

**INTEGRATION OF PARAMETRIC MODEL IN A DESIGN PROCESS  
OF STEEL STRUCTURES**



Bachelor's thesis

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ABSTRACT

Design work requires collaboration with different people in different roles. The final design solution will come after many changes and modifications. Computers and software are always integral part of the design process. They can be used at different stages of design work. Most of the design software are limited to pre-defined set of tools. When the design approach is static, it requires plenty of effort and time to make change a design. Bachelor's thesis aims to explore the concept of parametric design with the help of a modern design tool and software. The main objective of the thesis was to show integration process of parametric model in a design process of steel structures.

In order to fulfil the objective, a parametric model of truss was generated by script developed in Grasshopper. Later that parametric geometry of truss was converted into a FEA model using Karamba 3D and Grasshopper. Similarly, BIM model was created with the help of Tekla Live Link and Grasshopper. A detailed description of modelling and integration process were also presented in this thesis.

In conclusion, the integration of a parametric model in a design process of steel structures is very beneficial. It makes modelling and structural analysis work more dynamically. Various alternative design solutions can be explored in an effortless manner by avoiding the time-consuming repetitive modelling process. The overall design process becomes smarter and more productive.

**Keywords** Parametric, Integration, Rhinoceros, Grasshopper, Tekla Structures

**Pages** 29 pages

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# 1 INTRODUCTION

## 1.1 Background

Design of any structure requires the collaboration of a team of different roles and disciplines. The first phase of the design processes consists of architectural design, structural engineering and detailing work. In the second phase, structures will be constructed and delivered. The client, architect, engineer, consultant, constructor and end user are the different parties who get involved in a design process. They contribute both mentally and physically to the completion of a design process. Figure 1 gives a clear picture of different activities involved in the design process. At an early design phase, these different parties can have conflicting ideas for material choice and size of the structures. As a result, early design phase becomes more time consuming and lack of information makes it difficult to make informed decisions. Modification and changes are always associated with any design process. The final design of any structure comes after many iteration and changes. Change in design at any stage will have series of effect associated with it. For an example, after completing the final design of a roof truss, if the situation occurs where the length of the truss must be increased. A series of changes must be done, which includes making changes in drawing models, performing the structural analysis again and making new production drawings. Manually completing all the changes requires a great deal of time and energy. In this era of automation and computerization, it seems very outdated and inefficient. Transition into a design process where changes can be made without compromising the work speed and efficiency is much needed. While working with a multi-disciplinary team, introducing a flexible and efficient design process is quite a challenging task. (ScienceDirect, 2018) (Okur;Okur;& Altunisik, 2018)

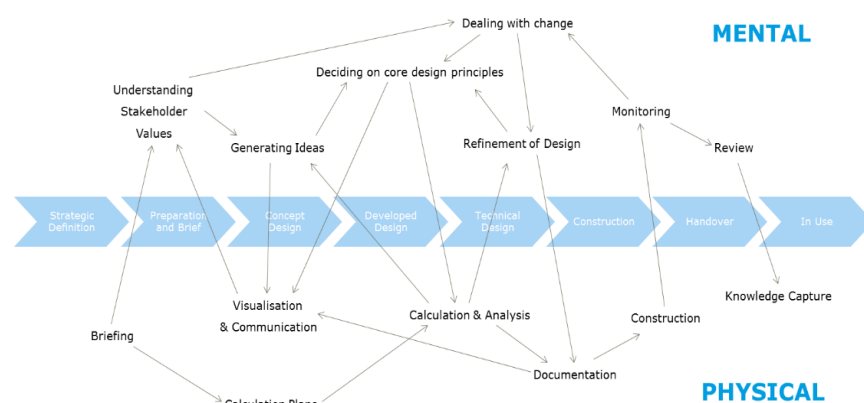


Figure 1. Diagram of the activities involved in a design process (Jeffries, 2016)

Parametric design involves defining the relations in a model rather than designing a static model. It allows to explore different design alternatives. This is the first advantage of choosing this design method. The ultimate benefits will take place after linking the parametric model to structural analysis. Once parameter of the model is changed, impact on structural behaviour can be observed immediately. On the other hand, when the parametric model is linked with BIM software, changes in any design parameter will be automatically updated to the detailing work. (Bohman, 2019)

The parametric design process is not widely used in the field of architecture, civil engineering and structural engineering. It requires plenty of time to create a parametric model, but it will increase the work flexibility. This would help to save time if small changes are required late in the project. So, at the end, it will become beneficial. The use of a parametric design technique within the building and infrastructure industries is on the rise. Different companies are investing in it and trying to apply as extensively as possible. The main goals behind this investment is to create effective methods for employees to analyse structures and to increase structural and architectural qualities. One of the challenges of using parametric design in companies is to give knowledge among employees which requires resources, such as education, training and software licences. If all parties do not have parametric design skills, collaboration work will not be effective. (Rayaan, 2018)

## 1.2 Aim and Objective

The main aim of this Bachelor's thesis is to integrate a parametric model into the design process of steel structures. It also aims to explore the concept of bringing different parties together to get involved at an early stage of project. To do so, parametric model of a steel truss will be created which can be used by a designer, structural designer and steel detailers simultaneously.

The main objectives of this thesis are:

- To create a parametric model of a steel truss by using a visual scripting language.
- To show the process of integration of parametric model with FEA software and BIM software
- To demonstrate the benefits of integrating parametric model into FEA software and BIM software.

### 1.3 Methodology

Applied methodology in order to accomplish the objective of the thesis consists of five main parts: (1) Literature review, (2) design of a steel structure (3) design approach and workflow, (4) modelling of a truss, (5) integration process and (6) conclusion.

The first part explains parametric design and parametric modelling software. The second part contains information about design of a steel structure. The explanation of new design process is shown in the third part, which can overcome the shortcoming of typical steel structure design. This part also describes the different software which are going to be used in the thesis. The fourth part describes the parametric modelling process of steel structures. The fifth part explains integration process of parametric modelling, structural analysis and detailing work. It also includes step by step process of using different tools and software. The sixth part tells about the findings and outcomes of overall thesis work.

## 2 LITERATURE REVIEW

### 2.1 Parametric Design

In mathematics, parametric equations are a set of equations that defines a group of quantities as function of one or more independent variables called parameters. The term “parametric” originally came from mathematics. It refers to the use of certain parameters that can be edited to change the end results of an equation. For example, in the equation  $x = \cos\alpha$ ,  $\alpha$  is the parameter. If we change  $\alpha$ , the result of the equation will be different. (Mathworld, n.d)

The parametric design process consists of different stages, which includes determining the parameters, defining the relation between parameters, creating the geometry, creating the variation and testing the resulting products. These stages are closely interrelated with each other. The shape of the modelled geometry could be changed as soon as the parameter is modified. There is no need of completely redrawing a model whenever it needs to change. It allows to explore different alternative solutions. This leads to a possibility to choose more efficient structures with a lower weight, smaller dimensions and better utilization of elements. As a result, environmental and economic benefits can be achieved. (Andersson & Hillberg, 2018)

The history of parametric thinking dates back to the 19<sup>th</sup> century. A Spanish architect, Antonio Gaudi’s design works between 1900 to

1914, seems parametric by nature. He had used gravity as one of the parametric inputs to shape the forms of design according to its force. He used to create an upside-down scale model by using strings and small weights. Later, the shape of the structure was determined by the force of gravity acted on string. He had used the hanging model methods as a design tool. The Sagrada Familia Basilica was constructed from masonry but the structural geometry was derived by using a scaled hanging model as shown in Figure 2 . (Tang, 2013) People at the era were familiar with the principles and characteristics of such design but they were not with the term “parametric”. Even Gaudi has not mentioned the term “parametric” in any of his design work. The upside-down scale model by Gaudi is shown in Figure 2, which has all the components of a parametric model. (Davis, 2013)



(a)



(b)

Figure 2. a) Upside down scale model (b) The Passion Facade of Sagrada Familia by Antonio Gaudi in Barcelona (Kuglmeier, 2016) (Musement, 2018)

