

Politecnico di Torino

Master of Science in Building Engineering

Parametric Modelling of concrete box bridges

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Academic Year 2025/2026

Graduation session September 2026

Abstract

This thesis investigates advanced computational modelling methods for parametric concrete box-girder bridges, with a particular focus on the integration of 3D modelling and Building Information Modelling (BIM). The main objective of the research is to develop a parametric approach to bridge modelling that improves the accuracy, flexibility, and efficiency of the overall project workflow.

The study employs Grasshopper, a visual programming and parametric design environment integrated with Rhinoceros 3D, and establishes interoperability between Grasshopper and BIM software, including Tekla Structures and Autodesk Revit. This integration enables the transition of parametric models between different platforms and facilitates the development and management of complex bridge geometries within BIM environments.

A significant part of the research focuses on determining the geometry of existing bridges from point-cloud data. Point clouds acquired through 3D laser scanning provide detailed geometric information about existing structures. By processing this data within a parametric workflow, the geometry of the bridge can be extracted and used for the automated generation of BIM models. This approach reduces repetitive manual modelling operations while improving the accuracy and efficiency of the modelling process.

For modelling complex bridge geometries in Autodesk Revit, the research uses Rhino.Inside.Revit to establish interoperability between Rhinoceros, Grasshopper, and the Revit BIM environment. Particular attention is given to the use of adaptive families, which enable complex bridge components to be generated and controlled parametrically with a high degree of precision and flexibility.

Finally, a user-friendly interface developed using the Grasshopper Human UI plug-in simplifies the bridge modelling workflow by automating geometry generation and reducing the need for direct interaction with complex Grasshopper definitions. Users can provide input parameters, point-cloud data, or alignment curves, preview the generated geometry, and transfer the resulting models to BIM software. The workflow also incorporates coordinate calculation and georeferencing procedures to ensure the accurate spatial positioning and integration of the generated BIM models.

Overall, the developed methodology demonstrates how point-cloud data, parametric modelling, BIM interoperability, and workflow automation can be combined to support a more efficient and flexible approach to the modelling of existing concrete box-girder bridges.

Keywords: Parametric design, Building Information Modelling, Bridge Design Automation, Bridge Information Modelling and Computational design

Acknowledgment

This thesis marks the culmination of a challenging and rewarding journey in the parametric modelling of concrete box-girder bridges, carried out through a collaboration between Politecnico di Torino and Masera Engineering Group Srl. I would like to express my sincere gratitude to both institutions for providing me with the knowledge, resources, and opportunities that made this work possible.

I am deeply grateful to my academic supervisors, **Prof. Valentina Villa** and **Prof. Bernardino Chiaia**, for their constant guidance, encouragement, and invaluable support throughout the development of this thesis. Their expertise, insights, and advice have been fundamental in shaping this research and have contributed significantly to my academic and professional growth.

I would also like to express my sincere gratitude to **Masera Engineering Group Srl** for giving me the opportunity to develop this research within a professional engineering environment and to gain valuable practical experience. In particular, I am especially grateful to my company supervisors, **Engr. Valentina Boretti, Engr. Mario Balestra, Engr. Rebecca Asso, and Engr. Davide Masera**, for their guidance, mentorship, availability, and continuous support throughout this work. Their experience and valuable feedback greatly enriched my learning process and helped me bridge the gap between academic knowledge and professional engineering practice.

I am also deeply thankful to my friends and peers in **Torino and India**, with whom I shared countless memorable moments throughout this journey. Their friendship, encouragement, and support made these years both meaningful and unforgettable.

Finally, my deepest gratitude goes to **my family**, whose unconditional support, trust, patience, and encouragement have been the foundation of everything I have achieved. Their constant presence has given me the strength and motivation to overcome the challenges encountered throughout this academic journey. I dedicate this achievement to them, as without their support, none of this would have been possible.

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CHAPTER 1

1. INTRODUCTION

An innovative method for bridge design and building are required to meet the changing needs of contemporary infrastructure. One such method is parametric modelling, an effective strategy that makes use of computational design tools to produce intricate structures with extreme efficiency and precision. This thesis investigates the use of Grasshopper, a parametric design tool in Rhino, in conjunction with Tekla Structures and Revit, two industry-leading platforms for Building Information Modelling (BIM), to investigate the parametric modelling of concrete box bridges.

Concrete box bridges are a type of bridge structure by its use of reinforced concrete and complex shaped cross-section. This design of bridges is particularly popular for its strength, durability and efficiency in use of both material and construction. The traditional method of designing these structures often involve time-consuming and sometimes leads to complexity in designing process. However, the advanced parametric modelling has transformed this process enabling the automatic generation of complex geometries and updates to designs in response to changing parameters.

Additionally, the geometric complexity of a box girder bridge adds to the challenge. The design must carefully balance the structure efficiency of the box section with the need for ease of construction and maintenance.

This bridge's main beams are made up of girders that are shaped like hollow boxes, either rectangular or trapezoidal. Prestressed concrete, structural steel, or a combination of steel and reinforced concrete are typically used to make box girders.



Figure 1. 1 Concrete Box bridge

The bridge span follows different cross section along the length; this method makes the modelling more challenge as you can see in the below picture the bridge section differs in the following path:

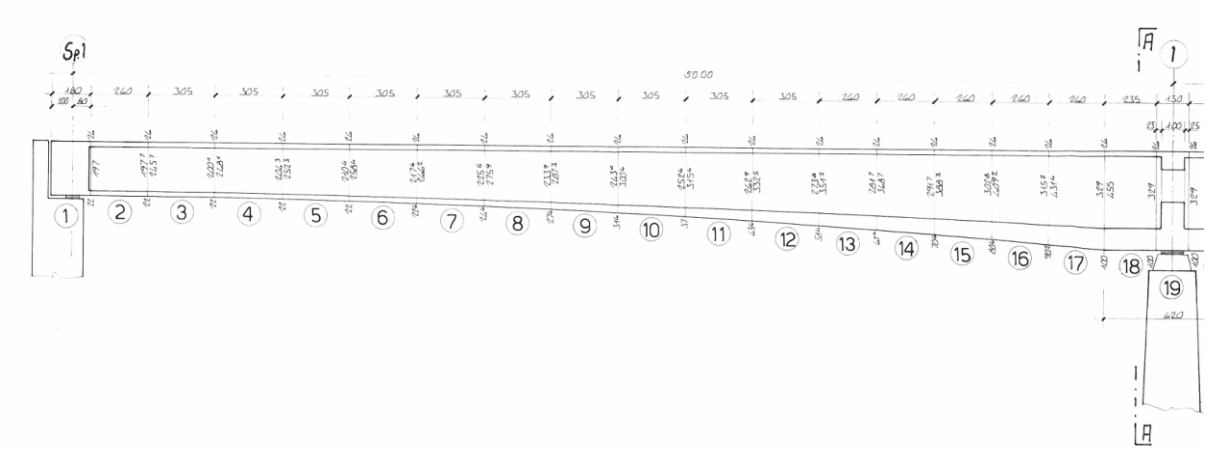


Figure 1. 2 longitudinal section

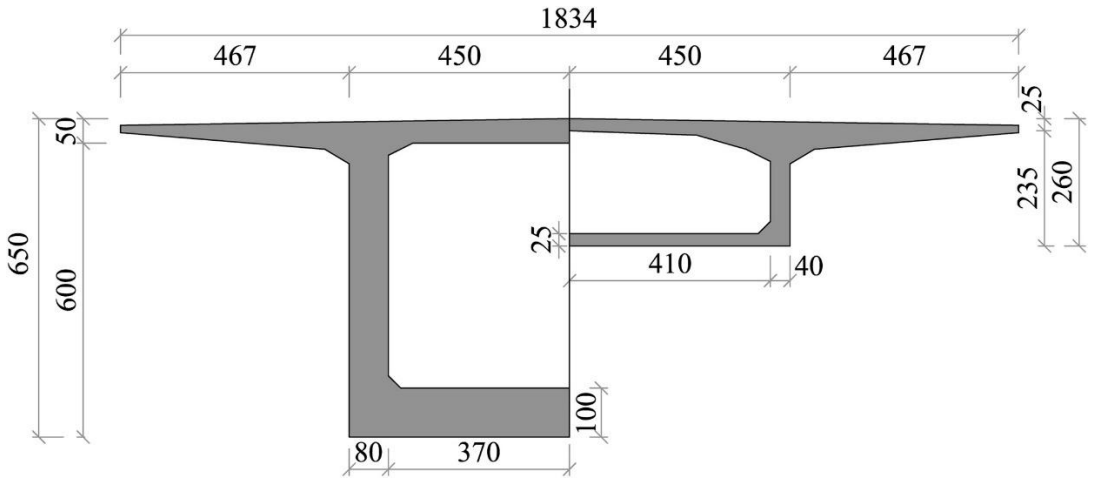


Figure 1. 3 transverse section

The internal structure of concrete box girder is not uniform. It typically includes complex arrangements of reinforcement bars and post-tensioning ducts, which must be modelled in detail to ensure that the design can withstand the intended loads without failure. These internal features need to be carefully coordinated with the external geometry, further increasing the modelling complexity.

Modelling a concrete box bridge with all its cross-sectional variations is a complex task that requires careful attention to geometric detail, internal reinforcement layout, integration with other design elements, and construction sequencing. It is a multidisciplinary challenge that demands a deep understanding of both structural engineering principles and advanced modelling techniques.

The software like Tekla Structures and Revit, Grasshopper provides a thorough workflow that helps close the gap between conceptual design and thorough documentation. Concrete box bridge designs can be developed quickly thanks to Grasshopper's capacity to produce and modify complicated forms using algorithms. In the meantime, Tekla Structures offers the documentation tools. By providing an integrated platform for managing every stage of the bridge's lifecycle, from initial concept to building and maintenance, Revit's BIM environment further improves this process.

1.1. OBJECTIVE

The objective of this thesis is to create the parametric model of a concrete box bridge to improve the automation method. The model will be designed using Grasshopper, this is a visual programming language that runs within the rhinoceros 3D. And the main objective of this thesis is to compare the BIM model and its limitation of workflow with Revit and Tekla Structures. This research aims to provide a comprehensive framework for the effective design and construction of concrete box bridge by analysing the interoperability between these tools. Using this process we can develop all the concrete box bridge structures. This will provide insights into how parametric modelling can be used to enhance the accuracy, efficiency, and sustainability of bridge projects.

This approach allows us to adapt this geometry of each model also considering inputs like point cloud, Grasshopper uses point cloud data processing to determine the geometry, altimetry, rotation, and position of a bridge. The development focuses on using the Volvox Grasshopper plugin, which enables the automation of complex processes by integrating point cloud data into the design environment. Using this technology, the study hopes to create a high-accuracy methodology for extracting important bridge features and metrics. To create a BIM model inside Tekla structures to know the complex of the workflow and trying to create the automated sheet development for the future purpose. For the future development process Human Ui plugin is used to create an interface to access the geometry by sliding the points number slider. This automation speeds up the modelling process, decreases errors, and reduces on manual input. By using this method, the thesis highlights how crucial it is to combine automation with sophisticated computational tools to produce precise and effective bridge modelling solutions.

CHAPTER 2

2. STATE OF ART

Over the past few decades, developments in materials science, computational techniques, and construction technologies have led to a considerable evolution in the design and construction of concrete box bridges. The most recent advancements in the industry are reviewed in this section, with an emphasis on parametric modelling, Building Information Modelling (BIM), and the use of these technologies to enhance the productivity of concrete box bridge construction and design.

The design and construction of concrete box bridges have seen significant advancements with the integration of parametric modelling tools. Among the most prominent tools in this domain are parametric designing and BIM, which together form a powerful ecosystem for the parametric modelling of such structures.

In recent years, advancements in point cloud technology have significantly enhanced 3D modelling capabilities, especially for complex structures like bridges. However, capturing precise geometries from point clouds has remained challenging, often leading to inaccuracies in bridge models. This thesis addresses these issues by developing a approach using Grasshopper, a parametric design tool, to extract precise geometric data from point clouds. The methodology ensures accurate bridge geometry representation.

Concrete box bridge design has significantly evolved through advancements in parametric modelling, high-performance and innovative construction techniques. The integration of Building Information Modelling (BIM) and parametric modelling in the design of concrete box bridges represents a significant advancement in modern infrastructure development. BIM provides a comprehensive platform for managing all aspects of the bridge's lifecycle, from initial design through to construction and maintenance, ensuring that every detail is accurately captured and coordinated.

2.1. Parametric Modelling

Parametric modelling is a powerful design approach that fundamentally transforms how engineers, architects, and designers create and interact with their projects. Unlike traditional modelling, where each element of a design must be individually crafted and adjusted, parametric modelling allows for the definition of a set of variables, or parameters, that drive the design. These parameters might include dimensions, shapes, angles, or other critical factors that influence the overall structure.

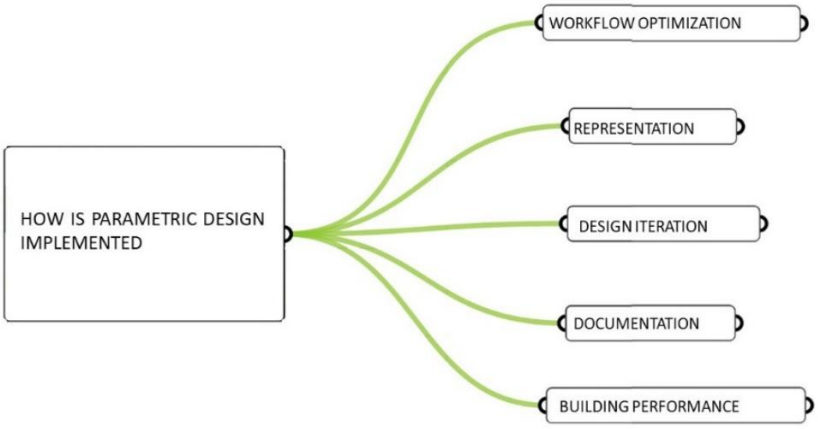


Figure 2. 1 parametric design Implementation

The dynamic nature of parametric modelling makes it especially valuable in fields where design requirements are complex and subject to change. By adjusting a few key parameters, designers can explore a wide range of potential solutions, optimizing the design for factors like material efficiency, structural performance, and cost. This capability is particularly beneficial in infrastructure projects, such as the construction of bridges, where engineers must consider various load conditions, environmental factors, and site-specific constraints.

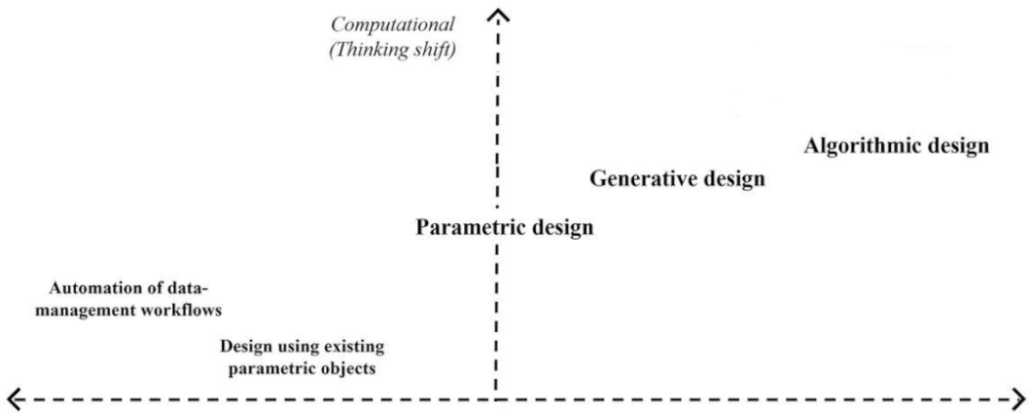


Figure 2. 2 Flow of parametric design

Recent years have seen a growing integration of parametric modelling with sophisticated computational tools and software, including Grasshopper. This platform allows designers to connect their models with structural analysis and BIM (Building Information Modelling) systems in addition to allowing them to be created and modified in real time. With a single, data-rich model that changes as the project moves forward, architects, structural engineers, and construction teams may collaborate more effectively across disciplines thanks to this integration.

Thus, parametric modelling increases the correctness and coherence of the final output while simultaneously making the design process more efficient. Error risk is decreased, and the project stays in line with its functional and aesthetic objectives by automating the updating process in response to design modifications. Parametric modelling is a vital technique in contemporary engineering and architecture since it can produce comprehensive construction papers straight from the model, thus streamlining the process from design to construction.

2.1.1. Application

- Architecture: When examining intricate forms and structures like facades, building layouts, and urban planning—where links between various design aspects must be preserved as the design changes—architects utilize parametric modelling.
- Civil Engineering: Roadway, tunnel, and bridge design are among the infrastructure projects in civil engineering that are designed using parametric modelling. It enables structural performance and cost-effectiveness material and shape optimization by engineers.
- Construction: In the construction industry, parametric modelling is especially important for creating Building Information Models (BIMs), which are databases that automatically manage and update comprehensive details about each component of a building or structure as design advances.

2.1.2. Software for Parametric Modelling

- Grasshopper (Rhino): A popular tool used primarily in architecture and civil engineering for creating complex forms and structures. It is a visual programming language that integrates with Rhino, allowing users to create parametric models through a node-based interface.
- Autodesk Revit: Widely used in BIM, Revit allows for parametric design in architectural, structural, and MEP (mechanical, electrical, plumbing) systems. It supports the creation of dynamic, data-rich models that can be used throughout the lifecycle of a building.
- Tekla Structures: Used in structural engineering, Tekla allows for parametric modelling of complex steel and concrete structures, facilitating the creation of detailed construction-ready models.

2.1.3. Benefits of Parametric Modelling

- Efficiency
- Accuracy
- Optimization
- Collabration

2.2. Building Information Modelling

A building or infrastructure project's complete lifecycle, from conception and design to construction, operation, and eventual demolition, is represented comprehensively through the digital process known as Building Information Modelling (BIM). Through the use of BIM,

several information types—such as geometric, spatial, material, and performance data—are combined into a single, cohesive model that is accessible to all project participants.

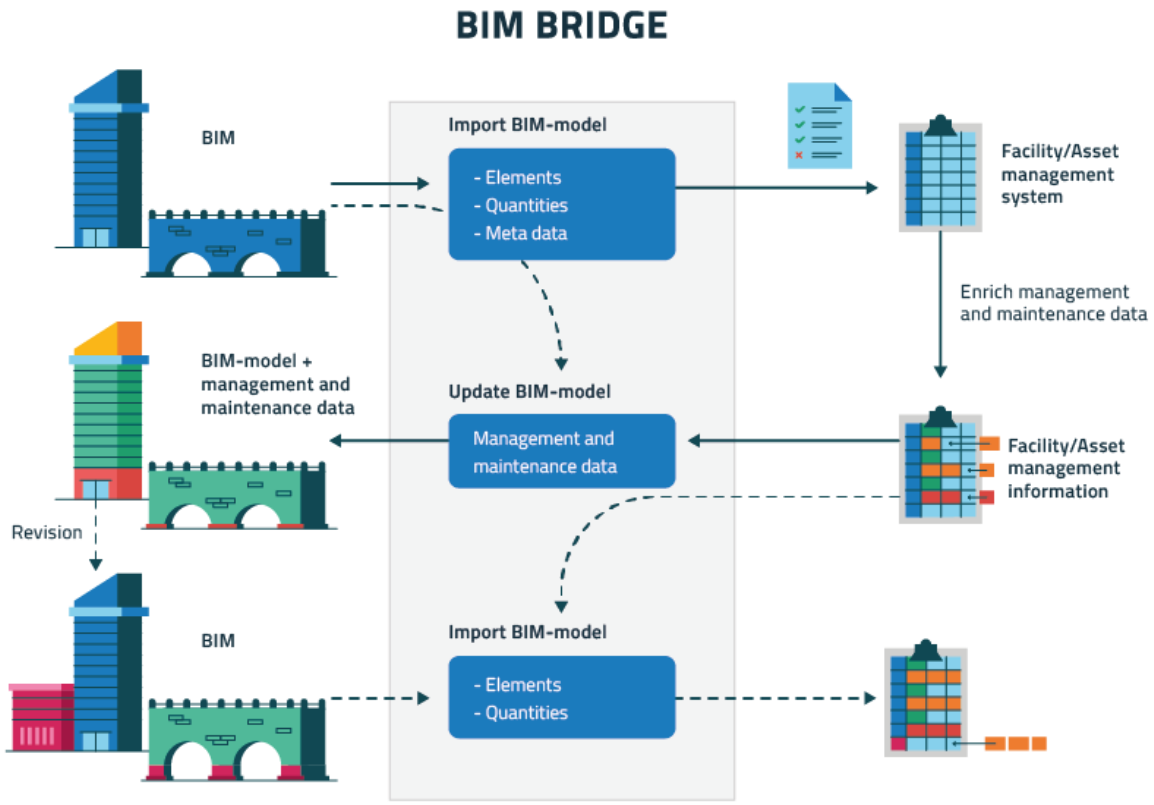


Figure 2. 3 BIM Bridge

BIM Levels

Level, which denote the degree of cooperation and integration in the BIM process, are frequently used to characterize BIM:

Level 0: No information models; 2D CAD drawing without collaboration. **Level 1:** Some collaboration was used to manage CAD in 2D or 3D formats, but models were not completely integrated.

Level 2: Cooperative work in which several stakeholders separately produce 3D models, which are subsequently integrated into a federated BIM model.

Level 3: A single shared project model that is available to all parties in real-time, together with fully integrated and collaborative BIM.

BIM's collaborative nature is one of its main advantages. Building Information Modelling (BIM) guarantees that all stakeholders are working with the same data by giving a centralized model that can be accessed and modified by architects, engineers, contractors, and owners. This lowers the possibility of errors and miscommunication. All facets of the project automatically update in response to modifications made to the model, allowing for real-time collaboration and reducing interruptions.

Additionally, BIM is essential for improving the general level of design and construction. Teams can identify and fix possible problems early in the process by using a virtual environment to view and model the building. This may substantially reduce the requirement for expensive construction adjustments. Furthermore, more precise estimation of expenses, organizing, and resource allocation are made possible by the comprehensive information in the BIM model, which promotes more effective project management.

2.3. Building Information Modelling approach in parametric modelling of bridges

A bridge's geometric and physical attributes are represented digitally using Building Information Modelling (BIM), which also offers an extensive amount of information about the bridge's materials, structural components, and building procedures. When it comes to bridge design, BIM makes it possible to create an intricate 3D model that contractors, project managers, architects, engineers, and other project participants can all use as a shared platform. Data that facilitates decision-making throughout the bridge's lifecycle, from initial design to construction to maintenance and operation, is included to this model.

Designing a bridge's design using parameters or regulations that determine the geometry and behaviour of the design is known as parametric modelling in BIM. This method is especially helpful for bridge projects where design modifications and optimizations are frequent because it makes it possible to create flexible models that are simple to modify by changing parameters.

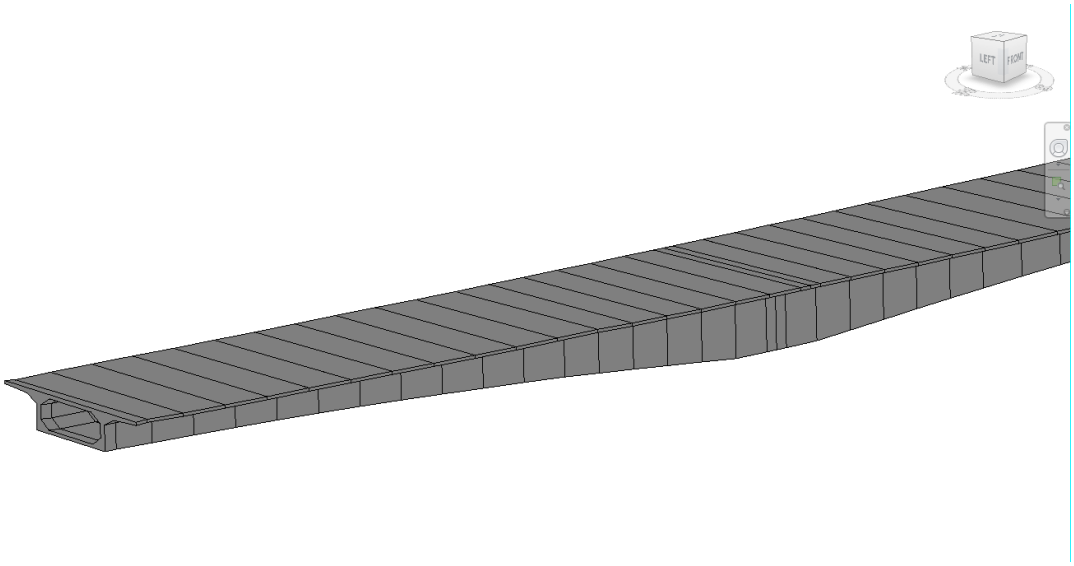


Figure 2. 4 Concrete Box Bridge

However, parametric modelling uses parameters to define connections and interactions between different aspects of the bridge design. These characteristics could be the bridge's span length, the piers' height and form, the deck's curvature, or the thickness of the structural components. Creators can develop flexible models with automatic propagation of changes to one part of the design throughout the model, guaranteeing that all associated components are updated consistently, by setting these parameters.

Bridge designs can be easily adjusted with parametric modelling. Modifications made to one area of the design instantly affect the entire model, guaranteeing consistency and saving time. Inaccuracies and mistakes are less likely when all design aspects are combined into a single model. For the complex geometry and load requirements common to bridge design, this accuracy is essential.

CHAPTER 3

3. SOFTWARE

3.1. Software selection

Following an evaluation of different computational modelling approaches, **Grasshopper** was selected as the primary parametric design environment for this research due to its ability to model complex geometries with the flexibility, efficiency, and accuracy required for concrete box-girder bridge modelling. Its integration with **Rhinoceros 3D** enables the development, visualization, and modification of complex bridge geometries through a dynamic and iterative parametric workflow.

Grasshopper also provides a flexible environment for interoperability due to its visual programming capabilities and its ability to connect with other software through dedicated plug-ins. Within the context of this thesis, the parametric models developed in Grasshopper can be integrated with BIM platforms such as **Autodesk Revit** and **Tekla Structures**, allowing geometric and parametric information to be transferred between different modelling environments. This interoperability supports a more integrated workflow and reduces repetitive manual modelling operations.

Based on the objectives of this research, different computational workflows were developed for the parametric modelling and BIM integration of concrete box-girder bridges. **Figure 1** presents the overall workflow followed during the development of the thesis.



Drone scanners

AUTODESK® RECAP™ +

Volvox

Rhinoceros® + Grasshopper + Plug-ins food 4 Rhino

Rhino.Inside®.Revit

Tekla Live Link

AUTODESK Revit

Tekla® Structures

3.2. Software Description

3.2.1. Rhinoceros 3D version 8

Robert McNeel founded Robert McNeel & Associates in 1980, the company first offered support services and CAD (Computer-Aided Design) software. Their main product, Rhino, was first made available in the 1990s and has since grown to be one of the most widely used 3D modelling programs globally. It is especially appreciated for its accuracy, adaptability, and capacity to work with intricate geometries.

Rhinoceros 3D, also referred to as Rhino, is a flexible 3D modelling program well known for its accuracy in handling intricate geometry. Rhino 3D version 8 is now available, expanding on the strong characteristics of its predecessors and bringing about a number of important improvements that address the changing requirements of professionals working in the fields of architecture, engineering, industrial design, and graphic arts.

The workflow is streamlined by the new interface's increased customisation choices and increased ease of use. The software will become more user-friendly as a result of the better organization of commands and tools for users, especially those working on large projects. The objective is to make things easier for beginners to use while increasing productivity for professional users.

In version 8, Rhino maintains its core strength in NURBS (Non-Uniform Rational B-Splines) modelling, which allows users to create highly accurate and intricate curves and surfaces.

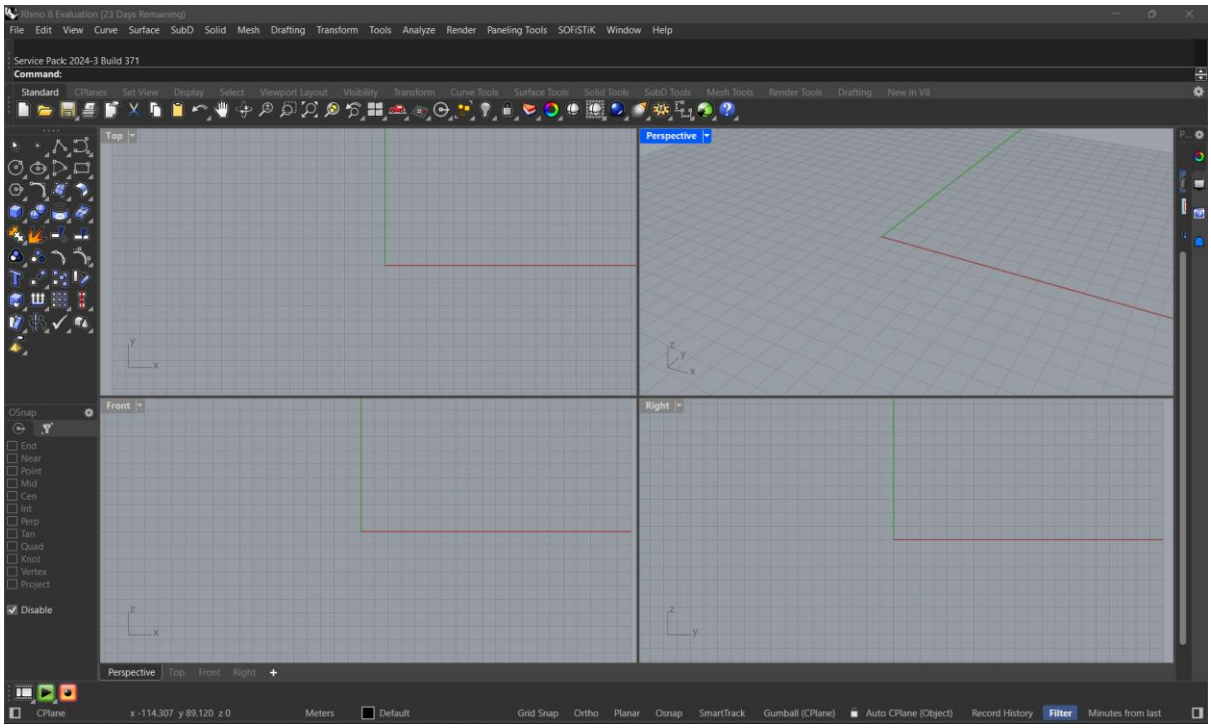


Figure 3. 1 Rhino Interface

3.2.2. Grasshopper

Grasshopper is a visual programming language that developed as an add-on for the popular 3D CAD program Rhinoceros 3D (Rhino). Grasshopper, created by David Rutten of Robert McNeel & Associates, facilitates parametric modelling and algorithmic design, allowing users to generate complex designs by adjusting parameters as opposed to using more conventional modelling techniques.

