, don't require the same amount of extensive planning as a large infrastructure project do, even though the project share similarities in many other aspects (Nordstrand, 2008). Furthermore, McGeorge and Zou (2013) argues that the stakeholders' needs should be reflected in the business strategy chosen.

Initial decisions concerning the designing of the structure are also made during this phase. Depending on which type of contract the contractor uses, the design is either done by the contractor or hired from another firm. Depending on the scale of the project, the design can be made either more or less advanced, be done in 3D or 2D, include additional information or not (Nordstrand, 2008).

2.2.2 Designing phase

The designing phase is the part of the construction process where the needs of the contractor/owner are taken into account and presented on, traditionally drawings and description drawings (Nordstrand, 2008). McGeorge and Zou (2013) argues that there is a need for a cultural change in the construction business to streamline the process. Eastman (2011) also states that there is a need for new technologies to make the process even more effective, further confirming the need for a broad understanding in all of the phases in order to make it better in all aspects.

As previously stated, the design can either be created by using 3D models or in 2D depending on several reasons. Limited knowledge about 3D programs, the extent of the project, and what's

requested by the project were some of the reasons stated by interviewees (Designer, 2020; Engineer, 2020). .2D drawings originally stem from drawings made by pen and paper but have developed into the term CAD, while digital 3D models were made available when modern software became more and more advanced.

2.2.3 Constructing

Depending on which type of contract is used, the construction can either be done in-house or contracted to a firm, and the activities performed during this phase can differ. Generally, in this phase ground preparation is done and the construction of the structure. In some projects, the construction is done mainly on the construction site while in others where components are pre-fabricated, the construction site is more or less just an area where they are assembled Nordstrand (2008).

Throughout the history of the construction process, different tools and techniques have been used in order to plan and control the production regarding time used, money spent and resources. The tools and techniques used differ depending on the knowledge on-site and the extent of the work, whereas a large construction project often requires a broader use of planning tools in order to deliver within budget Nordstrand (2008).

A common activity during this phase is to compute the amount of materials needed for a specific part of the building, e.g. "How much concrete is needed to produce the slab?". Typically, information on the drawings is used to calculate this volume. Moving forward to a more digital future, using BIM Software to extract this type of information can be done in just one click if using 3D models correctly. This will be described more in chapter 2.3.

(Nordstrand, 2008) stresses the importance of having a solid way of working with new drawings on the construction site. To only have one model, which continuously is updated when a new version is delivered to the construction site will reduce the risk of building something that has later been changed in another version of a model.

2.2.4 Using

When the building is built and delivered to the owner, the project enters a Using phase. For example, if houses are built, this is when owners start to move in (Nordstrand, 2008).

While the scope of this project is limited to the design phase, it is of value to mention that there is a tendency in the construction business to use more BIM during the Using phase, e.g. to include lamps, rooms, appliances, etc to provide the owner with information regarding e.g. age and when they are needed to be renovated (Eastman, 2011). This information can be included by the designers when creating the models, but will only do so in it is requested.

2.3 BIM

BIM (Building Information Model) is a tool used to extract additional information from the models in order to streamline the building process (Milyutina, 2018). Objects in models can contain information regarding volume, construction order, quality, material, contractor, supplier, execution time, and more. There are standards that regulate what type of information the models should contain, such as CoClass which is a new standard developed in Sweden by the BIM Alliance (BIM Alliance, 2020). While designing a structure mostly is limited to the designing phase, the use of BIM is an integrated part of all of the phases. However, the use is often limited depending on the level of expertise in the project (Milyutina, 2018).

Different software is used in order to extract the information available and companies work in different ways. Three software that is used to a greater extent is BIMsight, BIM360, and Navisworks. These software's are used as tools to collect information in the models and present them in ways to favor planning, calculate quantities and more.

2.3.1 Codes, classes and names

3D Models, and elements inside these models, can be labeled and named after functions, names, positions, and more. There are different initiatives that use their own set of codes in order to describe an element. The standards of codes exist in order for the client to extract the same information from the model as the designer does (Corporation, 2020). By using the same codes, the client can also prepare templates within the BIM software and start to organize its work even before the first model has been delivered (Corporation, 2020).

2.4 Parametric Design

Parametric design or modeling enables a more dynamic workflow for the creation and modification of geometric objects in the model than the classical way. According to Eastman (2011), a major benefit of parametric modeling, which heavily contributed to the extended implementation of this kind of workflow, was the fact that numerous objects could share parameters with each other. Objects such as walls can be bounded by floor plans, where slightest changes of the floor plan's attributes or characteristics (i.e. height between floor planes or dimensions), results in changes to the wall object connected to it. On the opposite side, changes to the wall object such as position correspond to the adequate transformation of the floor plane. To put it in another way, a large number of complex geometries can be bounded to complex curves, and therefore managed in a more simple way automatically unlike the error-prone, manual way in designs that contain an extreme amount of

objects.

Eastman (2011) elaborates that most of the parametric object families recognize the *if-then* conditions, instructing the objects on how to act when different conditions apply. For simple geometries as for instance a wall object, the software can determine an appropriate attachment type between wall and floor or ceiling. On the other hand, in more complicated cases where a slab has to incorporate reinforcement, the software can calculate the amount of reinforcement needed dependent on the load, but also place and space it according to the specification. To put it differently, objects can modify themselves to an extent, by using the simple data input from the engineer.

There is a distinction between *loose coupled* and *tight coupled* systems within parametric BIM workflow. *Tightly coupled* systems work through Application Programming Interface (API) equipped within the BIM system Janssen (2015). Within that system type, graph-systems transmit information through native API of the BIM software resulting in the direct insertion of the model in the BIM environment every time graph-system is updated. An example of that system is Dynamo/Grasshopper and Revit. On the other hand, *loose coupled* system work through the exchange of a model, where graph-system produces a model in a standard file format (i.e. IFC), which then can easily be imported into BIM software. In other words, the model can be created based on a set of inputs from the parametric model, this process is called *cooking*. Further, the cooked model can serve to generate the exchange model (i.e. in IFC-format) which then can be imported into BIM-system in order to create a BIM model.

Janssen (2015) argues that the benefit of the *loosely coupled* approach is mainly the ability to exchange files in the universal format and therefore combine diverse ways of working. However, the exchange of cooked models must be efficient enough to be able to output an associative model. A model that includes not only geometry but also interrelations between objects that would define their final form.

2.5 Software

Different software can be used in order to parametrically design a model. Software used in this thesis is chosen in regards to which ones are used at Skanska, especially in bridge projects. An evaluation of different software will not be included in this thesis. Grasshopper and its connection to Tekla will be examined. A few add-ons and other software were also used in order to enhance the functionalities and these will be described below.

2.5.1 Microsoft Excel

Microsoft Excel, further referred to as Excel, is a program used to calculate, store, and manage data and values. The program is included in the software suite Microsoft Office, developed by Microsoft and published by Microsoft Corporation (Properties, 2020). Excel is used worldwide and to a great extent at Skanska as well as the current department.

2.5.2 Trimble and Tekla Structures

Trimble is a technology company working in many different industries, such as Agriculture, Civil Engineering and Construction, Transportation, Rail and more, and their solutions are used in many countries. In 2011, Trimble bought the Finnish company Tekla. Tekla is the creators of the BIM software Tekla Structures (Trimble, 2020).

Tekla (2020c) describes Tekla Structures as a *"...advanced structural BIM software that lets you create, combine, manage and share multi-material 3D models packed with valuable construction information."*. Currently, Tekla Structures is used in some projects at Skanska, both during the design phase and in the construction phase, and this is the reason why Tekla Structures was chosen as the main modeling software of this thesis.

Traditionally, drawings have been used when building new construction. However, a paradigm shift is approaching where drawings are being replaced by 3D models where Tekla Structures in some Skanska Projects has been the software of choice. Furthermore, the models also provide the construction site with additional information, utilizing the techniques of BIM.

2.5.3 Tekla Bridge Creator

Bridge Creator is a feature included in Tekla 2018, and later versions, allowing cross-sections to be aligned and extruded along a double curved road line, creating complex geometries. (Tekla, 2020b).

2.5.4 Rhino

Rhino is a 3D modeling tool used to create models of various forms. It comes with a graphical interface where the user can either create models and surfaces through different tools or import DWG files and use these. The interface is constructed by windows, presenting different views of the model, together with toolbars containing functions.

Rhino 6, the latest version of the software, is delivered with the add-on Grasshopper (Rhinoceros, 2020). Rhino is developed and owned by Robert McNeel Associates with their main office in Barcelona, Spain (Rhinoceros, 2020).

Grasshopper

Grasshopper is an add-on included in the latest version of Rhino. It is a tool that, through graphical elements, enables the user to create models through parametric codes and algorithms. It provides the user with a user-friendly interface and boxes including different functions. The functions can be described as recipes, combining inputs to create new outputs. No knowledge of programming is needed in order to use Grasshopper but the software allows the creation of new boxes through Python programming. The eventual limitations of the software can, therefore, be mitigated by a skilled user. Grasshopper works seamlessly together with Rhino. Additional add-ons and functions can be implemented into grasshopper Rhinoceros (2020).

Tekla Live Link

In order to allow Grasshopper to communicate with Tekla, Tekla Live Link is used. Tekla Live Link is an add-on in Grasshopper which translates geometries created in Rhino into Tekla. Tekla Live Link also adds additional features into Grasshopper, such as creating rebars and other structural components (Tekla, 2020a).

Tekla Live Link updates the model generated in Tekla in continuously, allowing the user to make adjustments to the script and see the changes being made in real-time. Tekla Live Link is created and developed by Tekla (Tekla, 2020a).

Bumblebee

Bumblebee provides Grasshopper with features allowing the user to import or export data from and to an Microsoft Excel file (.xls). Bumblebee is created and developed by David Mans (Mans, 2016).

Human UI

Human UI is used to construct an interface into Grasshopper to increase the user friendliness in the programs and scripts created through Grasshopper. Buttons, sliders, prompts and more can be created to allow inputs directly into the model and Grasshopper (Heumann, 2019).

2.6 Retaining Walls

A Retaining Wall is made up of mainly two parts, a slab and a wall connected to the slab, see figure 2.1 (Sundquist, 2005). According to International Building Code (further referred to as IBC) by Thornburg (2018), retaining walls are structures whose main objective is to resist the lateral loads caused by soils on the other side of the wall. Those structures are particularly used when the long slope

is undesired. Retaining walls should meet the standards specified by IBC such as resisting overturning and sliding, as well as withstanding pressure caused by water uplift or backfilling weight on the slab.

The most common type of retaining wall is cantilever wall, including its variations (with or without toe slab or Z-profile - commonly used on train station platforms) Rutgersson (2009). Due to the weight of backfilling on the heel slab as well as its own weight, the retaining wall gets its stability. In the case of the higher wall, it can also be stabilized by a flange placed on the heel slab, which takes off some of the load from the stem. Occasionally, the retaining wall can be anchored in the backfilling. In that case, the anchor takes the majority of the horizontal forces that act on the wall stem.

Retaining wall of gravitation type gains its stability due to its own weight, and is not anchored in any way.

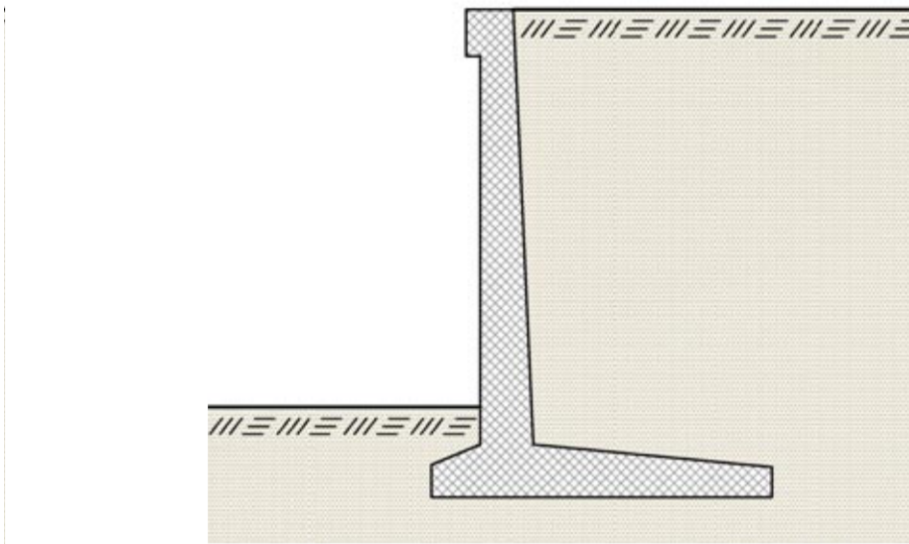


Figure 2.1: Example of a retaining wall (Rutgersson (2009))

During the modeling phase, retaining walls share many similarities with bridges. Sometimes, their edge girder has the same cross-section to allow a smooth transition from the retaining wall to the bridge. Also, they often follow the same road line and base points that the cross-sections are extruded from. This makes for a good example to try out different solutions on.

2.6.1 Concrete

Concrete's main characteristic is its ability to handle high compression forces. However its capacity to take tensile force is merely around 5-10 % of its compressive strength (Almgren, 2009), therefore pure, unreinforced concrete's bearing capacity is restricted to it. Damages that occur in the form of cracks lead to a sudden break. For that reason, in order to be able to use concrete in structures where tensile forces exist, the concrete structure is complemented with reinforcement.

Like any other building material, concrete is classified in categories regarding its physical properties. Exposure class refers to environmental conditions (i.e. exposure to seawater) that contribute to the process of degradation of concrete, leading for instance to corrosion of rebars. Strength class specifies compression that concrete can handle after a period of twenty-eight days. It is a classification system made up of increasing numbers with "C" as prefix (in Sweden, from C12/15 to C100/115). Those numbers correspond to minimal pressure concrete can handle expressed in Mega Pascal (MPa).

2.6.2 Piles

Piles are used in a retaining wall when the soil cannot maintain the support of structure by itself. Different types of piles can be used, e.g. concrete or steel. Piles are placed from a coordinate list composed of X, Y, and Z values. X and Y represent the horizontal placement, and Z the vertical (?).