The credit of using the term “parametric” goes to architect Luigi Moretti. From 1940 onwards, he conducted many researches and wrote extensively about parametric design under the topic “Architettura Parametric”. He has defined the phrase parametric architecture as “Defining the relationships between the dimension dependent upon the various parameters”. In 1960, he presented model of a stadium explaining how different form of the stadium can be derived from different parameters concerning things like viewing angles and the economic cost of concrete. (Heidari;Sahebzadeh;Sadeghfar;& Taghvaei, 2018)

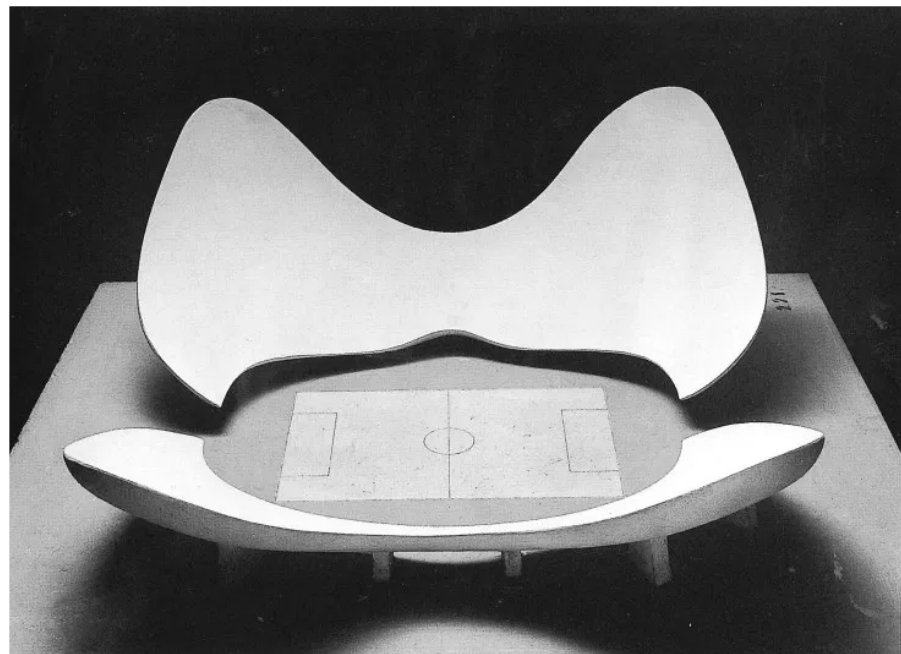


Figure 3. A model of stadium N by Luigi Moretti (Bianconi;Filippucci;Buffi;& Vitali, 2019)

## 2.2 Parametric Modelling

Conventional modelling only allows to work in two modes, which are add and erase. Parametric modelling goes beyond these two modes by introducing relate and repair options. (Davis, 2013) The act of relating and repairing distinguishes parametric modelling from other forms of representation. The invention of computers and other design tools has shifted design process from making drawing on drafting table to the screen of the computer through computer aided design. Modern design with extreme geometrics is emerging in the architectural and construction sector. However, the formation of complex structures with traditional modelling techniques is difficult and time consuming. This issue has been solved by computer assisted parametric modelling method. (ParametricCamp, n.d.)



In this era, the creation of a digital model based on definition and relation of different parameters is known as parametric modelling. The main principle of parametric modelling is to create a geometry by defining the relation between parameters. It uses variables and algorithms to generate a set of mathematical and geometric relations that allows to generate a design. Searching of different alternative solutions could be done by only changing the parameters. (BIMWiki, 2020) The number of different models obtained by changing the parameters of a column is shown in Figure 4.

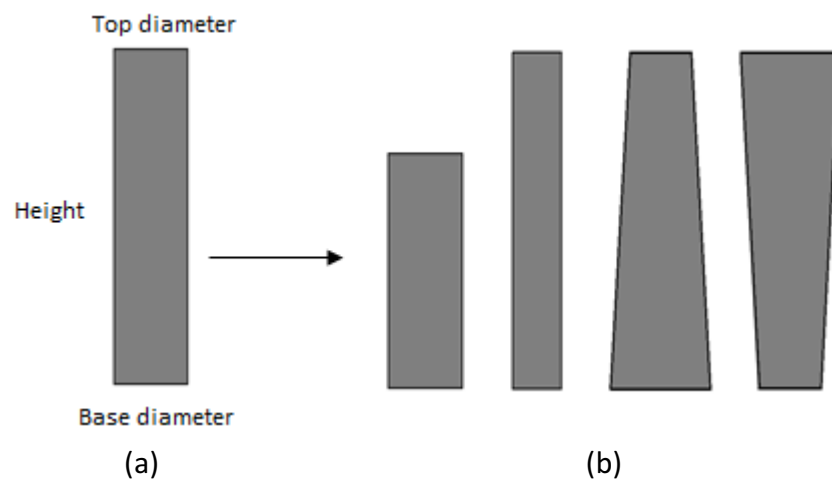


Figure 4. (a) Parametric model of column. (b) Different samples of column created by changing the parameters

### 2.3 Modelling Software

Looking back to the history and monitoring the present situation, Computer Aided Design (CAD) can be divided into three eras:

- i. 2D Drafting era,
- ii. BIM era and
- iii. Computational Design era

In 2D drafting era, computers were used to create 2D drawings. The use of this pencil and paper were replaced by mouse and screen of the computer. It was the first step towards the virtual world. Computers are machines which consist of logic and process. CAD process only used computers as an object. As a result, it failed to utilize the full potential of computer. (Humppi, 2015)

According to The National Building Information Model Standard Project Committee: "Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information

about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.” (National Institute of Building Sciences, n.d.)

BIM software utilizes the principle of shared information model. It has many advantages compared to traditional 2D CAD software. Currently, this software is the most used software in building design and the construction sector. However, people have pointed out some limitation of BIM software: it only uses predefined tools to create a model and parametric functions are only limited to object level. In addition to that, it is unable to use the computational and generative power of computers.

In both, 2D Drafting and BIM era, the medium of design expression was geometry. In computation design era, the medium of design expression is shifted from geometry to logic. The design task can be performed by a specific set of instructions. This set of instructions is known as an algorithm. Different scripts can be used to create these algorithms, which makes it possible to create your own tools. Design is not only bound by predefined tools anymore. This helps to develop a system which has potential to create various design solutions in an effortless manner. Figure 5 shows the Shanghai Tower in a twisted shape. The height of this mega tall structure is 632 meters. The shape of this tower was generated by algorithms. (Nagy, 2017) (Aguilar, 2018)



Figure 5. The Shanghai Tower (Roxburgh, 2016)

### 3 DESIGN OF STEEL STRUCTURES

Structural steel is one of the most used building materials in the construction industry, which accounts for more than 50 % of world's steel demand. Cross-section, chemical composition and mechanical properties of structural steel have been defined by different agencies such the American Institute of Steel Construction (AISC). It is also one of the most studied and best understood material. Considering the wide range of properties, structural steels are divided into four main groups: carbon steels, high-strength low-alloy (HSLA) steels, heat-treated carbon steels and heat-treated alloy steels. (ScienceDirect, 2016)

The use of structural steel as a construction material brings numerous benefits in the construction industry. Steel is used for almost every type of structure such as industrial buildings, high-rise buildings, bridge, towers, industrial plants etc. The high strength to weight ratio helps to reduce the size of the structure, resulting in cost savings. Parts of steel structure are manufactured inside the factory within a controlled environment which enhances the speed of construction and reduces the errors. Steel can be modelled into any shape, so the design is no longer restricted by a specific shape. Ductility is an important property of structural steel. Although structural steel is always used below its yield limit, ductility gives a warning signal before actual failure. Structural steel is 100% recyclable. It is one of the most reused and recycled material in the world, which makes it a sustainable and environmentally friendly construction material. Thermal aging, fatigue and corrosion damage may take place on structural steel under the prolonged influence of operational factor such as pressure, temperature, cyclic loads, radiation and environments. To get the most benefit out of structural steel, long term effects of operation factors must be considered in design. (Patel, 2019) (WorldSteel, n.d.)

When there is a need for a new structure, an individual or agency approaches an architect. The architect designs the layout of the structure in such a way that it will fulfil the functional requirements. Most of the times, the architect also decides the type of construction and materials. When the overall layout is ready, structural engineer is expected to do structural calculation and design to ensure the safety and serviceability of the structure. This process is known as structural design. (Kumar & Kumar, 2009)

A typical steel structure design process includes two phases.