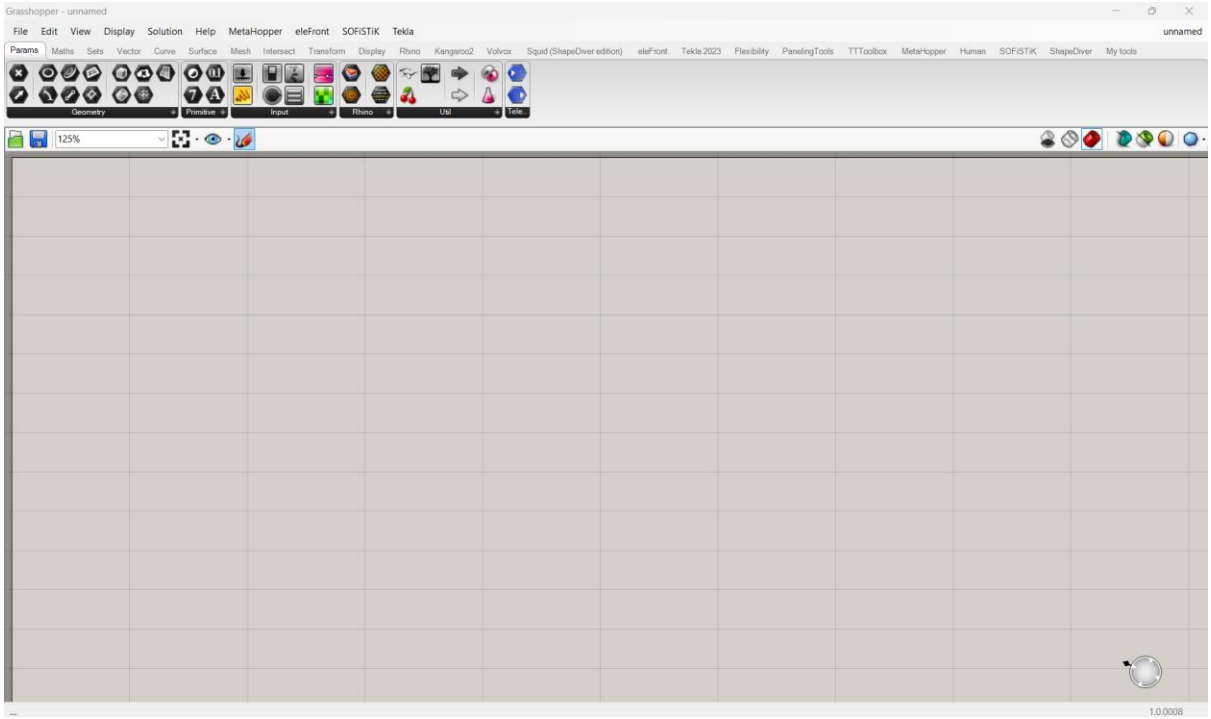


Figure 3. 2 Rhino Interface

Grasshopper's visual programming interface, which allows users to connect different parts of a node-based system, is its central feature. Designers can create dynamic and responsive models by defining relationships between many elements, including geometry, materials, and environmental conditions, with this approach. Adjustments to the input parameters have an immediate effect on the overall design, which is especially helpful for experimenting with different designs and improving structures.

- Each node has one or more input slots where data is received. Inputs can be numbers, points, curves, surfaces, or any other type of data.
- Nodes also have output slots where the processed data is sent out. This data can be passed on to other nodes for further processing.
- There are so many nodes which can give the result of parametric design

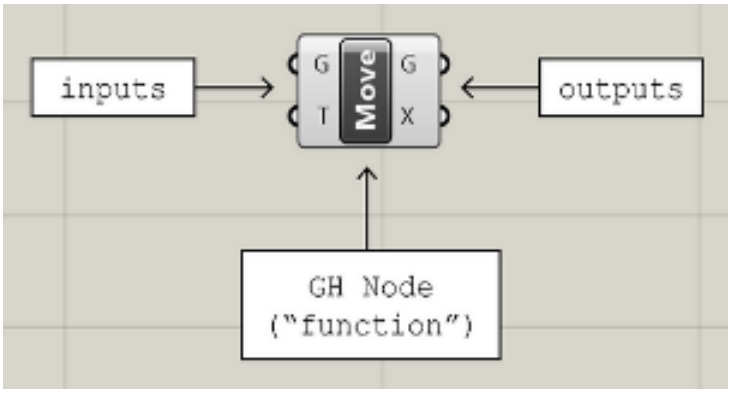


Figure 3. 3 Grasshopper Component Functionality

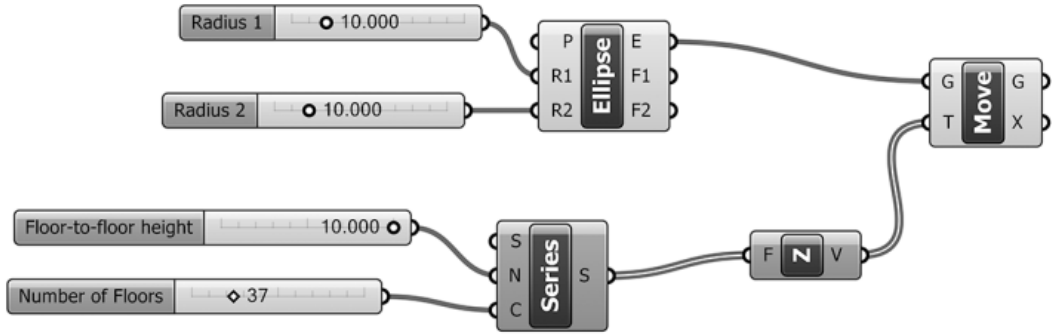


Figure 3. 4 Grasshopper Component

3.2.3. Plugins for grasshopper

A plugin for Grasshopper is an additional software component that extends the functionality of Grasshopper beyond its core features. Plugins often serve as bridges between Grasshopper and other software platforms, enabling data exchange and workflow integration. For example, there are plugins that allow for exporting Grasshopper models to BIM (Building Information Modelling) software like Revit.

3.2.4. Tekla Structures

Trimble has developed Tekla Structures, a Building Information Modelling (BIM) program that is both complex and flexible. Its main applications are in the creation, detailing, and management of steel and concrete structures. Tekla Structures has a reputation for handling extremely detailed 3D models that cover all facets of the structural design process, starting with conceptual design.

In Tekla Structures, modelling a concrete box bridges construction entails building an extremely accurate and detailed three-dimensional model that incorporates all of the bridge's components, including the deck, reinforcing elements, and box girders and piers. Tekla constructions is renowned for its proficiency in managing intricate constructions.

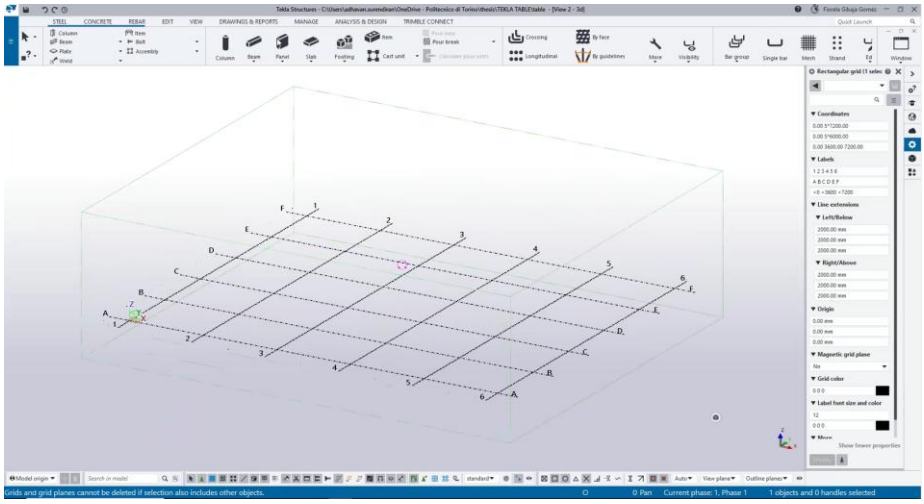


Figure 3. 5 Tekla Structure Interface

3.2.5. Tekla Structures plugins

1. Grasshopper-Tekla Live Link

   Users can design complex structural forms and geometries in Grasshopper using the Live Link, and then export them directly to Tekla Structures. Because of this relationship, changes made to the Grasshopper model can be automatically imported into Tekla, maintaining synchronization between the two models. This is known as dynamic updates. This feature makes design iteration and optimization faster and easier, allowing designers to quickly investigate different possibilities and evaluate their effects.

   This integration improves performance in the design and detailing processes by streamlining the automation of repetitive tasks and making it simpler for users to create custom scripts and automate workflows.



Figure 3. 6 Grasshopper-Tekla Live Link Logo



Figure 3. 7 Components of Tekla Live Link

2. Tekla Drawing

Tekla Structures has a tool called Tekla Drawing that lets users make comprehensive documentation and drawings from 3D models. It offers a strong toolkit for producing accurate, ready-to-assemble drawings for manufacturing, assembly, and building needs. Directly connected to the 3D model, Tekla Drawing enables users to make a wide range of drawings, such as assembly, detail, and general organization drawings.
The ability of Tekla Drawing to keep a live connection with the 3D model is one of its most noticeable features. As a result, modifications made to the model are automatically reflected in the corresponding drawings, lowering the possibility of mistakes and guaranteeing uniformity across the project. To conveniently organize their work, users can easily manage many drawing sheets inside a single project.



Figure 3. 8 Components of Tekla Drawing

- Drawing
  - creates assembly drawing of model object
  - creates cast unit drawing of model object
  - creates general arrangement drawings
  - returns currently opened drawing
  - closes active drawing
  - opens pointed drawing
  - returns size of pointed drawing
  - returns model object which is the parent of drawing
  - lists views inside drawing
  - deletes drawing

Figure 3. 9 Components details

3.2.6. Autodesk ReCap

Utilizing a range of reality capture data sources, including laser scans and images, users may produce and manage 3D models and point clouds using Autodesk ReCap (Reality Capture), a software program. It is extensively utilized for jobs requiring precise 3D representations of real-world environments or objects in areas including manufacturing, engineering, design, and construction.

With ReCap, users can process raw data from images or laser scanners (LiDAR) to generate intricate 3D point clouds. These point clouds can be utilized for many different things, like making as-built models, recording current conditions, or conducting inspections.

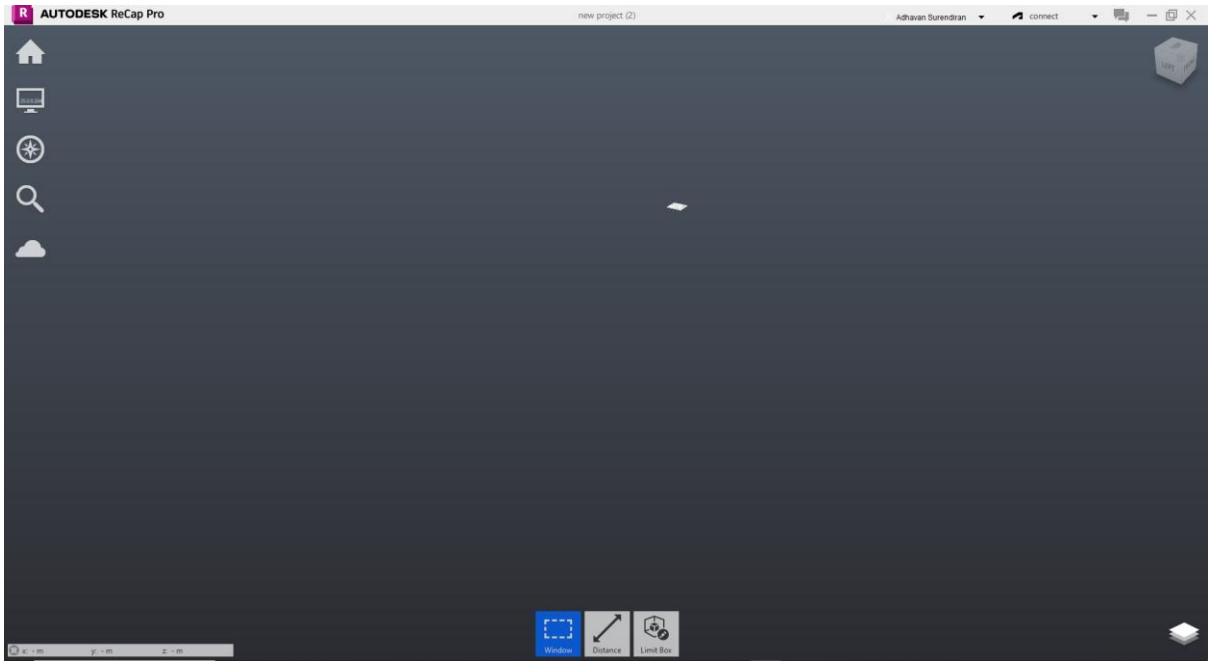


Figure 3. 10 Interface of Autodesk ReCap

3.2.7. Cloud Compare

Cloud Compare is an open-source 3D point cloud processing software designed to visualize, analyse, and manipulate large sets of 3D data.

Enormous point cloud datasets may be visually represented with ease because to Cloud Compare's accessible interface. Users have the ability to modify rendering parameters, change the perspective, and apply colour mapping according to different characteristics (e.g., height, intensity).

Cloud Compare supports a wide range of file formats for importing and exporting point clouds, including:

- **LAS/LAZ:** Common formats for LiDAR data.
- **PLY:** Polygon File Format, often used in 3D scanning.
- **E57:** A compact format for point clouds.
- **PTS:** Simple text format representing point clouds.
- **XYZ:** Text-based format for point coordinates.

Figure 3. 11 Cloud Compare Logo

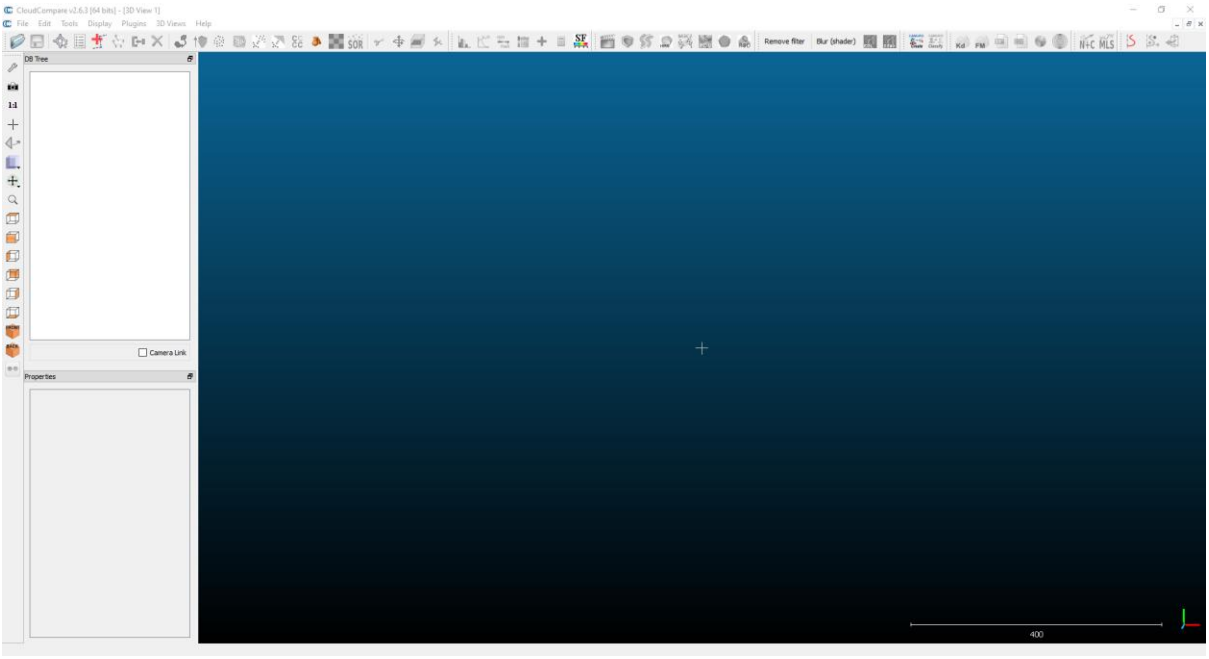


Figure 3. 12 Interface of Cloud Compare

3.2.8. Autodesk Revit

Revit is a powerful Building Information Modelling (BIM) software developed by Autodesk, primarily used in architecture, engineering, and construction. It allows users to design, plan, and manage building projects in a 3D environment, enabling a comprehensive approach to the building lifecycle from conceptual design through construction and maintenance.

Revit is unique in its focus on parametric modelling, meaning that all elements in the model are interconnected. When a change is made to one component, the software automatically updates all related elements, ensuring consistency and reducing errors.

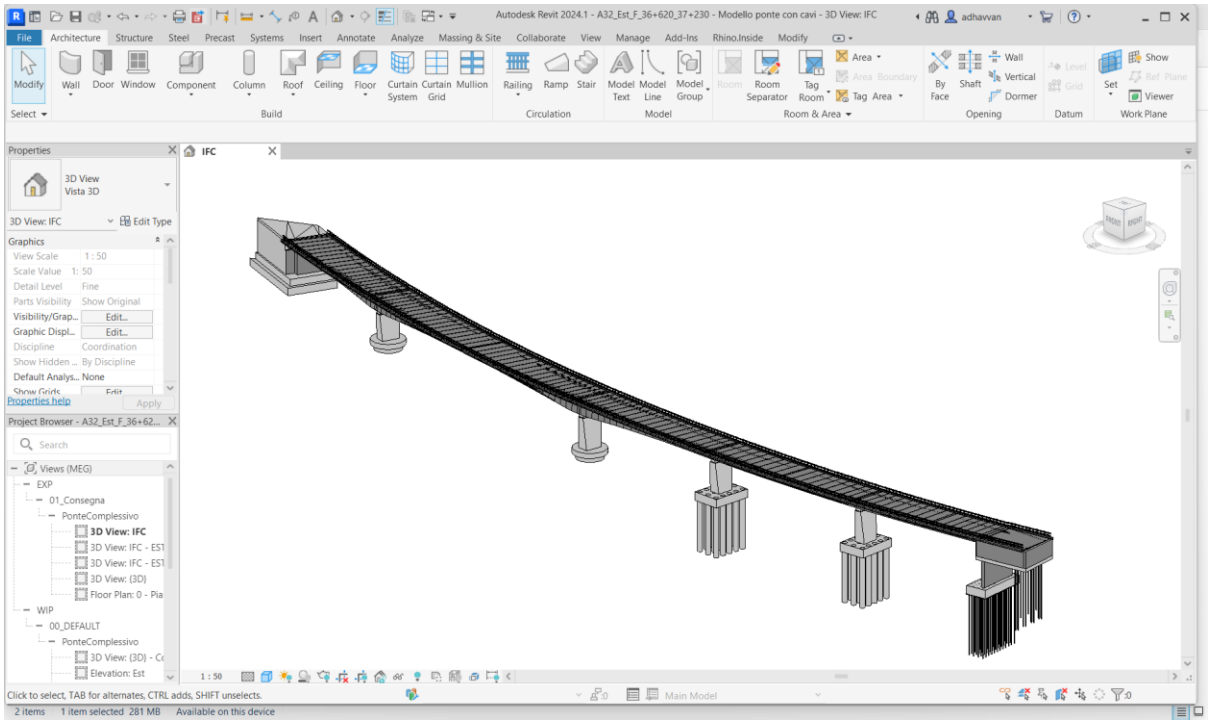


Figure 3. 13 Revit interface

3.2.9. Autodesk Revit Plugin

1. Rhino Inside Revit

   Inside Rhino Inside Revit is a dynamic integration that allows users to benefit from the advantages of both platforms by integrating the 3D modelling program Rhino directly within Autodesk Revit. This connection is a component of the Rhino Inside Revit technology, which allows Rhino to operate inside of other programs such as Revit, together with its parametric design tool, Grasshopper.



Figure 3. 14 Rhino Inside Revit Logo

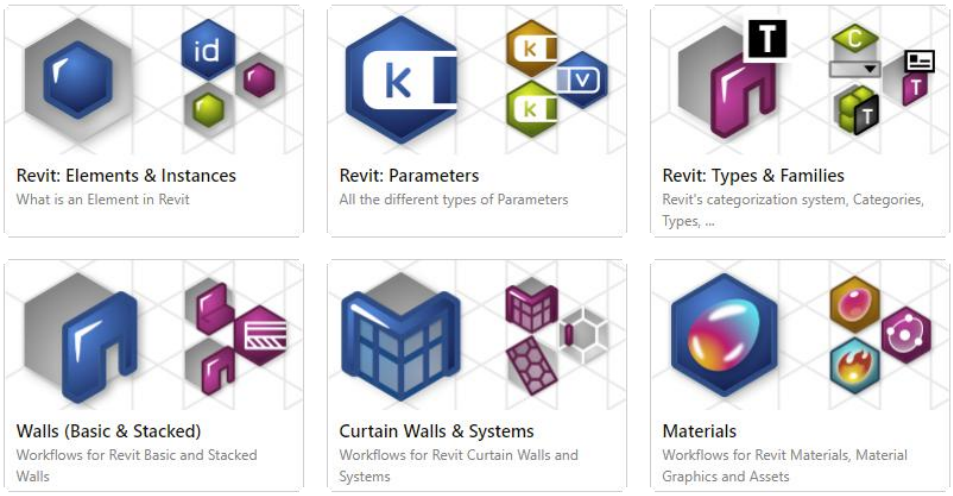


Figure 3. 15 Rhino Inside Revit Components

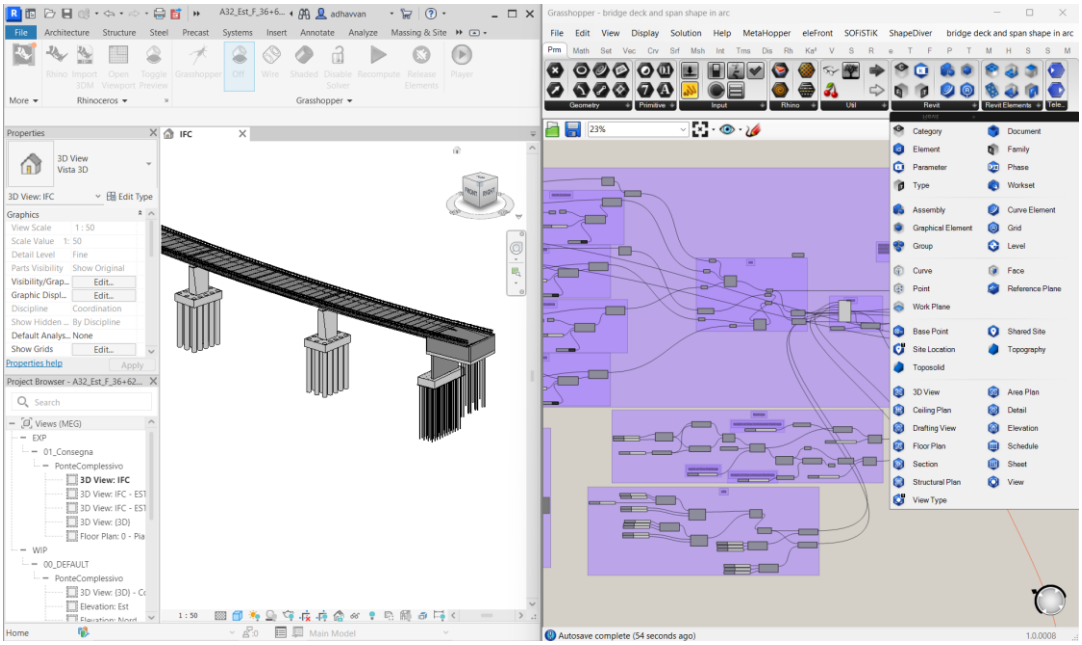


Figure 3. 16 Rhino Inside Revit Components Details

2. Volvox Plugin

   Volvox is a plugin for Grasshopper, which operates within Rhinoceros 3D (Rhino) and is designed to handle point cloud data. Point clouds are large sets of data points in space, typically generated through 3D scanning techniques like LiDAR, representing the surfaces of objects or environments.

   With Volvox, users can import and work with these point clouds directly in Grasshopper. The plugin facilitates the visualization of point clouds, allowing users to see and understand the spatial relationships within the data. It also provides tools for manipulating the point clouds, such as filtering, segmenting, and transforming the data to extract useful information or prepare it for further modelling and analysis.

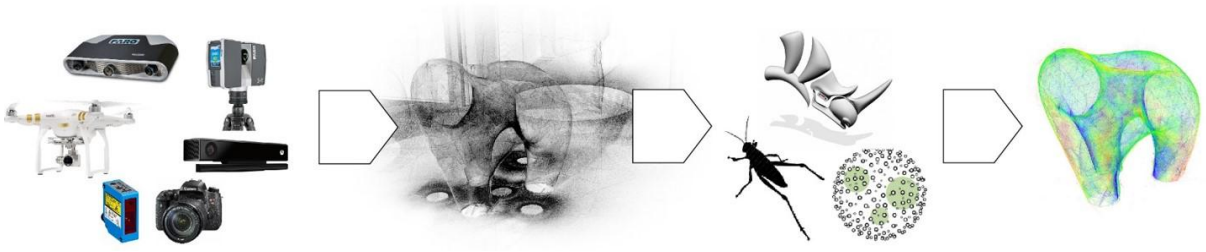


Figure 3. 17 volvox Workflow

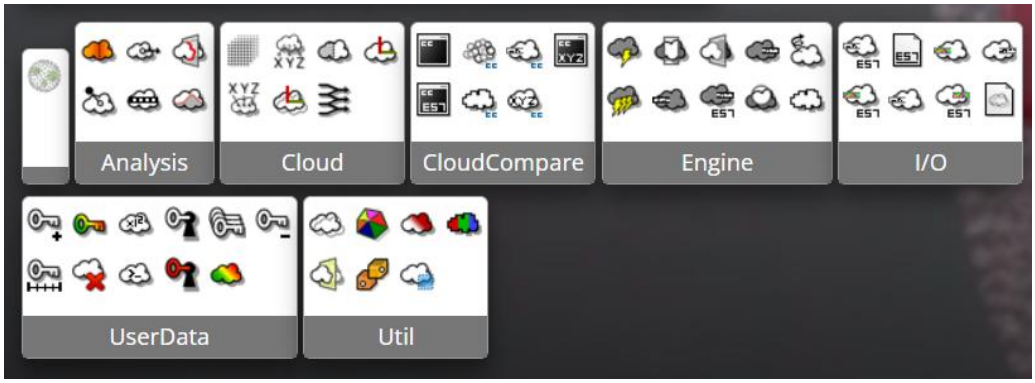


Figure 3. 18 volvox Components

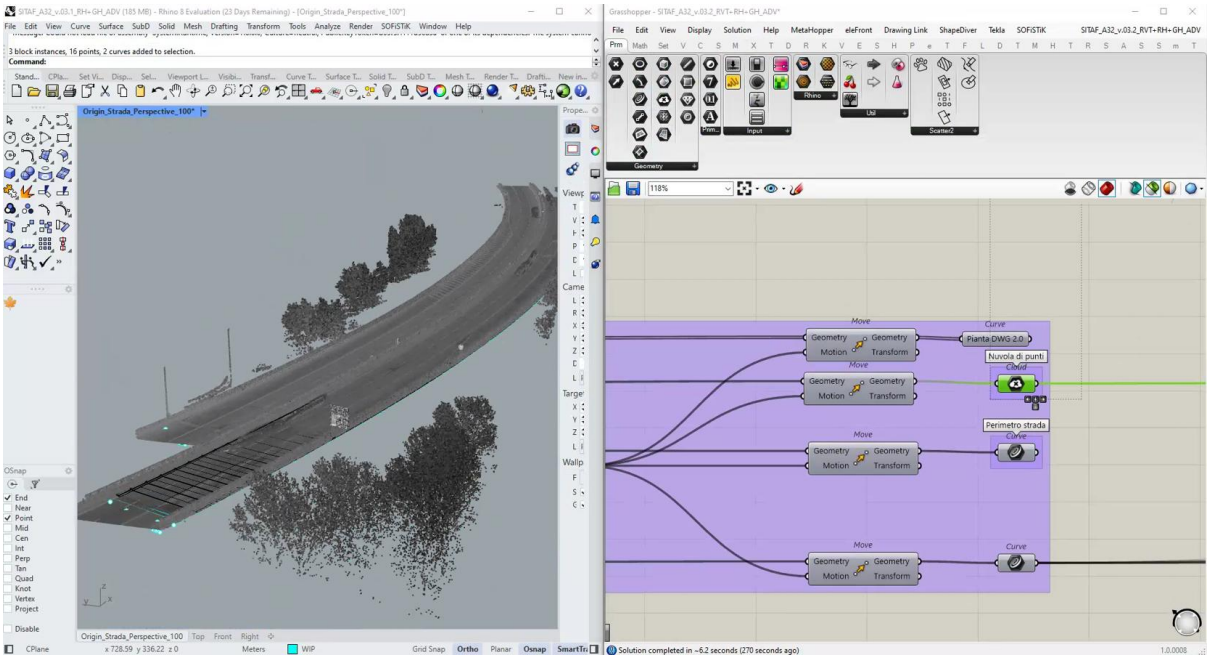


Figure 3. 19 volvox and Grasshopper Interface

3. Vectorize Plugin

   An effective tool for converting raster images into vector graphics within the Rhino environment is the Vectorize plugin. Designers can convert scanned photos, hand-drawn sketches, or photographs into editable vector files for use in additional modelling.