2.6.3 Reinforcement

Reinforcement can be classified into two main groups - main reinforcement, whose main task is to handle tensile forces, and secondary reinforcement - which supports main rebars, helps to distribute cracks but also functions as safety reinforcement (Berg, 2009). Moreover, rebars are classified with respect to finish quality, which commonly refers to its solidity/strength.

All reinforcement must be labeled in order for it to be separated from other types (Almgren, 2009). According to Swedish Standard (NAD(S)/SS-ENV 10 080), B500A and B500B (B=Betonsthal) are the two main classifications used today, where only reinforcement of B500B (in older standards labeled as Ks500ST) type is allowed due to its higher ductility. Despite the new standard, the older ones are still frequently occurring. Over the years, development in the construction industry has led to a reduction in the amount of reinforcement used. This in turn, results in the increased importance of supervising the positioning of rebars in the cross-section (Almgren, 2009).

In order to protect reinforcement in the concrete structure, the concrete cover layer is defined as the shortest distance in the cross-section, from the edge of the structure to rebars. This distance is dependent upon several factors, as environmental conditions that the structure will be exposed to. Moreover, the covering layer acts as an assisting mechanism for transmission of drag force between the main structure and reinforcement, especially next to anchoring points of rebars (Almgren, 2009).

There are different standard shapes of rebars depending on their placement in a structure. A few shapes are shown in figure 2.2. Rebar shapes, in Sweden, are named after the alphabet.

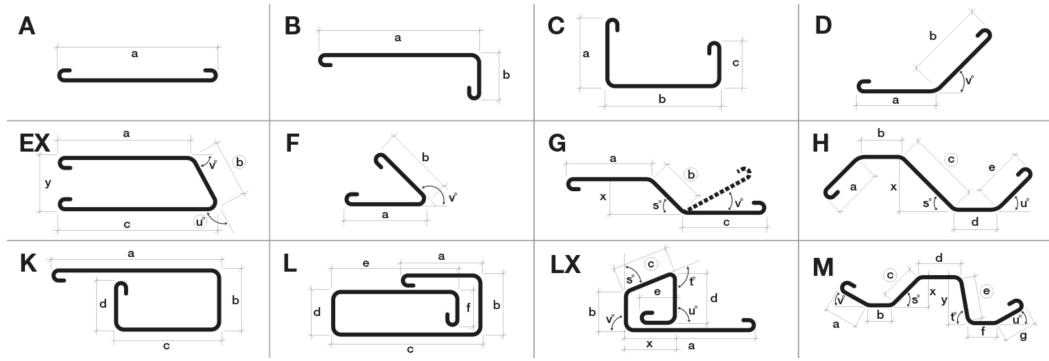


Figure 2.2: Rebar shapes and names (Steelservice, 2020)

An A-shaped rebar is a straight bar, and B-shaped is a rebar bent one time. Adding another bend, will make in a C-shaped bar, and so on.

Chapter 3

Current state and status analysis

The following chapter presents the current state of the construction business and at Skanska's Bridge Department. It is constructed by information collected from interviewees, all currently working, or has worked with the design phase of a construction process. Furthermore, a market analysis was done in order to further understand how the construction business is dealing with problems and possibilities regarding parametric design today, and future possibilities.

3.1 Interviews

Four persons were interviewed for the collection of empirical data, to define the different challenges and possibilities within the design phase. This information laid the foundation for decision about which software to use and which part within the field of parametric design to focus on. Interviews with designers and civil engineers working with both Tekla and Revit has been conducted.

The titles of the interviewees were: Designer, BIM-Strategist, and Civil Engineer. Their daily work routines differed a lot however they all worked with digital tools and bridges, and expressed a desire to improve and streamline current workflow. Additionally, they all have previous experience in digitalizing different parts of the construction process. They all stated that the construction processes need to be streamlined and more effective in order to save time and money.

All of the interviews were conducted in a semi-structured way, divided into two parts. Firstly, interviewee could talk freely about what he or she did follow by a second, a more structured part where guiding questions were asked. Guiding questions can be found in appendix A.

Designer 1

The designer had worked on Skanska for almost ten years and had good knowledge about BIM, Tekla Structures, and the design structures.

The office where the interviewee have worked at had developed a few new functions in the house to cope with problems that the current software they used could not handle. It was expressed that when a new function is developed, the user-friendly part of the function is often something that is not considered. This leads to difficulties during the learning process when new users are trying the understand new features and therefore does not fully understand the new function as a result. This is an aspect of digital change management that needs to be dealt with.

Another expressed concern was that different projects have different clients, and different clients have different needs. As an example, some clients do not require a 3D model of a building whereas in some projects it is absolutely critical to have one in order to plan work on the building site. Also, in some projects, the level of detailing in the model does not need to be absolute whereas in others the model needs to fully represent the actual construction. These differences tend to lead to a discontinuity when working on several projects with different needs. The interviewee's office, therefore, made a strategic choice to design each model to the highest level of detail possible, even though in some cases this was not required by the client. Whether the level of detail was accurate or not was a discussion that often took time. The time lost by, in some cases, "over-designing", was motivated by the gains in continuity.

The interviewee stated that there are many elements when designing a bridge model that are re-occurring, and there is a possibility to mitigate these by introducing parametric modeling. The design process of modeling a Retaining Wall share many similarities with a process of designing a bridge, especially the parameter of the road line. The interviewee also indicated that it is one structure that at least theoretically would be easy to parameterize. The design process of a Retaining Wall was described as using a set of inputs to design the model:

- Cross-section
- Road line
- Height
- Ground Surface
- Mesh of rebars

Additional features could include railing, bolts cast into the construction, electrical goods, and more. Many of these features are placed with a certain c/c distance.

The interviewee had put some thought into a possible parametric process and continued to explain it. The road line is a common problem in many processes. The curve often bends both in X and Y direction as well as in Z direction and extruding a cross-section along a curve bending in two directions

at the same time is something many CAD softwares have problem with, Tekla included. The road line could be used to calculate a sort of a baseline that the retaining wall was fixed to, and the height of the wall could be defined by, for example, the ground surface minus the baseline, making it a function instead of a fixed height. The respondent argued that changes to the design always appear, even though unwanted, and the more the model is defined by parametric inputs, the easier it is to apply these changes.

Today, the extension Tekla Bridge Creator is used when modeling in reference to a double-curved road line. It is useful, but required re-modeling if inputs of the cross-section change, as well as additional manual input when performing revision of drawings.

Designer 2

The interviewed designer has been working at a different company, however with similar tasks but with Revit as the main design software instead of Tekla. The interviewee also worked at a bridge department at a large consultant agency.

In many companies, employees use different software to, in this case, design different structures. While this can be seen as a strength, it can also be seen as a weakness. The office risks to be "sprawling" and the software knowledge tends not to be extensive regarding one particular software, but instead, finding programs that solve specific problems. A strategic decision was made by the interviewee's company to only design in Revit. Obviously, large decisions like this affected the workflow, but through innovation and collaboration, problems that occurred were always solved in one way or another, and through extensive knowledge sharing within the company; the risk of re-inventing the wheel was mitigated.

The interviewee expressed that parametric modeling was already used currently to some extent in different projects through a component called Dynamo which comes when installing Revit. While large bridges were not subject to parametric design, smaller components and features were created in Dynamo to solve specific problems that were previously solved using other softwares. Furthermore, through an in-house IT department, one could easily deal with a problem where programming was needed, in order to create scripts and more.

Digital Manager

The Digital Manager had previously worked as a designer but has recently switched into a more managerial role focusing on the digitalizing aspect of CAD/BIM. The interviewee had extensive knowledge in BIM and many thoughts on how to include 3D models into planning on the building site as well as how to make the overall construction process more effective.

The interviewee expressed that the building process is currently somewhat fixed and to mitigate the gap between the design process and the construction process would in many cases be beneficial for all parties. To aim towards a more agile approach where designers and constructors could exchange information more easily, would reduce the sometimes unnecessary tension that could occur from the lack of communication.

One specific problem that easily could be prevented was one concerning 3D models and the level of detail of the model. The Digital Manager stated that when the planning of a project starts, basic geometries of an object would be enough to plan with, but the requested 3D model is often delivered firstly when completely done, when it is fully reinforced and designed correspondingly to the level of detail required. For the Digital Manager to obtain a model earlier in the planning processes would ease the planning. The interviewee argued that the basic geometry is done in the first part of the design process, and could be delivered before the design of the other elements in the model starts.

Additionally, the building process is in some conditions hierarchical, which also leads to absent information exchange, since the channels where information flows are limited. One solution to this would be to include the person doing the models and drawings more into meetings and deliveries of models/drawings. This would, according to the respondent, make the process more agile. The designer knows often more about what information is available in the model, what is subject to change, and what could be delivered to the construction site during the early stages.

More, the Digital Manager discussed and evaluated the concept of inputs. When a script is functioning regarding all the geometrical inputs, one can program the script so that geometrical inputs are a function of many other aspects, such as costs, volume or environmental parameters such as CO₂ et cetera. During the early phases in a project, the designer could then quickly compare many different designs and make better decisions regarding which design to use.

Civil Engineer

The Civil Engineer had worked at the company for somewhere between five to ten years, and have good knowledge about the design phase, how to design bridges and 3D modeling in Tekla. The interviewee expressed that the designing phase could be divided into two schools, a new one and the old one. The old one is an extension of making drawings with pen and paper, making 2D drawings and details, whereas the new school uses modern software to create 3D models and take advantage of BIM.

Likewise what Designer #1 expressed, the Engineer stated that the retaining wall shared similarities with a bridge, and the experience gained from trying to parametric design a wall would be useful when, in the long run, parameterizing a bridge.

One interesting problem with the parametric design is that many things constructed are adapted

and adjusted to be easier to construct. For example, it is favorable for a retaining wall to look the same for e.g. 50 meters than changing shape each meter. Another limitation of current processes and software is that if there is a geometrical change, e.g. in case the road line gets updated, one would need to redesign the whole model. If the model was done through parametric inputs, changing the road line would change all the other elements as well.

Talking about what have been previously done regarding parametric or automatic designing, there has been some development in a few fields, especially calculations. Some elements have been automated in the design process as well: piles, rebar specifications and metadata of PDF drawing are to some extent. The interviewee means that there are great possibilities for including parametric design into the process, whether it is to create finished model or to only make a few elements adaptable. Currently, when an input or parameter is changed in a model, extensive work is often needed in order to adjust and update all of the elements, so that e.g. rebars correspond to the updated geometry.

3.2 Market Analysis

There are different standards and ways of working in regards to the BIM ecosystem, depending on the client and the contractor. Bertheden (2020) explains in their guiding document for CAD and BIM in Gothenburg, that models and drawings need to reach certain standards in order to fulfill the contract. It is also stated that CAD models should be delivered but only drawings in PDF format are legally binding (Bertheden, 2020). A 3D model should be delivered both in the native file type, such as a Tekla or Revit file, as well as in IFC type format. The elements should also be coded in line with the BIP system, described in chapter 2.3.1.

The Swedish Transport Administration, Trafikverket, works strategically with questions concerning BIM. They are a frequent and major client regarding large infrastructure projects in Sweden, and therefore also indirectly sets the pace of the development and requirements of BIM and CAD models. To visualize and concertize the strategy, they are using a concept called "The levels of BIM", presented in figure 3.1 which is developed by the British Institute of Standards (Trafikverket, 2020).

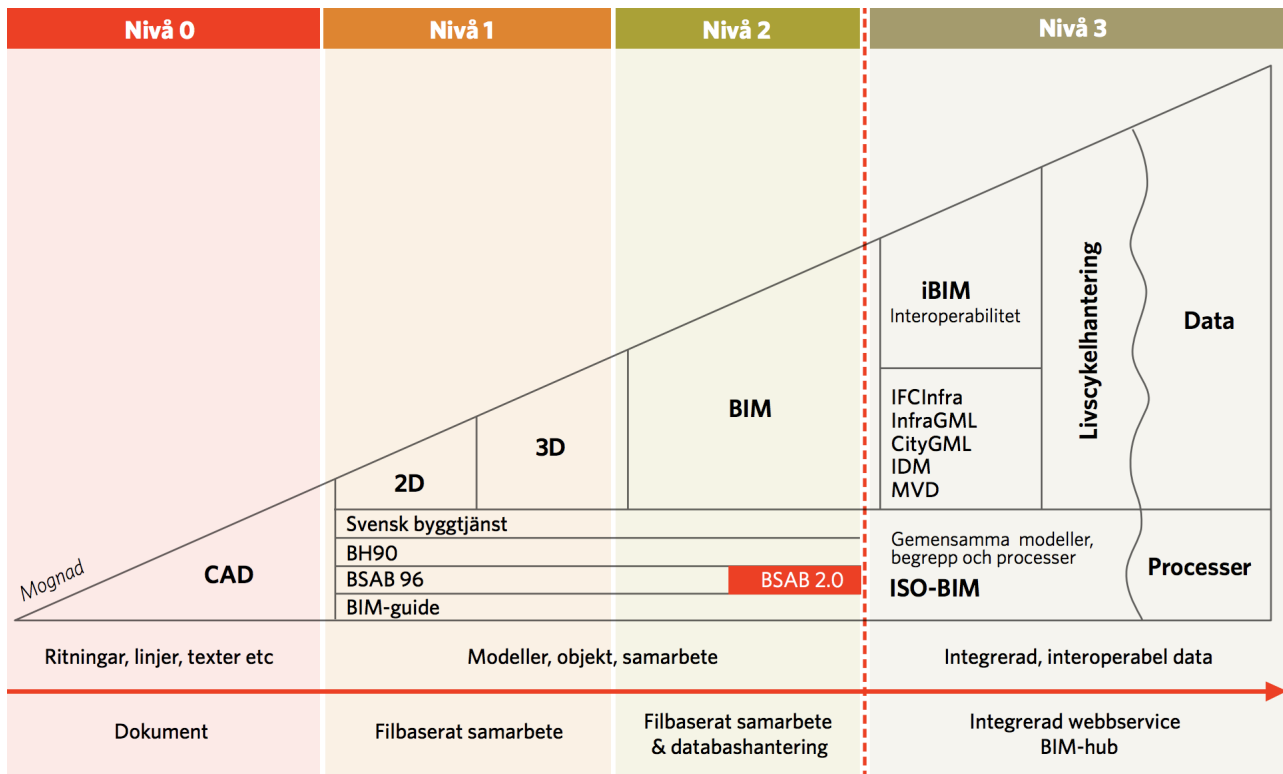


Figure 3.1: BIM Trappan - The Levels of BIM (Trafikverket, 2020)

The concept is divided into four levels, each defining a certain standard of the level of design produced. Level Zero, the first one, are drawings produced by lines and texts and are not considered "smart" or adding any additional information. The following levels indicate a more complex model and introduces BIM, interoperability, and more. The Swedish Transport Administration states that they currently circuit around level one and two, but aims towards level three (Trafikverket, 2020). While these levels do not include the process of parametric design, it is important to include this information in the process.