- i. Design phase
- ii. Construction phase

Figure 6 shows different activities involved in the design phase. After the idea development, concept design will be represented by a geometry. A model of the structure will be developed according to the geometry in order to proceed design verification and detailing work.

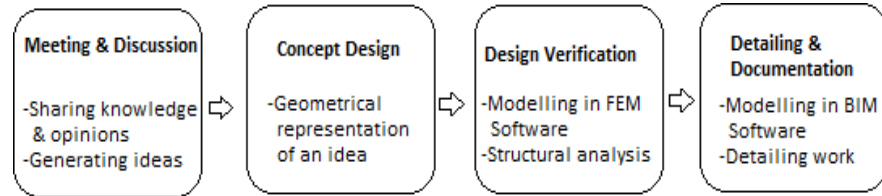


Figure 6. Activities involved in conventional design phase

Production and installation work take place during the construction phase. Most of the parts are fabricated inside a factory and later those parts are combined and installed together to build a complete still structure at a desired location.

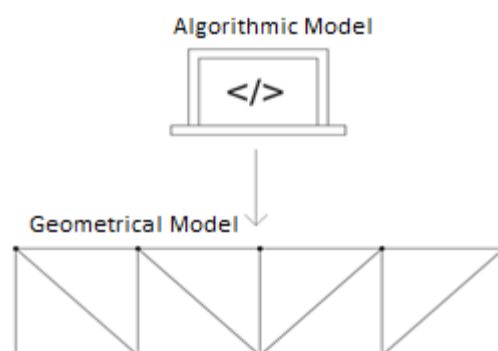
## 4 DESIGN APPROACH AND WORKFLOW

### 4.1 Design Approach

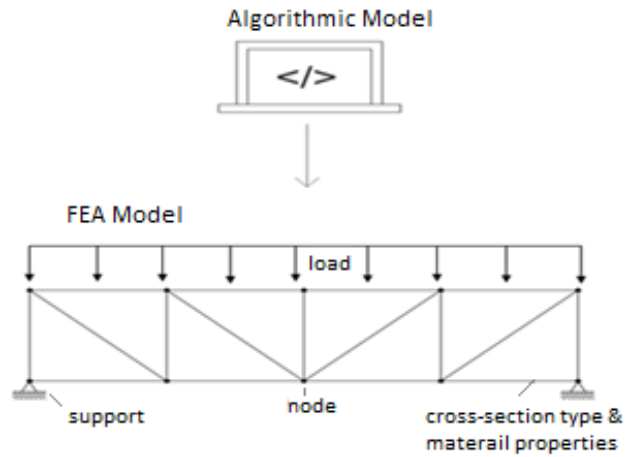
In the conventional design process, design idea will be expressed in terms of geometry. For this thesis, a new design approach has been used in order to proceed the design of a steel truss. Concept design of a truss will be developed by an algorithm. Those algorithms will define the geometry of the truss. As a result, geometry of the structure will be parametric. Later, geometry will be converted into FEA and BIM models. Making of only one parametric model is needed. It completely terminates the creation of three models, which exist in the conventional steel design work.

### 4.2 Work Flow

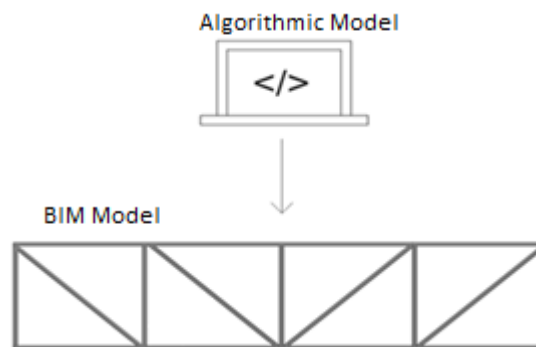
- i. The algorithmic design tool will be used to create a script that can generate a parametric geometry of a truss.



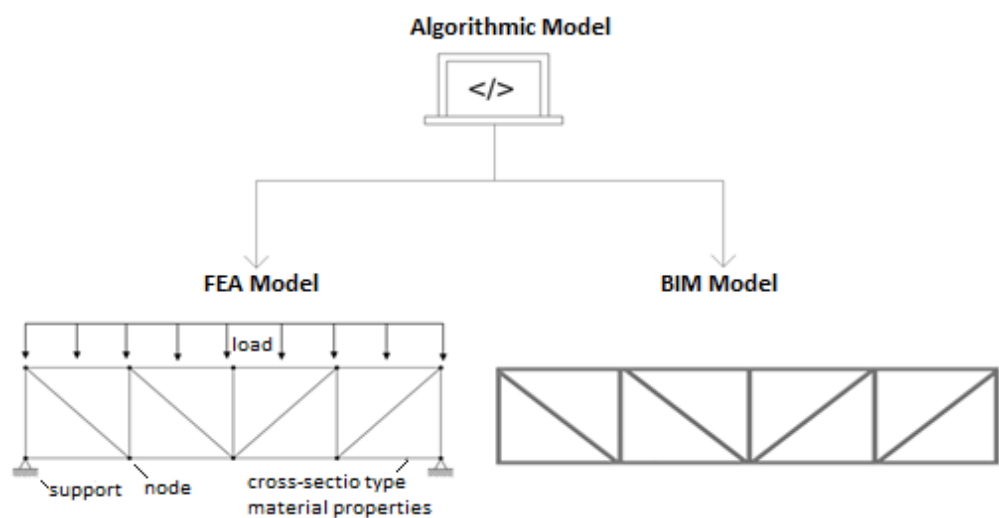
- ii. The algorithmic design tool will be used to create a script that can develop a FEA model of a truss from parametric geometry.



- iii. The algorithmic design tool will be used to create a script that can develop a BIM model of a truss from parametric geometry.



- iv. Integration of script, FEA model and BIM model



## 4.3 Software for thesis

### 4.3.1 Rhinoceros and Grasshopper

Rhinoceros, also known as Rhino, is 3D modelling software. In addition to direct modelling, it also allows to create a model using the algorithms. A variety of geometrical shapes can be generated by defining the parametric relation between variables.

Grasshopper is a computational design framework of Rhino. It was developed by Robert McNeel & Associates. It is an algorithmic design tool. It is based on a different programming environment called a visual scripting language. Instead of individual lines of code, it uses a collection of visual nodes to represent operations. Different visual nodes can be linked with each other to create a specific instruction. It is simple to use and requires low knowledge of programming or scripting skills. Script written in Grasshopper has a live link with Rhino. The result of every script in Grasshopper can be seen instantly in Rhino. (Rhinoceros, n.d)



Figure 7. Method of using Rhino and Grasshopper for thesis work

### 4.3.2 FEA Software

Mathematics has been extensively used to understand any physical phenomena such as structural behaviour, fluid behaviour, thermal behaviour etc. Most of the physical phenomena are described by using partial differential equations (PDEs). Numerical methods have been developed in order to solve these PDEs in computer, known as the Finite Element Method (FEM). The Finite Element Analysis (FEA) is the simulation of any given physical phenomenon by FEM.

The working principle of FEA is based on breaking down a real object into a large number of finite elements. Numbers will vary from thousands to hundreds of thousands. The use of the mathematical equations helps to predict the behavior of each

element. A computer then sums up all the individual behavior to predict the behavior of a real object. (Autodesk, n.d.) (Harish, 2020)

Karamba 3D is a FEM based parametric structural engineering tool. It gives accurate analysis of spatial trusses, frames and shells. It is a plug-in for Grasshopper. Parametric geometry and finite element analysis can be combined together. This makes easy to make a decision of initial geometry and properties of design. However, this tool has some drawbacks. Karamba can only perform linear calculations. It can only be used within the Rhinoceros software. It lacks the capacity of showing the displacement of all nodes, it can only show the maximum displacement node. (Karamba3D, n.d.) (Aguiar, 2018)