Figure 3. 20 vectorize Logo

3.2.10. Autodesk AutoCAD

Autodesk AutoCAD is a widely used computer-aided design (CAD) software developed by Autodesk. It is known for its versatility and precision in creating 2D and 3D designs and drafts across various industries, including architecture, engineering, construction, manufacturing, and product design.

AutoCAD provides a comprehensive set of tools for drawing, editing, and annotating designs. Users can create detailed plans, technical drawings, and models, which can be used for everything from building blueprints to mechanical components. The software supports a wide range of file formats, making it compatible with other CAD programs and allowing for easy sharing and collaboration among professionals.

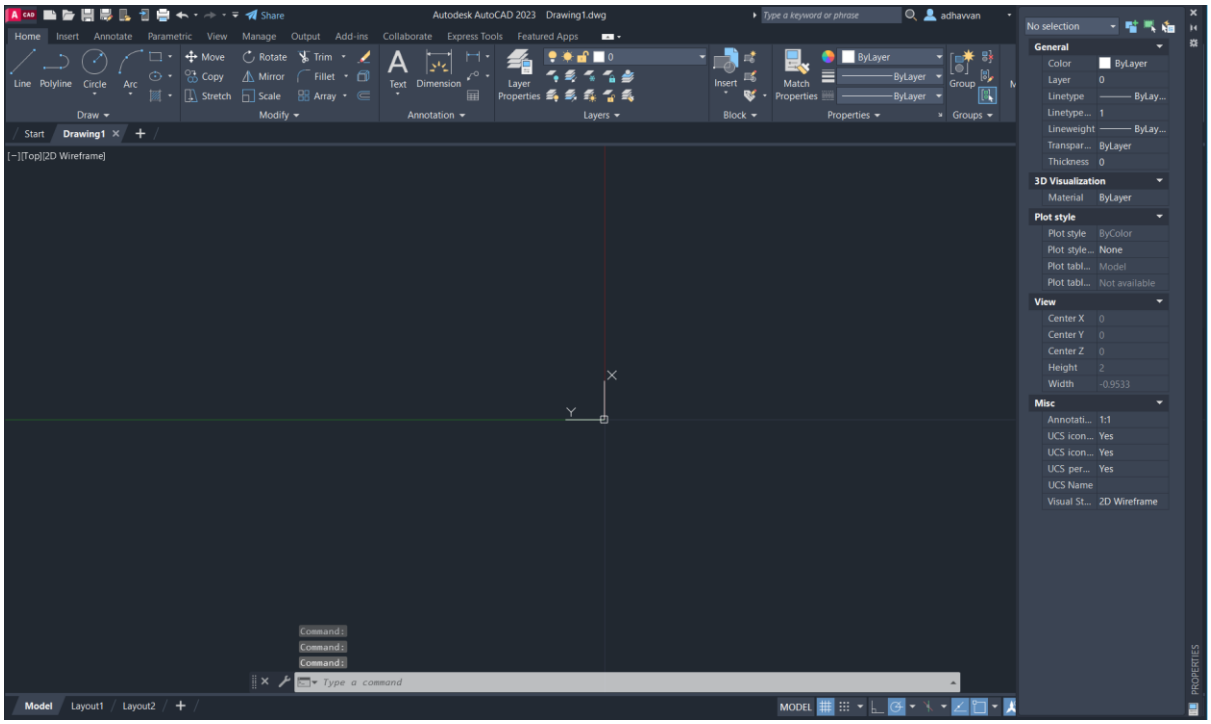


Figure 3. 21 AutoCAD Interface

AutoCAD is used to import the profile of the bridge to rhino easily. This another way which is possible to create the bridge formation.

CHAPTER 4

4. Optimizing Point Cloud Data

4.1. Methodology

The complexity of the bridge geometry and the integration of point-cloud data required the use of multiple software environments throughout the modelling process. This approach also enabled the interoperability between parametric modelling and BIM platforms to be investigated, which represents one of the main objectives of this thesis.

The methodology was structured into two main stages. The first stage focused on the processing of the point-cloud data and the development of parametric bridge geometry using **Grasshopper** and **Rhinoceros 3D**. The second stage involved transferring and integrating the generated geometry into BIM environments, primarily **Autodesk Revit** and **Tekla Structures**, for the development of the complete bridge model.

This workflow establishes a connection between survey data, parametric modelling, and BIM, providing the basis for the automated reconstruction of the existing bridge geometry.

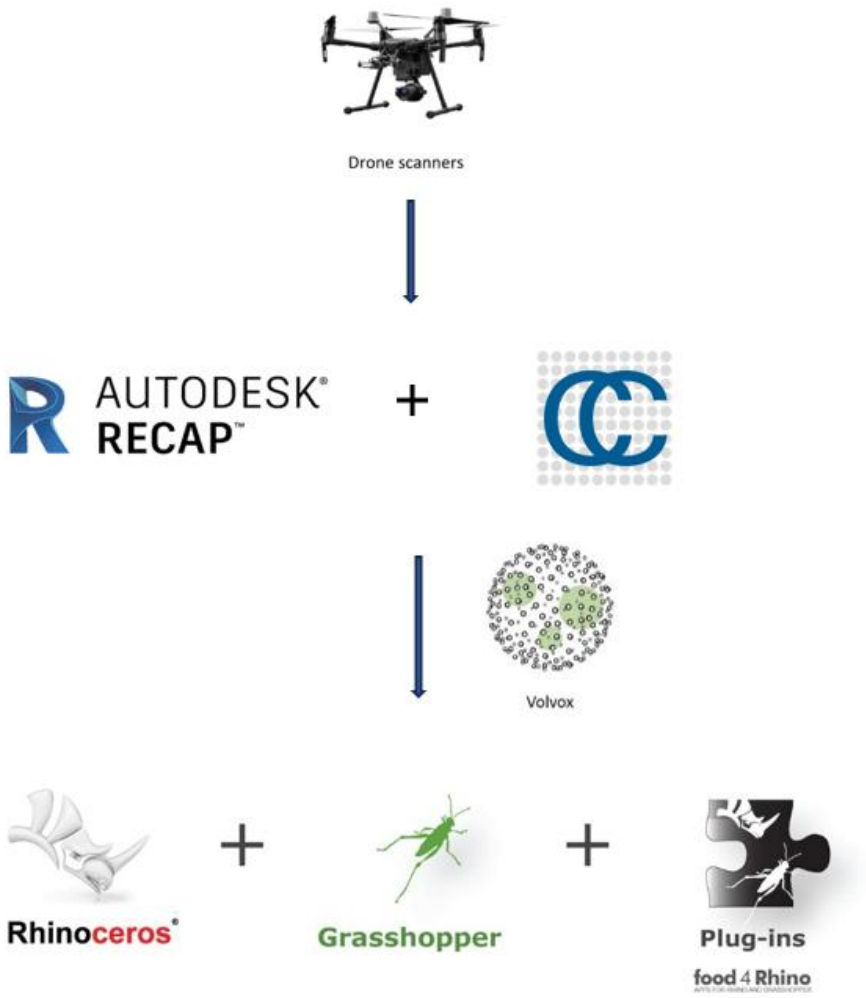


Figure 4. 1 Drone to bridge model Workflow

4.1.1. Point Cloud Data

A group of points with coordinates (x, y, z) defining each one in a three-dimensional space is called a point cloud. These points are utilized to depict an object's, scene's, or environment's outside in three dimensions. Typically, point clouds are produced using 3D scanning technologies such as LiDAR, photogrammetry, or stereo cameras. These technologies record the spatial positions of several points on an object's surface to capture the object's shape. There are many types of equipment that can capture and record the position and collect the points to send them for analysis.

To capture point cloud data, various types of equipment are used depending on the application, precision required, and environment. In this case, drone has been used for collecting the data of the bridge. Drone is used to collect all the sides of the bridge even in the bottom.

Drone Equipped with LiDAR can capture the aerial point clouds over large and inaccessible areas. This is an advantage of covering the large or difficult to reach areas.



Figure 4. 2 Bridge Scanning

4.1.1.1. bridge point cloud data complexities

Collecting point cloud data of bridges involves several complexities due to the unique challenges presented by the structure and environment.

- Larger bridges are challenging to approach from all directions since they frequently cross valleys, rivers, or roadways. Certain regions, such as the underneath or high sections, require for certain tools or techniques, like drones, to collect data.
- Scanning during peak traffic hours can cause significant disruptions. Scheduling around traffic and ensuring minimal impact can complicate the planning and execution of data collection.

4.1.1.2. Format of Point Cloud Data

Autodesk uses unique point cloud file formats called RCS and RCP, which are specifically utilized by their Recap (Reality Capture) program. Large point cloud datasets can be handled and processed more efficiently with these formats, notably in applications like infrastructure modelling, design, engineering, and construction.

- designed specifically to work well with big point cloud datasets in Autodesk applications, providing quick loading times and excellent performance.
- It works perfectly with Autodesk's toolkit, which makes it perfect for CAD and BIM workflows.

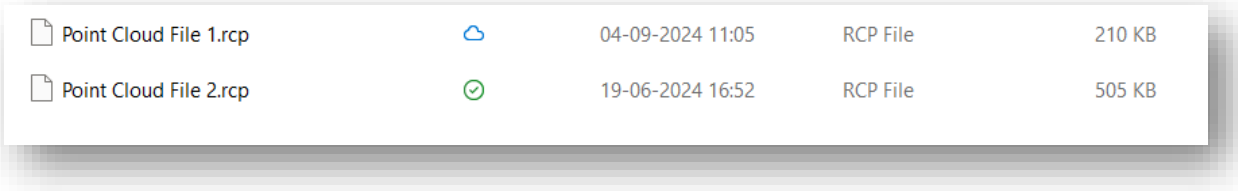


Figure 4. 3 ReCap Files

4.1.2. RCP to LAS

The ".rcp" file for the analysis has been put into Autodesk Recap once we received it. The file is converted from ".rcp" to ".las" using this software. This platform makes it simple to carry out this procedure.

Depending on how the RCP was configured, you can see several scans or point cloud layers when the RCP project loads. Make sure the point cloud you wish to export is the one it's have selected. We should control the coordinate systems you are working with. Ensure that the exported LAS file uses the appropriate coordinate system for intended application.

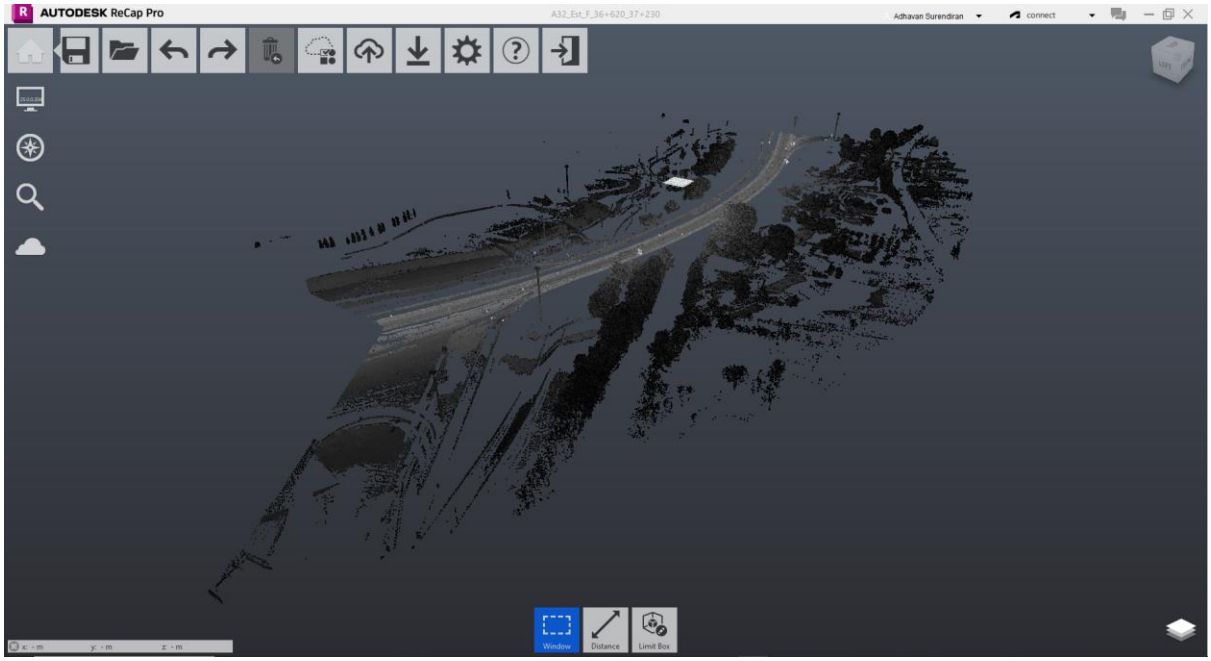


Figure 4. 4 Autodesk ReCap Interface

4.1.3. LAS to E57

Several programs can be used to convert a LAS (LASer) file to E57 format. Several techniques are available for converting point cloud data into the flexible E57 format. Here I have used Cloud Compare for converting the files. The method for converting LAS to E57 with CloudCompare and Autodesk ReCap,

- Import the LAS format file to the CloudCompare
- After the file loaded, we must export them with choosing the file format of E57

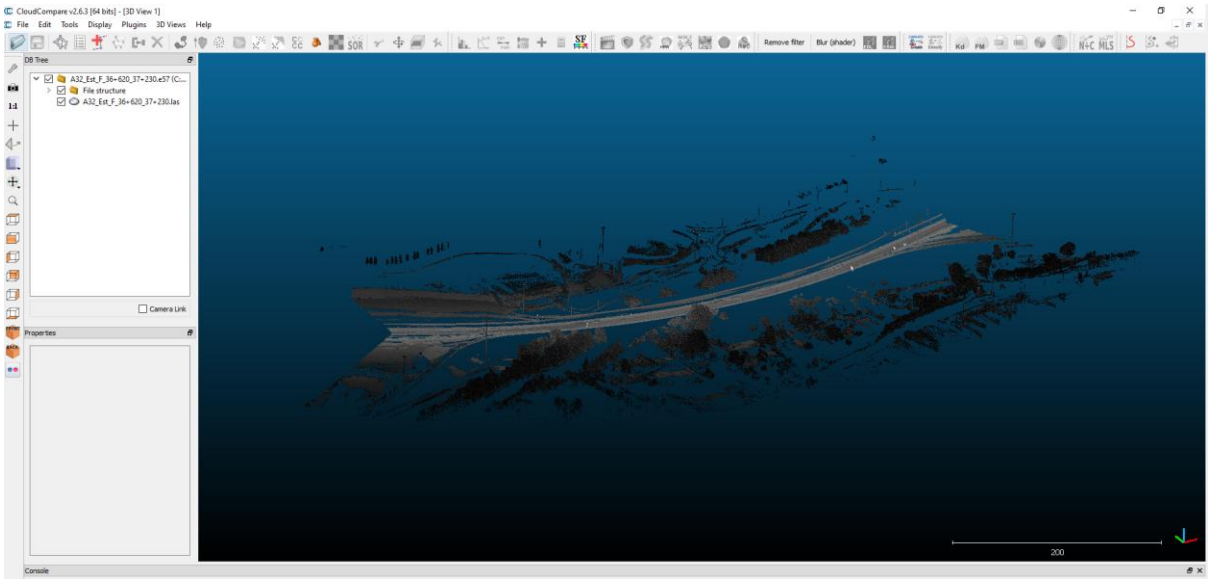


Figure 4. 5 Cloud Compare Interface

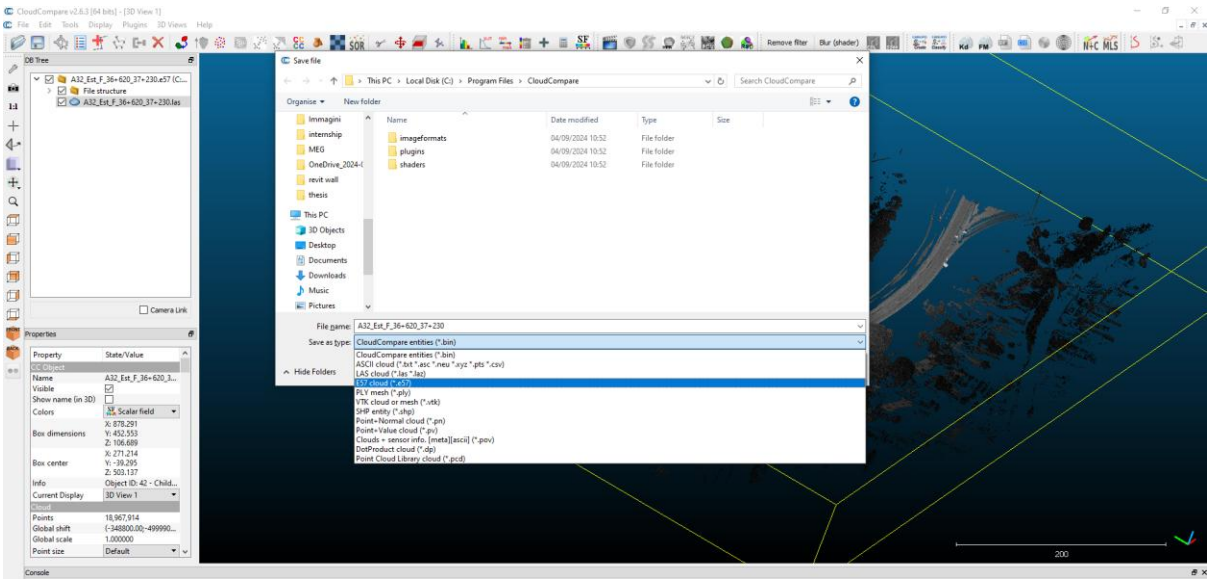


Figure 4. 6 Exportation of e57 File

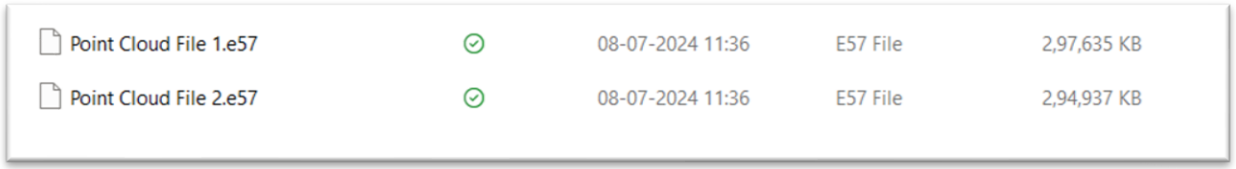


Figure 4. 7 Final e57 File

4.1.4. Grasshopper

Grasshopper offers numerous plugins for analysing different project aspects. Additionally, a plugin that imports the file for activity processing is available for cloud point analysis. Through the "Food for Rhino" website, installing the plugin is simple.

- Grasshopper uses a node-based interface where users can drag and drop components, creating connections between them to define data flows and logic.
- Each component represents a specific function or operation (e.g., geometric transformations, data manipulation, etc.).



Figure 4. 8 Grasshopper Plugins

- An essential component of managing cloud point data handling is the Volvox plugin.

4.1.4.1. Import the Point Cloud

The point cloud is imported using the Volvox components. Several components are present, with "Load E57" being specifically utilized for gathering the direct file location.

To import an E57 point cloud file into Grasshopper, the "Load E57" tool is a powerful resource. This tool allows users to seamlessly bring E57 data into the Grasshopper environment for further manipulation and analysis.

By utilizing the "Load E57" component, designers can visualize and interact with the point cloud data directly within their parametric models.

The component facilitates the handling of large datasets, making it easier to extract relevant features and apply custom algorithms. This integration enhances design workflows, enabling professionals to leverage point cloud data for various applications, such as architectural modelling, analysis, and optimization.

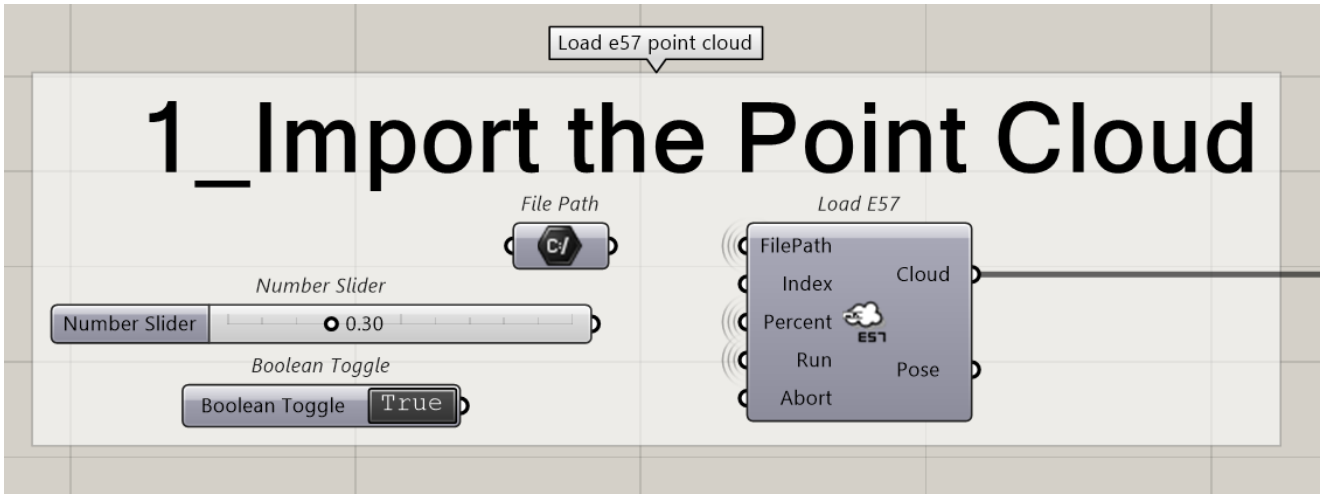


Figure 4. 9 Import Point Cloud

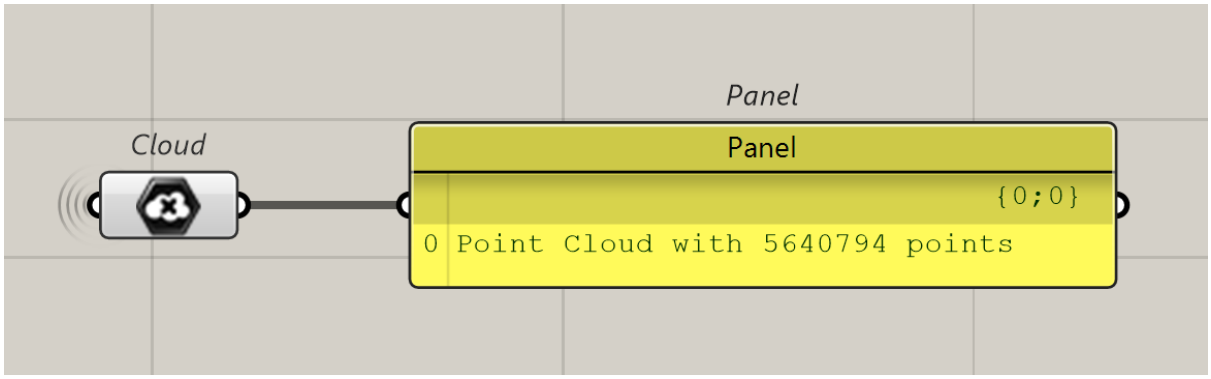


Figure 4. 10 Point Details 1

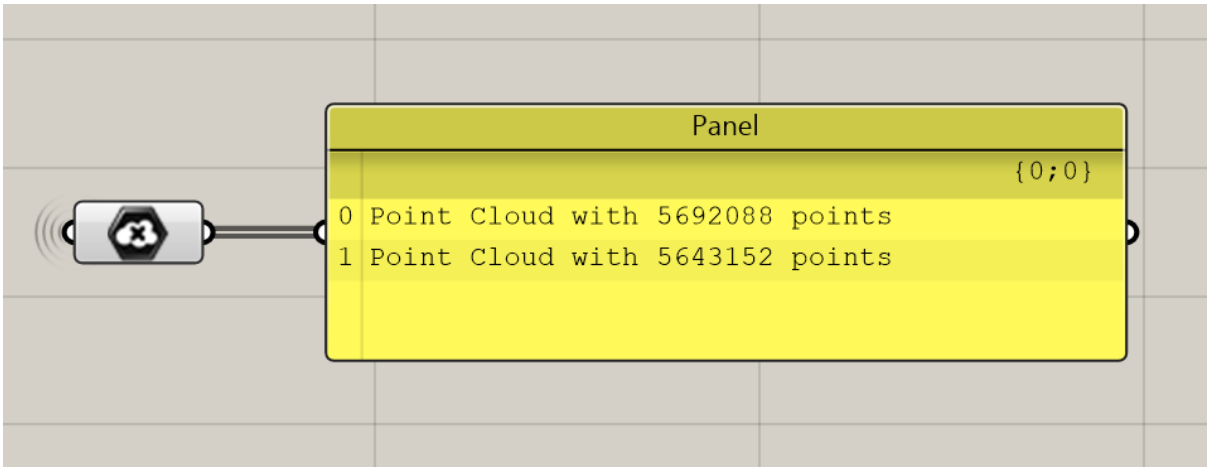


Figure 4. 11 Point Details 2

The Component can be used to upload the input data more than 50,000,000 points.

The point cloud dataset consists of **56,407,794 points**, which presents both an opportunity and a challenge for analysis and modelling. While this extensive data captures a rich representation of the environment, it also contains unwanted points that can hinder accurate measurements and geometric representations.

Among these, **tree points** clutter the dataset, obstructing views of the underlying bridge geometry. Additionally, **car points**, **Atmospheric points**, often resulting from reflections or environmental conditions, contribute further to inaccuracies. To achieve a clear and precise representation of the bridge geometry, it is crucial to isolate and retain only the relevant points.

This involves filtering the point cloud to remove the unwanted tree, car, and atmospheric points. By employing advanced point cloud processing techniques, such as segmentation and classification, we can effectively refine the dataset.

The goal is to extract a clean point cloud that accurately reflects the bridge's structure, allowing for detailed analysis and modelling that can support engineering assessments, maintenance planning, and potential renovations. Ultimately, this targeted approach ensures that the resulting data is both useful.

4.1.5. Method to define shape of bridge

Here we must define the shape of the bridge curve to filter the unwanted point clouds. The Methods are,

- Import from AutoCAD
- Create using Grasshopper
- Import PDF (Vectorise Method)

4.1.5.1. Import from AutoCAD

When we have the information in AutoCAD. We can export them directly to rhino to work with them, but this method considers as manual method but gives the accuracy of shape.

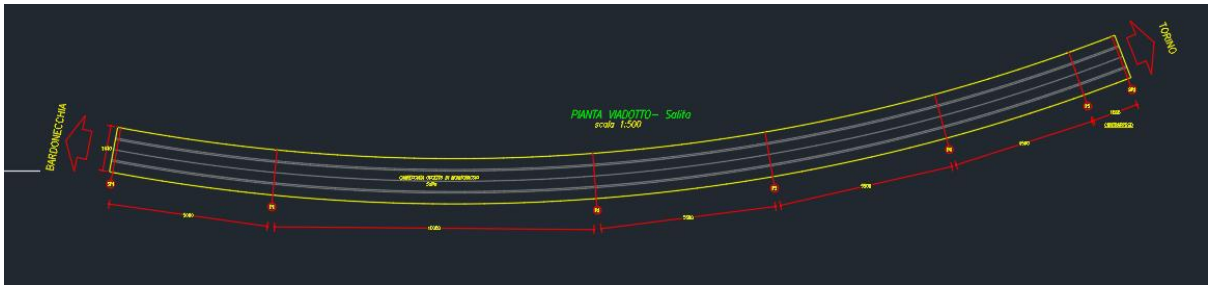


Figure 4. 12 AutoCAD file

4.1.5.2. Create using Grasshopper

As we know, the grasshopper method is an automation way of creating the shape but in this method using grasshopper we can only create the shape in origin co-ordinates. But the point cloud data is far from the origin. Which makes the method little slow to perform. But this Is also a possible way to create them.