Currently at Skanska, parametric design is not a part of the design process. One research and development project has been initiated, to parametrically design a retaining wall. The designer responsible for this project has only briefly started with it, but it is been put on hold waiting on a real-life bridge project starting later this year. In this construction project, a couple of retaining walls are going to be made in Tekla and one of these is going to be done through parametric design in Grasshopper. The aim is to compare these two embodiments, in a real-life project, to see the pros and cons of using these two different approaches.

While the parametric design has not yet been used, Dynamo together with Revit has been used to some extent. Dynamo is software very similar to Grasshopper but communicates through Revit as modeling software instead of Tekla. There have been some examples where scripts were used to solve specific problems, e.g. to place a large number of piles from a coordinate list into a model, and while

these are not examples of parametric design, it still is a valuable experience to learn the software.

Chapter 4

Results

The following chapter will present the results obtained from the practical part of this thesis. These results will be evaluated in chapter 5 and analyzed in chapter 6 together with theory. Figure 4.1 (below) represents a general overview of interrelations between user and software as well as data flows in between. The optional link of Tekla to Grasshopper is presented for analysis in chapter 6, however, it is not part of the result presented in this chapter.

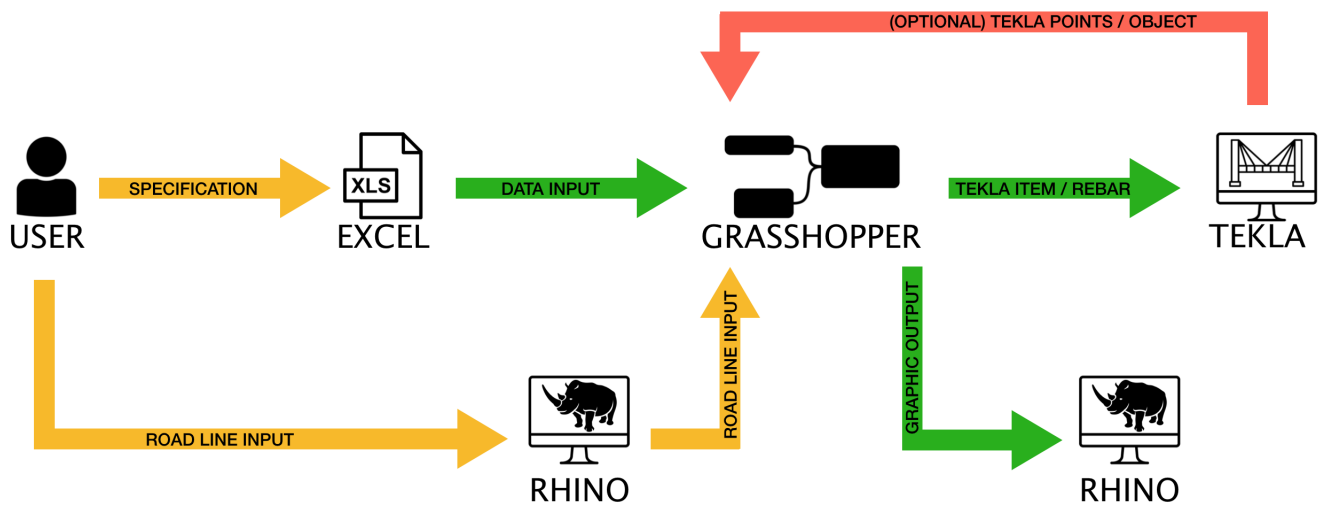


Figure 4.1: Schematic visualisation over relationships between user, software and data flows. Yellow: action that requires manual interaction from user. Green: automatic action.

4.1 Interface

New programs, software, and features need to be user friendly, otherwise, they will be left untouched. This was also validated by the interviewees. Therefore, some time was put into making a user-friendly interface to lower the threshold for new users. Two different methods of constructing an interface where the user could insert inputs were done, one through Human UI and the other through Microsoft Excel. Human UI was chosen because it is constructed inside Grasshopper, while Excel is already today used by many people at the office and something that many already are comfortable with.

Human UI

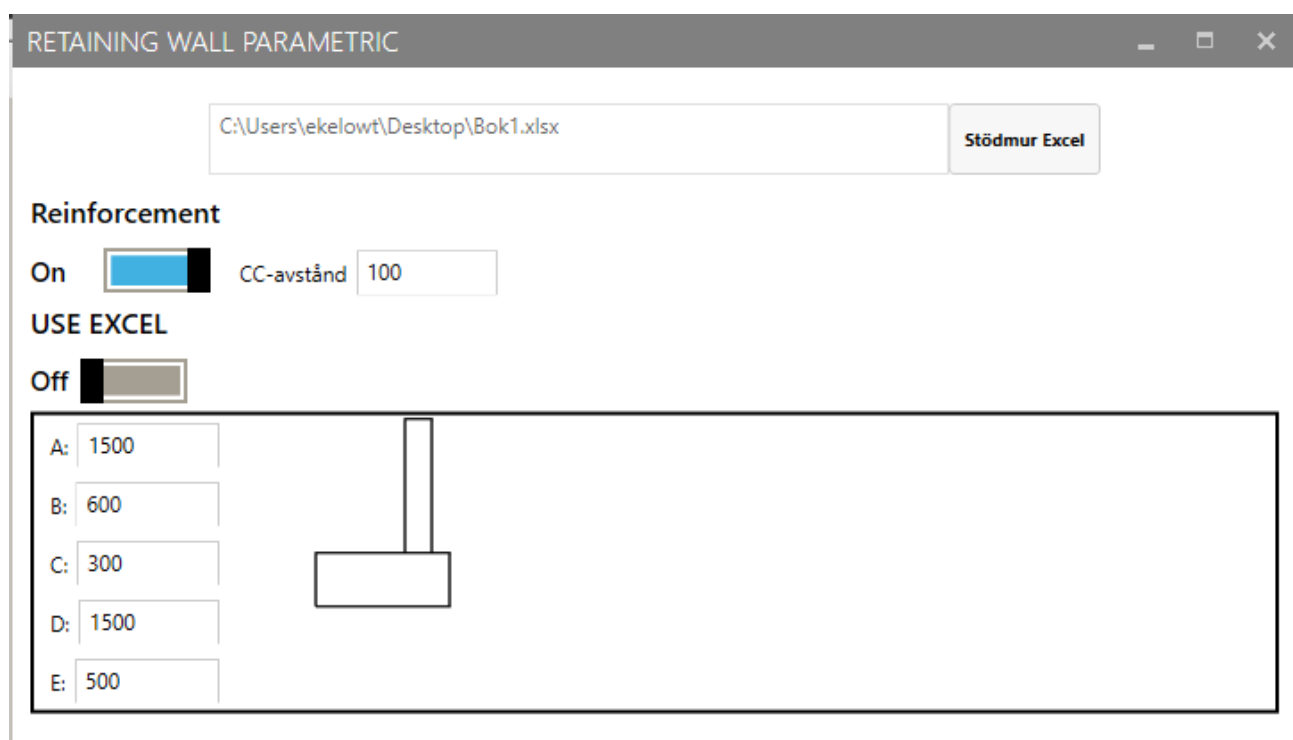


Figure 4.2: Interface - Human UI

Figure 4.2 shows an example of an interface created through Human UI. Buttons, figures, and other inputs then sends the information to the script constructing the geometry. The Human UI interface allows the user to either insert geometrical parameters directly or indirectly through an Excel file, and this is controlled by the "USE EXCEL" button. The text field at the top specifies where on the computer the Excel file can be found. Another button controls whether or not the Retaining Wall should be reinforced or not, with the additional input to control the c/c measurement of the rebars. If the user chooses to manually insert measurements and not use excel, it can also be done. The interface uses these measurements to preview a cross-section, as seen in figure 4.2 to the right of the inputs.

Since Human UI is an add-on to Grasshopper, it is created through components and functions

within the software. This leaves the user with great freedom in how he or she want the interface to look, but it also requires certain knowledge about how Grasshopper and the add-on works

Microsoft Excel

Microsoft Excel was also used to create a user-friendly sheet where the user provides the parametric model with geometric inputs. Meanwhile, the user can also see directly how the cross-section is changing depending on geometry. The user can also select to include different rebars into the cross-section and see where they are placed within the model.

A graphical representation of a cross-section constructed by inputs in the Excel sheet can be seen in figure 4.3. The letters seen in figure 4.3 represents which dimension/inputs are which.

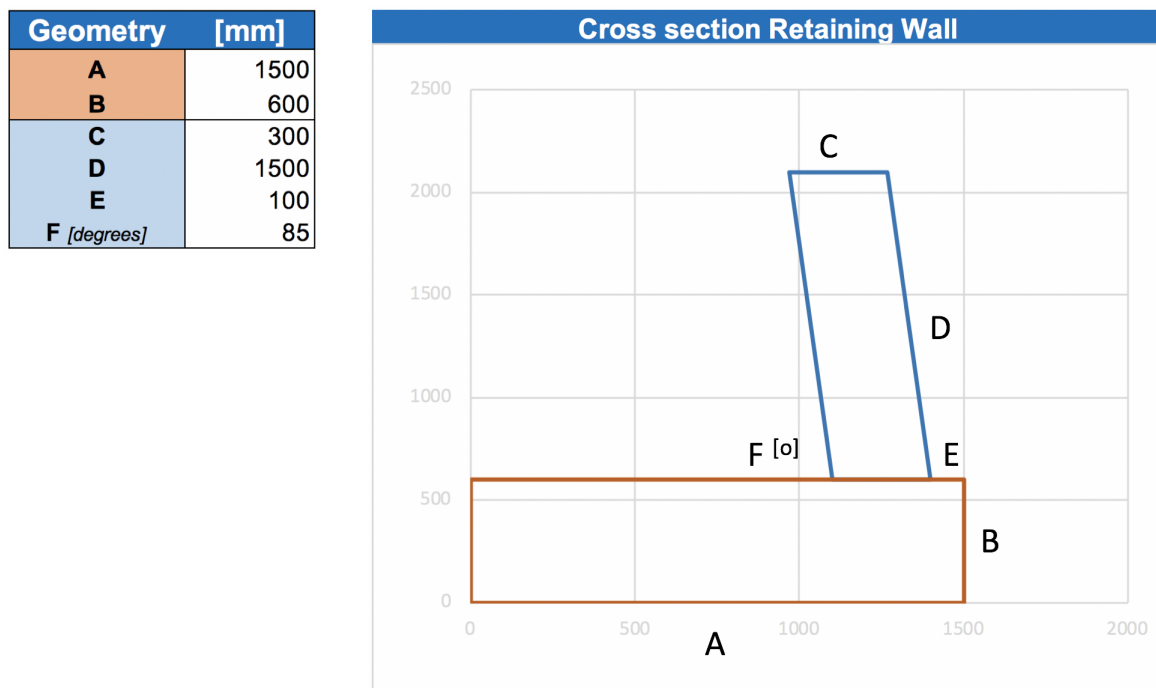


Figure 4.3: Geometrical inputs constructing a cross section

Depending on how the structure is designed, the user can also choose to include rebars into the cross-section and also decide which diameter the rebar should have and how much cover (TB) should be left out on each side of the surface. These are then also shown in the figure, as seen in 4.4. Additional features could include c/c distance, type of steel, and code class to name a few.

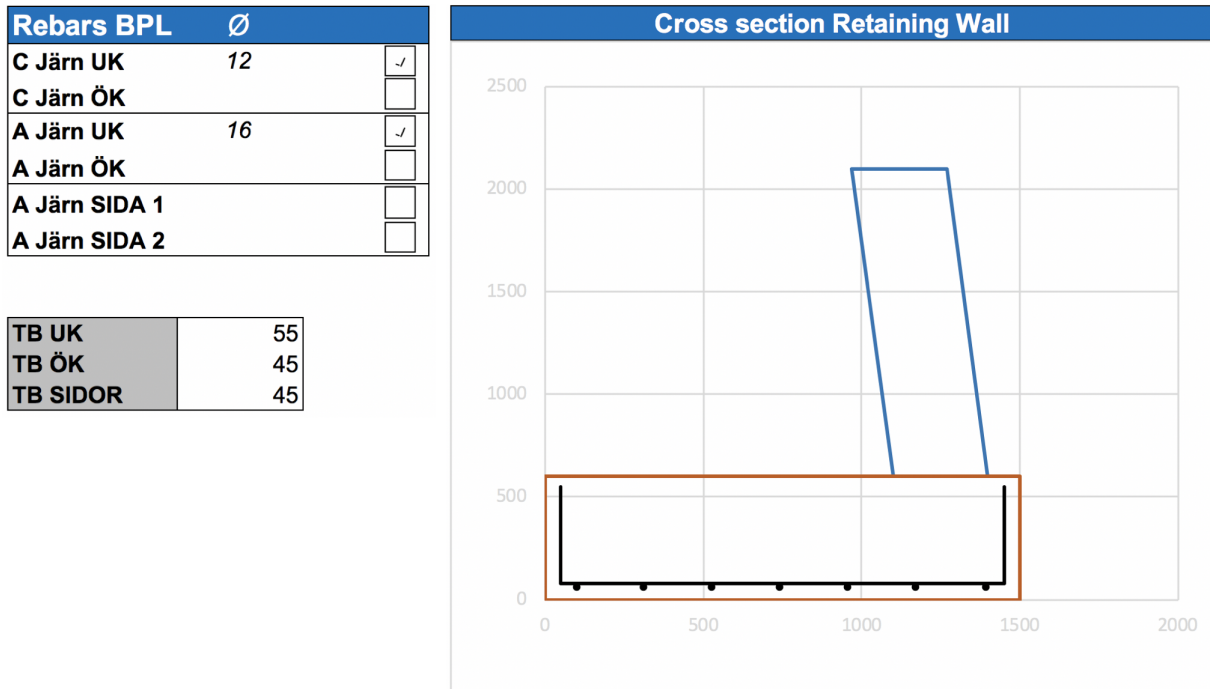


Figure 4.4: Cross section with rebars placed in the lower edge together with cover as input

The figure in excel is constructed by coordinates collecting information from geometrical inputs. A example of a set of coordinates can be seen in Table 4.1.