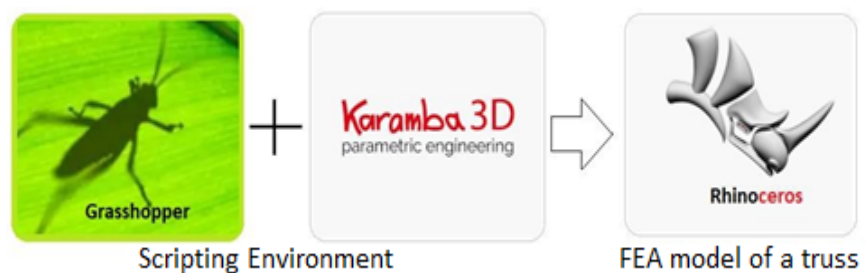


Figure 8. Method of using FEA tools for thesis work

#### 4.3.3 BIM Software

Building information modelling (BIM) software is based on 3D modelling platform that helps the structural designer to design, detail, document and fabricate structural systems. BIM software makes it easier to work more collaboratively with team members. It helps to improve accuracy in design and connects design to the fabrication process. (Lorek, 2018)

Tekla Structures is BIM software which allows to create a 3D model of the structures using different kinds of building materials such as steel, concrete, timber and glass. In 1966, the software company named as Teknillinen Laskenta Oy (Technical Computing) was founded in Helsinki, Finland. Later, the company's name changed to Tekla. The first version of Tekla Structures was launched in 2004. Tekla was merged with Trimble Solutions Corporation in 2011. (Rai, 2016)

“The Grasshopper-Tekla Live Link” is a plugin which enables live interaction between Tekla Structures and Grasshopper. After installation of this plugin, different components of Tekla Structures will be available in Grasshopper. This allows to link a geometry created in Grasshopper to a real model in a Tekla Structures. (Trimble, 2020)



Figure 9. Method of using BIM software for thesis work

## 5 PARAMETRIC MODELLING OF A STEEL STRUCTURE

### 5.1 Truss

A truss is a triangular rigid structure, which is made by an assembly of straight interconnected structural elements. The top chord, bottom chord and diagonal bracing are the three major components of a truss. Connections at nodes are assumed as pinned. Mathematically triangulation is a stable configuration, which also defines the significance of triangular shape of a truss. The top and bottom chords of the truss provide resistance to compression and tension. Bracing resists the shear force. (Diya, 2019) (ScienceDirect, 2017)

When spans exceed a certain limit, the use of solid beams becomes heavy and uneconomical. A primary use of trusses take place where there is need for covering very long spans, such as airport terminals, aircraft hangers, auditoriums, sports halls and other leisure buildings. (Vishwanath, 2017)



(a)



(b)

Figure 10. (a) Use of Steel roof rafters to support the purlins and roof sheeting (b) Use of trusses for the same purpose (SteelConstruction, n.d.)

Considering the workspace trusses can be divided into two types i.e. planar truss and space truss. In a planar truss all the members lie in two-dimensional plane. A simple roof truss is an example of a



planar truss. Space truss is a three-dimensional structure. An electricity transmission tower is an example of space truss.

There are wide varieties of truss forms that can be created depending upon the materials and design condition. Pratt truss (Figure 11) consists of a number of vertical and diagonal members that form an “N” shape. It was first proposed by Thomas Pratt in 1844. It also known as “N” truss. (Carroll, n.d.) Pratt truss was used for the thesis to show the parametric modelling and integration process.

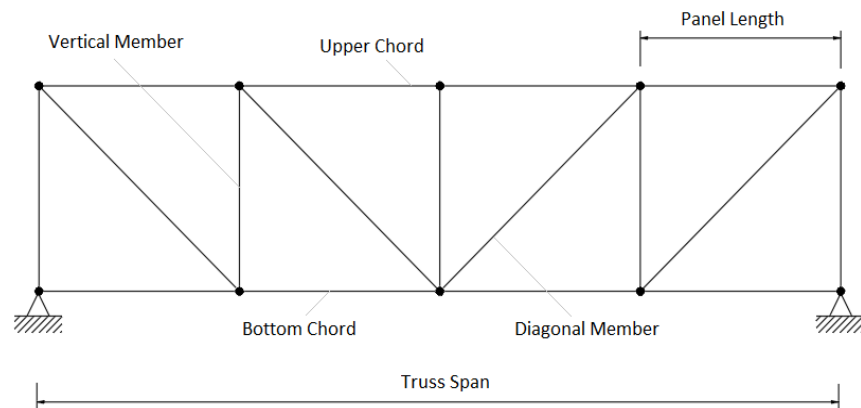


Figure 11. Pratt Truss

## 5.2 Modelling Process

### 5.2.1 Getting started with Rhinoceros (Rhino) and Grasshopper

A new project file must be created in Rhino in order to start the modelling process. A file can be created by clicking the “File” icon from tool bar. Once a new file is opened, there will be an option to choose template files, which allows to select the unit of a modelling process.

Once new file is created, Grasshopper could be launched by clicking its icon from Rhino’s toolbar or typing the word “grasshopper” in command bar. Two interface windows can be seen on the screen, one is for Grasshopper and other is for Rhino. Then script can be written with Grasshopper to develop a desired model and the result can be shown in Rhino’s window.