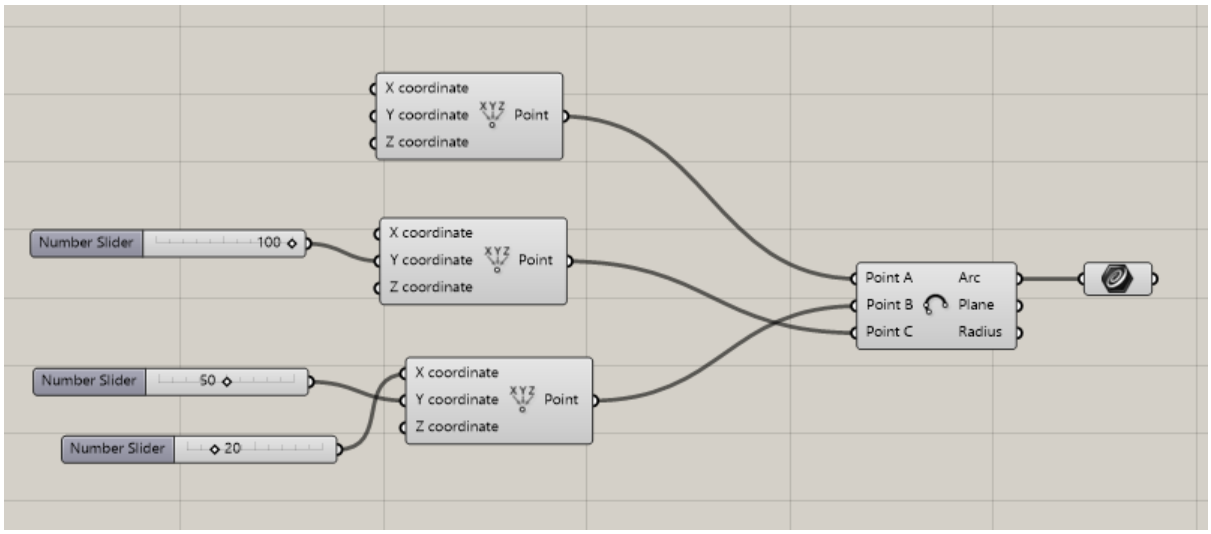


Figure 4. 13 Grasshopper Components to create the shape

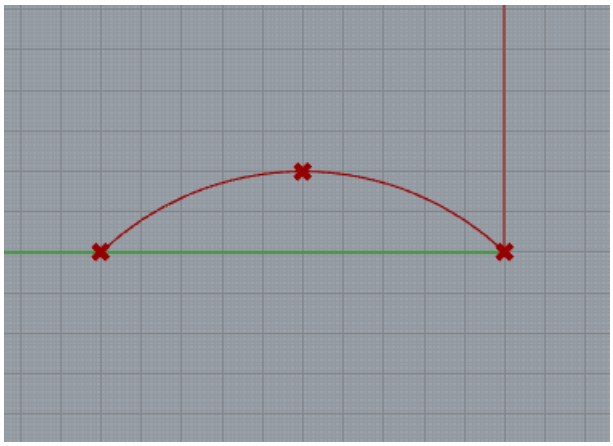


Figure 4. 14 Curve in Origin

4.1.5.3. Import PDF

Importing a PDF into Rhino and utilizing the Vectorize plugin provides an efficient way to extract detailed geometry for further analysis, such as determining the dimensions of a bridge.

The process begins by importing the PDF file, which often contains critical drawings or schematics of the bridge structure. Once the PDF is imported, the Vectorize plugin is employed to convert the rasterized content into editable vector lines and shapes.

This conversion is crucial, as it transforms the 2D representation into a format suitable for manipulation within Rhino. After vectorization, users can refine the resulting curves and shapes, ensuring accuracy in the geometric representation of the bridge.

With the vectorized geometry in place, Grasshopper can be utilized to analyse and extract specific dimensions of the bridge. By using Grasshopper's parametric modelling capabilities, users can create algorithms that measure lengths, widths, and heights directly from the vectorized data.

The integration of the Vectorize plugin with Grasshopper streamlines the workflow, enabling designers to automate dimension calculations and visualize results in real time. This method not only enhances precision in determining the bridge's dimensions but also facilitates design iterations, allowing for informed decision-making in structural analysis, maintenance planning, and potential renovations. Overall, this approach significantly improves the efficiency and accuracy of bridge design workflows.

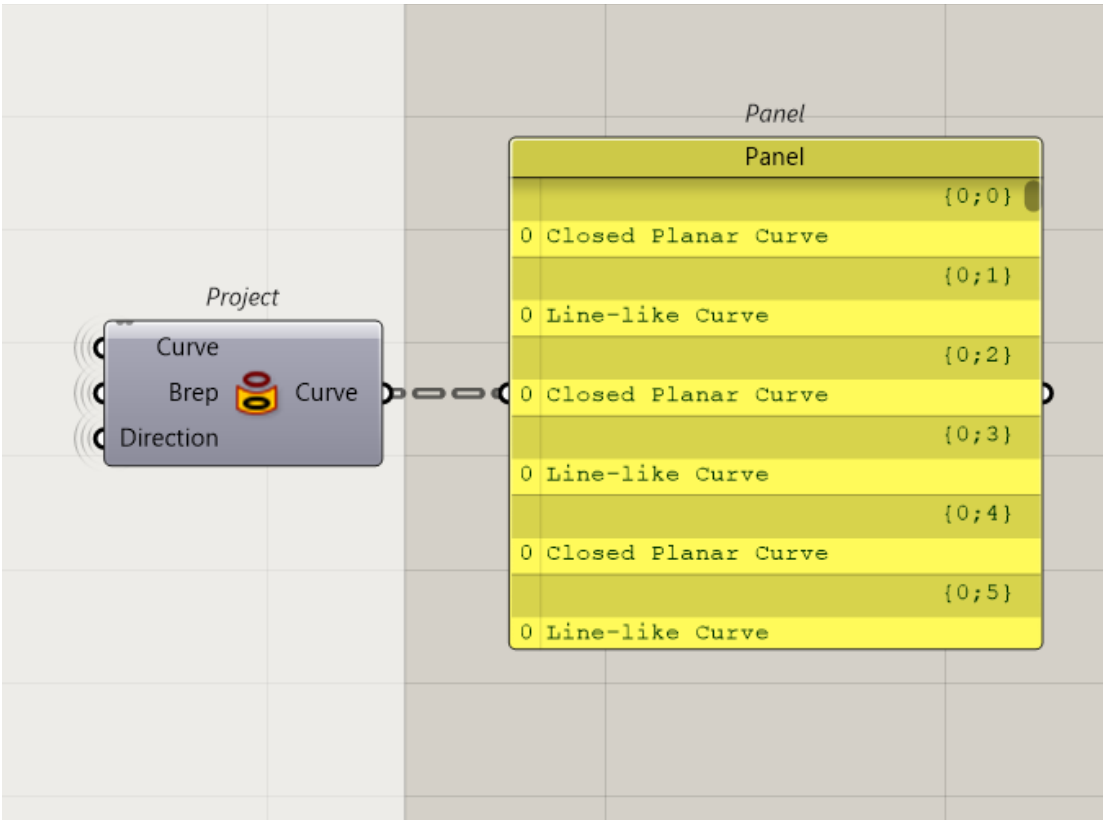


Figure 4. 15 Vectorized Line

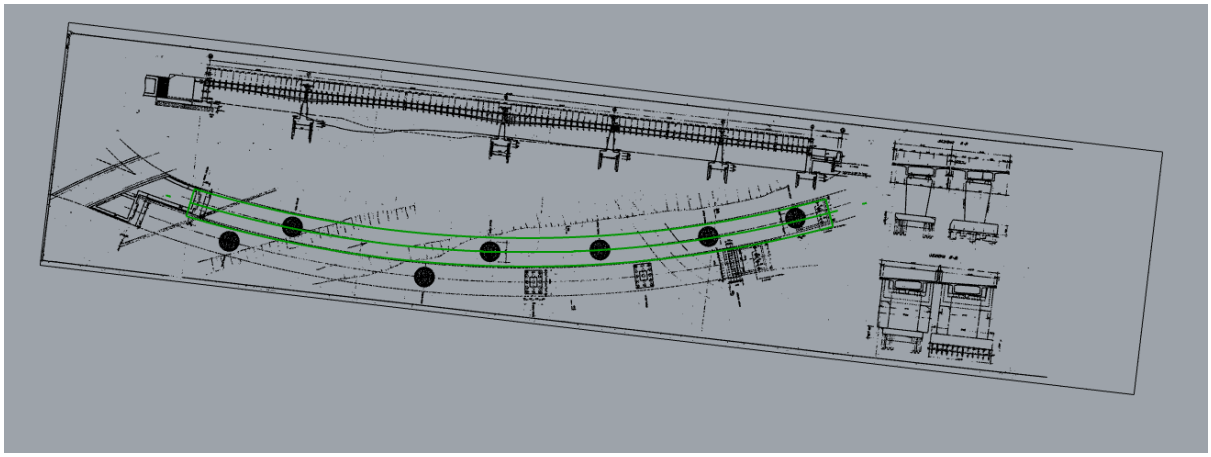


Figure 4. 16 Visualization of line in Rhino

4.1.6. Place the co-ordinate in point cloud

After accurately determining the dimensions of the bridge using the Vectorize plugin in Rhino, the next step is to integrate these measurements into the point cloud data. This process involves aligning the vectorized geometry with the existing point cloud, ensuring that the bridge's precise dimensions correspond accurately to the spatial information captured in the point cloud.

By carefully positioning the vectorized elements within the point cloud environment, designers can visualize how the bridge interacts with its surroundings. This integration not only enhances the accuracy of the model but also facilitates comprehensive analyses, supporting effective decision-making in design and engineering processes.

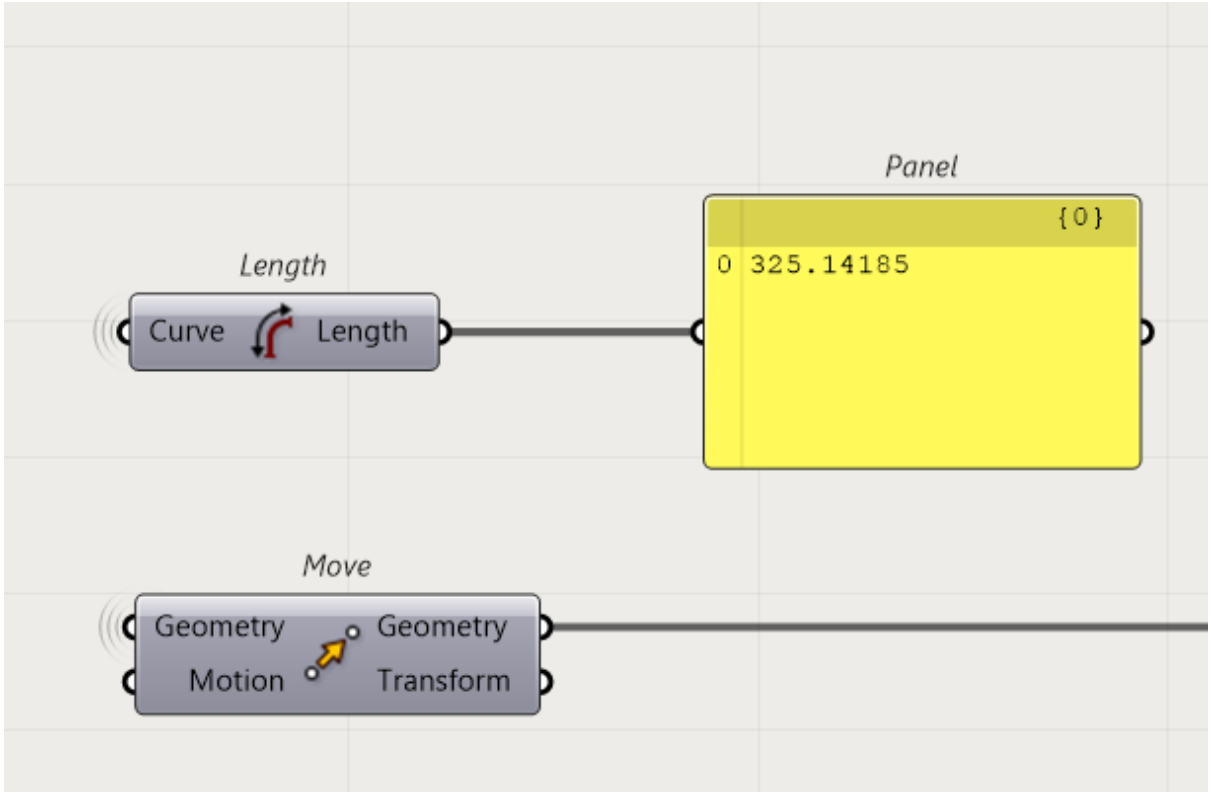


Figure 4. 17 Move Component

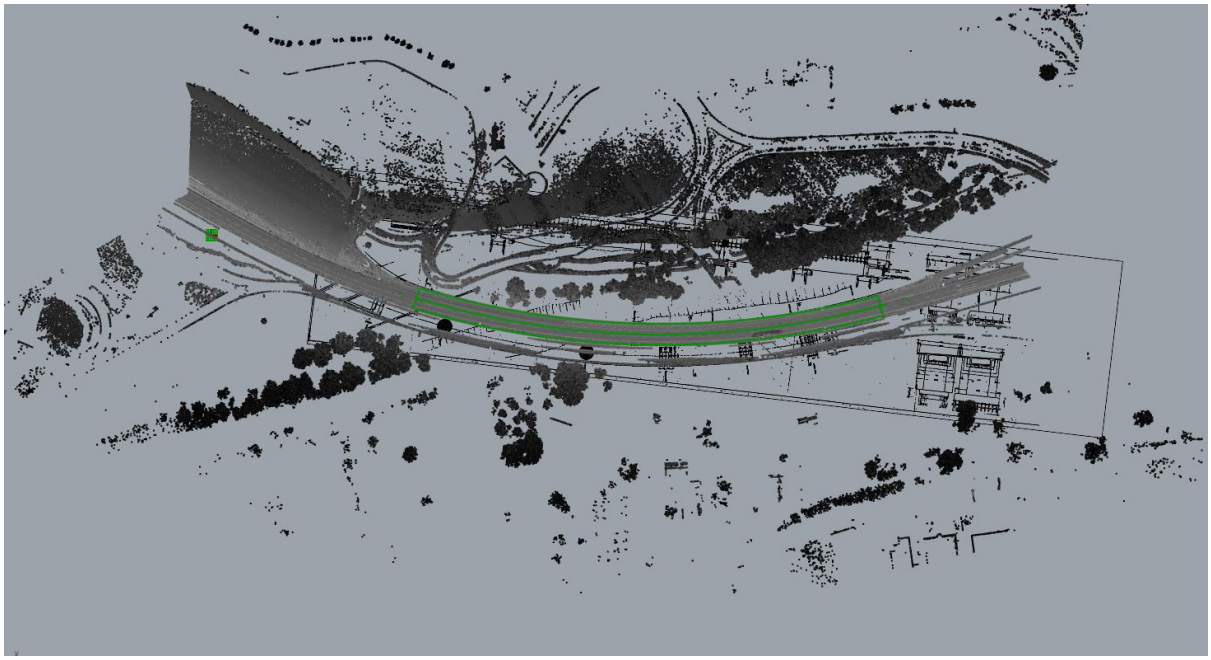


Figure 4. 18 Accuracy of placement

4.1.7. Filtering the cloud points

After determining the vector line that accurately represents the bridge's path, the next step is to use this path to create a solid rectangular model in Grasshopper.

This process begins by inputting the vector line into Grasshopper and using it as the base curve for generating a rectangle. The rectangle, defined by its width and height parameters, is then extruded along the vector line to form a solid that represents the structural bounds of the bridge.

This solid serves as a precise volumetric model that corresponds to the bridge’s dimensions and orientation.

With the solid in place, the next task is to refine the point cloud data by trimming away any points that fall outside the bridge’s structure.

In Grasshopper, the **Cloud Engine** component is a powerful tool for refining point cloud data. By utilizing this component, we can efficiently trim away unwanted points that lie outside a defined solid box. The process involves creating a solid box that encapsulates the area of interest—typically the bridge geometry—and then using the Cloud Engine to filter the point cloud. Points within the box are retained, while those outsides are discarded. This approach ensures that only relevant data remains, significantly improving the accuracy and

manageability of the point cloud for further analysis and modelling tasks.

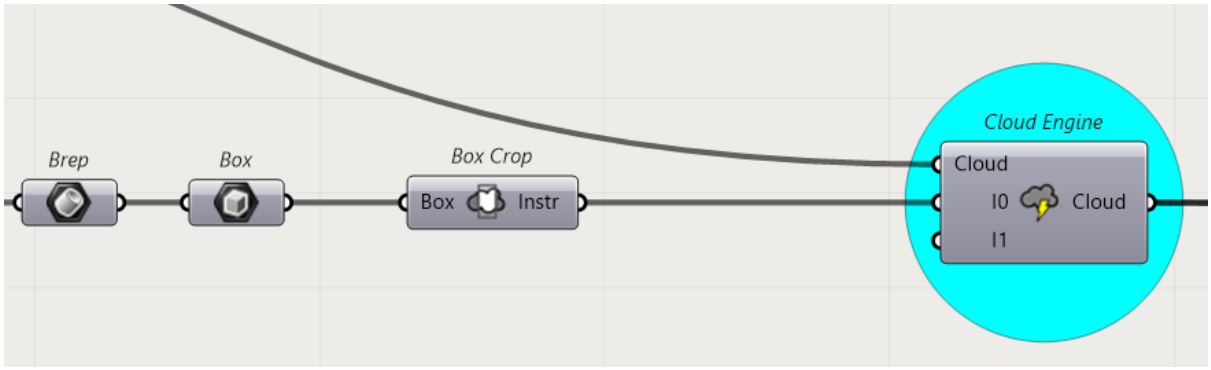


Figure 4. 19 Cloud Engine Component

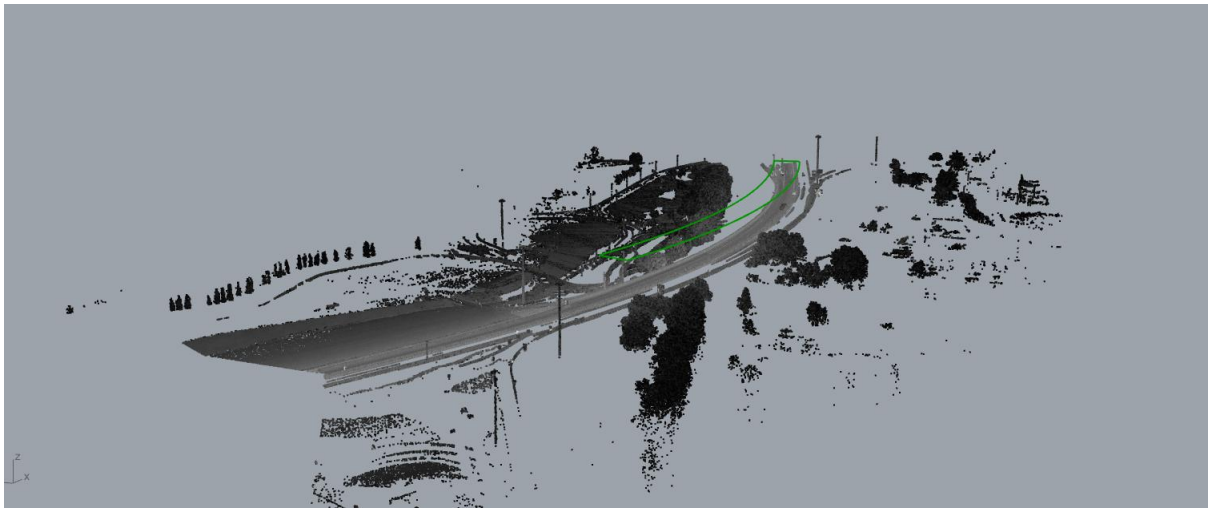


Figure 4. 20 Finding the Right Points

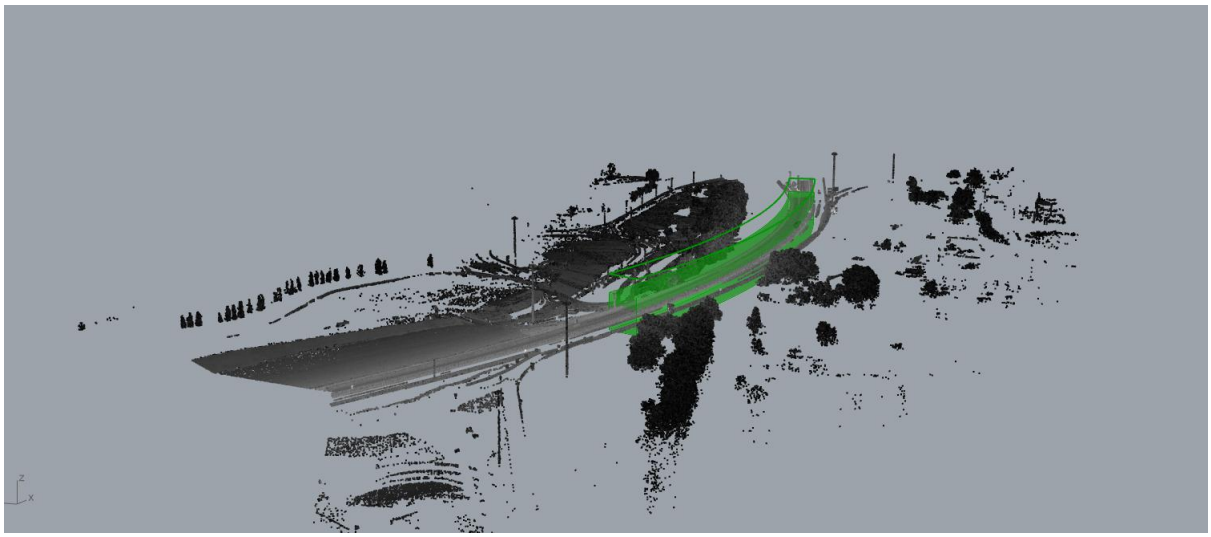


Figure 4. 21 Filtering process

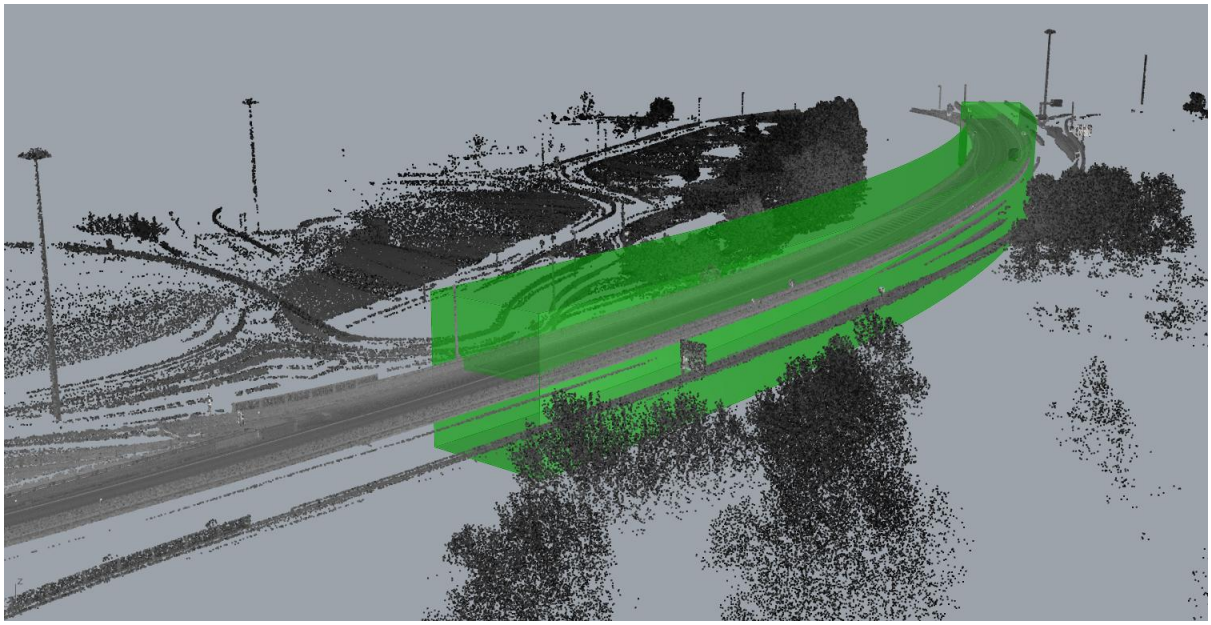


Figure 4. 22 Solid box for filtering

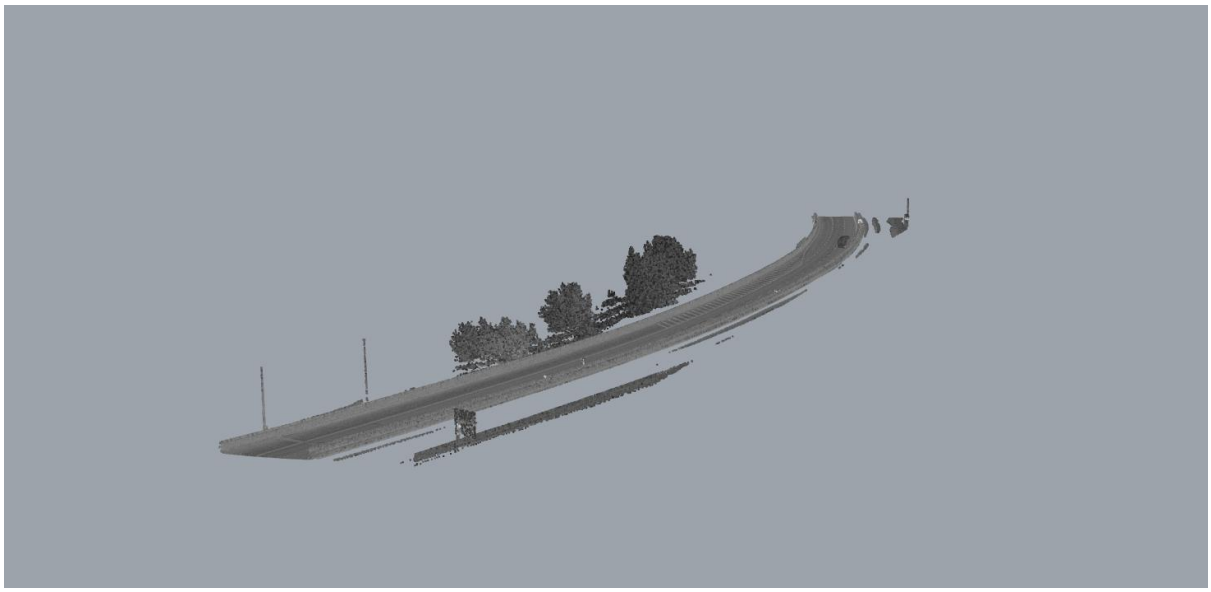


Figure 4. 23 Filtered Point Cloud Data

This operation isolates the accurate bridge points, ensuring that the final point cloud dataset is clean and focused on the bridge geometry. This refined dataset is essential for precise analysis, modelling, and further engineering tasks.

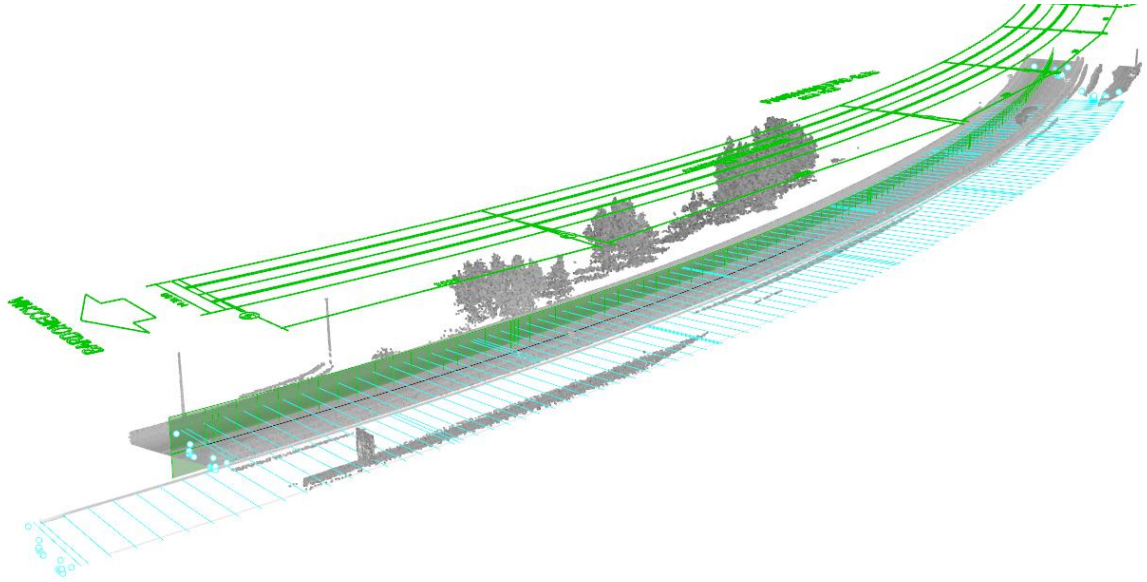


Figure 4. 24 comparing vector data with point cloud

4.1.8. From Co-Ordinate point to origin

When working with bridge point cloud data, it is often the case that both the point cloud and the determined lines are positioned far from the origin in the 3D modelling environment. This displacement can complicate the modelling process, making it challenging to accurately manipulate and visualize the geometry.

To address this issue without altering the integrity of the data, it is essential to bring both the point cloud and the vectorized lines closer to the origin. In Rhino, this can be achieved by using the **Move** command to translate the entire dataset effectively.

By selecting both the point cloud and the vector lines, users can specify a movement vector that aligns them closer to the origin while preserving their relative positions and dimensions.