X	Y
0	0
1500	0
1500	600
0	600

Table 4.1: Coordinates constructed from geometrical inputs

Using this way to construct a cross-section is favorable when grasshopper later collects data from the excel sheet, importing it into a CAD program. Grasshopper and Rhino use these coordinates to construct points and then connect the points to create a, in this case, a rectangle. The X values represent the width of the construction and the Y values the height. The same process is repeated to create the rest of the wall, and the angle is calculated with basic trigonometry functions.

4.2 Rhino and Grasshopper script

The following chapter will present the result of this thesis as a description of the script used to obtain the model of retaining wall with corresponding reinforcement in Rhino/Grasshopper with correspond-

ing notes. Moreover, the functionality of the model in Tekla software with the addition of drawing revisions capabilities will also be described.

4.2.1 Grasshopper script

This section will present the Grasshopper script's different phases and functions.

Geometry

The model of retaining wall is obtained through script made in Grasshopper and can be seen in figure 4.5. The script is building upon data flow from left to right, beginning with a set of two crucial inputs creating the foundation for the model. In order to run the code, grasshopper must be pointed to the location of an excel document (containing input parameters) - the exact file path written in the panel-component. At the same time, the desired road line must be selected in Rhino, which can be imported as a previously drawn CAD-line or sketched freely with Rhino itself. The line itself can be double-curved, meaning that it can vary in all three dimensions - X, Y, Z.

The simplified flow of the script can be summarized in the following way: Excel input data is passed on sequentially to the groups of components responsible for creating 2D forms, alignment in 3D-space, and sweep along the picked road line. Both slab and wall are converted into solids and related reinforcement form is arrayed with predetermined spacing within related solids. Lastly, both reinforcement arrays and the solids are connected to corresponding Tekla-component, which is feeding the information to the Tekla software.

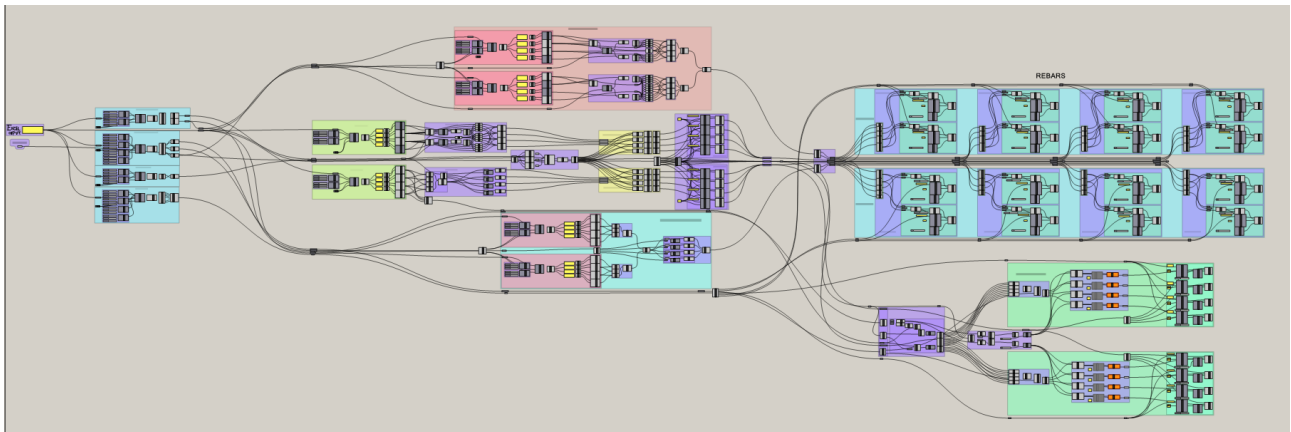


Figure 4.5: Overview of Grasshopper script used for parametric modelling of retaining wall with basic reinforcement

In more detail, the document path is fed into a Grasshopper component looking at the desired cells in order to read the information about dimensions of cross-section as well as the desired reinforcement configuration and size. The exact cells are specified through two sets of X , Y , Z (*corresponding to row,*

column, sheet) coordinates, making up the boundary for the region to be read. Obtained parameters are presented in the form of data lists, which in some cases are put through *Clean Tree* component in order to reduce the noise caused by unwanted data.

In the case of wall and slab forms, as shown in 4.6, the *List Item* components together with custom clusters, are used to divide the input list into manageable data sets consisting of *X- and Y-coordinates*. These coordinates are then used to construct points and by later fitting lines between those points, the 2D cross-sections of the wall and slab are created.

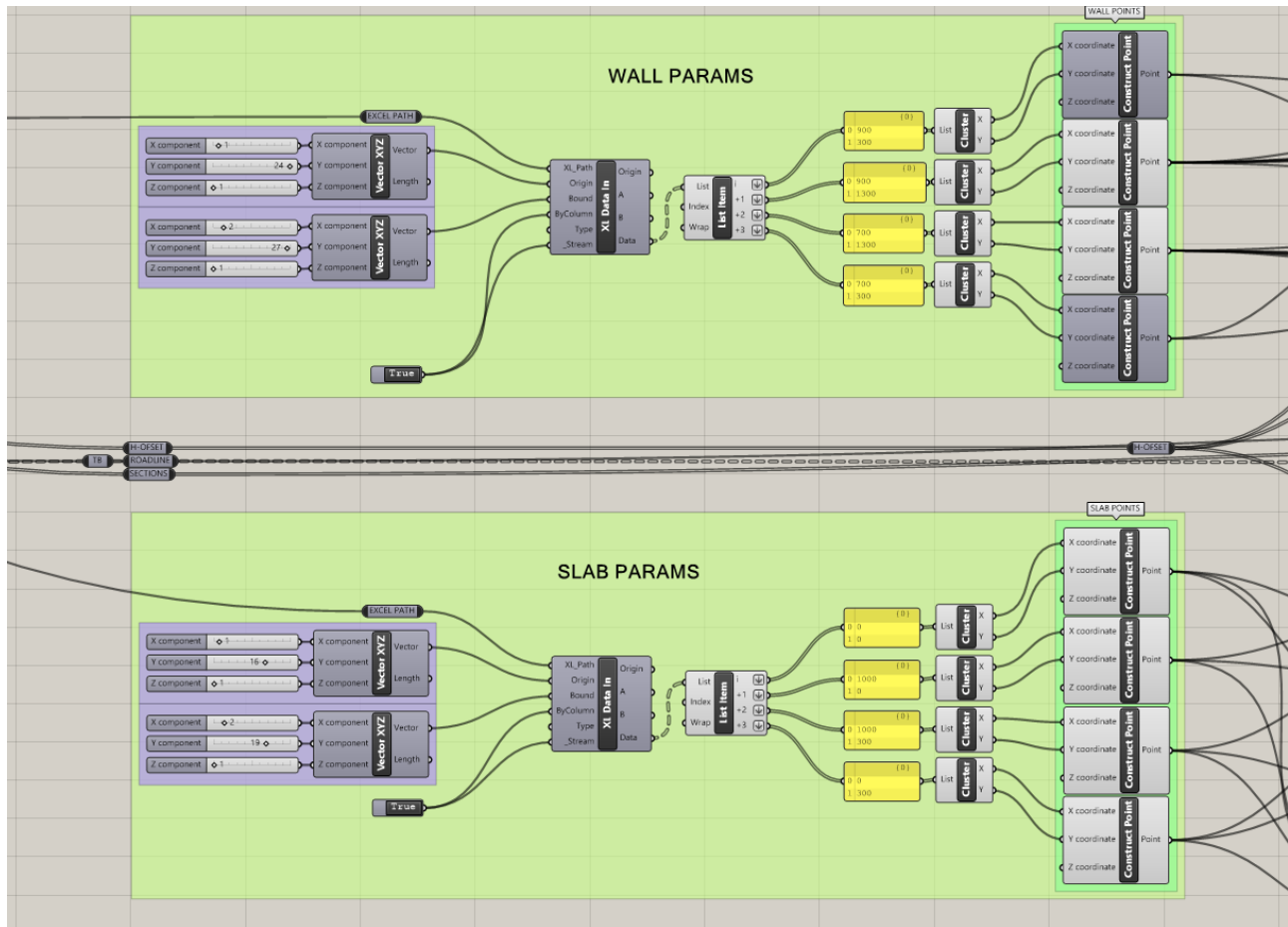


Figure 4.6: Input groups for wall and slab parameters, read through excel component.

In order to achieve the possibility to offset the position of the slab along the Y-axis, the road line is divided into four sections. The exact length of each section, as well as the value by which each section is offset, is specified through the excel document, schematics are shown in figure 4.7. Obtained data from excel is divided into lists (sections and Y-offset) using *Entwine* component which allows indexing of the input resulting in reliable filtering. In order for Grasshopper to run script correctly, sections must be specified in the correct order, each with a bigger value than previous, even if the division into sections is not desired. In the case of Y-offset, the value can be set to "0" if the offset is not required, in all other cases value must be bigger than "0".

Moreover, users can specify input data for cross-sections prior to choosing the road line and the information fed to Grasshopper is static, meaning that information stays the same whether or not a road line is present. This concept can be used to change the path of the retaining wall by simply choosing different road lines in the Rhino. Additionally, road line made with, or imported to, Rhino can be modified in real-time where the change is reflected automatically and simultaneously in both Rhino and Tekla.

Since slab form offset is uniform (the whole cross-section is moved), the same cross-section can be fed into four *Move component* where the only variable is the vectored offset value, resulting in four forms shifted in Y-axis. Regarding the wall part, in order to avoid parts crossing each other, a new set of points must be created for each section. The shift along Y-axis is done identically to the slab however, since the only points to be moved are bottom points, the location of top points can remain constant. In like manner, the shift of slab reinforcement is done as the slab itself and reinforcement of the wall are done accordingly. Both input of offset and section values as well as offset actions is shown in figure 4.7.

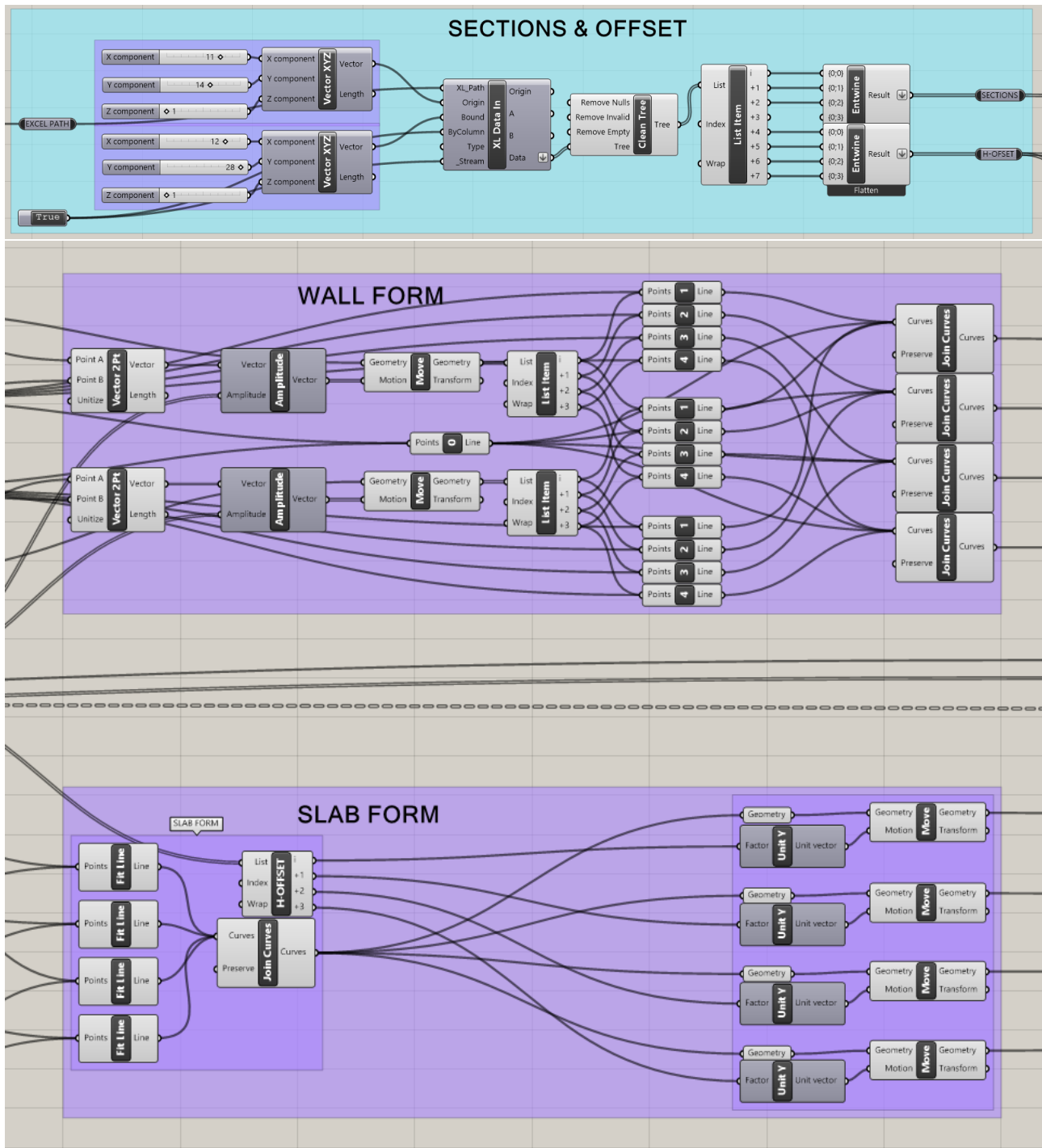


Figure 4.7: Above: input structure for offset and section division. Below: how wall and slab forms are shifted along Y-axis.