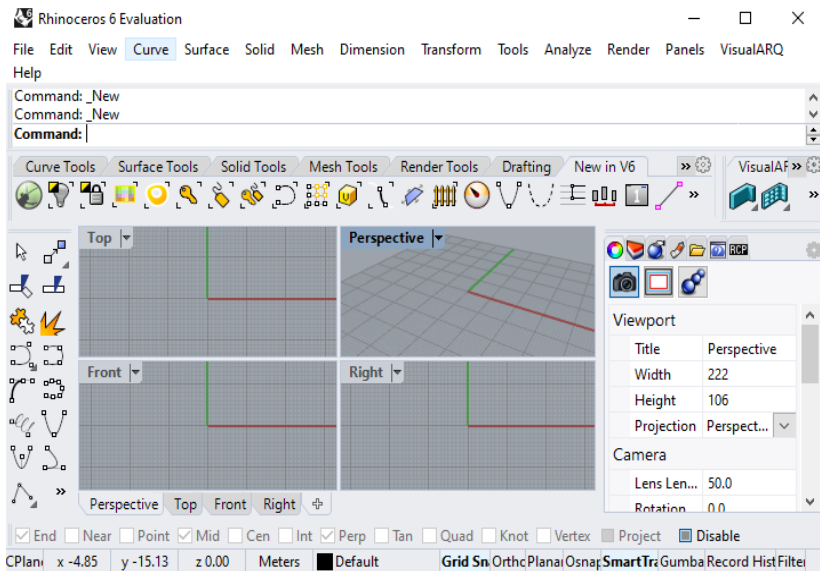


Figure 12. Interface in Rhino

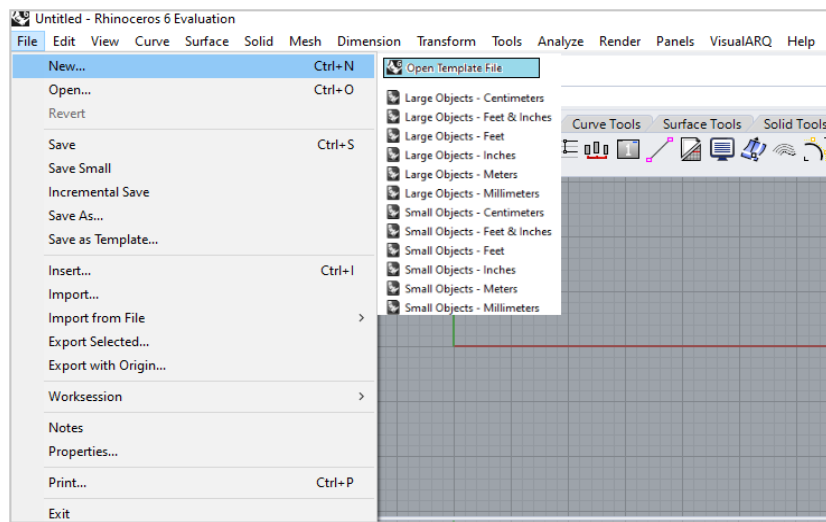


Figure 13. Creating a new file in Rhino

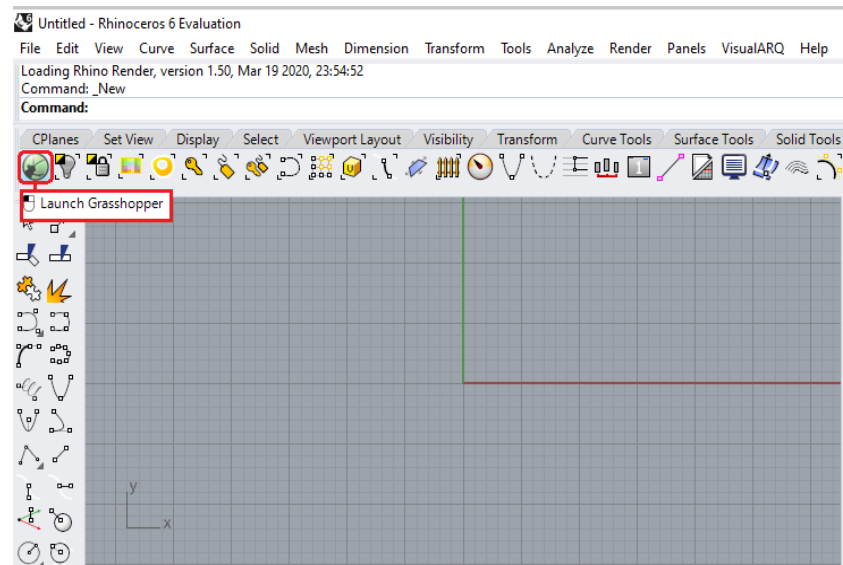


Figure 14. Launch of Grasshopper in Rhino

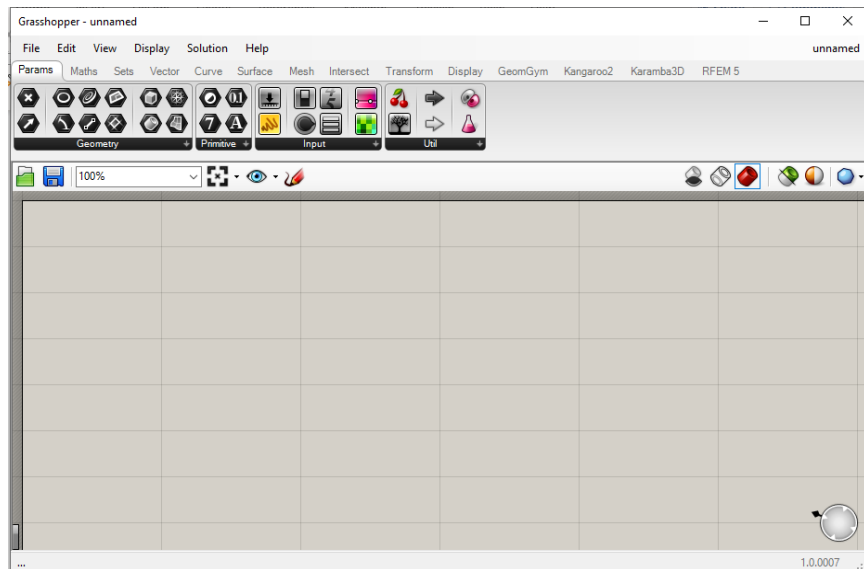


Figure 15. Interface of Grasshopper in Rhino

### 5.2.2 Creating parametric geometry of a truss

Script was created using different components in Grasshopper to create a model of a truss. A line component, vector component, move component, divide component and number slider were used to create a two parallel lines. These components can be selected from a specific tab of the Grasshopper interface. The easiest way to choose the desired component is to double click on screen and search for the component.

Two major procedures were carried out to get the parametric geometry of the truss.






#### i. Creating two parallel lines:

At first a single line was constructed. Then the line was moved into z-direction in order to create a parallel line. The length and height of these lines can be varied. In this way parametric two parallel lines, which represents the upper and lower chords of the truss were created. Then two lines were divided into an equal number of parts. After that, each point which was used to divide the parallel lines was extracted. Figure 16 shows how different components were used to create the required geometry.

Components used for modelling and their functions:



**Number Slider:** Sets the range of input value. This function was used to create parametric length and height of a truss.

-  **Unit X:** Sets the direction of input according to unit vector direction.
-  **Line:** Reads the coordinates of start point and end point and makes a line.
-  **Move:** Takes a geometry as an input and moves it according to input direction.
-  **Divide Curve:** Divides the curves into equal length segments.
-  **Explode Tree:** Extract the points from divided line segments.

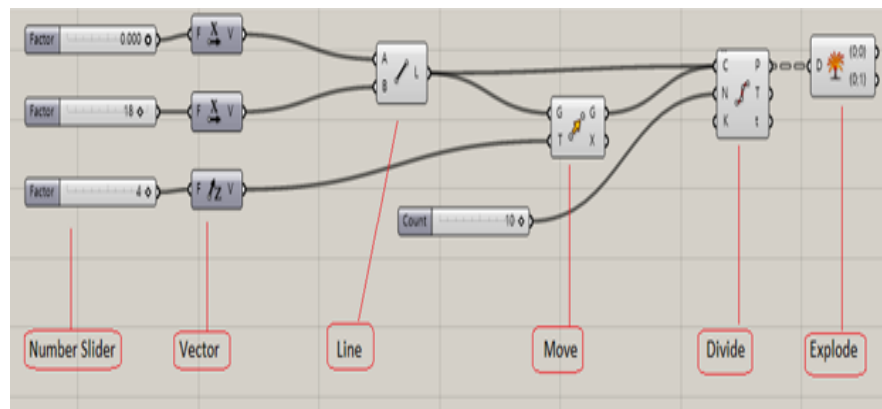


Figure 16. Script in Grasshopper to create parallel line

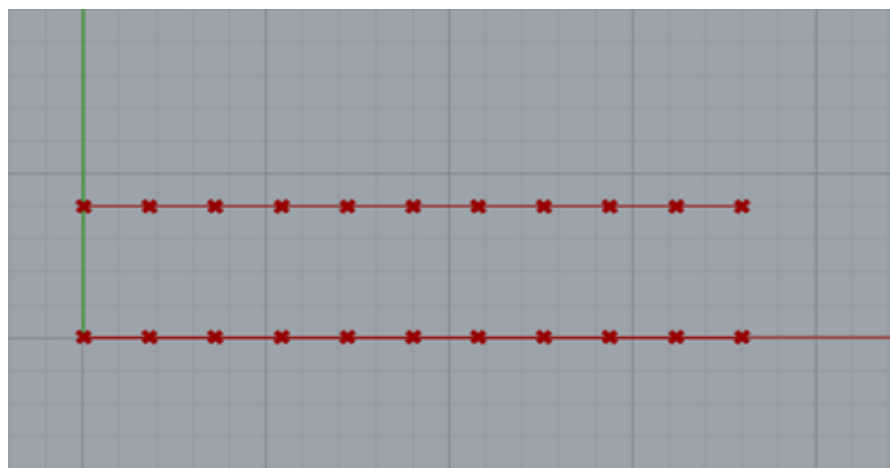


Figure 17. Output in Rhino according to script

ii. Connecting points between two parallel lines:

Extracted points from two parallel lines were split into two different parts. The first point from one of the parallel lines was connected to the second point of another line. In this way, the first part of two parallel lines were connected via an inclined line as shown in Figure 19. This inclined line represents the diagonal member of a truss. List length, split list, point, shift list and line components were used to make these diagonal members.

Components used for modelling and their functions:



**List Length:** Counts the number of points in a line.



**Split List:** Takes geometry and split list as inputs. Splits the points into different parts according to the expression.