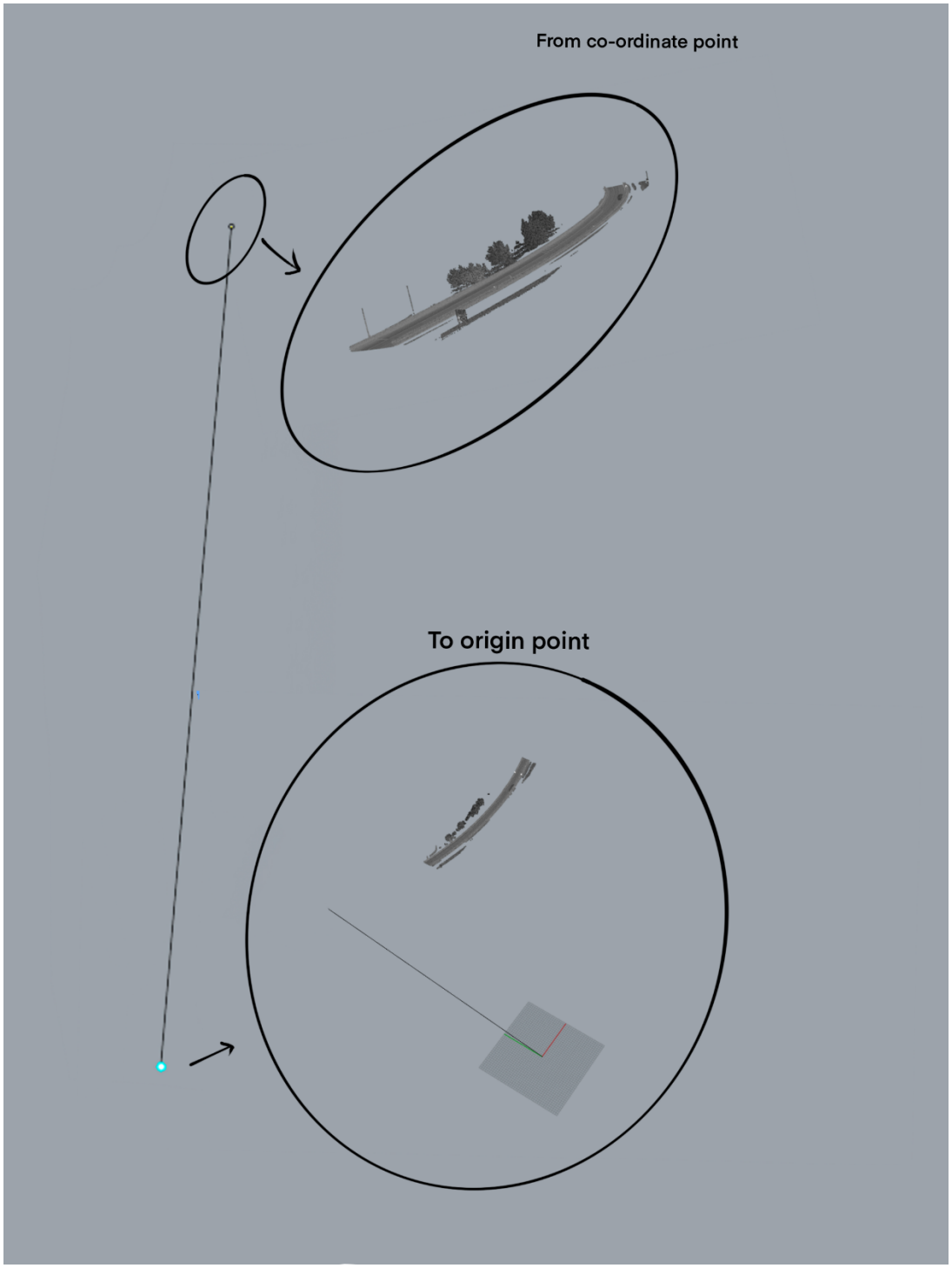


Figure 4. 25 movie the point to origin

This method ensures that the original data remains unchanged, facilitating a more manageable modelling environment. Once relocated, users can continue their work with enhanced precision and clarity, making it easier to conduct further analyses or modifications.

CHAPTER 5

5. Bridge Modelling

5.1. Methodology

5.1.1. Parametric geometry from AutoCAD

A sequence of procedures must be followed when converting a concrete box bridge geometry from AutoCAD to Rhino to ensure that the design data is correctly transferred and used for parametric modelling in the Grasshopper environment.

- The bridge profile was produced in AutoCAD and exported in Rhino software to ensure the accuracy of the dimensions. After the design is finished, export the AutoCAD 2D or 3D geometry. Typically, this is accomplished by saving the file in a Rhino-compatible format, such DWG or DXF.
- To import the AutoCAD file, open Rhino. Since DWG and DXF files are natively supported by Rhino, the design's geometric integrity should be preserved during the import process.
- Verify that all the sections have been transported correctly by examining the imported geometry in Rhino. If required, clear up the geometry by eliminating any unnecessary lines, points, or layers.
- We also looked at the units, and they must be the same. For instance, there would be a unit error and an incorrect measurement if the rhino file was in mm and the CAD file was in cm.
- We should check and export the rhino units before exporting the CAD file.

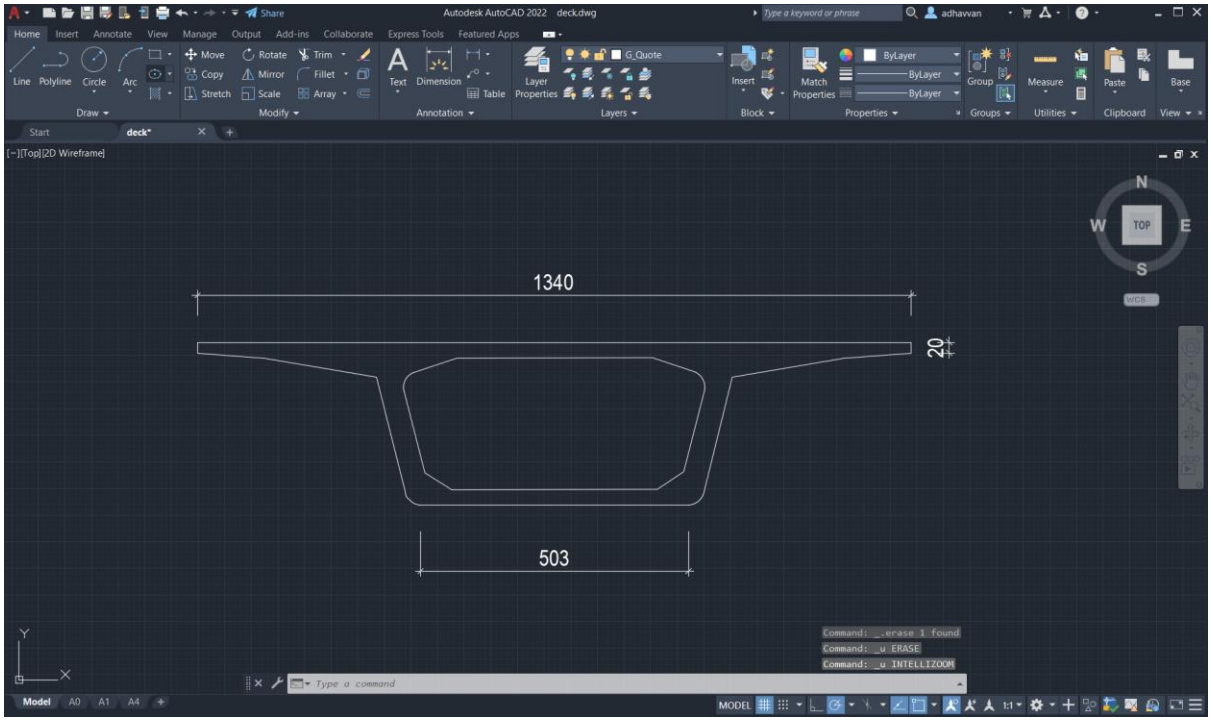


Figure 5. 1 Cross Section in AutoCAD

It may be necessary to simplify or alter the geometry after it is in Rhino in order to prepare it for parametric manipulation in Grasshopper. This could involve dividing complicated shapes into simpler segments or transforming surfaces and curves into formats that are convenient for Grasshopper to work with.

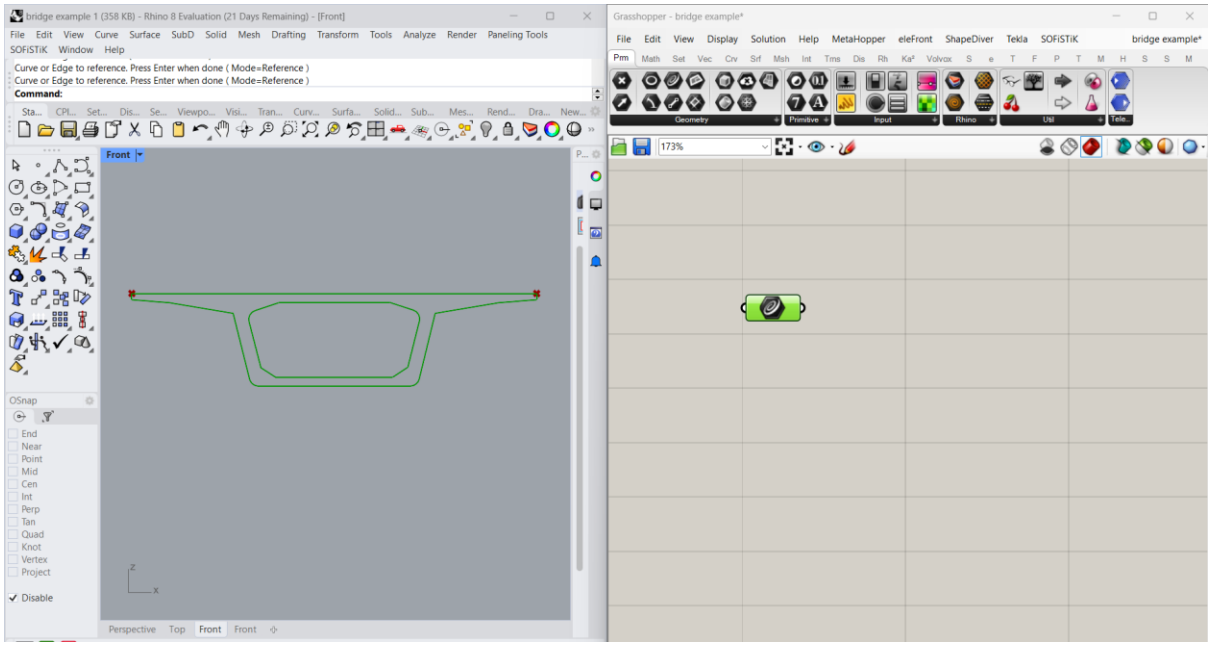


Figure 5. 2 Cross Section from AutoCAD to Grasshopper

To refer to, work with, and study curve geometry in Grasshopper, utilize the "Curve" component. Curve geometry can comprise lines, polylines, arcs, circles, ellipses, and more

intricate freeform curves. By choosing the curve and connecting it to the Grasshopper component, you can import pre-existing curves from a Rhino model.

Once a curve is referenced, Grasshopper provides a variety of tools to manipulate it. You can adjust control points, offset the curve, divide it into segments, or apply transformations like scaling, rotating, or moving. The curve can also be analysed to extract useful information such as length, curvature, or points along its path, which can be used to inform other parts of parametric design.

Curves are often foundational in creating more complex geometries. For example, they might be used to generate surfaces or solids through operations like lofting, sweeping, or extruding. Additionally, Grasshopper allows for the construction of new curves within the software, whether by defining control points, interpolating through points, or using mathematical definitions.

This a method to create the solid shape of geometry. But using this method we can make the multiple cross sections with different dimensions.

When we have the cross section of bridge is equal in shape along the length this is an automation method to create the bridge.

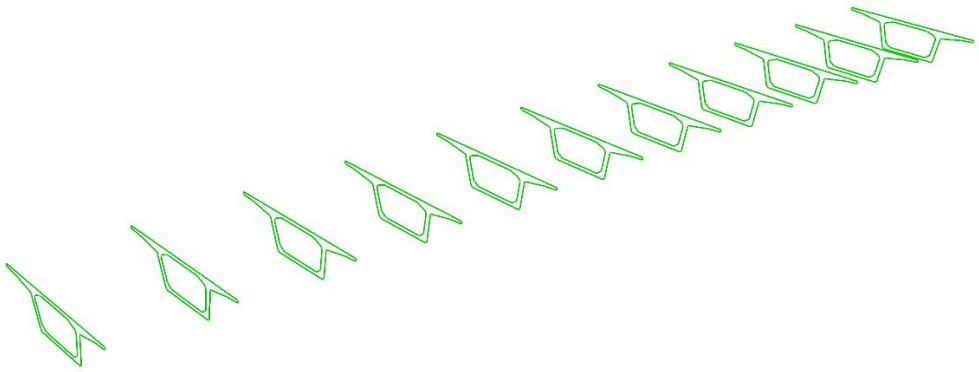


Figure 5. 3 Linear Cross section along the length

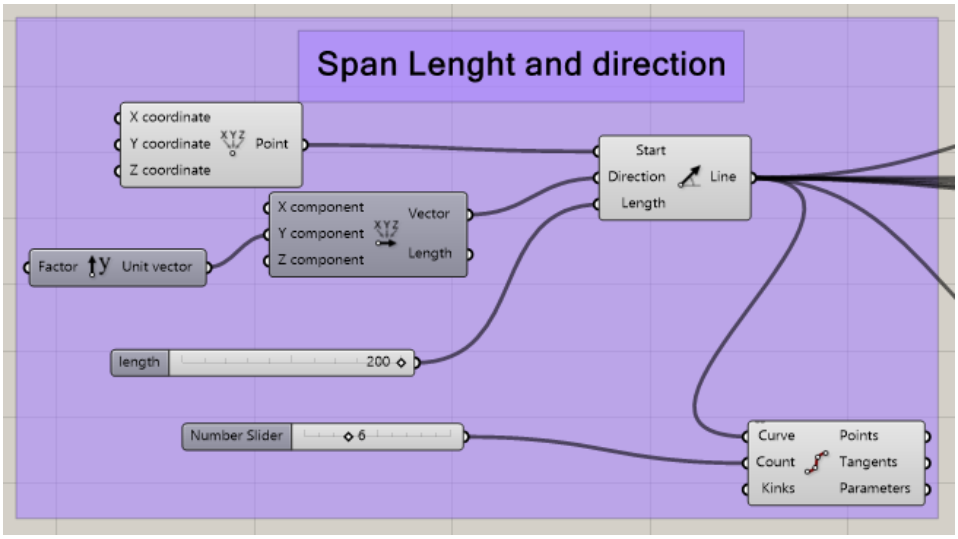


Figure 5. 4 Length of span

The curve as the output of the bridge profile. So, it is the origin to create a solid form of concrete box bridge. There are so many components where they can take the curve line as input and give the output as we want. For example, there is a component called "spread," which can be used to create the solid form of a bridge cross section. In the length component, we have the input called "rail," which is the length of the bridge, and we can modify the length depending upon the needs.

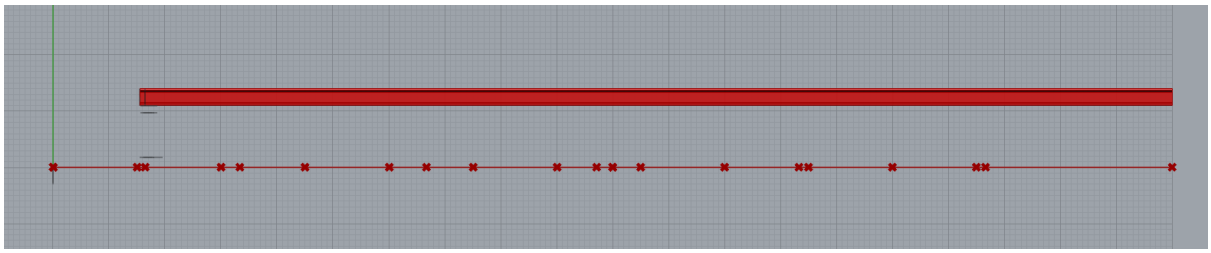


Figure 5. 5 Extrusion of span View 1

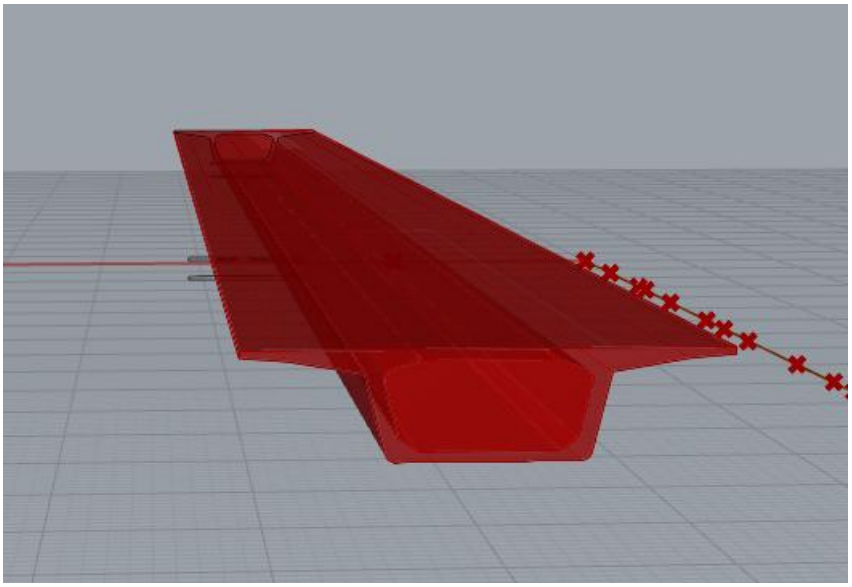


Figure 5. 6 Extrusion of span View 2

To create a bridge pile from a CAD drawing in Rhino and sweep it using Grasshopper, start by importing the CAD file into Rhino. This will give you the cross-sectional profile of the pile.

Grasshopper and reference both the cross-sectional profile and the path curve. Use the Curve component to bring these elements into Grasshopper. With the geometry in place, you can then use the Sweep1 component to sweep the profile along the path, creating the 3D geometry of the bridge pile. This process allows you to take a 2D CAD cross-section and transform it into a fully realized 3D model in Rhino using Grasshopper's parametric capabilities.

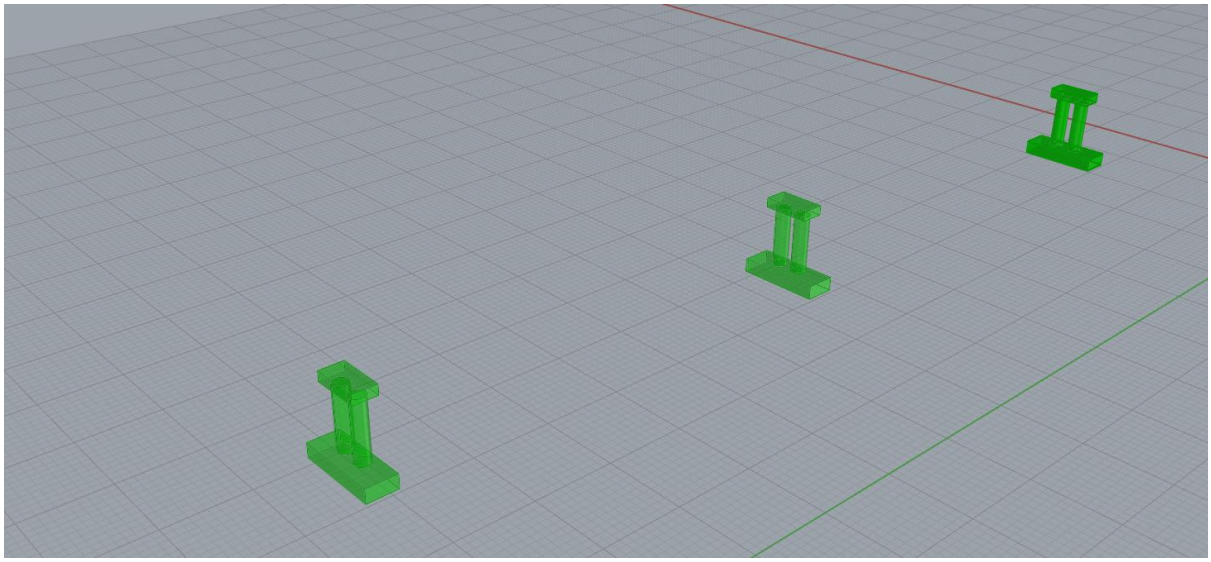


Figure 5. 7 Pile Creation using grasshopper

As in this instance, the number component can be used to both enhance and decrease the desired result. A number component is used to generate and connect the number of simple geometric piles, allowing for automatic increases and decreases. In the parametric environment, numerical data is entered and managed using the "Number" component. This part is crucial for setting parameters, including size, angles, and other numerical values, that regulate different parts of model. When paired with other components, the "Number" component can be used to input a list of numbers or a single numerical value.

Double-clicking a "Number" component that added to the Grasshopper canvas allows to manually enter a specific value. This value can then be linked to other elements in model such that it affects the parameters or geometry. To adjust the radius of a circle, the length of a line, or the distance between components in a pattern, for instance, may attach a "Number" component.

5.1.2. Positioning the points of profile from Grasshopper

To create a bridge cross-section using points in Grasshopper. In Grasshopper, use the Point component to define the specific points that will outline the cross-section of bridge. You can manually input the coordinates for each point using the Construct Point component, which allows to set the X, Y, and Z values.

Ensure that the points are organized in a logical sequence that follows the perimeter of the cross-section. This is crucial for creating a continuous and accurate profile.

Once you have your points in place, use the Polyline component to connect these points. This will create a closed or open polyline that represents the outline of the bridge cross-section.

It can adjust the positions of the points to refine the shape of the cross-section. By connecting sliders to the point coordinates, you can create a dynamic model where the cross-section can be easily modified.

If necessary, close the polyline to form a closed curve, which can then be used in further operations such as extrusions or sweeps to create the 3D geometry of the bridge.

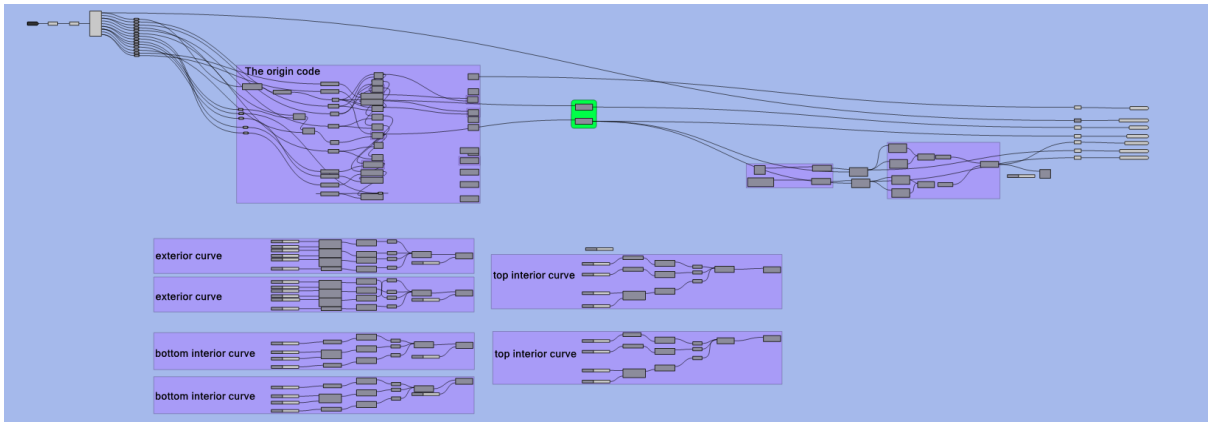


Figure 5. 8 Cluster Components

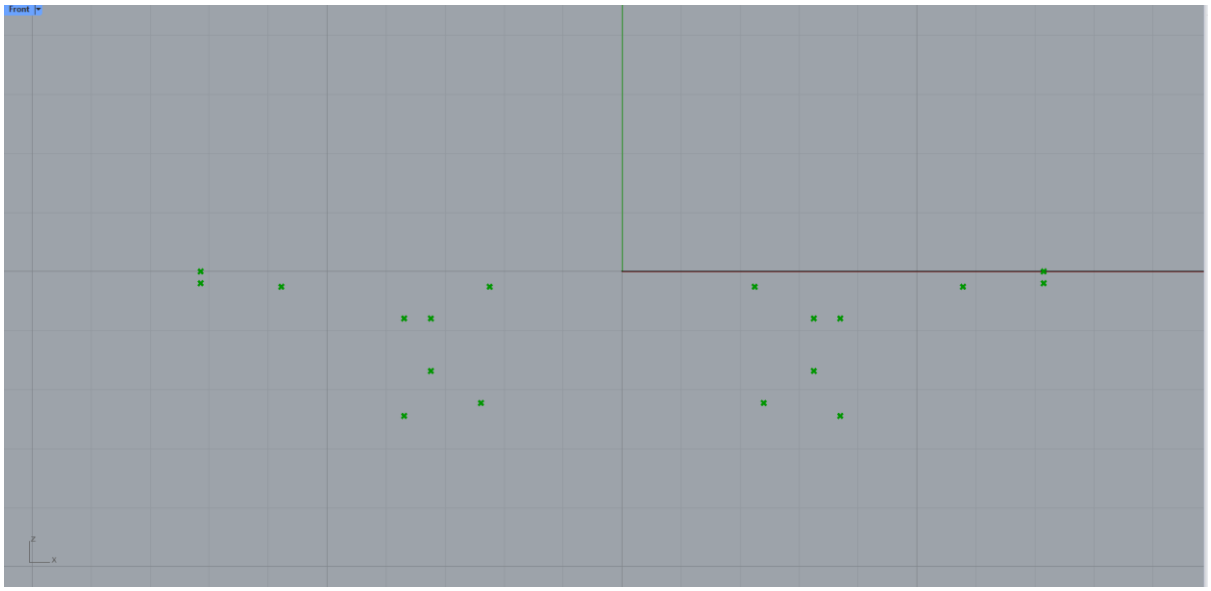


Figure 5. 9 Different position of geometry points

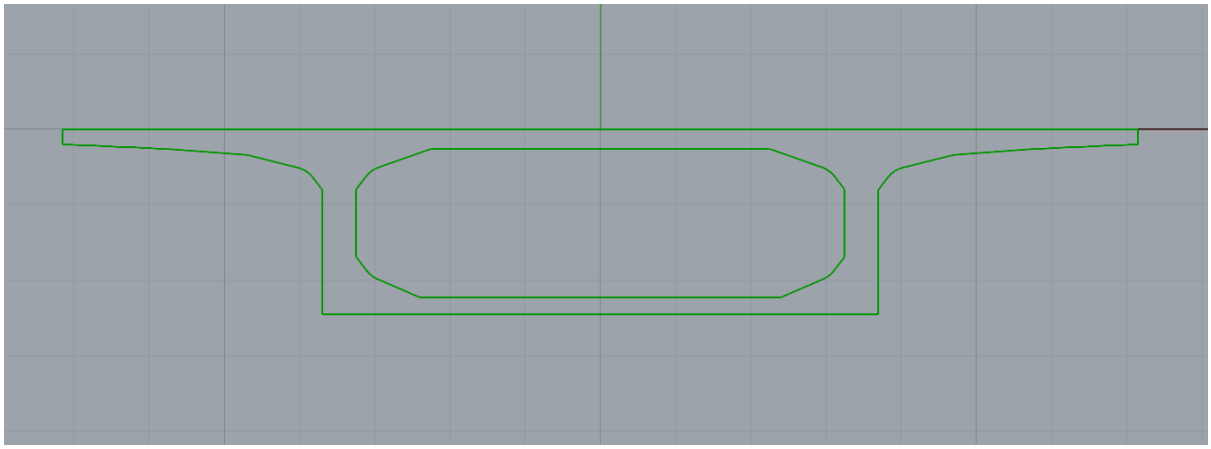


Figure 5. 10 Bridge Cross Section

5.1.3. Customisation of Cluster

After accurately positioning the bridge points within Grasshopper, a cluster can be created to streamline the process of generating complex cross sections of the bridge. A Grasshopper cluster encapsulates multiple components and operations into a single, reusable block, making it easier to manage and automate repetitive tasks. By feeding the positioned points into this cluster, the input data is processed to generate various cross-sectional profiles of the bridge. Each cross section is derived based on specific parameters and design criteria, allowing for the creation of complex and accurate representations of the bridge's structural geometry.

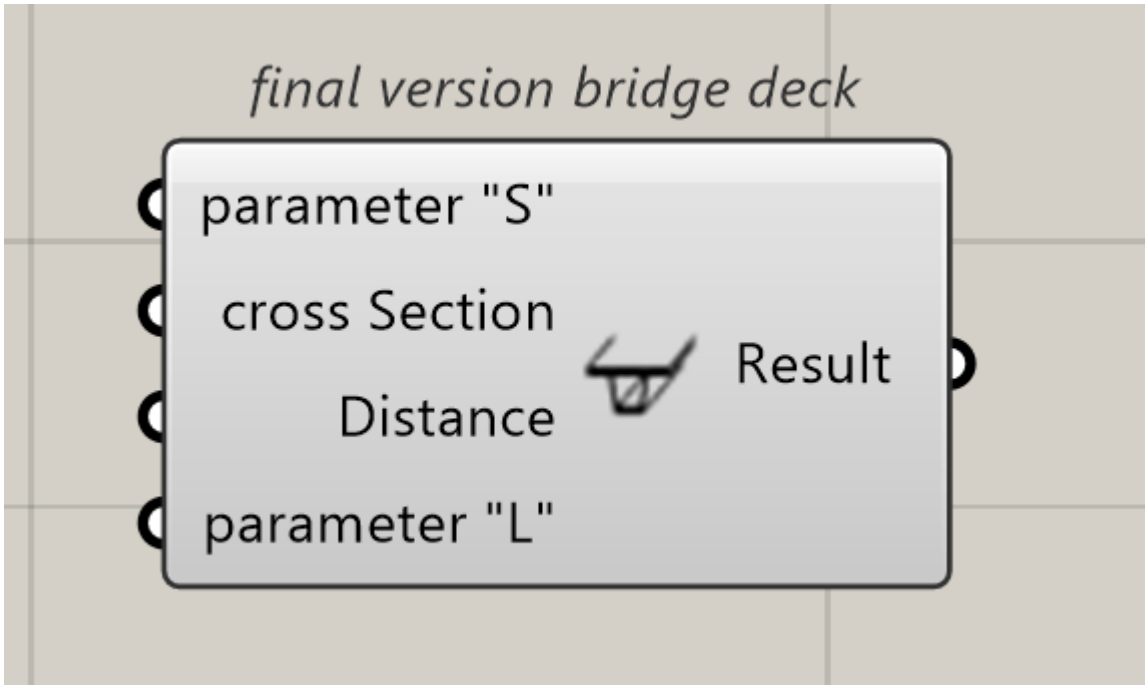


Figure 5. 11 Grasshopper Cluster

This method is particularly useful for modelling intricate designs, as it ensures consistency across multiple sections while allowing for easy adjustments. The clustered approach not only simplifies the workflow but also enhances flexibility, enabling designers and engineers to explore different cross-sectional variations quickly and efficiently. This is crucial for optimizing the bridge's design and ensuring structural integrity across its span.