The offset forms are fed into groups of components responsible for correct alignment and orientation in 3D-space, following by sweep along the preset part of the road line and lastly made into solids through *Cap Holes* component. In the next step, solids are input into *Tekla Item* component. This allows Grasshopper to link with Tekla (see figure 4.8). At this point, the section of the road line corresponding to the correct geometry is connected to the component, resulting in four *Tekla Items* for

both slab and wall. Besides geometry, *Part Attribute component* is used to add additional information to the item leading to the possibility of taking the benefits that come with BIM-capabilities in Tekla software. Parameters such as concrete class, quality and finish, however *class* and *name* are assigned in correspondence to Skanska's design manual. At this point, obtained geometry in Tekla is self-sufficient and can be manipulated further in the Tekla software.

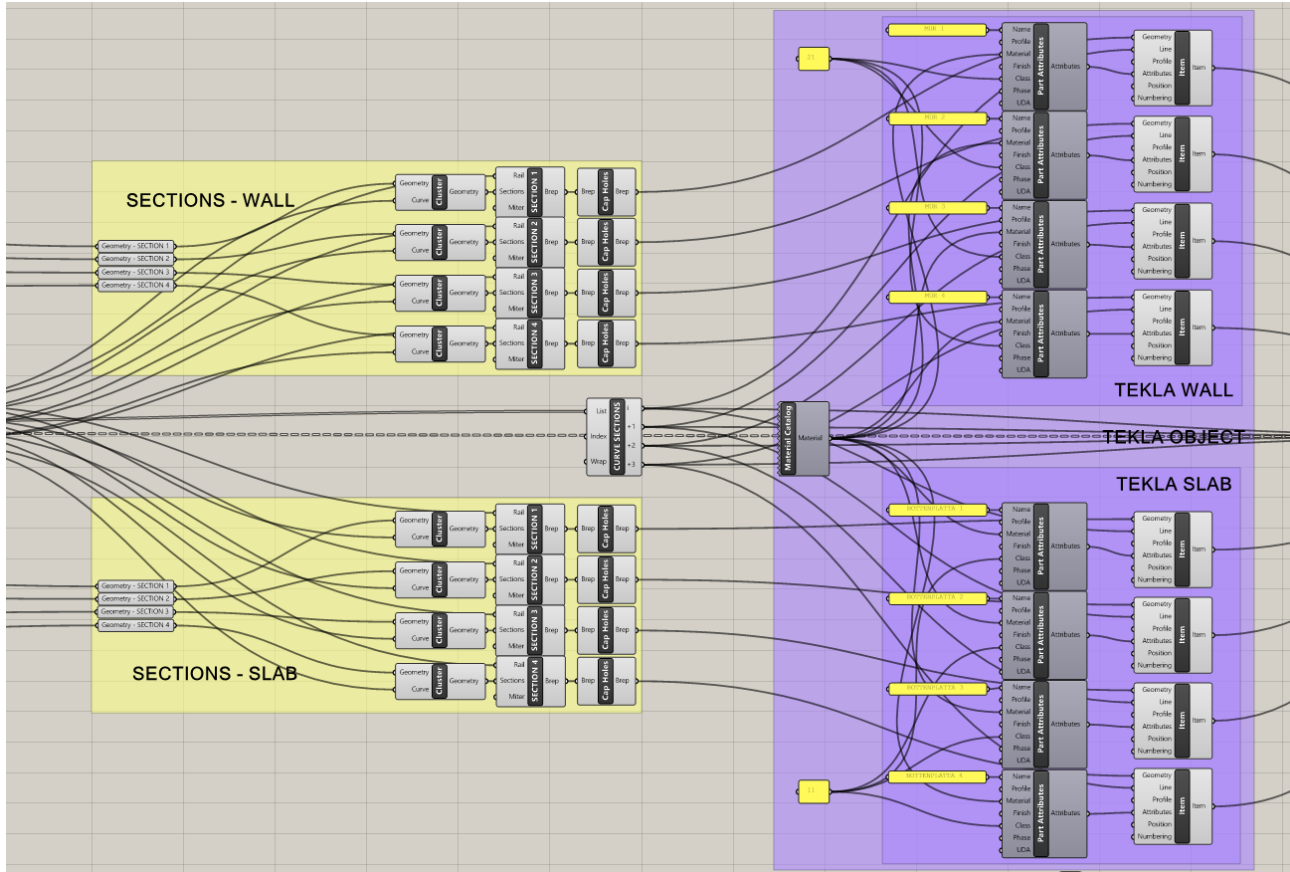


Figure 4.8: Aligning wall and slab forms in 3D-space and conversion to Tekla objects.

Reinforcement

The shape of the rebar is defined with the geometrical input as a baseline and is similar to how the cross-section is defined. C-shaped rebar, for example, is defined by three lines. These lines are chosen from the cross-section of the retaining wall. The lines are then connected to each other, creating the shape of the bar. This shape is then slightly modified. The cover and diameter of the rebar are removed from the lengths and are positioned correctly within the cross-section.

When the geometry and shape are defined in the script, the reinforcement is added to its corresponding part. Since there are four sections of the road line, with the corresponding offset in each part, reinforcement sections are divided accordingly. Figure 4.9 shows an example of how the script is built to place reinforcement within the walls. Different groups are created to visualize different groups of rebars, as well as within which section the reinforcement is placed. As with the solids, rebars are firstly created in 2D and then aligned and oriented in 3D-space. Additionally, in order to achieve an array of rebars with a certain c/c distance, it is arrayed with *Curve Array* component along a section of the road line with the possibility to define the amount of rebars in that section. The array is then fed into Tekla through the *Rebar* component, which creates rebar objects in Tekla software for every single arrayed reinforcement form. The process of creating reinforcement in the slab is equivalent to the process of the wall, with the addition of A-shaped rebars. Since these are shaped perpendicularly to other C-shaped rebars, they are arrayed offset along the X-values of the Slab, and shaped as the road line but cut to fit the different sections.

At this point, similar to the process of solids, *Attribute* component is added to the Rebar, with the addition of *Cover Attributes* component to allow information such class, name, numbering or cover size to utilize BIM-capabilities in Tekla. Enabling/Disabling of reinforcement types for the corresponding part is done in an excel worksheet that is connected to *Boolean toggle* in Grasshopper. When set to "true" inside Excel, Grasshopper reads this information and allows it to flow through the component, working as a digital switch. The information fed into *Attribute* components is intentionally done permanent due to the fact that information such as class, describing the type or name is not changing between projects. However, there is a possibility to include more information into the Excel worksheet giving the user the freedom to specify own input.

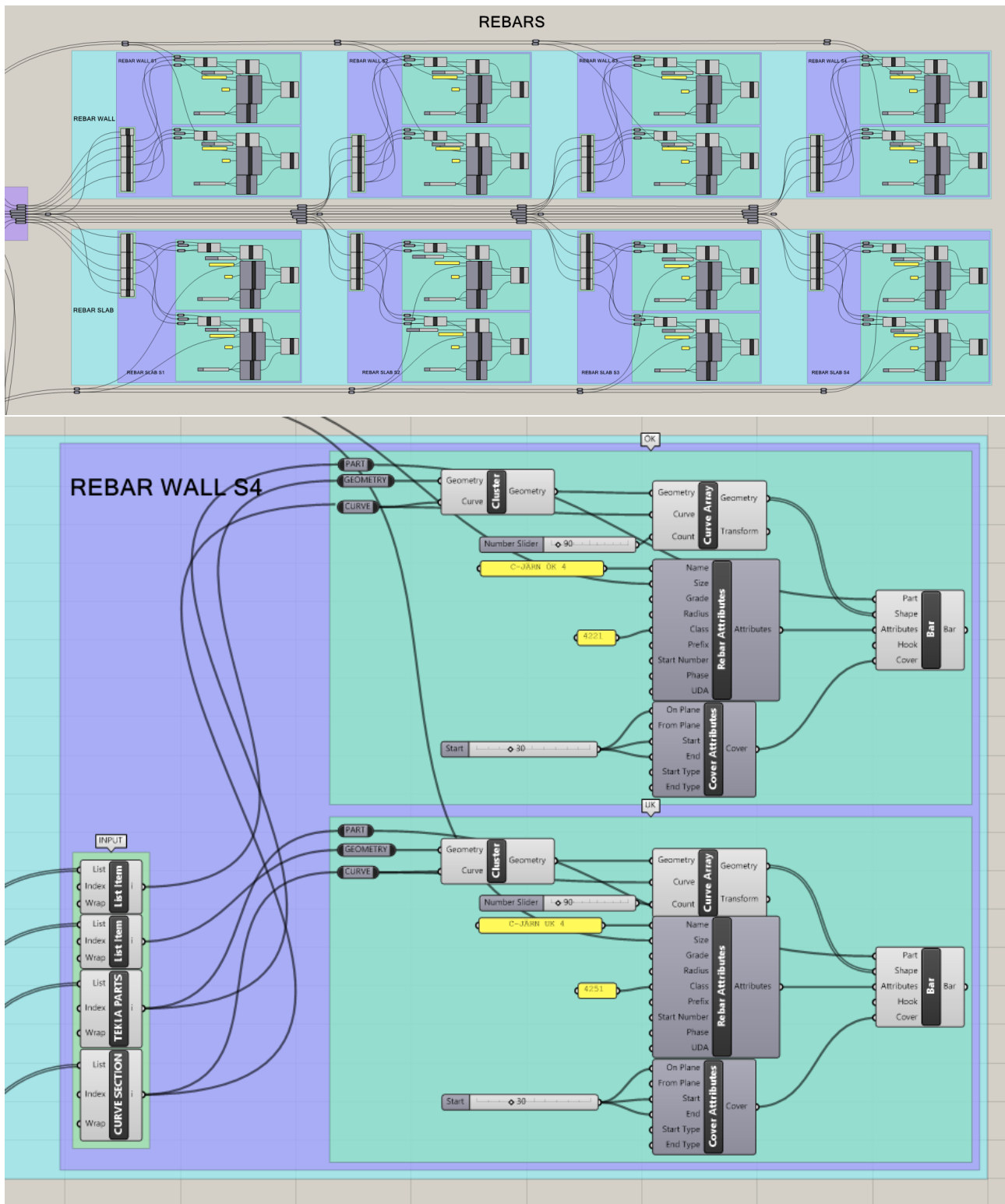


Figure 4.9: Above: Overview of reinforcement in the wall part of retaining wall for each section of roadline. Below: Reinforcement of wall for a single section

Piles

In some cases, piles need to be placed beneath a Retaining Wall. They are placed in the model from a list of coordinates. Grasshopper was used to automatically load a certain set of coordinates into Rhino, loaded from an Excel file. Coordinates have X and Y values, as well as Z values, and all of these were loaded into Grasshopper. When values were obtained, points were constructed and these points worked as insertion points. The points worked as inputs to a Column component that sent information to Tekla, placing a pile at a certain location.

This script did not handle inclined piles and the angle of these. This was something one in-house developed add-on to Tekla could do and therefore, this was not further developed.

4.2.2 Rhino

While the add-on Grasshopper mainly is used in order to create a parametric model, Rhino runs in the background and renders the geometry in real-time. Figure 4.10 shows the overview of a complete model in Rhino created by Grasshopper script. The four different sections can be seen represented between the lines going across the structure in the top view. Additionally, the height offset of the slab can be seen in the front view, where section division is also visible.

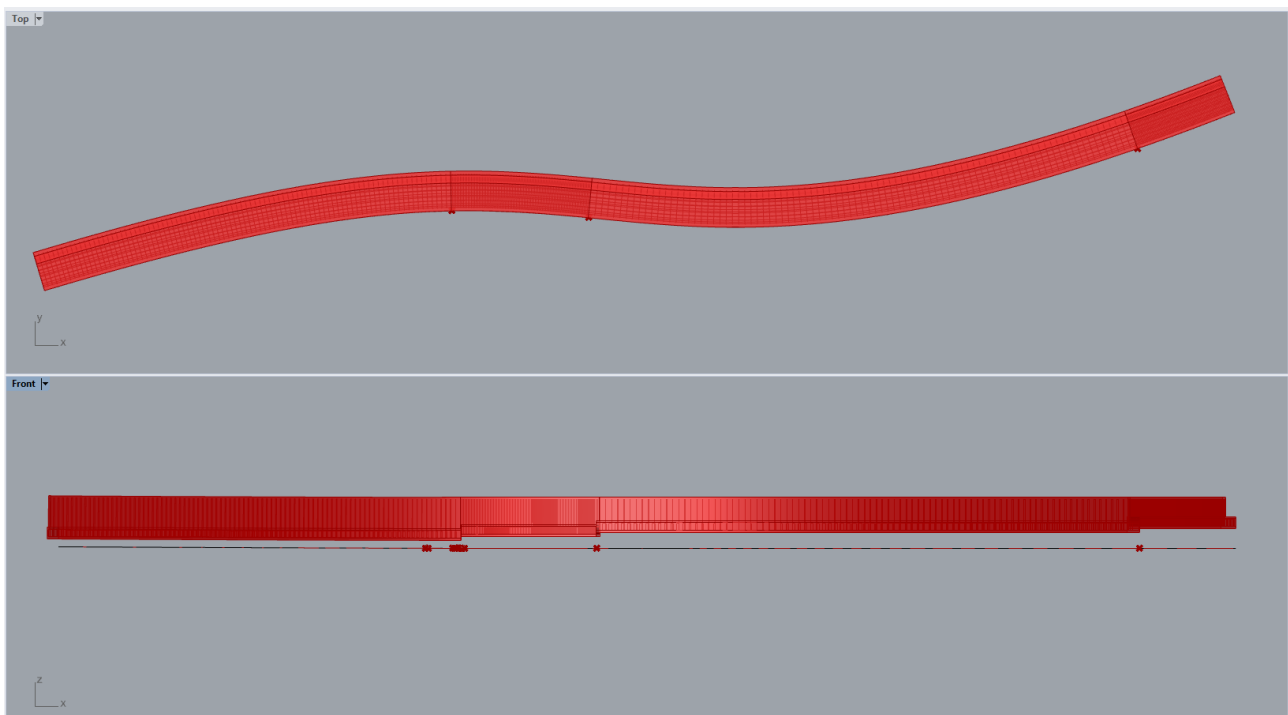


Figure 4.10: Overview of modelled retaining wall through Grasshopper script in Rhino

4.3 Tekla model

As mentioned earlier, the components within the add-on Tekla Live Link are used to connect geometries created in grasshopper and translating these into Tekla. Figure 4.11 shows the model in grasshopper and how it been constructed by points and lines between these, as well as how they geometry in Grasshopper is translated into Tekla. Figure 4.12 shows how the model looks when the cross-section is extruded along a road line. The colors are a result of providing the rebars with different names depending on section and placement.