**Points:** Acts as a container to collect the points.



**Shift List:** Shifts the position of points.



**Shortest List:** Trims the end point from the list.

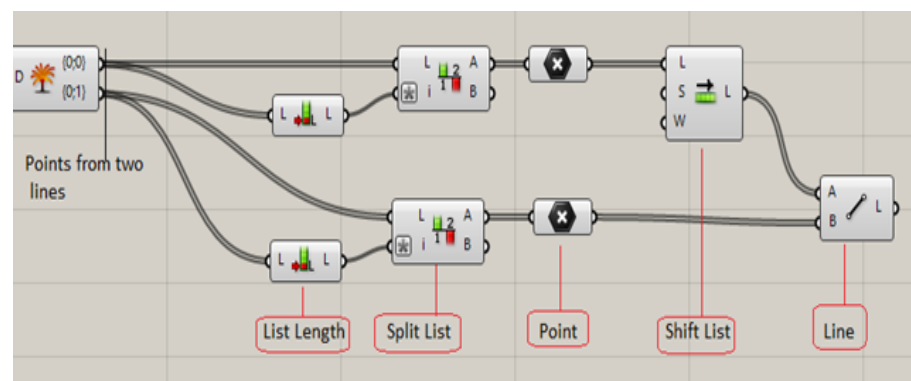


Figure 18. Script in Grasshopper

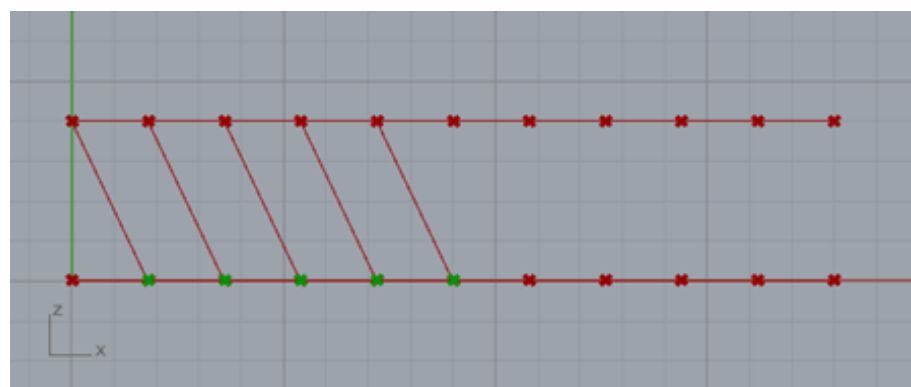


Figure 19. Output in Rhino according to script

The same principle was used to make the connection between the second part of the two parallel lines. All extracted points were connected by using line command to make a perpendicular connection. These perpendicular lines represent the vertical member of a truss.

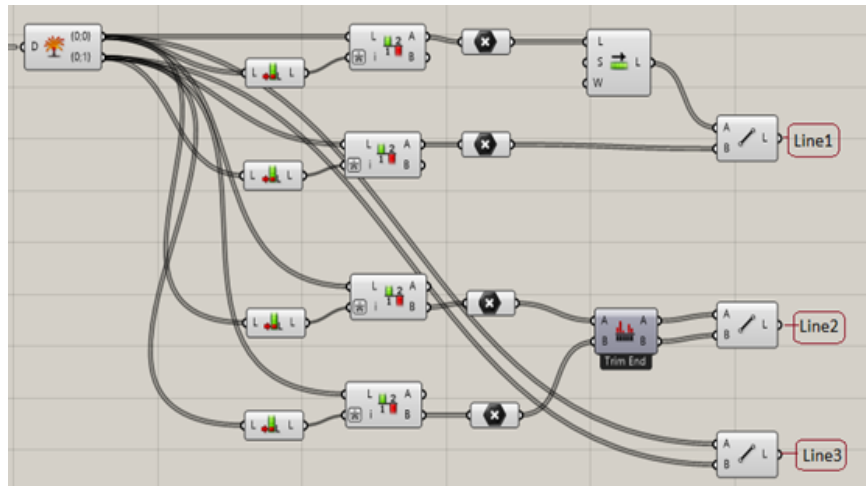


Figure 20. Script in Grasshopper

In this way a complete parametric geometry of a truss was created via script in Grasshopper. Truss span, height and panel length of the truss can be changed in an effortless and fast manner.

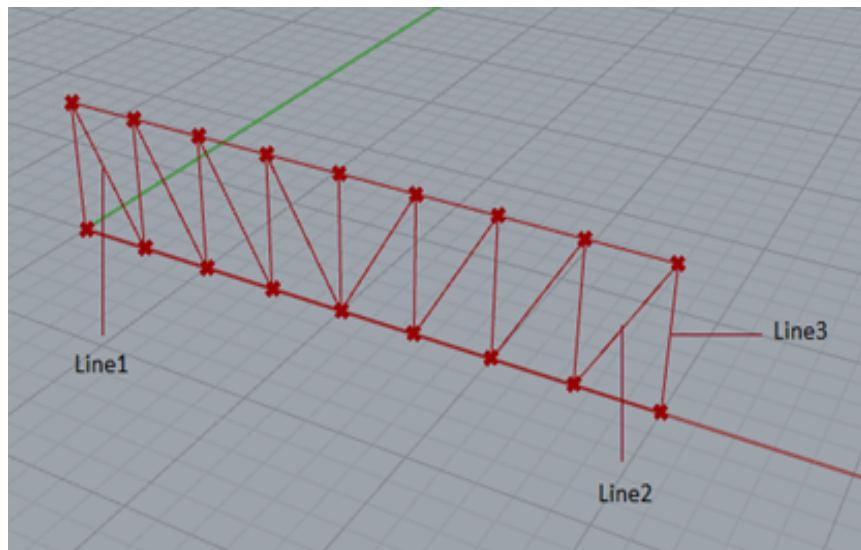


Figure 21. Parametric truss geometry in Rhino

## 6 INTEGRATION OF PARAMETRIC MODEL

### 6.1 Integration with FEA Software

A parametric model of a truss was successfully created. FEA model of a truss must be created according to the geometry of a truss. Grasshopper and Karamba 3D make it possible to create FEA model and do the analysis.

Three major procedures were carried out in order to make a FEA model and do the structural analysis:

- i. Defining the entities

The parametric model of a truss in Grasshopper was only represented by lines. Necessary information about different entities such as element type, loads, support condition, cross section and material must be provided to make a FEM model from the geometry of a truss.

The following components were used to define the entities:



**Line to Beam:** Creates beams with user defined from the given lines.



**Panel:** To write custom notes and values. This function has been used for giving names and cross-section of chords and diagonals.



**Loads:** Creates different types of loads for a structural model.



**Support:** Creates support on nodes.



**Cross Section Selector:** Helps to select cross section by name or standard expression from list of cross sections.



**Material Selection:** Helps to select material by name or standard expression from the list of materials.

Firstly, line segment of a truss was converted into a beam element using “line to beam” component in Grasshopper.

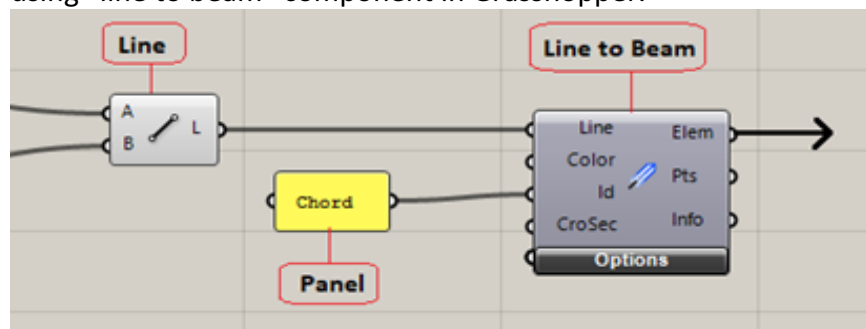


Figure 22. Script in Grasshopper

Cross section type and material properties of line to beam element was provided by using two components as shown in Figure 23.

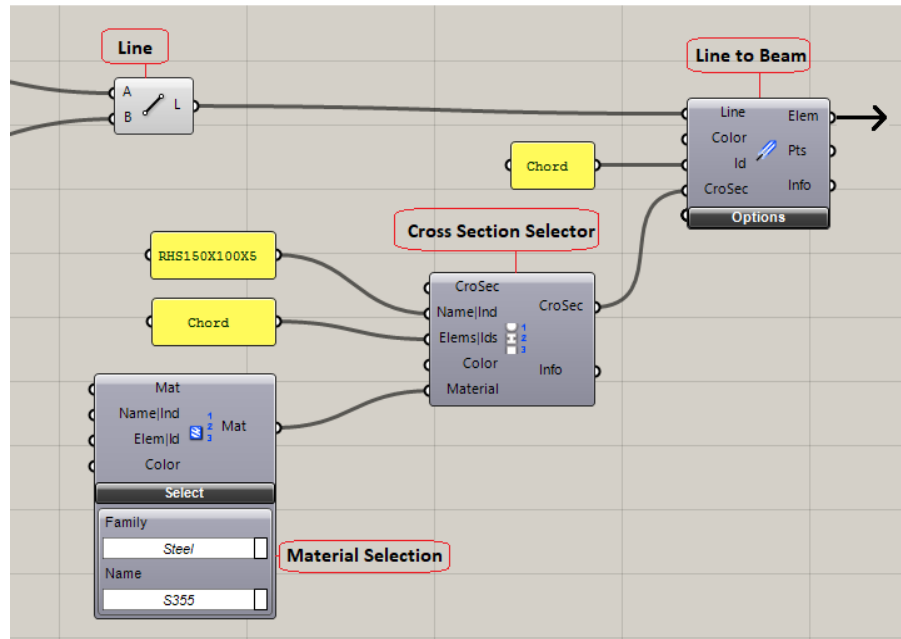


Figure 23. Script in Grasshopper

After successfully converting line into a real steel profile, the support conditions and loads were provided by using two other components in Karamba (Figure 24). Supports were provided at both ends of beam. Uniformly distributed load was provided to the beam from the z direction using a “Load” component (Figure 25).