5.1.4. Optimizing the bridge cross section from excel

Grasshopper doesn't natively support Excel files, so you'll need a plugin. Lunchbox and TT Toolbox are popular choices. You can download these plugins from platforms like Food4Rhino. Once installed, these plugins will add new components to your Grasshopper interface.

Ensure your Excel file is properly formatted, with data organized into rows and columns. Each cell should contain the data you want to use in Grasshopper, such as numerical values, text, or coordinates. "Read Excel" component onto the Grasshopper, the input from the excel can be words or numbers.

Creating an Excel file to store all the parameters of the bridge is an essential step in automating and managing the design process within Grasshopper. The Excel file serves as a central repository for key data, including dimensions for various cross sections of the bridge. By

organizing this information in a structured format, we can easily modify parameters as needed

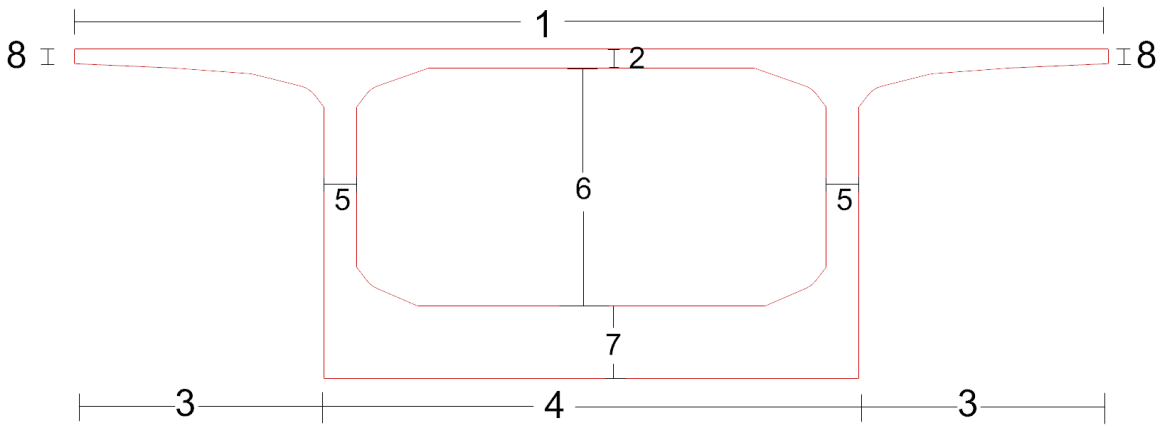


Figure 5. 12 Definition of cluster Inputs

and ensure consistency across the entire project.

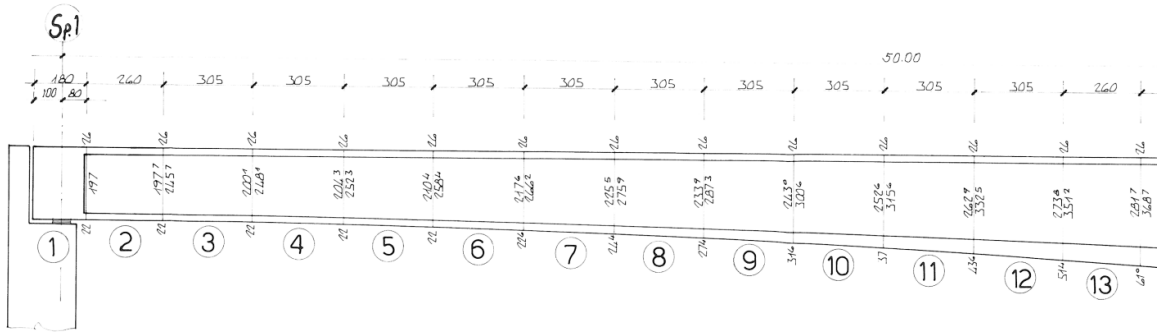


Figure 5. 13 Various Bridge Cross Sections

Tabel 1: Excel File

Distance between each segment length of cross section	1	2	3	4	5	6	7	8
0	14.3	0.26	3.45	7.4	0.45	1.97	0.22	0.2
0.8	14.3	0.26	3.45	7.4	0.45	1.97	0.22	0.2
2.6	14.3	0.26	3.45	7.4	0.45	1.977	0.22	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.001	0.22	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.043	0.22	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.104	0.22	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.176	0.226	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.255	0.244	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.339	0.274	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.43	0.316	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.526	0.37	0.2
3.05	14.3	0.26	3.45	7.4	0.45	2.629	0.436	0.2

3.05	14.3	0.26	3.45	7.4	0.45	2.738	0.514	0.2
2.6	14.3	0.26	3.45	7.4	0.45	2.817	0.61	0.2

Once the Excel file is prepared, it can be connected to a Grasshopper cluster that has been designed to generate the complex cross sections of the bridge. This connection allows Grasshopper to dynamically read and apply the parameters stored in the Excel file, enabling the automated creation of various cross-sectional profiles. As parameters are adjusted within Excel, the changes are instantly reflected in the Grasshopper model, allowing for real-time updates and iterations. This integration not only streamlines the design process but also enhances flexibility, enabling designers to explore a wide range of design possibilities with minimal manual input. By leveraging Excel and Grasshopper together, complex and customized bridge cross sections can be generated efficiently, ensuring that the final design meets all required specifications and optimizes both performance and aesthetics.

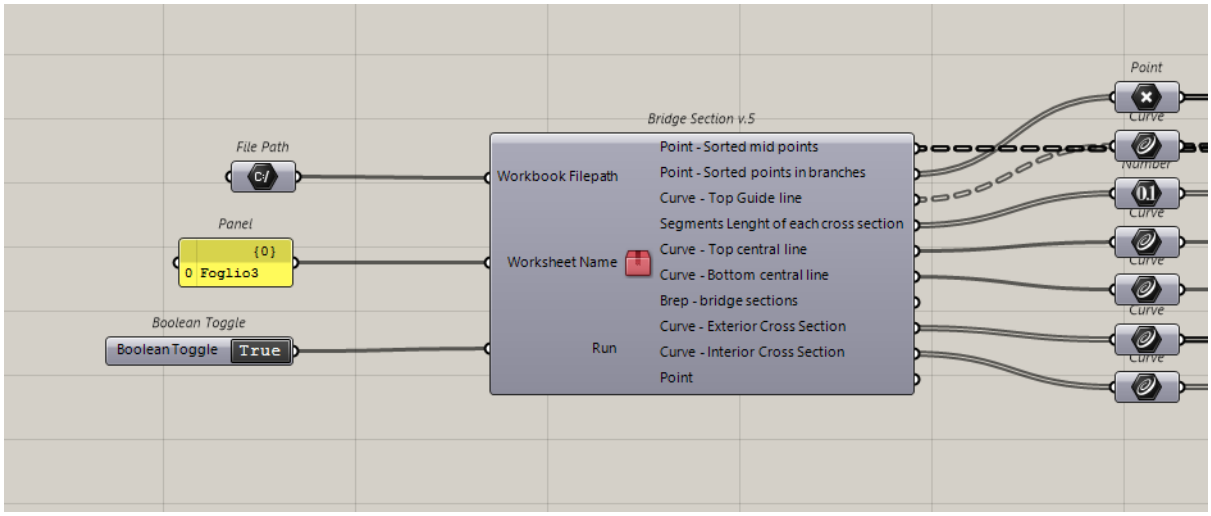


Figure 5. 14 Final Cluster

In the Grasshopper workflow for creating bridge cross sections, three key inputs are provided to the cluster: **file path, sheet number,** and **Boolean toggle**. The **file path** input specifies the location of the Excel file containing the bridge parameters, ensuring that the correct data is accessed. The **sheet number** input allows users to select the specific sheet within the Excel file that holds the relevant data, making it easy to switch between different sets of parameters. Finally, the **Boolean toggle** serves as an activation switch, enabling the cluster to generate the bridge cross section based on the provided inputs. This setup streamlines the process, allowing for efficient and flexible design iterations.

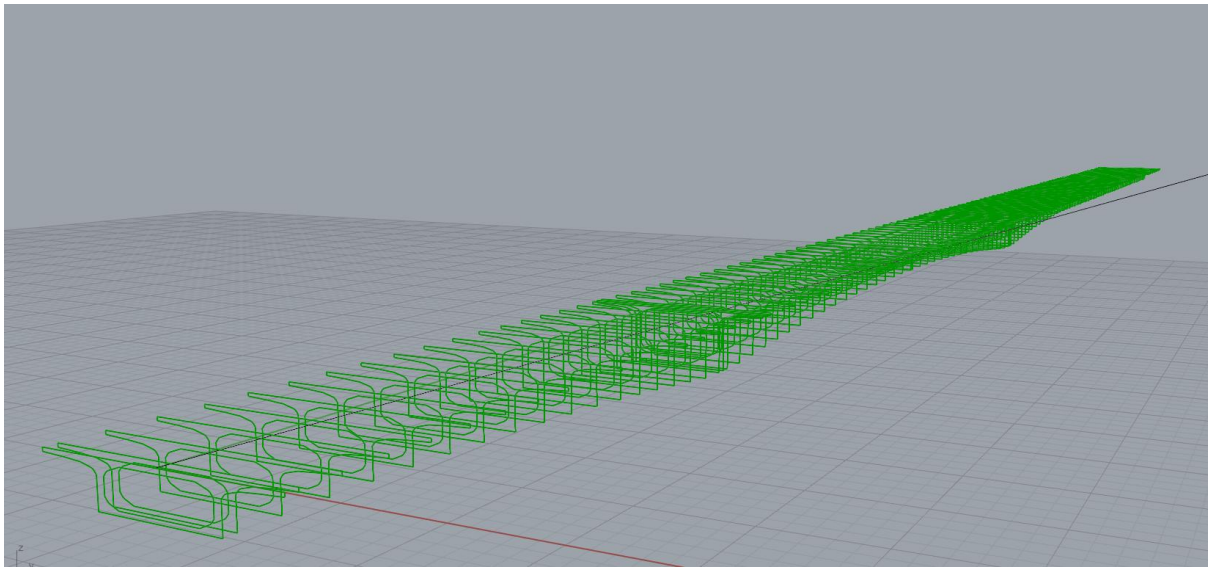


Figure 5. 15 Various Cross section of the Bridge from excel (Perspective view 1)

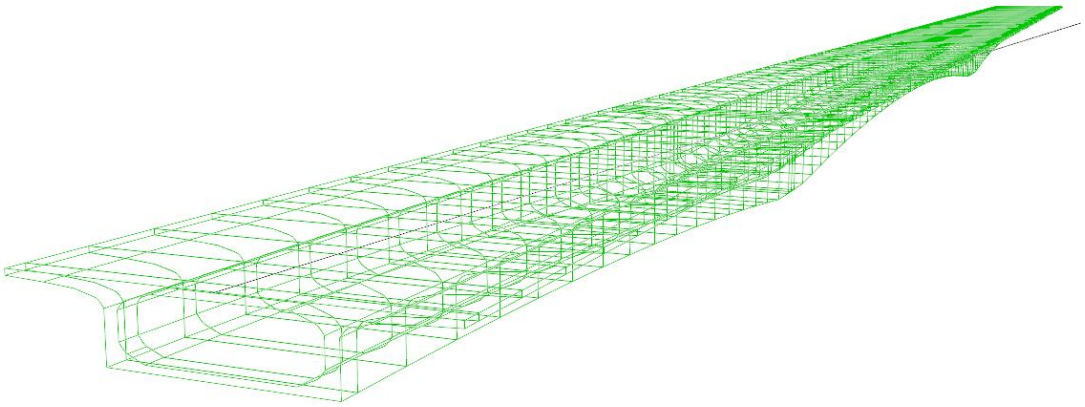


Figure 5. 16 Various Cross section of the Bridge from excel (Perspective view 2)

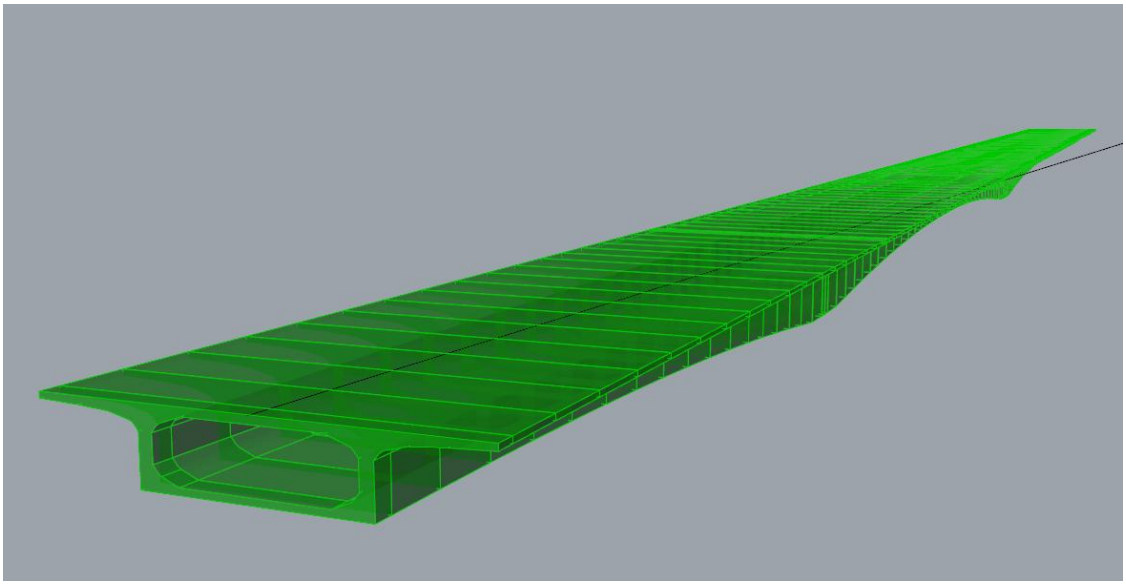


Figure 5. 17 Various Cross section extrusion of the Bridge from excel (Perspective view 1)

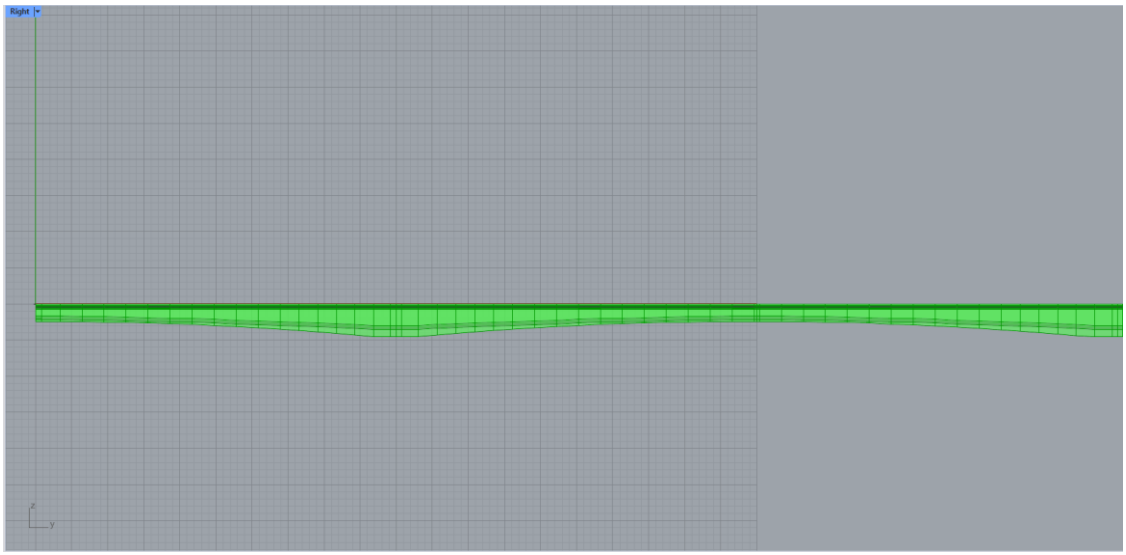


Figure 5. 18 Various Cross section extrusion of the Bridge from excel (Right View)

5.1.5. Creation of Plane

Two planes must be created,

1. Origin Plane
2. Destination plane

Origin Plane:

The origin plan for the bridge design is created using the length of each cross section, as specified in the Excel file that stores all the relevant parameters. This Excel file contains detailed measurements for each cross section of the bridge, including their respective lengths. By referencing this data, an origin plan can be accurately constructed in Grasshopper, serving as the foundational layout for the entire bridge structure.

In the Grasshopper environment, the length values from the Excel file are read and used to position each cross section at the correct interval along the bridge's span. This process ensures that each section is aligned according to the design specifications, maintaining consistency and precision throughout the model. The origin plan not only helps in organizing the cross sections spatially but also provides a clear reference for further design and analysis tasks.

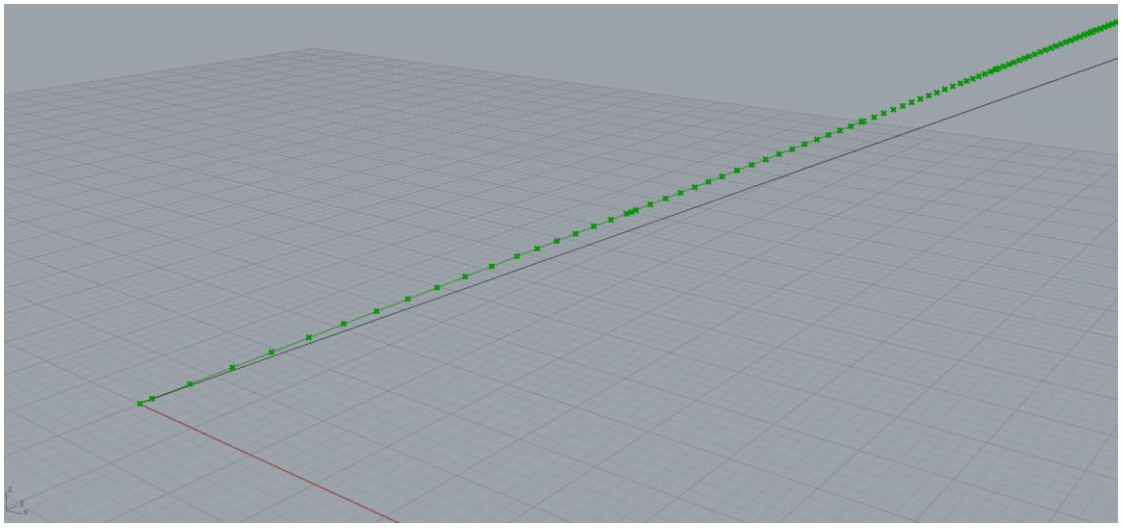


Figure 5. 19 Cross sections points

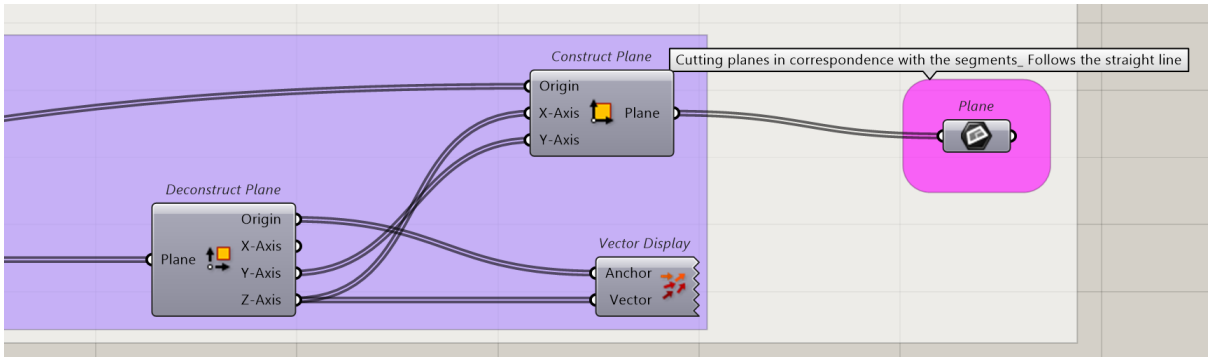


Figure 5. 20 Grasshopper plane component

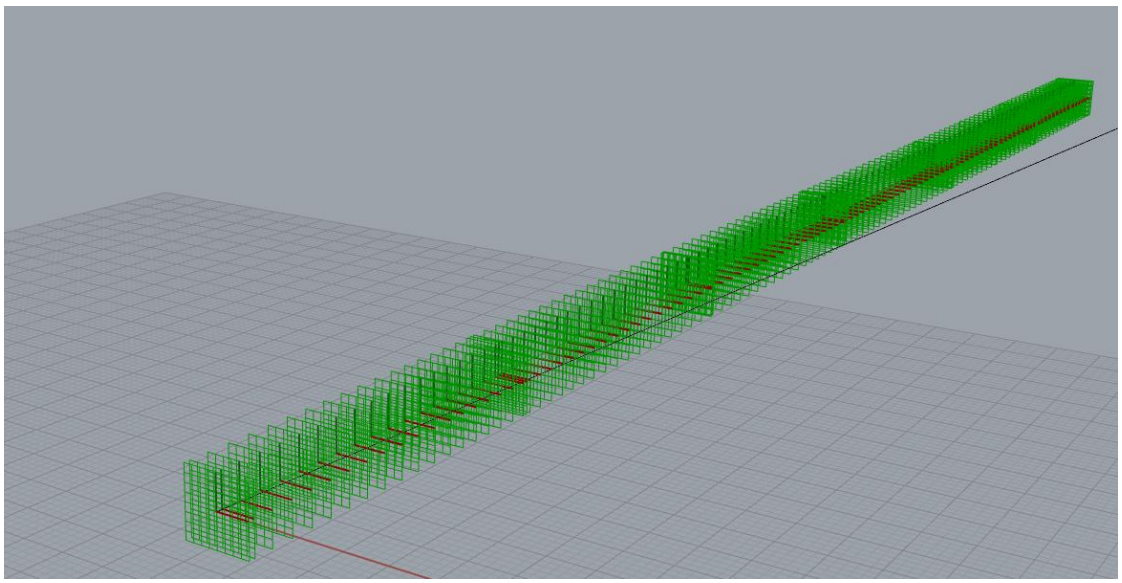


Figure 5. 21 Creation of planes

Destination Plane:

The destination plane for the bridge design is generated by utilizing the line derived from the point cloud data, combined with the length of each cross section specified in the Excel file. This approach begins with the extraction of a central line from the point cloud, representing the bridge's main path or alignment. This line serves as the baseline for positioning the cross sections accurately along the bridge's span.

Using the lengths provided in the Excel data, each cross section is placed at the correct interval along the derived line, effectively mapping the bridge's structure from start to finish. The destination planes are created at these intervals, ensuring that each cross section is correctly oriented and positioned according to the bridge's overall design intent.

This method ensures that the bridge's geometry aligns perfectly with the real-world conditions captured in the point cloud. By integrating the precise lengths from the Excel file with the spatial data from the point cloud, the model achieves a high level of accuracy, reflecting both the intended design and existing site conditions.

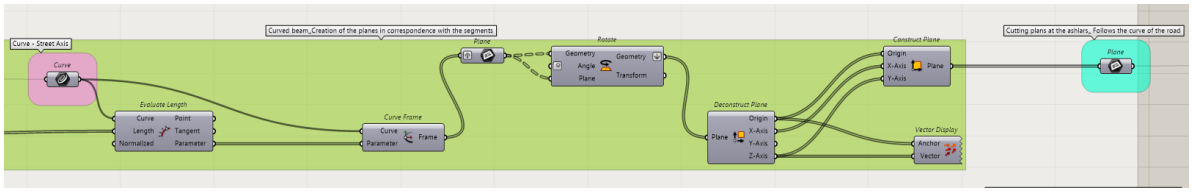


Figure 5. 22 GH plane Script

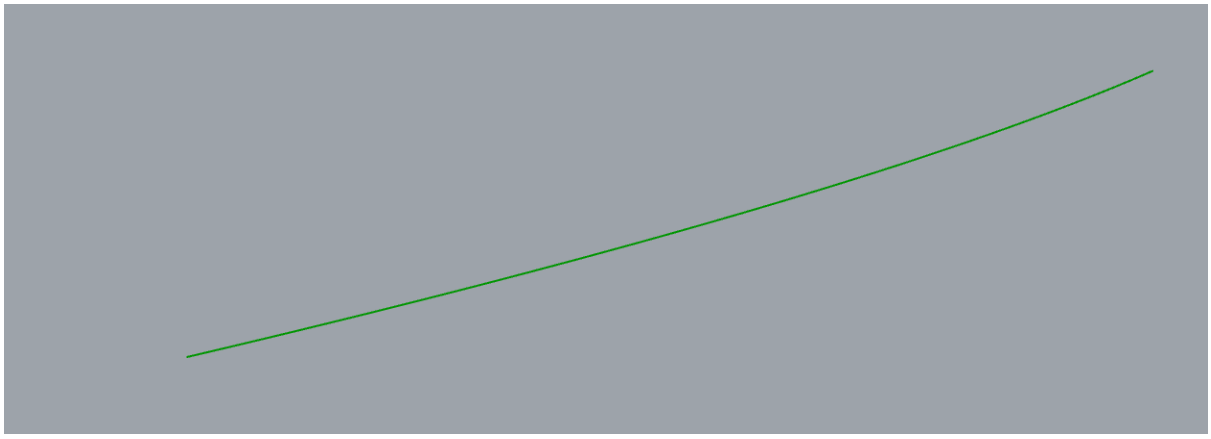


Figure 5. 23 Original shape of bridge in right Co-ordinate

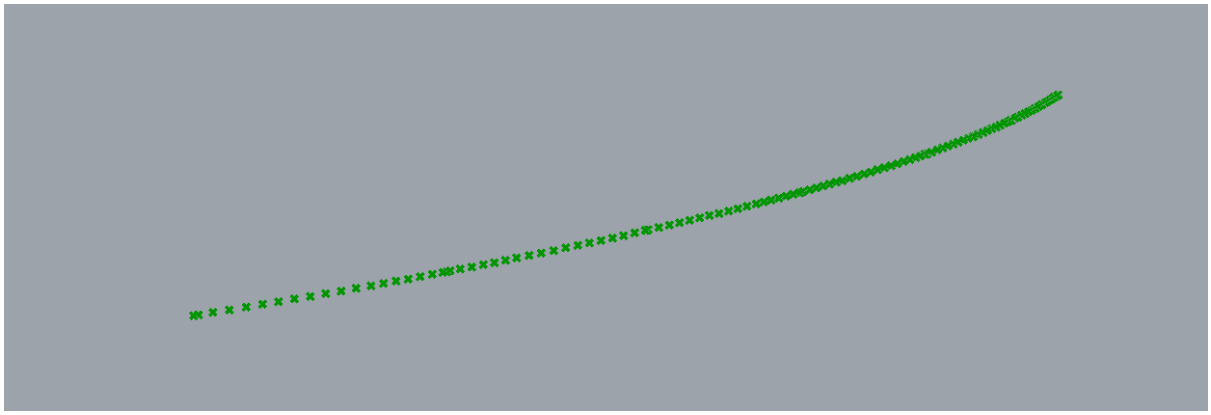


Figure 5. 24 Dividing the curve according to cross section

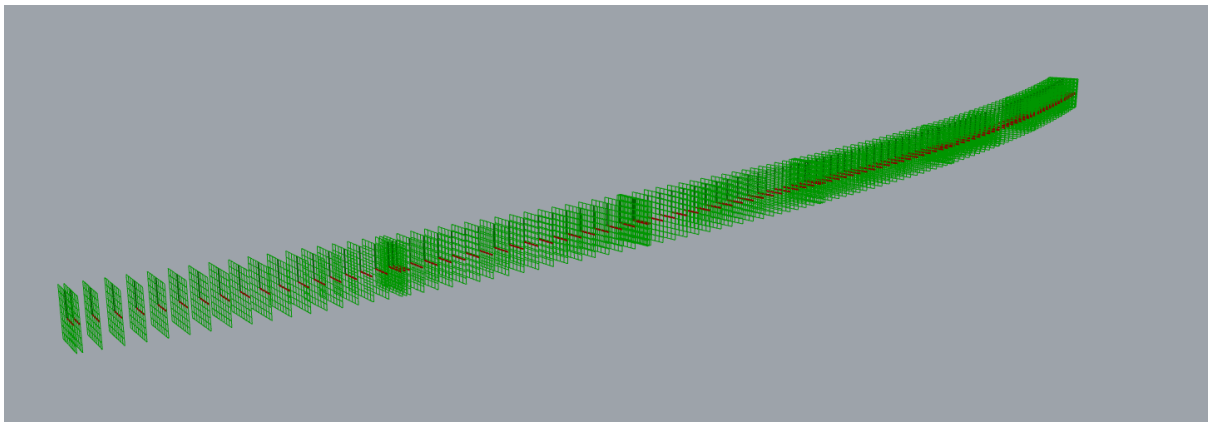


Figure 5. 25 Creating plane with divided points

Each plane in the design process represents a specific cross section of the bridge, holding its unique geometric details. These planes are crucial for transitioning the geometry from the origin plan to the destination plane, which is aligned with the bridge's actual path. By associating each cross section with its respective plane, Grasshopper enables the precise movement of geometry from the origin plan to the destination plane along the bridge's span. This method ensures that the bridge's structure is accurately positioned and oriented in the 3D model.