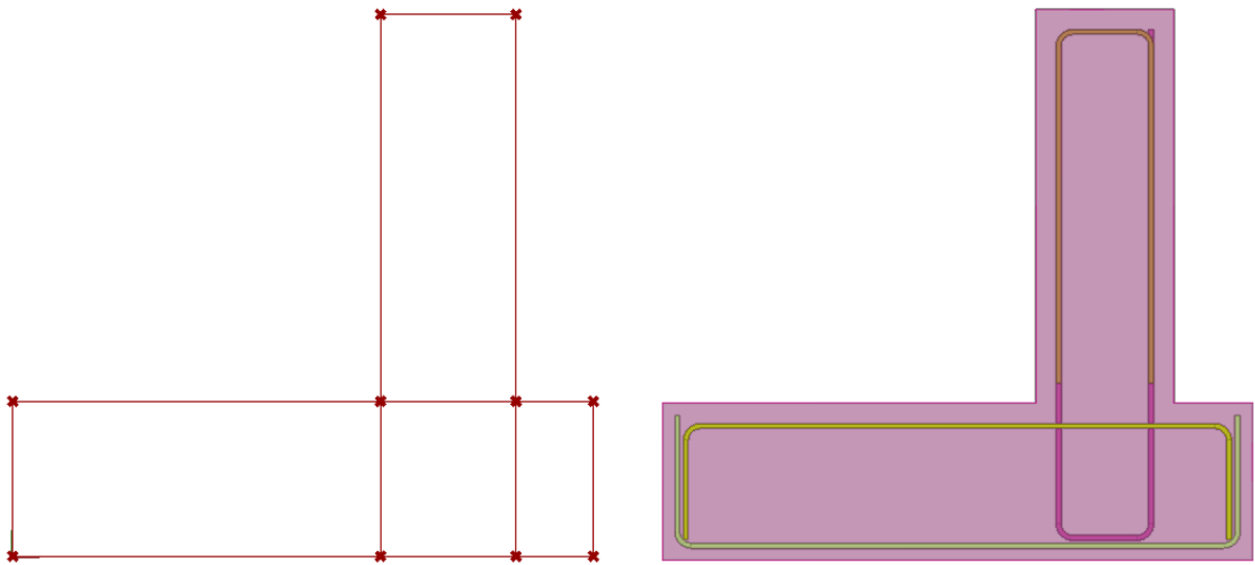


Figure 4.11: A visual transformation, from Grasshopper (left) to Tekla (right), with basic reinforcement.

In order for Grasshopper script to compute model based on new sets of inputs from excel it must be triggered by the *recompute* function in Grasshopper every time input data is changed such as enabling/disabling reinforcement in order for the changes to appear in Tekla. At the same time, before recomputing the model, the old one must be removed from Tekla in order to avoid clashes between the geometries. However, if the change is regarding the selection of an additional road line, in the case where two road lines do not cross each other, re-computation can be done without prior removal of the Tekla model giving the possibility to compare two variants of retaining wall simultaneously.

A parametric model created through Grasshopper can be freely modified, and additional elements can be added, in Tekla. However, if inputs are changed in the grasshopper script, a new model will be created and the additional elements created would have to be added once more to be included in the model. A new GUID is obtained by the model, leaving old connections such as drawings more or less outdated.

The rebars in Tekla are created from simple lines in Rhino, through the component *Single Rebar*

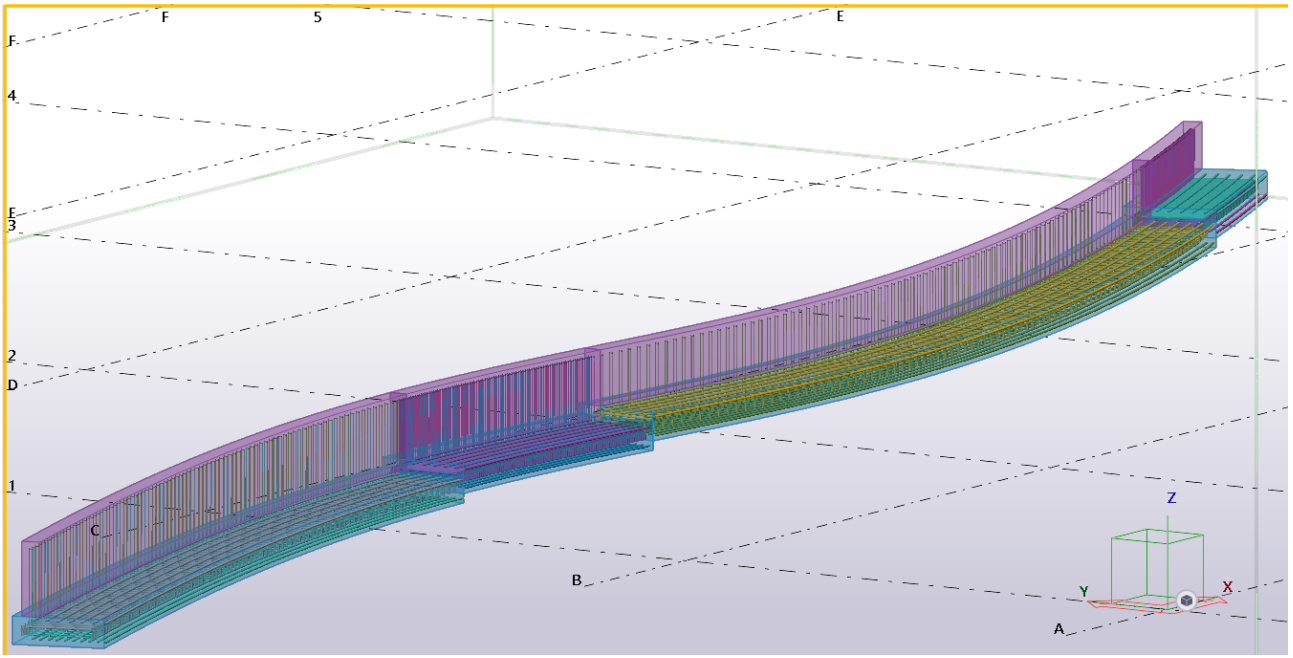


Figure 4.12: Overview of a Retaining Wall in Tekla

and not as a group of rebars. There is a component that creates groups of rebars in Grasshopper, but it does not cope with geometries that follow a double-curved line, hence *Single Rebar* is used. All the rebars created will however have specific names and can in Tekla be filtered by name, and grouped thereafter.

Figure 4.13 shows a more detailed view over the model in Tekla, with reinforcements, colors, and geometry, following a double-curved road line.

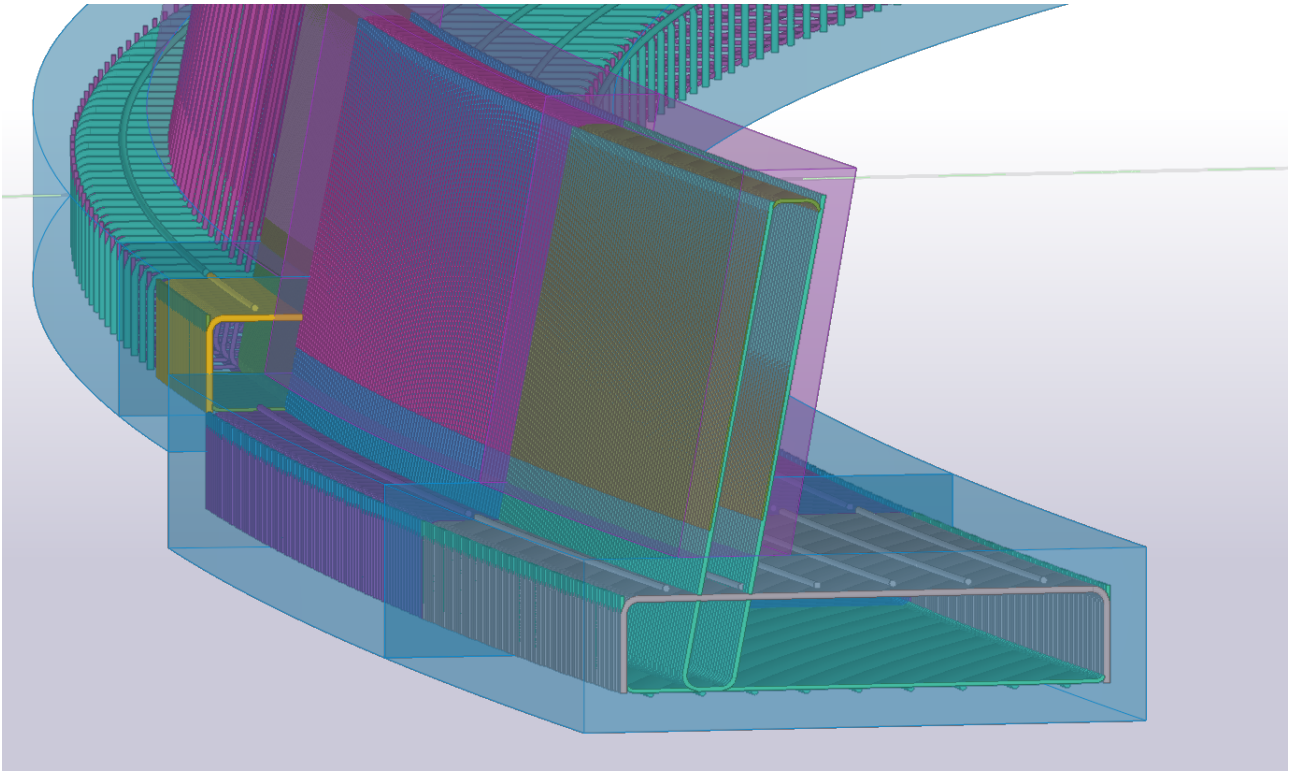


Figure 4.13: A close up of a retaining wall in Tekla.

4.4 Drawings

Tekla supports the making of drawings that are interlinked with each other by utilizing the views created by the user. If the model is updated, the drawing is updated as well, and the drawing creates a cloud around the change, indicating that the model on this specific part is updated. The drawing view also supports filtering by name, class, element, and more. Name's given to the component in grasshopper can, therefore, be filtered when making a drawing in Tekla if certain elements need to be isolated.

Grasshopper requires a Tekla Model to be open in order for the Tekla Components to work. The user does not specify which file the script creates the model in, it is the one open that Grasshopper will create the elements in. Therefore, the user can choose previous models to use and the risk of losing drawings in a new Tekla model is therefore mitigated.

However, if a change is done through Excel or Grasshopper, it will create a new model within the same file. The model is given a new GUID, even if the model looks more or less the same, replacing the old one. Clouds indicating change is therefore not shown in drawings already produced.

Chapter 5

Evaluation

The following chapter will evaluate the parametric script and its functions related to the process in relation to the design process. The chapter is divided with regards to categories - model, ease of use, and level of detail. Each section contains both positive and therefore profitable elements, as well as negatives - representing concepts that are not fully satisfying and would require further development.

This chapter also presents comments coming up during evaluation with designers at Skanska, both positive and negative. In some cases, the parametric way of working is directly compared to the current process.

The analysis of the evaluation will be presented in chapter 6.

5.1 Input, Geometry and Model

Road line

The way of choosing a road line for the retaining wall to sweep along must be done through the grasshopper script and selected in Rhino software. While in many cases, Skanska is responsible for what they design, but the road line is often delivered from the client and can be delivered usually in two forms; either as an XML file containing coordinates and other information in text form or through a digital DWG file. Rhino can not handle XML files, only DWG. However, in today's design process, AutoCAD and/or Civil3D are used to generate a road line from XML and creates a DWG of this. While this is considered an additional step, it is also an important one to handle since the road line is in many projects the baseline of the structure.

This produces an additional step that can cause unintentional modification of a script resulting in disrupted functionality. This is also an extra step that could be avoided through i.e. implementation in Excel interface, and therefore streamlining the process as a whole limiting it to fewer software platforms. Additionally, the connection of Excel and Grasshopper which is done by manual entry

of file path in the *Panel component* in the script can be seen in the same way, as an equal issue as the choice of road line. Both actions require additional basic knowledge in order to be conducted properly. At the same time, the road line can be changed instantaneously, by simply choosing the new one, resulting in a new model computed around the new path. This on its own is a major time-saving aspect considering the designer does not have to create a completely new model, since all previous data such as i.e. dimensions, is already stored and recalled. This gives the possibility to evaluate construction based on multiple road lines.