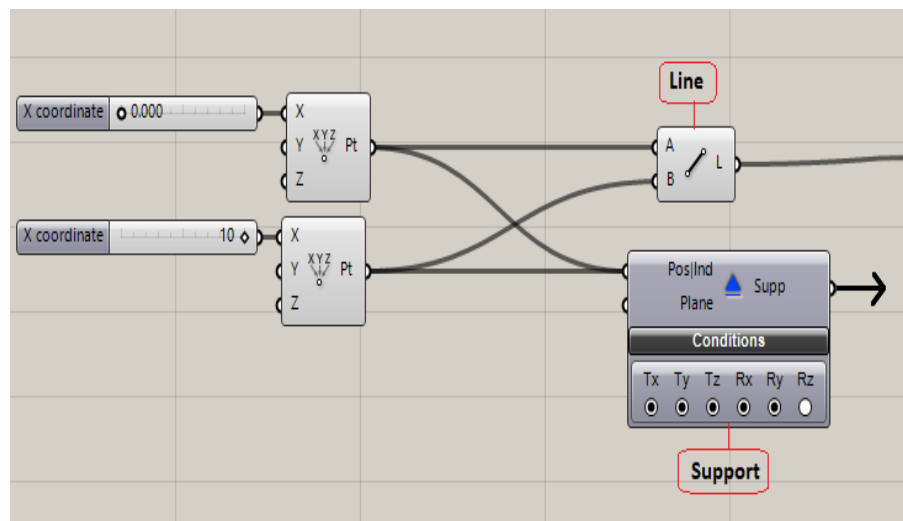


Figure 24. Script in Grasshopper



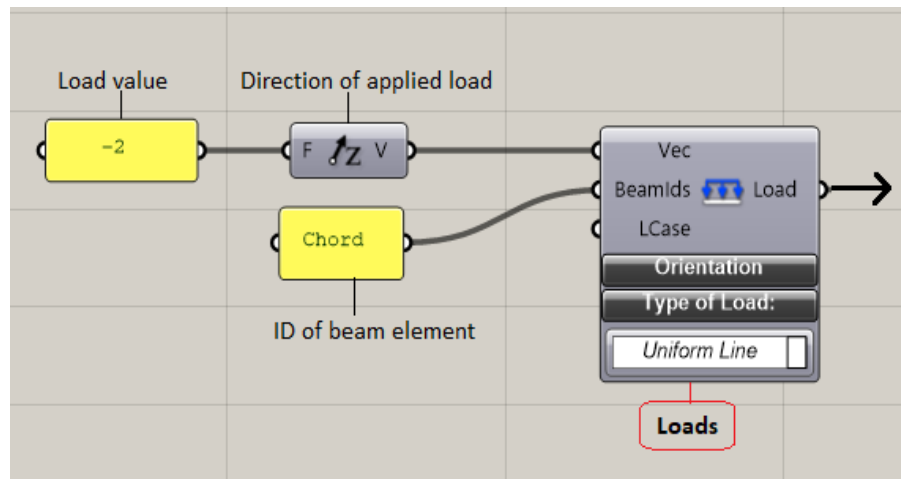


Figure 25. Script in Grasshopper

ii. Assembling the FEM model

Line was converted into beam. Then support and load were provided to the beam. In this way, the process of providing all necessary information for structural analysis was completed. During the second phase, all these components were assembled in single FEM model. "Assembly Model" creates finite element model from defined entities as shown in Figure 26.

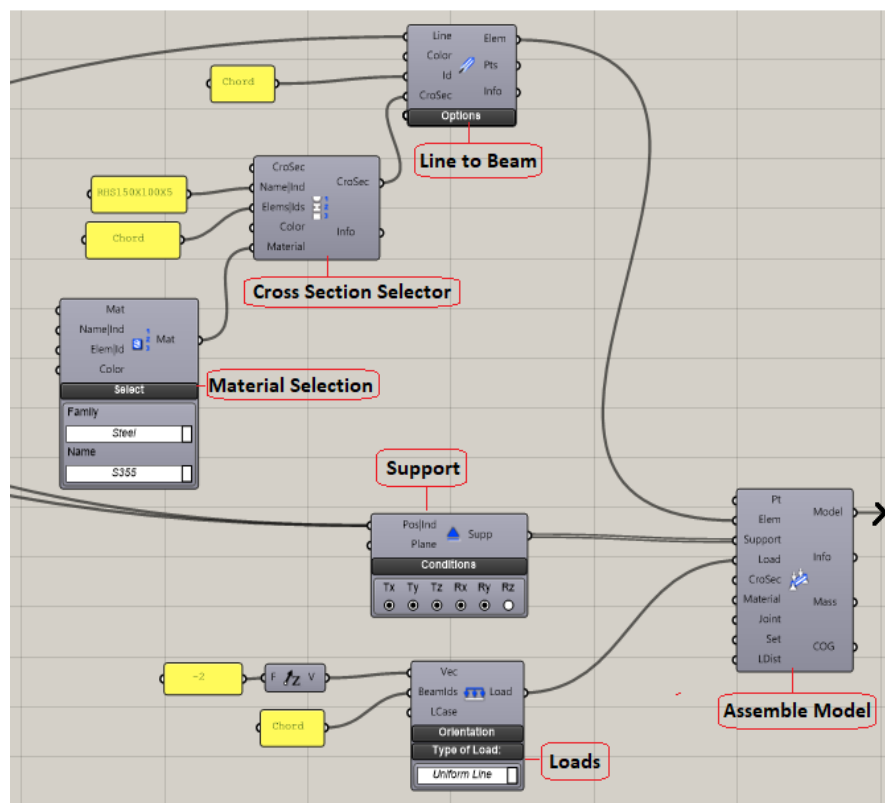


Figure 26. Script in Grasshopper

### iii. Analysis and Results

The model which comes out of the “Assemble Model” component gives a complete FEA model. Once FEA model was ready, finite element analysis process was carried out.

Different components and their functions:



**Assemble Model:** Creates finite element Model from defined entities.



**Analyze:** Calculates the deflection of a FEM model.



**Model View:** Shows the current state of model.



**Beam View:** Helps to show the properties of a beam.



**Resultant Beam Forces:** Retrieves maximum resultant section forces for all beam elements of the model.



**Legend:** Display the legend consisting of tags and colours.

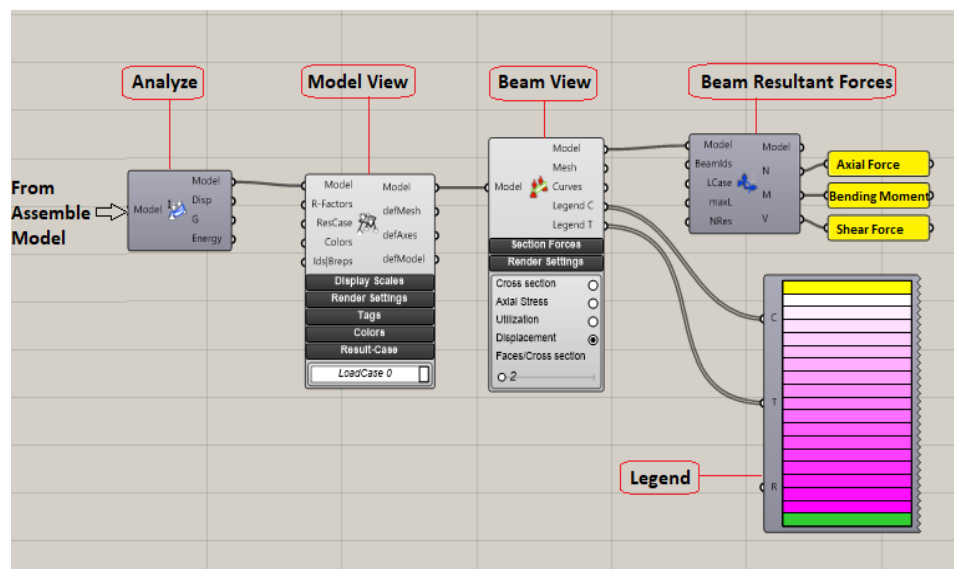


Figure 26. Script in Grasshopper to perform FEA and show results

In this way, integration process between parametric model and FEA tools was achieved. A complete FEA model of a truss was obtained from parametric geometry of a truss. This FEA model is also

parametric by nature. Span length, height and panel length can be changed easily.