5.1.6. To determine the altimetry of the bridge

Using the point cloud and plane input in Grasshopper, we can effectively filter out unwanted points and accurately determine the altimetry of the bridge.

With the plane in place, the next step is to implement a filtering that trims the point cloud. This process involves using the plane as a cutting tool to remove points that do not intersect or touch the defined plane. Points that fall outside this boundary are discarded, allowing for a cleaner dataset that focuses on the points representative of the bridge's structure. This approach not only enhances the accuracy of the altimetry measurements but also simplifies the modelling process, ensuring that the final output reflects the true height and elevation of the bridge

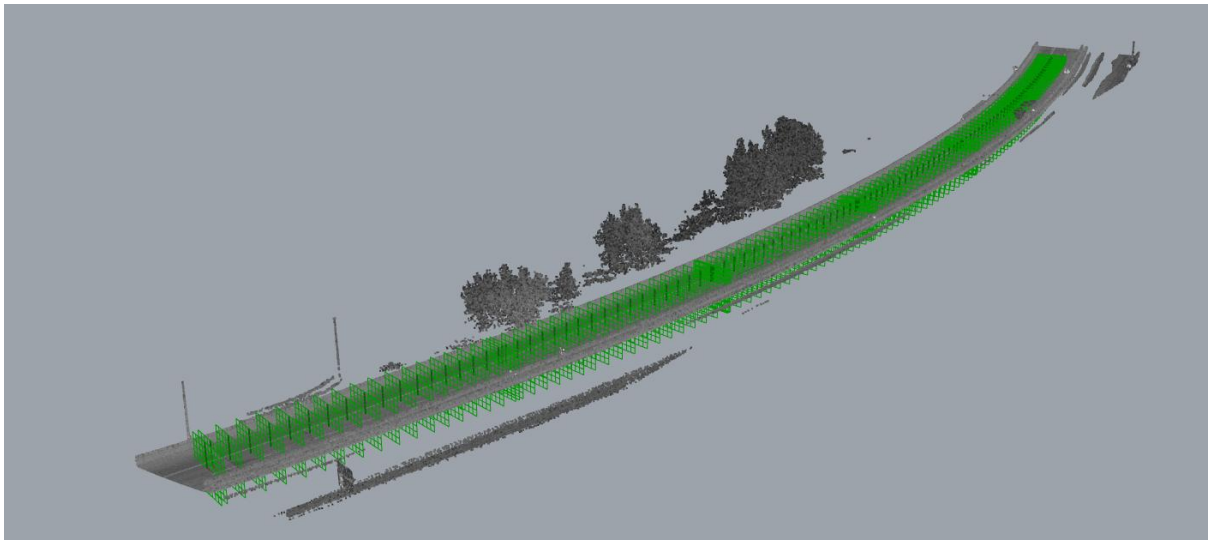


Figure 5. 26 Comparing the point cloud data and planes

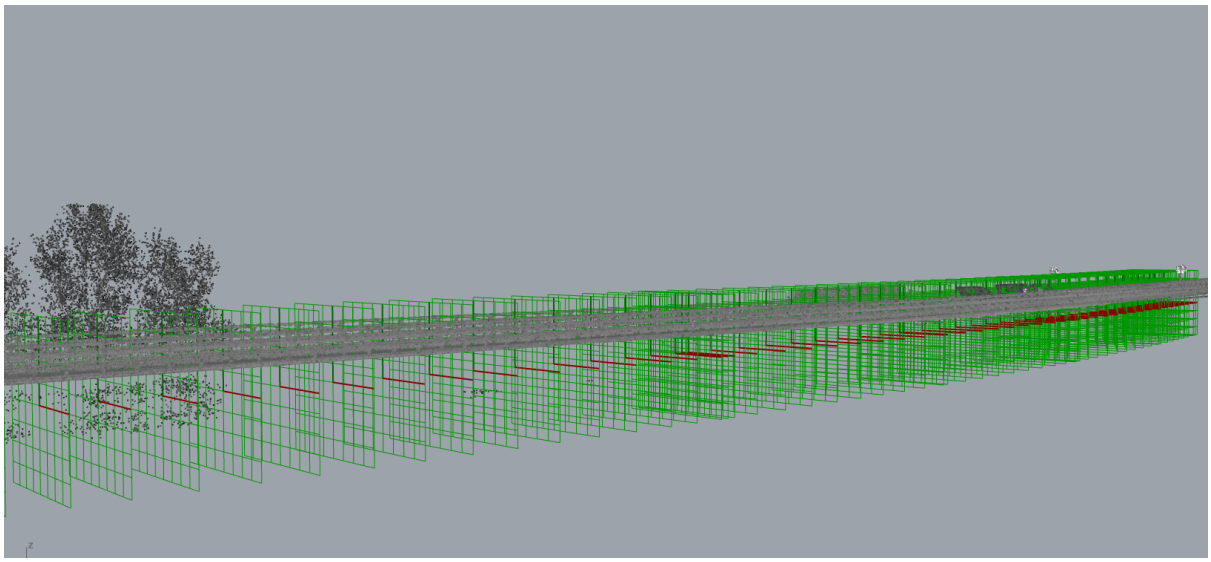


Figure 5. 27 Different altimetry

Using the plane create the solid box to filter the unwanted points from the point cloud that give us the accurate altimetry of the bridge

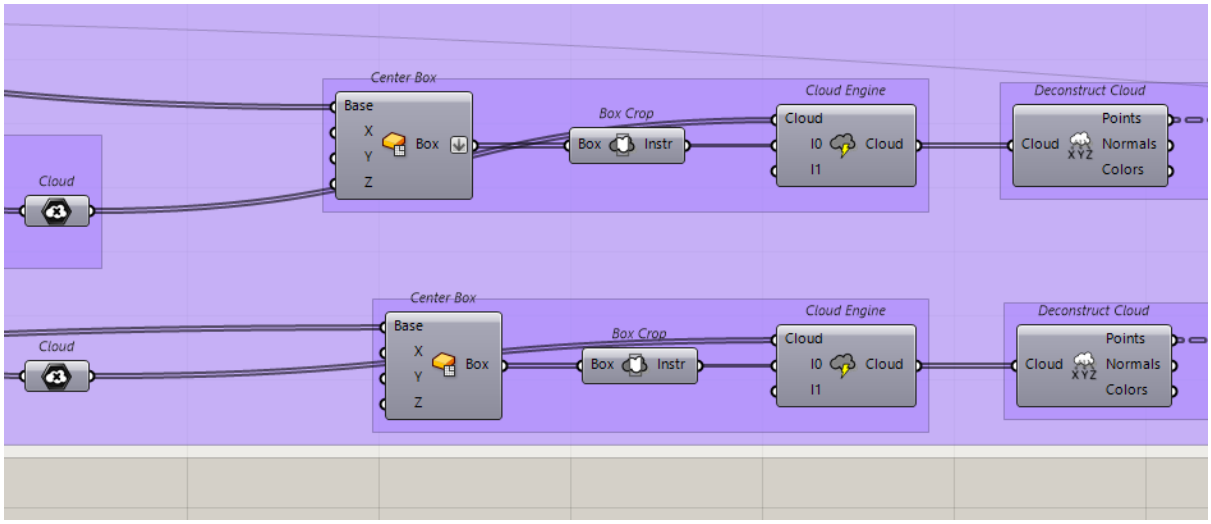


Figure 5. 28 GH "cloud Engine" component

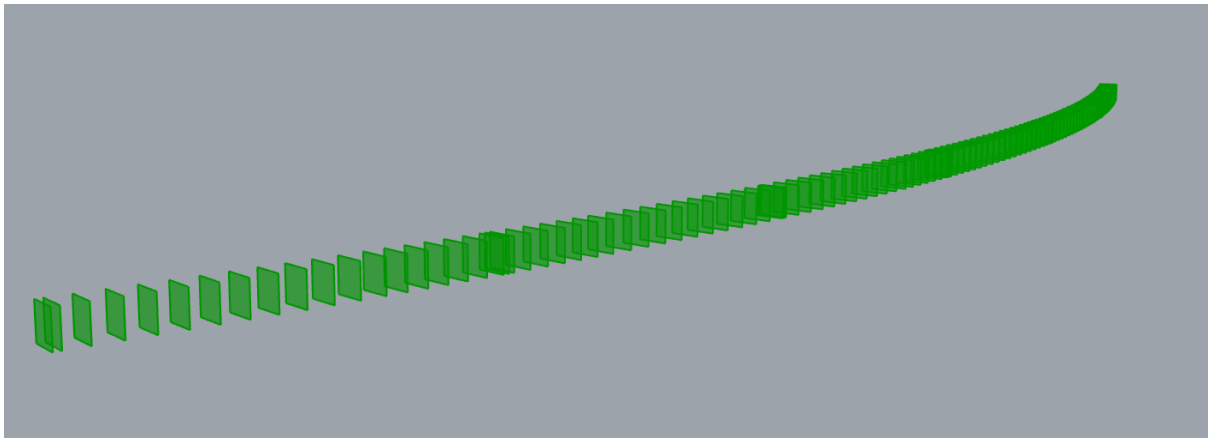


Figure 5. 29 point cloud Filtering box

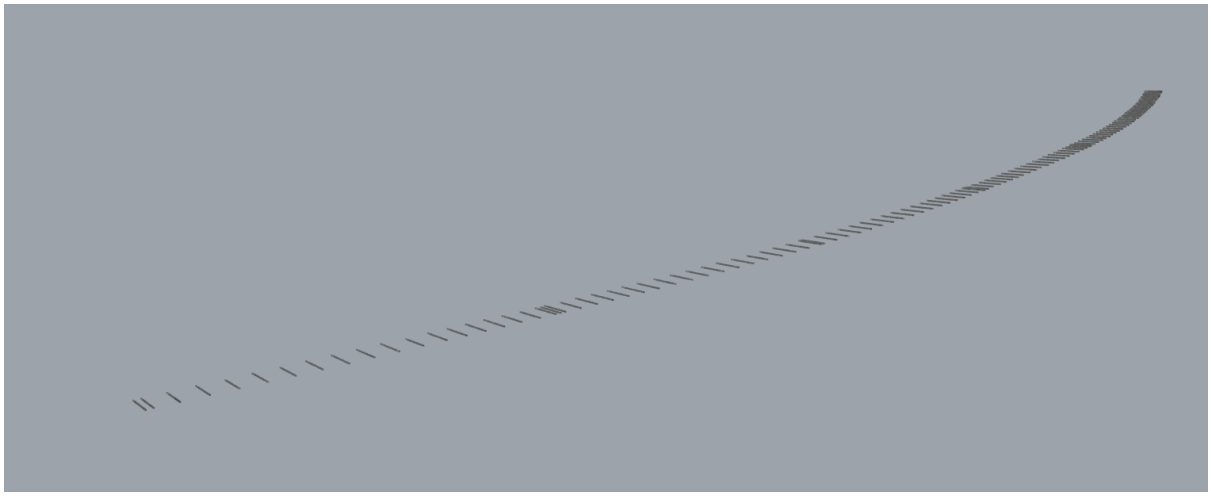


Figure 5. 30 Correct Altimetry

From this method we can extract the right altimetry of the bridge and give us the point cloud data only on the planes.

As you can see in the below picture the floor of the point cloud and the line which we created as different altimetry. Using the filtered data, we can determine the correct position

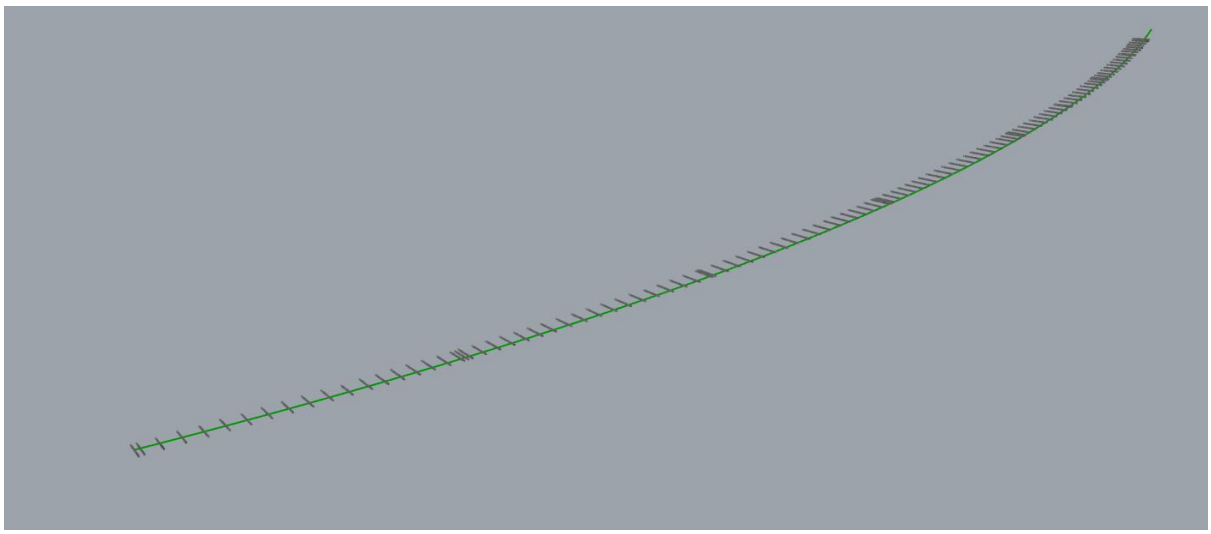


Figure 5. 31 Altimetry difference View 1

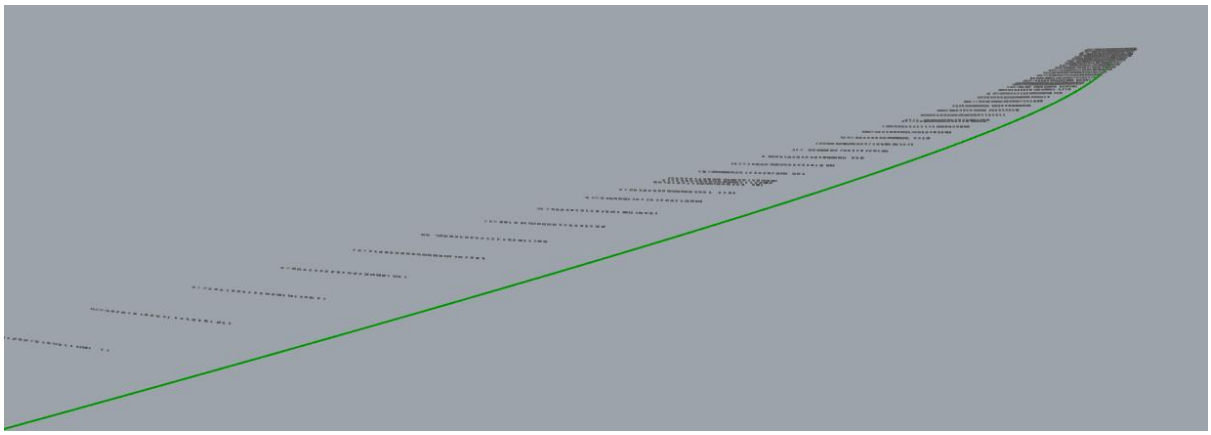


Figure 5. 32 Altimetry difference View 2

We can create an extrusion from the line that intersects with the cloud points to accurately determine the bridge's altimetry. By utilizing the central line derived from the point cloud data, we can extend this line vertically to form a solid extrusion that captures the relevant elevation data. As the extrusion interacts with the filtered point cloud, it identifies the intersecting points, which represent the exact altimetry of the bridge.

These intersection points provide critical information about the bridge's height and elevation at various segments along its span. By analysing these points, we can generate a detailed profile of the bridge's altimetry, ensuring that the design reflects the actual conditions of the site. This method not only enhances the accuracy of the bridge's vertical measurements but also facilitates further analysis, such as structural assessments and design optimizations, leading to a more reliable and effective bridge model.

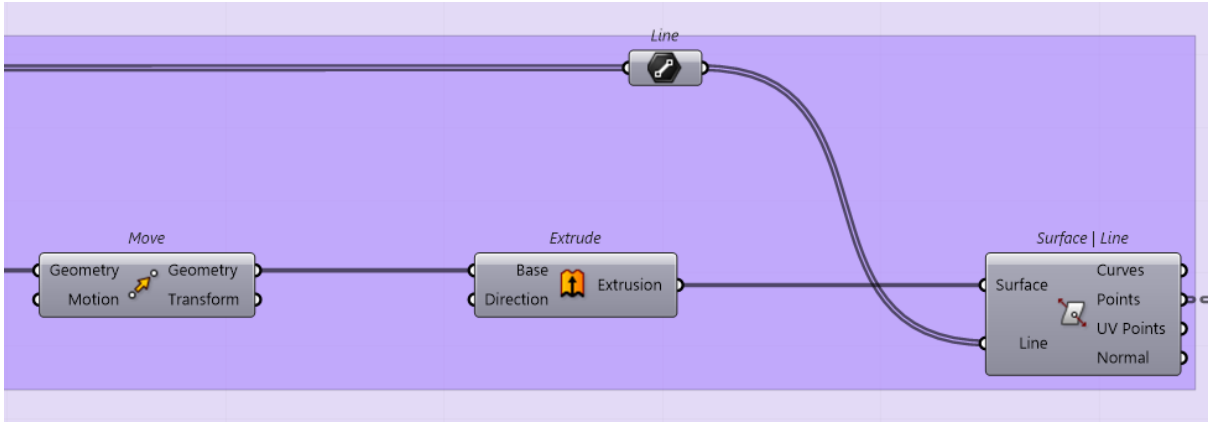


Figure 5. 33 GH "Surface Line" Component

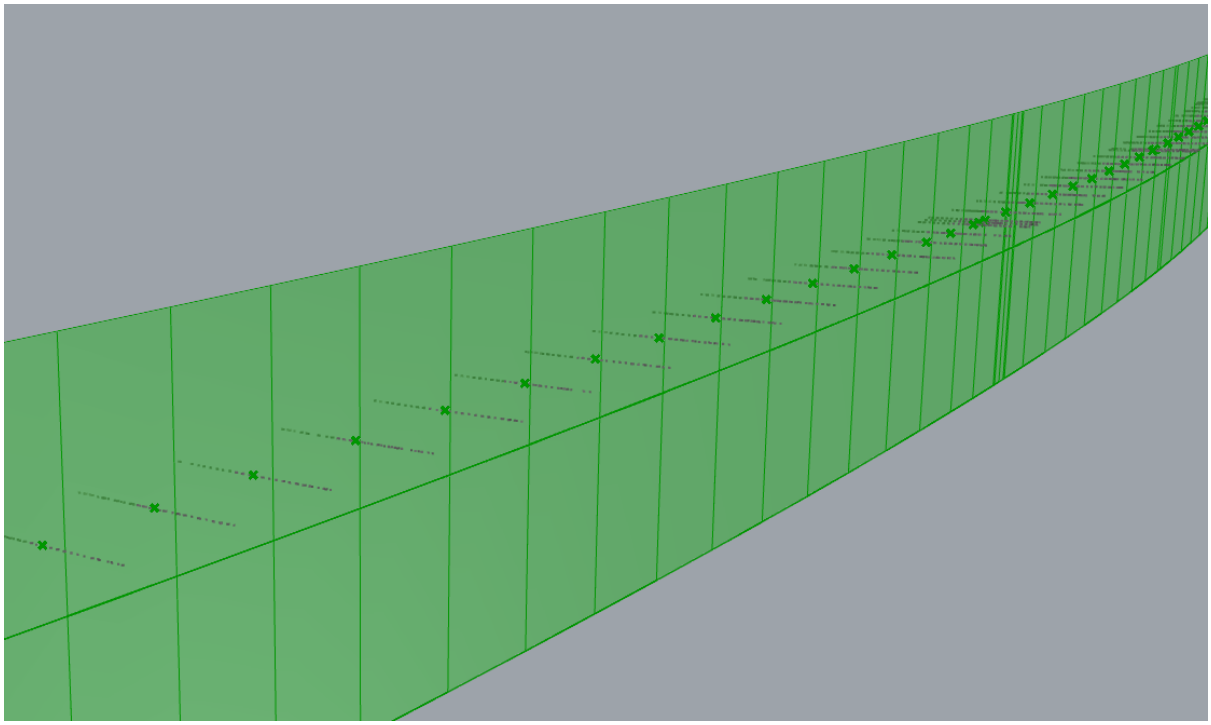


Figure 5. 34 Surface creating using line

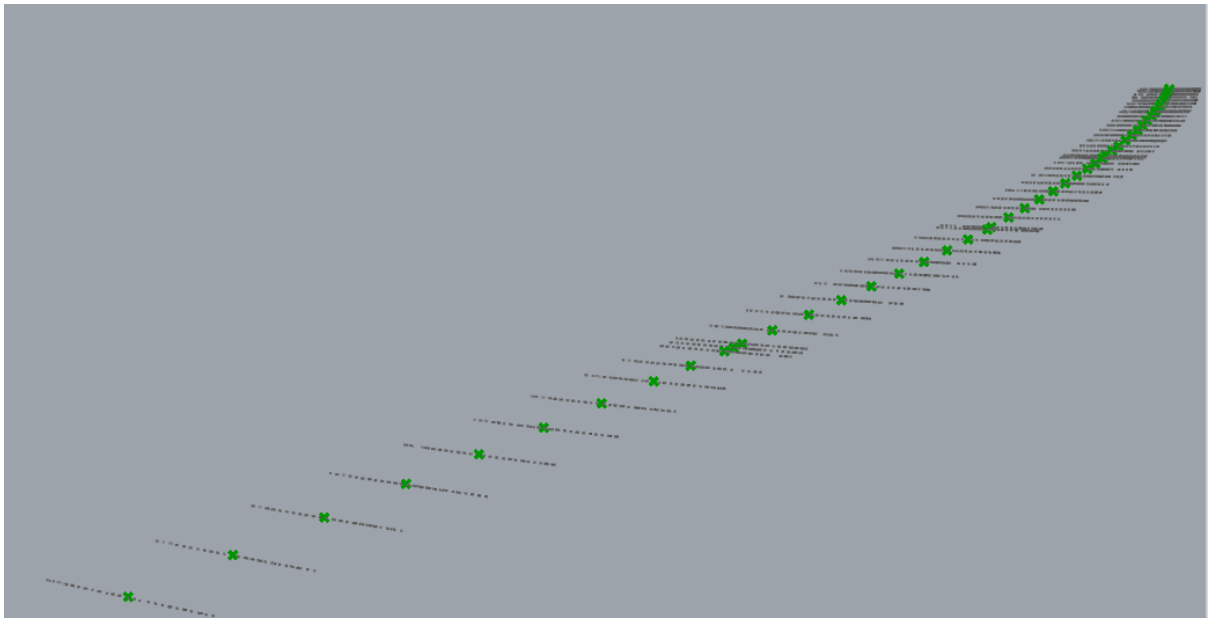


Figure 5. 35 Determining the point from surface

Using the filtered points from the point cloud, we can create a precise line that represents the final altimetry position of the bridge in Grasshopper. This process begins by analysing the cleaned point cloud data, which contains only the relevant points that accurately reflect the bridge's geometry. By connecting these points with a line, we establish a continuous representation of the bridge's elevation along its span.

Once the line is created, it can be used to generate a plane that aligns with the bridge's final position, providing a foundational reference for further modelling and analysis. This plane is essential for visualizing the bridge's height and ensuring that all subsequent design elements adhere to the correct altimetric position.

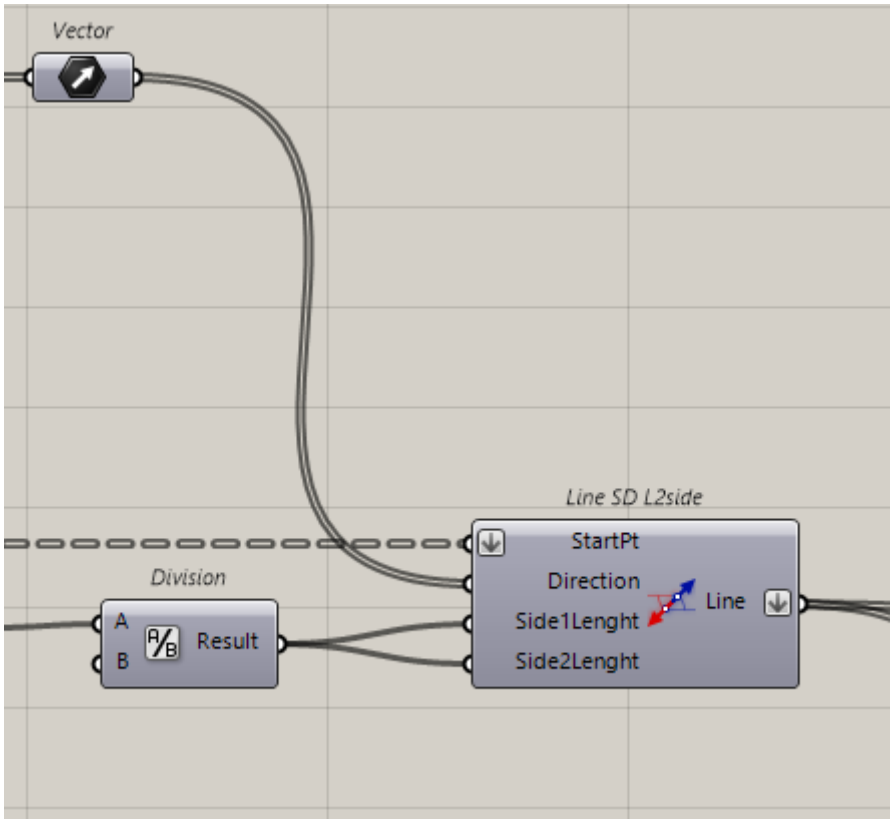


Figure 5. 36 GH "Line SD L2side" component

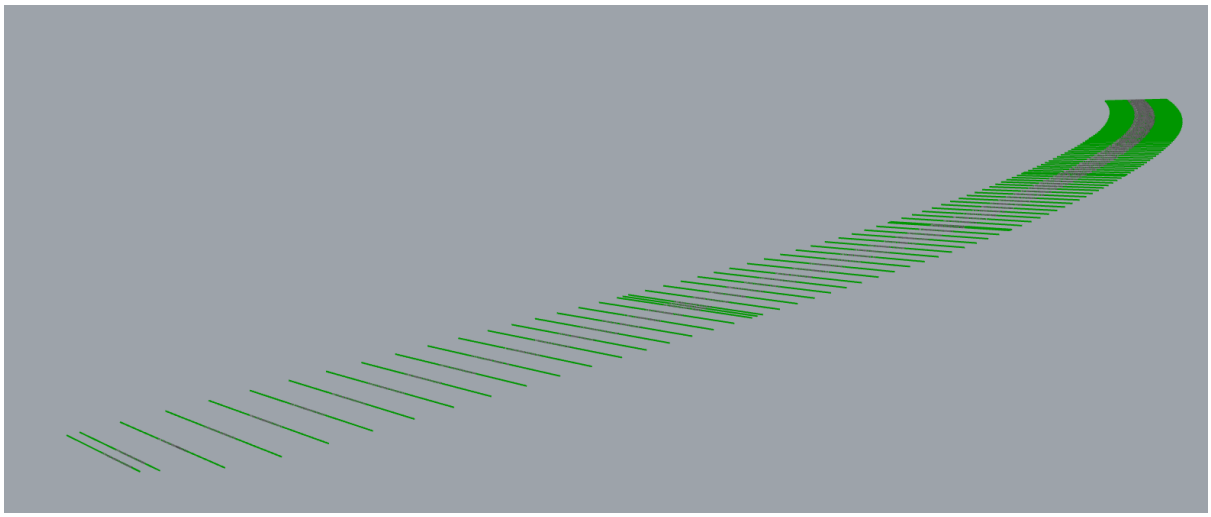


Figure 5. 37 Lines from Points

5.1.7. To determine the rotation of the bridge

5.1.7.1. Rotation Derived from point cloud data

With the straight line defining the altimetry position of the bridge, we can utilize the position points, and the Grasshopper component called "Angle" to determine the slope and orientation of the bridge structure. By selecting two or more position points along the line, the "Angle" component calculates the angle of inclination relative to a defined reference plane, such as the horizontal plane.

Once the angle is calculated, designers can analyse how variations in elevation along the bridge influence its overall geometry.