Another important aspect when designing bridges, roads as well as retaining walls is that the road line is often double-curved. This imposes problems for many modeling software, Tekla Included when a cross-section needs to be extruded along these curves. Its been shown in the script that Tekla Items can be extruded along double-curved paths, but slabs and panels cannot.

The now built-in Tekla tool Bridge Creator allows cross-sections to be extruded along double-curved paths, but these tools does not allow a model to be parametrically designed.

Comments by Skanska

When a designer evaluated how the script handled the road line, it was not described as a major issue despite the additional step to import it to Rhino and define it in Grasshopper. More, the designer stated that it is important that the user knows how the road line is constructed and how the process behind works to generate it. On some occasions, the road line is revisioned. If the user got limited knowledge of how the model is connected with the road line, it jeopardizes the structure and leaves uncertainty, what information is to trust, and what is not. Moreover, the designer mentioned that creating a script to perform tasks that, e.g:

1. Import XML file in a CAD software
2. Generates a road line
3. Save as DWG
4. Import DWG-file into Rhino

is somewhat easy to construct with little to no knowledge about programming.

Further, it was expressed that the Grasshopper provided the user with a way to parametric design a reinforced concrete structure, and this had not been done at the department prior to this. Tekla's own add-on Bridge Creator has been used to deal with the problem concerning double-curved paths, but it does not allow the model to be parametrical and changeable during the design phase. If the cross-section changes in Bridge Creator, the user needs to redo the model and update the rebars to fit the new geometry. This is not the case when done correctly in Grasshopper. Bridge Creator was

described as a good tool that solved many problems concerning double-curved extrusion, and the time to design a similar Retaining Wall as in this thesis was expected to take roughly 30 minutes, and to model it without the help of Bridge Creator is not considered a reasonable option due to time and complexity. 30 minutes compared to just a few minutes to construct the model through the Grasshopper script is a notable improvement, but the strength was pointed out to be the parametric aspect, that the model could be changed easily, not adding another 30 minutes to the design process when inputs changed. More so, the script was described as generic but that in the future a library of many generic scripts could be created, and many of these scripts could be used to stitch together structures.

Tekla Live Link and reinforcement

Grasshopper creates Tekla geometry through Tekla Live Link, and the geometry is done with the *Item* component for the slab and wall. Normally when modelling in Tekla, *Slab* and *Panel* components would be used. This since these components can not handle double-curved solids through Grasshopper. By using *Item* instead of slab or panel, the element loses some of its functionality and BIM information. For instance, when the model is delivered to the construction site if the BIM manager wants to filter the model to display all of the slabs in a project, it does not appear. In smaller projects this could easily be handled by instead filtering for *Items* with a specific name or class, but in larger projects, where models need to follow certain BIM regulations like BIP Codes, causing friction.

As previously mentioned, reinforcement is created through *Rebar component*, which creates a single instance of a reinforcement bar in the Tekla model for every line that is fed into it. The correct component to be used for this is *Rebar Group*. However, this component can not handle double-curved solids and as a result, reinforcement was computed outside of the solid. One disadvantage of this is that the user has to group reinforcement bars manually in Tekla, creating an additional time-consuming step in the design process. Additionally, certain functions such as deciding c/c, class, size, and more, for a whole group is lost. To mitigate the problem regarding the rebars, the user can filter objects in Tekla by class or name and therefore select only appropriate instances and re-group them.

Moreover, the *Rebar group* component does not align perfectly perpendicular to the surface, but with a few degrees offset depending on the curvature of the road line. In the case when the curve bends even slightly in one or two directions, the displacement is barely noticed, however, if the curve's length is long and bends relatively much, the displacement is noticeable. Theoretically, if a mathematical relationship is found between the replacement and the bending of the curve, this could be added into the script.

Furthermore, single bars must be arrayed with *Array* component and while it achieves the goal of

distributing rebars in the section, it can cause more confusion regarding the correct spacing of rebars. This as well could be avoided through the use of *Rebar Group* component, where spacing can be entered as a designated number, and as a result software calculates the number of bars needed in the section to fulfill conditions. In addition, cover functionality is impaired and has to be done manually by either adjusting the form of reinforcement or more advanced calculation linked to array function. Even in this case, the use of *Rebar Group* would solve this issue. The cover functionality works in the same way as in Tekla today, by defining the offset from elements of different surfaces. In the script, this is done once, and then all the rebars placed after following these rules set up, mitigating the need for manual input in the model.

A-shaped rebars are placed in the slab slightly offset along Y-axis, which is possibly caused by not using *Rebar Group* component, where this can be adjusted. Moreover, at the present time of development of the prototype, the A-rebars are curved after the road line. In the real-life situation, the rebars are delivered to the site straight and bent to the desired form at the site. This can be seen as a positive aspect, where the script shows a more final form of rebars.

Comments by Skanska

The problems concerning rebars and its placement when modeling rebar groups do not seem to be isolated to Grasshopper and its functions. When a designer evaluated the script it was stated that Tekla itself struggles sometimes with the positioning of the rebars when following a double curved line. Through Grasshopper, the main problem with *Rebar group* is that the rebar creates a new origin every time a new bar group is placed, leading to displacements. The designer stated that since the problem is identified, it can be solved in further development.

Script and software

Although Grasshopper is updating many of the changes done automatically, some adjustments require the script to be re-run. As mentioned before, changes made to the dimensions of the cross-section can be done without additional steps, however, changes regarding enabling/disabling reinforcement require re-running the script from within Grasshopper. This minor yet significant step can, similarly to the concept of changing the road line, require additional basic knowledge of the software and therefore cause confusion leading to an unintentional modification of the script.

This whole approach to parametric modeling requires that all used software - Excel, Tekla, Grasshopper, and Rhino; must be running simultaneously in order to perform the desired action (the evaluation of ease of use regarding this aspect is addressed in chapter 5.2). This on its own requires more computing power than it would be needed for a single software. Additionally, the bigger the model computed, the more computing power needed, leading to a slower performance which was

also acknowledged during the tests. This also leads to an increased risk of software crash and as a result can cause loss of work.

It is worth pointing out that Grasshopper is powerful software, capable of performing all of the tasks mentioned in this report on its own. As a matter of fact, with basic knowledge and understanding, the whole process of parametric modeling can be simplified resulting in minimizing the amount of software needed to perform these operations. Add-ons such as Human UI (described further in section 5.2) can be used in order to streamline the workflow by replacing Excel interface, and other scripts or BAT-files can be created to automatize, for instance, the software starting order.

Comments by Skanska

During the evaluation with a designer, it was pointed out that BIM information, such as BIP codes, classes and object names, and more, can be set already in the Grasshopper script. This removes the need to manually inserting these when creating models. The process of providing the model with this information was described as somewhat boring and repetitive. By defining these in the script will more or less remove this part of today's design process, allowing the designer to focus on other aspects. BIM-information is often specific and does not change from model to model, mitigating the script's need for maintenance, and also possible errors that can occur when information is defined manually. From a change management point of view, it was noted that small things like this show the potential of time-saving for the designer, and promotes a change of the current process, increasing the curiosity of wanting to try out new methods of working.

While the functionality of placing rebar is one important part of the parametric process, especially since most of the structures constructed by the office are made by reinforced concrete, the functionality of quickly creating a 3D model is something that was expressed during an interview as a desirable feature. Through the grasshopper script, the user can quickly create a model that can be sent to the construction site, initiating the process of planning. The level of detail not always important during this phase, and rebars and other details can be added in a later phase. To quickly create a model is also desirable during the tender phase, where the parametric model could be used to better estimate and quantify materials.

Also, concern about entering a script that someone else had done could be challenging. A large script inside grasshopper was expressed as overwhelming with many functions and paths, and to change some things would require knowledge of grasshopper as well as how the script is built. In the future, certain guidelines of how a script should appear could work as both valuable for the creator as well as the user, to backtrack a script and update it.

5.2 Ease of use

Some interviewees stated that if a new feature is not user friendly, it is not likely to be used at all. Before the choice of using Excel as an input tool was made, an add-on called Human UI was used. This add-on allowed the creation of user interfaces inside the grasshopper script. While this looked promising in theory, it also made the script a lot more complex. Furthermore, Human UI only worked if the user installed it. By adding even more things to install would decrease the user-friendliness even further. Even though Excel is considered additional software, it comes pre-installed on everyone's computer at the company, and many of the employees already use it on a daily basis. It was also easier to use Excel to construct a figure of the cross-section of the retaining wall, so the user could see how the different inputs affected the model. Even though the user needs to specify the file path of the Excel file inside the Grasshopper script, the benefit of using Excel was larger than creating an interface, through Human UI, inside the script.

Furthermore, the road line is also a factor that needs to be dealt with by the user. Since road lines can be delivered in different ways, either as a text file with coordinates or as a DWG file, the user needs to import this to Rhinoceros so that the line appears in the software. As previously stated, the user needs to point at which line in Rhino to use, adding an additional input that manually needs to be added. In this thesis, the retaining wall is limited to one road line. However, in other real-life projects, many road lines can be inside the model, increasing the risk of choosing the wrong one if the user does not possess a basic knowledge of Rhinoceros and Grasshopper.

Another concern touching the topic of user-friendliness was that a number of software and add-ons need to be pre-installed and open at the same time in order for them to communicate with each other. Additionally the specific order of opening software (1. Tekla with model file, 2. Excel, 3. Rhino and Grasshopper), can cause confusion and obstruct functionality since Grasshopper checks which software is running in the background. In case when Grasshopper can not find Tekla, the Tekla Live Link add-on is disabled and requires a reboot of software in the correct order.

Comments by Skanska

When showing the interface to the supervisor and to the interviewed designer, it was stated that it was a good idea that the interfaced showed a figure that was updated as the inputs changed, and to handle the inputs through Excel that people were familiar with. Regarding the handling of the road line, it was considered not to be a major issue, since the workflow is similar to the current one. It was also pointed out that the concern with multiple software and order can be tackled with the help of a script performing the startup given that it can cause irritation and abandoning the parametric workflow presented.

5.3 Level of detail

At the time being, the level of detail of the model is notably general. The lack of casting joints, angle fillets, and additional local reinforcement can be seen as a major imperfection. Nonetheless, the model produced by the script is containing simple forms and objects, which in our evaluation is at a satisfying level of detail to function as overview and base model for further development in order to meet the required level of detail.

Comments by Skanska

It was expressed that simple geometry in many cases is more important than a high level of detail, and therefore usability of Grasshopper script in this regard high. However, it was concluded that the model was not ready to make drawings and be built from, but the concept of parametric modeling was proven.

5.4 Drawings

Though the construction business aims towards a state where drawings are no longer needed, they are still an important aspect of the construction process. Particularly when the construction is done and the drawings are stored during the aftermarket. Today, as-built documents are a requirement in most projects.

When conducting the interviews, one aspect of evaluating parametric modeling was to see how changes in models throughout the design process affected the drawings. As previously stated, the current process creates new models if larges changes, e.g. the road line is updated, when using Tekla's Bridge Creator. This removes the connection Tekla has between already created drawings and the elements within the model since the elements GUID are re-generated and not updated. The cloud marking that indicates change, together with other elements used in the drawing mode, is not updated accordingly and the need for manual work is required.

It would have been favorable if these changes were indicated, but from the testing and evaluation, this feature is not included. However, this limitation seems to be restrained to how the software works, and not the user.

AutoCad is used to some extent when making drawings in the office. When using AutoCad to create models and drawings, different files are used for the models and for the drawing, leading to a large number of files in case the project is large and/or complex. A model created in Tekla does not have this problem, since only one model is used, and inside this model, all the drawings created are listed. One defect of this method is that when a new model is created in Tekla, e.g. through Tekla Bridge Creator, because of a change in the road line or thickness of the bridge, the drawings created

are not available in the new model.

Comments by Skanska

It was concluded that the connection between an updated model and the drawings collapsed once Grasshopper updated the Tekla model. Problems occurring during the evaluation phase was however still valuable information to gain. Comparing Tekla's own Bridge Creator with creating models through Grasshopper and Rhino showed no significant difference regarding the process of making drawings.

Chapter 6

Analysis

The following chapter will analyze the result and the evaluation, and connect it with the theoretical part. The analysis will lay the foundation for the conclusions and further recommendations. More so, possibilities and risks by introducing new ways of working will also be interpreted.

6.1 Current state

The current state of the construction businesses is described differently depending on the narrator. On the one side of the business there are clients and on the other contractors. The client is, in this case, the one deciding which level of BIM to use, as explained by e.g. the staircase of BIM.

One interviewee stated that a change in paradigm is taking place, moving from traditional 2D drawings towards a 3D way of working, and implementing BIM. Describing the design process is different depending on which process you want to define. Skanska's Bridge Department in Gothenburg often works with large clients, such as *Trafikverket* or *Trafikkontoret* and the structures they are building are buildings that are going to last for a long time, up to one hundred years or more. This challenges how the client should store drawings and information about structures since these should be available as long as the structure stands. There is a concern regarding how to store 3D models, and currently PDF is the only reliable option, leaving the contractor with a need to produce PDF drawings even though there are good examples where bridges and other structures are being built by 3D models instead of drawings. 3D models can not be stored through the file type of PDF.

The result showed that there is a limitation in Tekla and how it connects new elements in the model with the drawings generated. However, from the testing done, it is believed that the time lost to update the drawings are less than doing the remodeling. More, the remodeling process today also removes the coupling when using Bridge Creator, further strengthening the pros of Grasshopper and Parametric Modelling. The possibility to adapt the software to this way of working is however something to

examine further in order to streamline the process even more. There is also an ongoing discussion on whether drawings should be included today in the construction process or not. One interviewee stated that they've pushed the client to exclude drawings from the building phase, but the as-built document could not be excluded from this, and these will not be removed from the requirement list in a foreseeable future. Even though the bridge could be built from 3D models, as-built documents and drawings still needs to be produced leading to an ineffective design process.