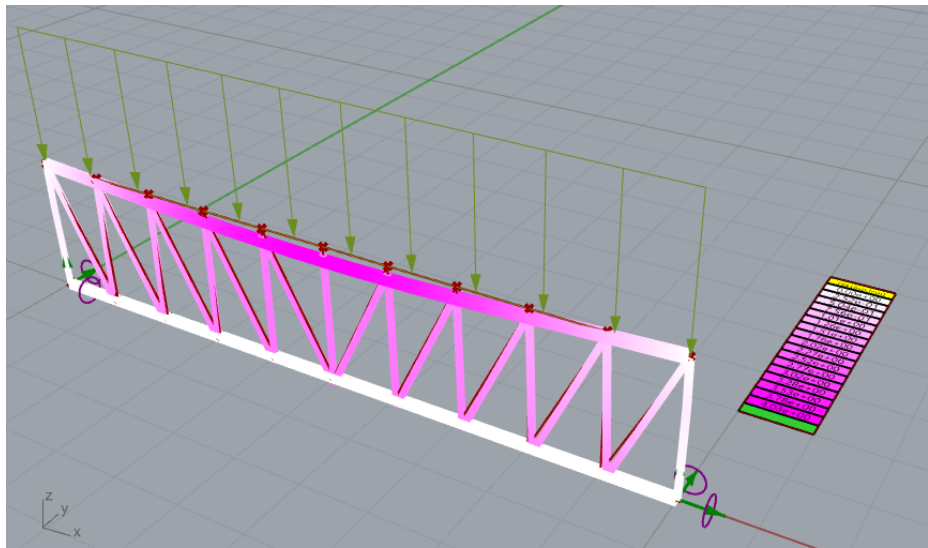


Figure 27. FEA model of a truss in Rhino

## 6.2 Integration with BIM software

Once parametric geometry is ready, it must be integrated with BIM software. Getting BIM model out of a parametric geometry is crucial because it makes possible to perform detailing and documentation work. Grasshopper and Tekla Live Link makes it possible to convert geometry of a truss into a complete BIM model.

Components used from Tekla Live Link's toolbar and their functions:



**Beam:** Creates steel beam in Tekla.



**Part Attributes:** Helps to set name, profile, material, class, phase and user defined attributes of the part



**Profile Catalog:** Helps to select the cross-section profile.



**Material Catalog:** Helps to select the material.

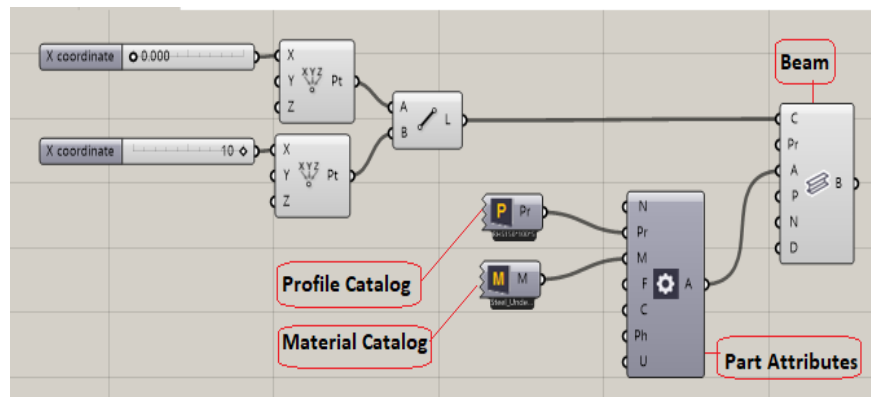


Figure 28. Script in Grasshopper to convert line into beam in Tekla

The same approach as shown in Figure 28 was used to create a complete BIM model. In this way, integration between parametric model and BIM software was completed. A complete BIM model of truss was obtained and presented in Tekla Structures. The BIM model is also parametric by nature. Span length, height and panel length can be modified very easily.

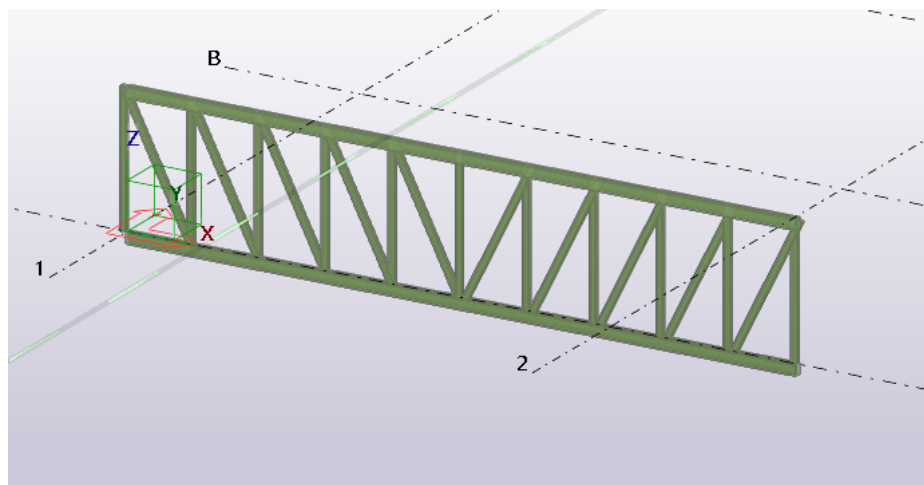


Figure 28. BIM model of a truss in Tekla Structures

## 7 CONCLUSION

Designing work of a steel structure requires teamwork. Final design will not be final until it is handed over to the client. There will be always a place for change in the design work. Changes can occur at any stage of design work. Computer and software are integral part of design work and they make the design process easier. The

majority of design software's workability is limited to predefined sets of tools. They can draw any structure easily but cannot create a tool that will generate a structure. Limited number of design software is available which uses predefined tools as well as facilitates users to create their own tool. Rhinoceros/Grasshopper is an example of this kind of software. Instead of creating a structure by a tedious step by step process, it allows to develop an algorithm that will create a geometry in the desired shape.

The main aim of this thesis was to integrate the parametric modelling technique in a design process of a steel structure. Using a proposed workflow, the parametric model of a truss was created by script in Grasshopper. Then parametric geometry of a truss was integrated to FEA model and BIM model. A single parametric model of a truss was shared by both software. When there are any changes in a parameter, the results can be observed simultaneously from both software in a real time. Detail description of modelling and integration process were shown in this thesis. This thesis was more focused on the process of integration rather than analysis of results. Detail description of modelling and integration process was also shown in the thesis work. It might be helpful to those who would like to make a model in Rhino/Grasshopper and integrate it with Karamba and Tekla.

In conclusion, parametric modelling makes design process more dynamic and reduces time significantly to modify designs. It allows to create repetitive geometries with less work. When parametric model is integrated with FEA and BIM software, outcomes will be very beneficial. When parameter gets changed, the result can be seen simultaneously. It helps to speed up design process. Various design solutions can be explored in an effortless manner by avoiding the time-consuming repetitive modelling process. Overall design process becomes smarter and productive.

The load used for structural analysis was assumed. For future work, FEA model with a real load with different load case combinations can be used. In addition to that, the results from analysis can be compared with results from other FEA software such as Dlubal RFEM using the same boundary conditions. In Tekla Model, the position of diagonal member and vertical member on a node needs to be fixed before making a production drawing.

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