The question of which software to use is a reoccurring one. As previously mentioned, there are more or less two camps, the 2D and the 3D camp. 3D software, more or less, has the possibility to create drawings inside of them, while in some cases they are used to export 2D views of a 3D model and then later processed in another drawing software such as AutoCad. The processes can be defined through the BIM maturity level, as shown in figure 3.1. Working in 2D is considered a more conservative approach while 3D more innovative. A low level on the staircase leaves the company outside the discussion of which 3D software to use, but also missing out on the possibilities of streamlining their process with new modern tools. There are trends pushing towards the higher maturity levels, and by being first in line, a company can be very attractive in a competitive market.

While this thesis is indirectly limited to Grasshopper and Tekla and even though many obstacles have been overcome, some key issues still remain. To examine these within the Revit and Dynamo environment would be wise in order to make a good decision on how to move forward. One interviewee, working in another company, stated that the strategic choice to only focus on Revit and Dynamo as a tool to automate and parametric design worked for them. But to introduce a new 3D modeling software to an office where many already work in another environment could be very time consuming and would require extensive change management. It is, however, important to evaluate strategic questions like these to improve as a company and continue to be competitive in the market. Most of the software's receive yearly updates and sometimes comes with new features that will enhance some design processes a lot. To continuously evaluate the software is also a wise choice.

Large companies, with many users working on a certain platform, would theoretically have more to say to a Software developing company, such as Trimble, than a smaller company with only a few users. The economic incentives to Trimble are higher from a company with a high amount of users than the opposite. Using this position in order to push for new features would be a wise strategy, to solve some of the key issues of the result. Trimble and Tekla seem to be aware of some of the problems that could be solved by using Grasshopper and are implementing new functions yearly. Dynamo, however, is integrated within Revit, leaving the user with greater freedom in implementing features to its current model.

6.2 Prototype

In essence, the purpose of parametric modeling is first and foremost to simplify workflow for the design engineer. As expressed in chapter 2.4 by Eastman (2011), interconnection, or sharing of parameters between objects is a key factor for functioning parametric modeling. This concept turned out to be critical for the function of our script, as it can be seen in the chapter 4.2.1, the functionality of the script depends solely on the links between points that lay the base for the construction of cross-sections. The trimming of solids due to Y-offset would be impossible to carry out without objects being bridged by shared points.

This concept might cause the impression of being very basic and almost implied, however, this is not a case for Tekla software on its own. As an illustration, it is evidently possible to make changes to the geometry or reinforcement of for instance an already reinforced slab in Tekla. However, changes made to geometry affect solely geometry itself, leaving the reinforcement untouched. Likewise, modification of rebars does not influence the geometry. As a consequence, the designer has to adjust the unchanged part to fit the updated geometry. This might not be an issue for small models as previously mentioned examples of slab and reinforcement, where only two instances are present. However even in the case of a relatively simple retaining wall, it most certainly will be a time-consuming task. Retaining wall consisting of wall and slab solids, with multiple types of reinforcement requires a number of adjustments even for as little modification as an increase of slab width. As pointed out by one of the interviewees, most changes are handled by manually re-modeling parts to fit, leading to inefficiency and additional time-consuming steps. These modifications can be handled with simple actions and definitely in a matter of minutes by use of the script developed during this thesis. As a result, parametric design is leading to major time savings and therefore decreasing the costs of the designing phase.

6.3 Practical Application

The question can arise if the presented prototype is usable as the complete solution in real-life projects, or if it should rather be used more as base template. Depending on the desired outcome it can fill both roles. As pointed out earlier, possibilities given by parametric modeling are nearly unlimited. Restrained mainly by the time needed to be invested in order to prepare the script, where the required detail level has a major impact. As exemplified by the interviewed digital manager, simple geometries in major projects are often sufficient in order to plan but rarely available at the right time. With that in mind, the simple geometry can be created at a moment's notice using basic input parameters, such as general dimensions. Time spent on creating such a model, based on our own tests, is comparable to a matter of minutes (for especially simple geometries) to barely hour, and as a consequence presents

no argument against this approach.

Comparatively, the use of a parametric approach in order to create a starting model (as a base template) has nearly no claim against. As presented in chapter 4, a prepared script can create a model of retaining wall with basic reinforcement included. This model can function as a starting point for further development in Tekla software, where all parametric modeled parts can be modified as usual. As a result, the designer can concentrate and put more time on more project-specific adjustments rather than spending it on basic modeling work at the start of every new project. Moreover, the ability to reuse the script in similar projects means that scripting work can only be done once for general models.

It is fairly obvious to state that both of the cases described above carry with them enormous time-saving potential and therefor economic benefits. However, it can be argued that in both cases, additional knowledge needed and a very limited time frame for projects can stand as a barrier for the incorporation of this approach. Moreover as described in academic research, there is a resistance for new ways of working coming from the more senior engineers and designers. While it is an issue on its own, another aspect can be the short amount of time given to try new solutions but also the number of tries. Although this may be true, this issue can be tackled in many different forms. Even though solutions to these issues can seem fairly simple, it can be hard for a company to deal with all of them, and therefore it is important to prioritize to some extent. Regarding the software startup itself, the creation of simple automation file opening software in a specific and required order could be one functional yet simple and quick solution to overcome the initial resistance. On the other hand, resistance can be also dealt with in form of design of friendly user-interface as well as straightforward manuals and under clear leadership of managers, whose role is to explain the concepts and advantages, but more importantly - managing the cultural change mentioned by McGeorge and Zou (2013), however, these are more time-consuming.

With regards to the friendly interface, the use of Excel as a platform for inputs was therefore of strategic importance. While *HumanUI* plugin looked promising with its possibilities of making a clean and appealing design, the theoretical studies as well as conducted interviews show that it can cause a sense of frustration, common during the introduction of new digital tools, with connection to foreign design and functionality. Whereas the majority of engineers are working with Excel on a daily basis or at very least has used it in the past, and therefore can feel more comfortable with it. Regarding the use itself, only a user manual would be required, equipped with a description of necessary steps and therefore avoiding being overwhelming to the reader.

During the development of the prototype, it was discovered that adding additional components and functionality to the preexisting script came with certain challenges. Challenges mainly linked

to the structure of the script and connections between the components. It turns out that the clean structure of the data flow is essential in order to improve or develop new functionality. However on the opposite side, it becomes excessively demanding and problematic to follow in cases when the script is extensively compressed by the skilled scripting (i.e. extensive use of data trees). It can be seen as a paradox considering the fact that a smart script is easy to use and essentially more stable, however, it is also challenging to modify. By the same token, script with an extensive structure that makes it easy to follow can be perceived to be less stable (which was also noted during the test runs), yet rather simple to modify.

A point that could be overlooked is the fact that parametric modeling can be done not only with a single script but also with a number of smaller, independent ones. Given the possibility of Grasshopper to read information from Tekla as shown in figure 4.1, a large model can be created by building upon the preexisting models. In this case, only the scripts with required functionality would be used instead, as for instance adding reinforcement to preexisting geometry linked from Tekla. Additionally, shorter scripts can be modified easily due to their size and complexity, but are also light enough for the computer to process it without slowing down. This approach however brings up yet another aspect, namely the necessity of some kind of script library where users can easily find needed scripts. While such a library can remind of a library over detailed drawings which many companies use, it must not be confused with it as scripts act as a tool for creation of the model, unlike detailed drawings which are mostly complete drawings modifiable only to some extent.

At this point, it is also important to specify that not all designers and engineers would have to perform the scripting work. This preparation of scripts could be done with a small, designated team of design engineers, and only this particular team would require additional knowledge of the software and coding. The two cases mentioned can in the end offer the same level of flexibility regarding both scriptings itself as well as user experience. However with more flexibility, more competence is needed which must be considering while choosing the approach. The main factor for the choice of either one is simply the desired way of working as well as available resources in the form of staff's competence.

Although the fact that the presented script is not fully complete regarding for instance the detailing, it already can fill a substantial role in the design process and planning as mentioned at the beginning of this chapter. Besides the possibility of delivering geometries, it is possible to perform quantity takeoff. Despite the probability of wrong placement or length division of rebars in the model, the quantitative amount of reinforcement can be assumed to be close enough in order to get an overview. The largely simple steps and a short amount of time needed to recompute different designs give an opportunity to evaluate a number of different alternatives in a short amount of time.

6.4 Future of Parametric Modelling

It must not be overlooked that parametric modeling is not only concerning the classical type of input as i.e. geometric dimension. Based on the ability to read various types of data combined with condition-based scripts, inputs such as environmental or economic factors can be incorporated. Especially in the current era of focus on environmental impacts caused by the construction industry, information as i.e. CO2 footprint could be used as a numerical boundary which would have an impact on amounts of material used and therefore the design itself. In the same manner, an economic constraint as a budget could be used as a boundary for the model, alerting the user if values of the created model exceed the specified ones.

The question can arise if all parts of a model should be parameterized. While at a first it can seem like an obvious assumption, it can cause issues. Firstly, this approach would disable the possibility of making more flexible inputs. Additionally it decreases the number of possible inputs to concern only those which are specified in the script prior to the modeling. Therefore, in case of some desired changes regarding input type or input information are impossible to conduct without changing the script. Additionally, a more extensive script is more error-prone due to its complexity. Evaluating how extensive a script should be is therefore an important discussion.

To put it in other words - it can easily be stated that retaining walls does not differ so much between each project, however, there are some project-specific adjustments which in case of extensive script, should be included. At the same time, there is a possibility of creating a script library where users can create own scripts for project-specific tasks and later uploading them to the company's library in order to be accessible by others.

The detail drawings library can be seen as a smaller revolution in the design phase when it was first introduced, in the same manner - the script library has the potential to be the next major step in the digitization of the industry. It can be stated that parametric modeling is at a similar stage of development as the concept of BIM was two decades ago: new.

An ongoing discussion when digitalizing through robots, or historical industrial changes, has been that these mitigate the need of human input. In the eyes of more conservative engineers, a script that could create a complete model in a few minutes instead of weeks could jeopardize the traditional design process, implying that their role is becoming residual. However, it could also be seen as a potential opportunity for a shift in tasks performed by engineers, moving from classical design role towards computational design. The future engineer would instead take on a more managerial role, coordinating the software and focus on the development of new scripts.

Chapter 7

Conclusion

7.1 Conclusion

Concluding the analysis, parametric modeling shows its real strength when the design changes. As shown previously, there is already an undisputed edge that comes with parametric modeling over the classical design process, which is increasing at a steady pace. It can be considered as a natural step in the development of the construction industry, having a lot to offer in regards to streamlining the workflow as well as cutting largely costs and time-saving. To revise a model during the later stages during the design phase could include a lot of extra work, when all the rebars and details are set in place, up to weeks of extra time. By having the model fully parametric, these changes would only take a few minutes. This creates very large economic incentives, to be paid for a week of work when in reality, the changes are made in just a couple of minutes. The remaining time could be used to evaluate and further develop parametric scripts, to include new models, details, rebar shapes, piles, different bridges, and more.

The study showed that parametric design can be included in today's workflow. While it may not save time and money initially, scripts and parametric models can be re-used, leading to savings in the following projects. The parametric design process can include different structures, but a script for a retaining wall can not be used to design a bridge, even though certain parts within it can be copied into it. It is also possible to easily provide the model with BIM information, such as class structures, reducing the need for manual input and possible errors.

However, all things considered, the concept of parametric modeling has one main obstacle - the resistance for change. Without dealing with this in the first place, parametric modeling has no clear potential to ever be as commonly used as 2D-CAD or BIM. Parametric modeling should, therefore, be included at the education level, as in the case of BIM during last years. Equipping new engineers with this skill would be a major step towards a new age of digital design, helping the construction

industry to be more up to date and keeping up with other industries.

7.2 Recommendations

The result presented in this report is a proof of concept and intended to lay the ground for the development of a new workflow. Based on this, recommendations for Skanska can be summarized in the following five points:

1. Conduct analysis of the current state in the construction industry

In order to understand which direction and what to focus on, an analysis of the current state of parametric design, how other companies work, needs to be conducted. Challenging the way of working, and striving to be more innovative should be a natural element in the work process in order to stay competitive on the market.

2. A strategic decision in regards to which software platform to choose

Evaluation of workflow available through Revit and Dynamo should be conducted, based on the fact that this software platform offers native support for parametric design and therefore can be more stable.

3. Conduct parametric design in real-life project

By creating a parametric design within a real-life project, the parametric process is put to the test. It also acts as an additional driver for the introduction of this workflow, allowing for further evaluation.

4. Creation of script library

This study showed that it is very time-consuming, and somewhat unnecessary, to create a large script which contains all the functions needed. Instead, by creating a library of scripts and functions, the need for a large script is mitigated. The features can also be used between projects and structures. The library of the script should be a living place, where scripts are updated and new ones are added.

5. Designated group for coordination and management of parametric design

A designated group to coordinate and introduce parametric design into today's workflow should be organized. The group would be responsible for managing the script library but also act as a support for engineers using this method. Moreover, having a liable team in charge of the development of new functionalities in the form of scripts would help to keep the library alive.

7.3 Further studies

During the course of this study, a number of aspects came through linked to the topic which the authors had the will to investigate, however it would affect both the scope of the study as well as the time frame to an extensive degree. These aspects are presented below, and dedicated to the future study in regards to parametric modeling.

On a general basis, an evaluative study of software with native support as Dynamo and Revit, compared to Tekla and Grasshopper, showing the differences as well as pros and cons in a more extensive way could be examined.

In regards to the result, the Grasshopper script, a more exact geometry could be developed. Both in regards to dimensions of the cross-section but also regarding the correct placement and orientation of the reinforcement bars. Moreover, the script could be redesigned into a more compact one, either by studying relations between the components or through the design of own components. Additionally, focus on hardware efficiency due to the number of software running in the background.

An extensive study concerning the ease of use, both in regards to the user interface and script library but also how to efficiently incorporate the new workflow into the current one at the company is in our opinion one of the most important aspects.

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Appendix A

Interview questions

- What do you currently work with?
- Describe the design process as you see it
- If you wanted to change any aspect of this process, what would you change?
- Which inputs are useful if you would like to parametric model a retaining wall?
- What can be prepared before a design process starts, before the e.g. road line is delivered?
- What problems do you see with today's design process?
- How are design changes dealt with?
- What has been automatically designed before?