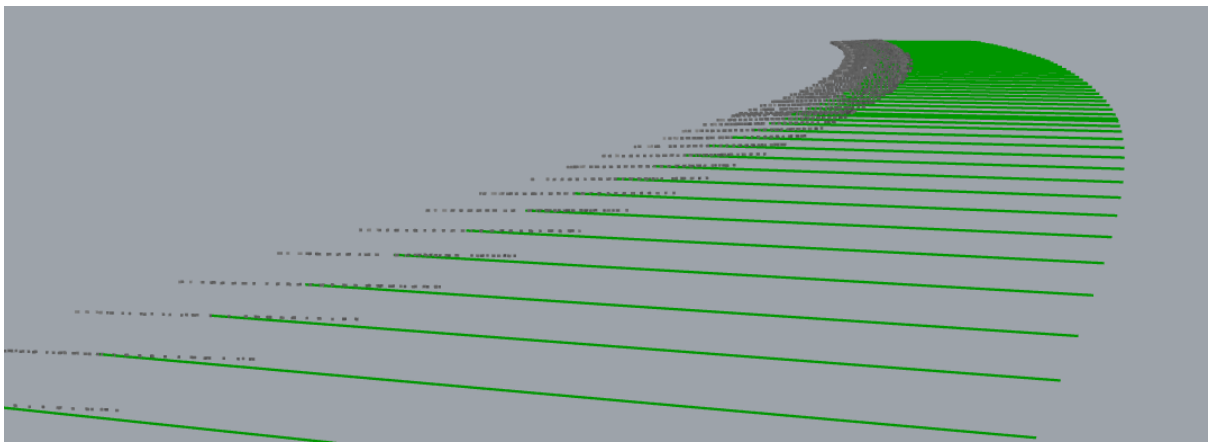


Figure 5. 38 Rotation differences

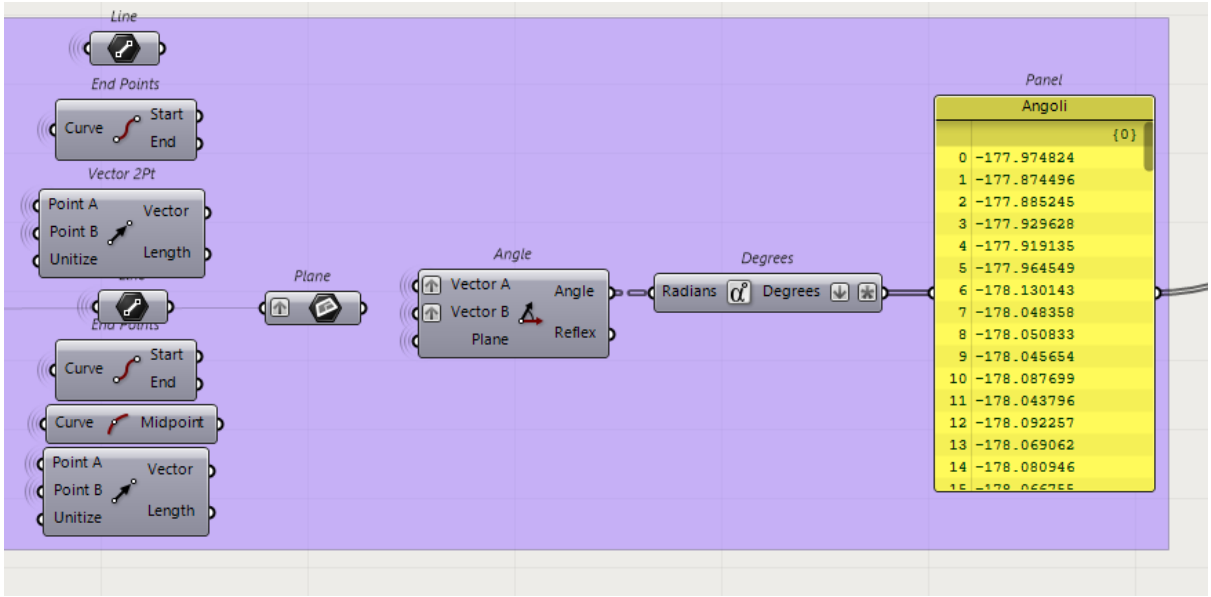


Figure 5. 39 Angle of the bridge

5.1.7.2. Rotation from Designs

This method gives an alternative way to create the bridge's rotation using input values. By utilizing a custom **cluster** in Grasshopper, we can generate both the bridge geometry and its corresponding rotation.

The geometry for each cross section is created using data from an Excel file, where I have modeled 120 cross sections for the bridge. When the rotation for each cross section is known such as 120 distinct angles each angle is applied to its corresponding cross section.

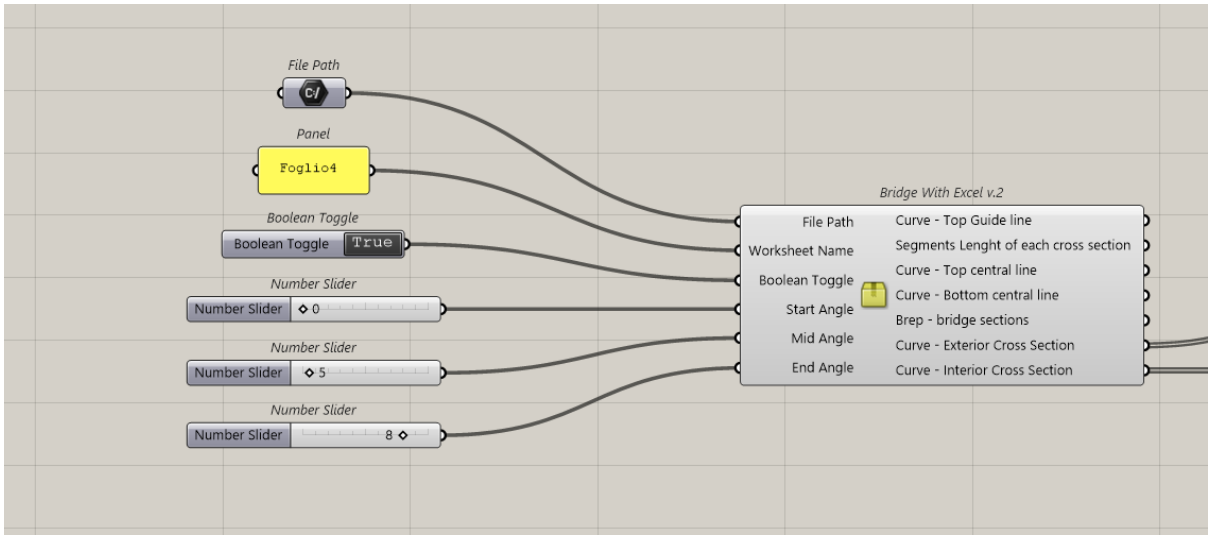


Figure 5. 40 Cluster to determine the angle

The relationship between the 120 cross sections and the 120 angles must be mapped accurately, ensuring that each cross section receives the correct rotation angle. If the angle changes linearly, for example, starting at 0 degrees at the beginning of the bridge, increasing to 5 degrees at the midpoint, and reaching 8 degrees at the end,

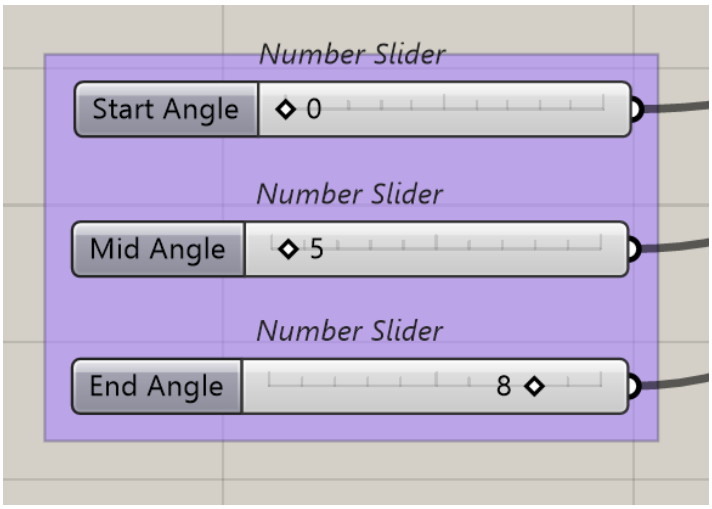


Figure 5. 41 Angle Inputs

Grasshopper will automatically calculate the intermediate angles. This interpolation ensures that the angles are distributed evenly across the entire span of the bridge.

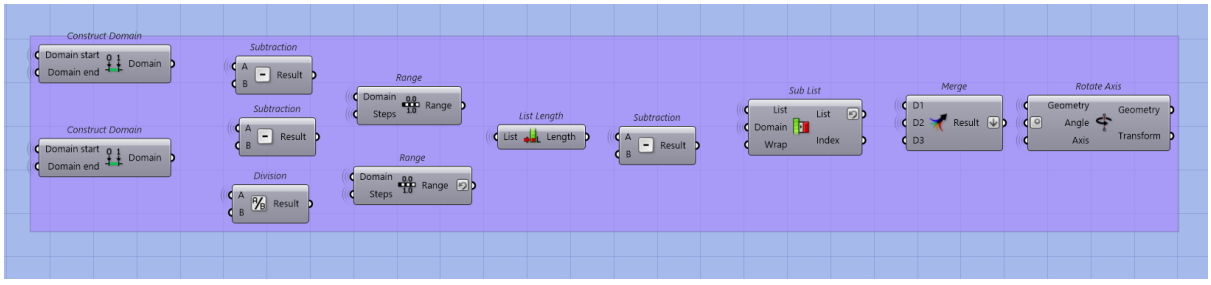


Figure 5. 42 GH script to determine the angle

By leveraging this method, the rotation of the bridge is applied systematically, making it ideal for scenarios where the rotation follows a predictable pattern. This automated process simplifies the modeling of the bridge's complex geometry and the structure remains consistent with the intended design, especially when dealing with large numbers of cross sections and rotations.

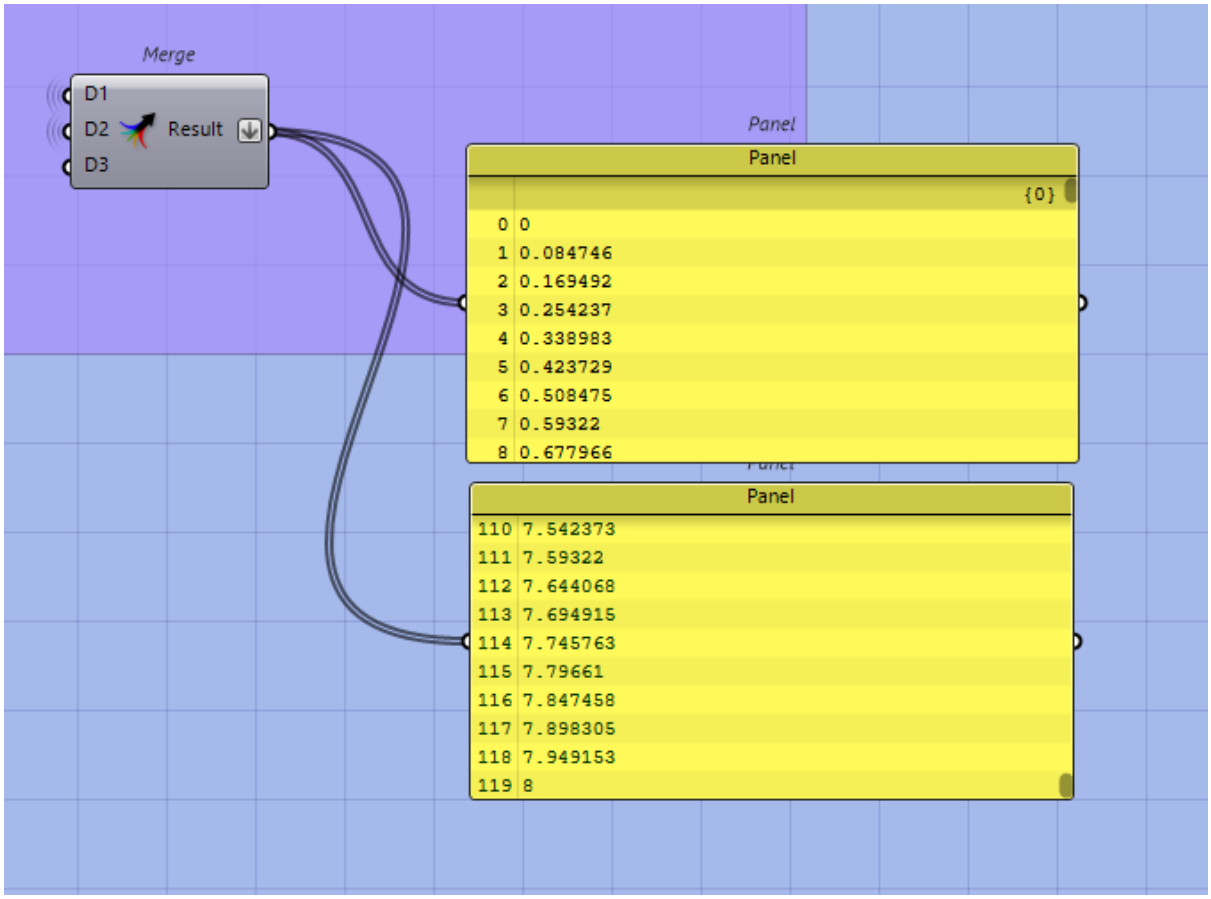


Figure 5. 43 linearity of the angle inputs

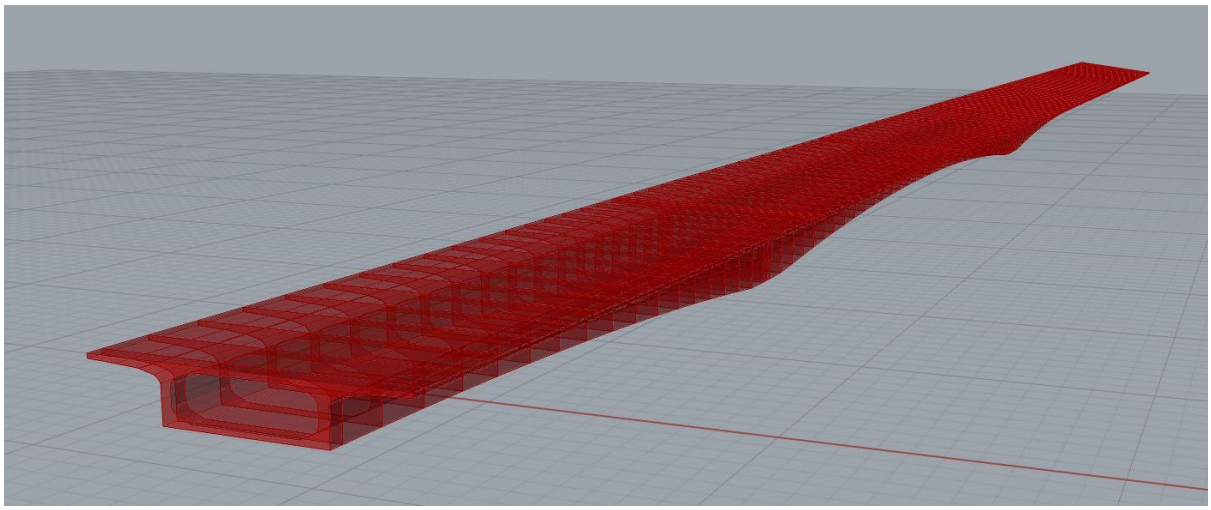


Figure 5. 44 Final bridge geometry with angle inputs

The result is a smooth, well-rotated bridge model that accurately reflects both the geometry and the required rotational adjustments for each section.

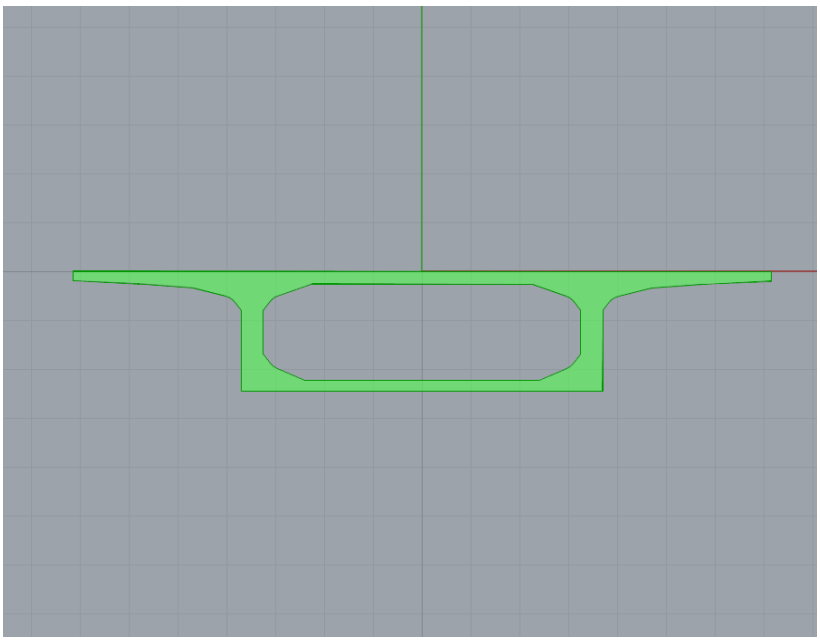


Figure 5. 45 First Cross Section

As shown in the above picture, this is the first cross section of the bridge, where the angle is set to 0 degrees. The shape of the geometry has been perfectly automated using data from the Excel file.

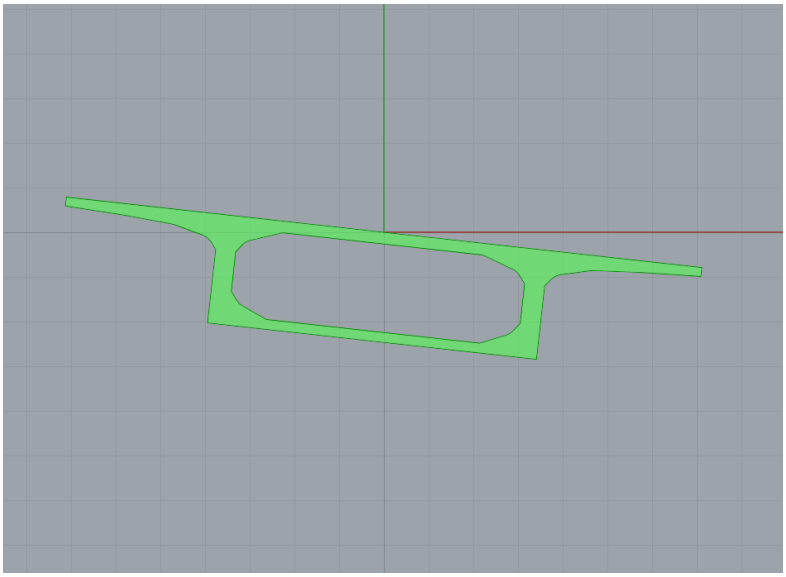


Figure 5. 46 Final Cross Section

As shown in the above picture, this is the last cross section of the bridge, where the angle is set to 8 degrees.

Here I give another example for the rotation of the bridge. In the first example I gave the angle starts 0, mid angle 5 and end angle is 8 degrees. In this example, I gave the angle input starts

in 3, mid angle 8 and end angle is 7 degrees. To create the linear automation of angle throughout the bridge sections.

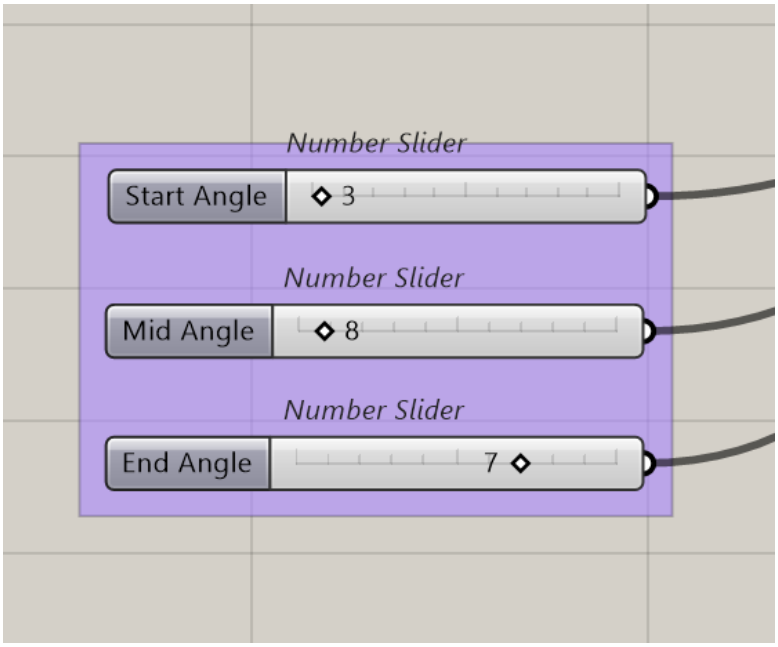


Figure 5. 47 Different angle inputs

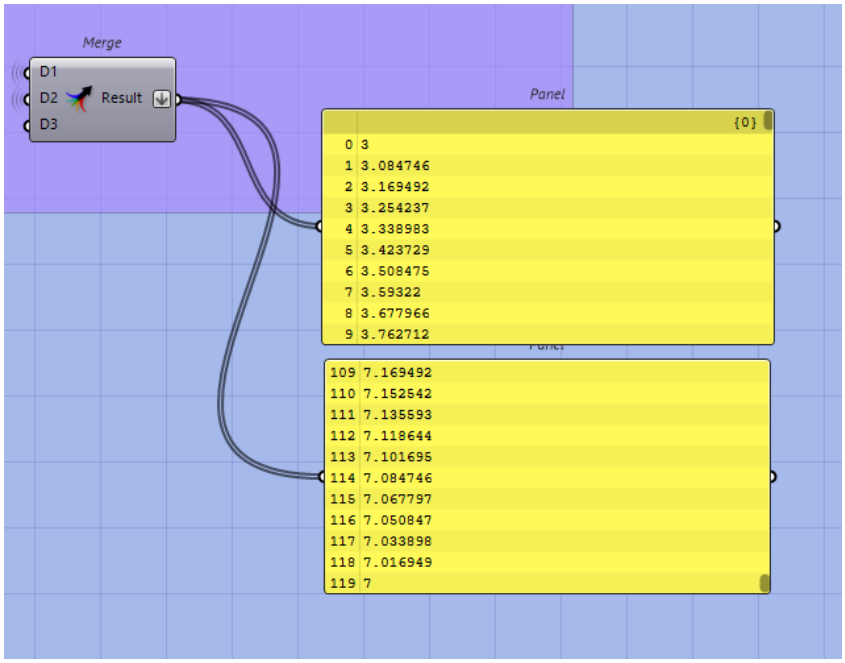


Figure 5. 48 Angle outputs

From the result of various input, we can determine the angle along the bridge cross section. Below the image can examine the position of the geometry

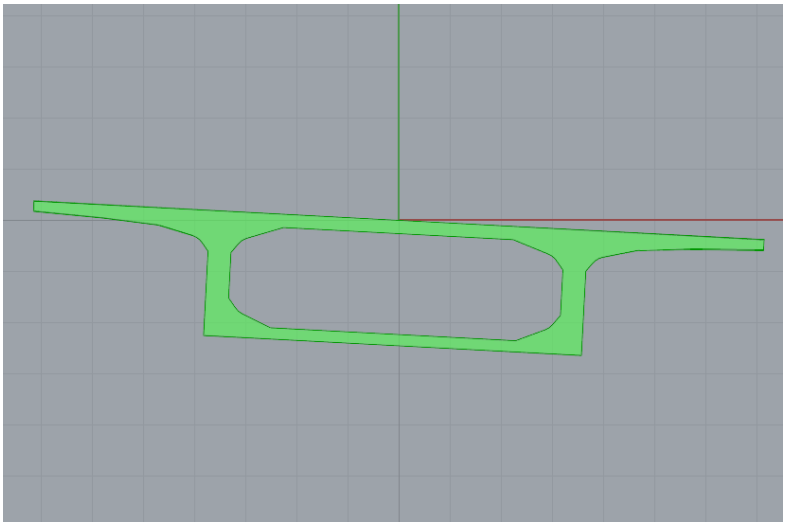


Figure 5. 49 First Cross Section

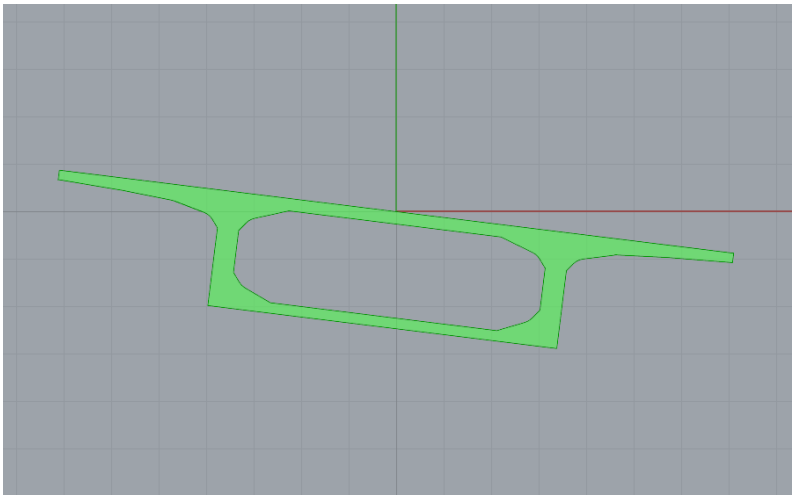


Figure 5. 50 Final Cross Section

5.1.8. Geometry of the bridge

Now that we have established the origin plan, which contains the geometry of the bridge cross sections, and identified the destination plane with the correct altimetry and rotation, we can seamlessly transfer the bridge geometry using the Grasshopper component called "Orient." This component is instrumental in positioning the cross-sectional geometry accurately within the 3D space.

To utilize the **"Orient"** component effectively, we first define the source geometry—essentially the bridge cross section from the origin plan. Next, we specify the destination plane that represents the intended location and orientation of the bridge in its final position. The **"Orient"** component uses the defined planes to calculate the necessary transformations, including translation, rotation, and scaling, ensuring that the geometry aligns perfectly with the new location.

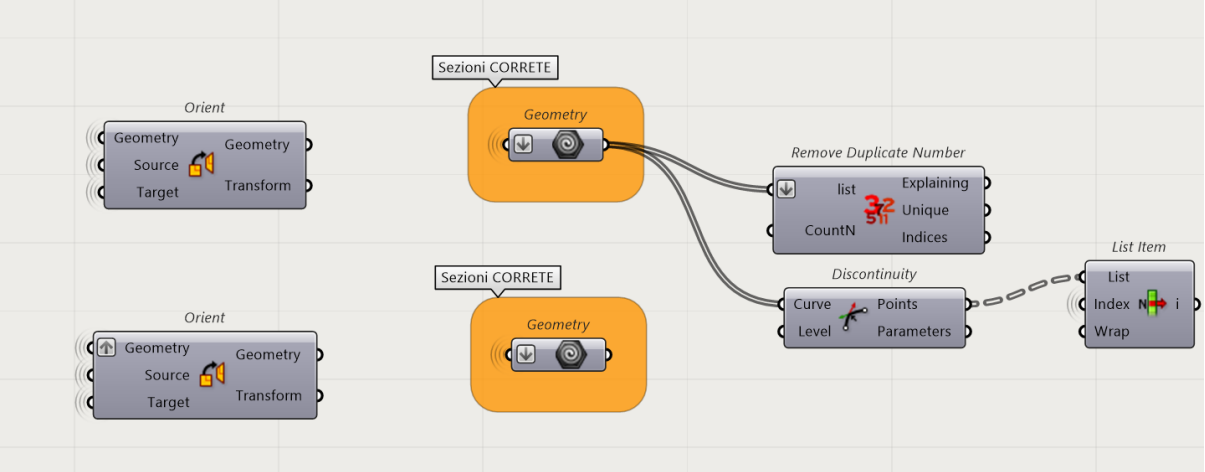


Figure 5. 51 Bridge orientation

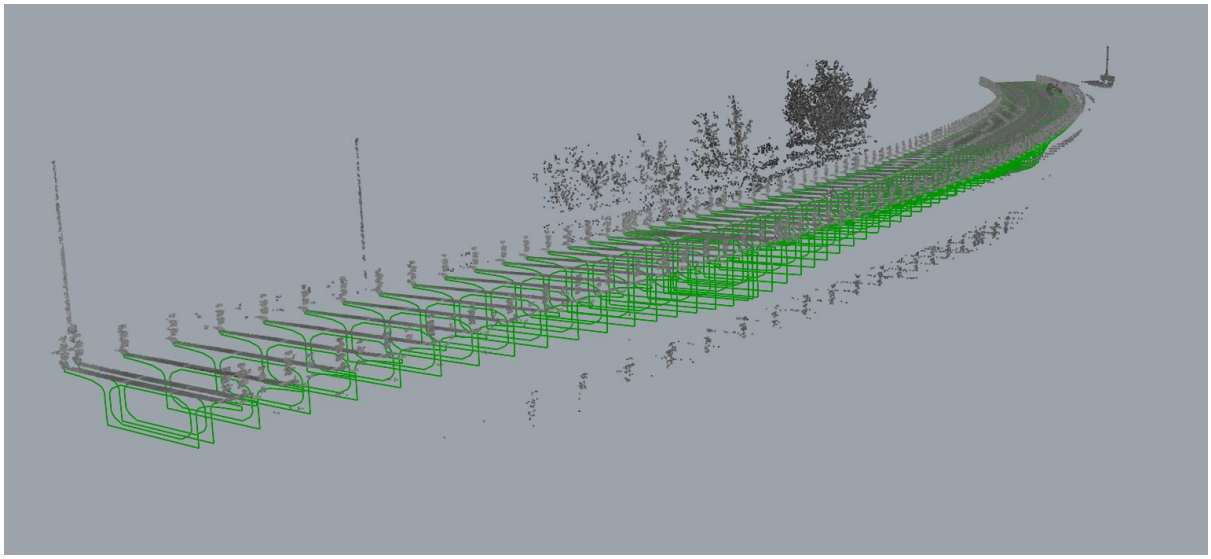


Figure 5. 52 Final position of Bridge geometry

5.1.9. Solid formation of bridge

The component called “Cull Index” in grasshopper used to make the loop of every two cross section to make the loft of each two cross sections of the bridge. And another component called “Cap Hole” is used to close the loft according to the geometry structures.

In Grasshopper, the **"Cull Index"** component plays a crucial role in simplifying complex geometries, particularly when working with a series of cross sections for a bridge. This component allows us to selectively remove or isolate elements in a list, such as alternating cross sections. By using **"Cull Index"** to loop through every two consecutive cross sections, we can pair them to create loft surfaces between each pair. The **lofting** process generates smooth surfaces between the cross sections, effectively forming the body of the bridge based on the structural profiles at different intervals.

After generating the loft between each pair of cross sections, we can use the **"Cap Holes"** component to close the open ends of the lofted geometry. This is particularly useful for

ensuring the integrity of the model by capping any holes that result from the lofting process, such as the ends of the bridge structure. The **"Cap Holes"** component works by sealing these open edges, giving the bridge model a solid, watertight form that accurately represents the physical structure.



Figure 5. 53 GH Script for Solid Formation of Bridge

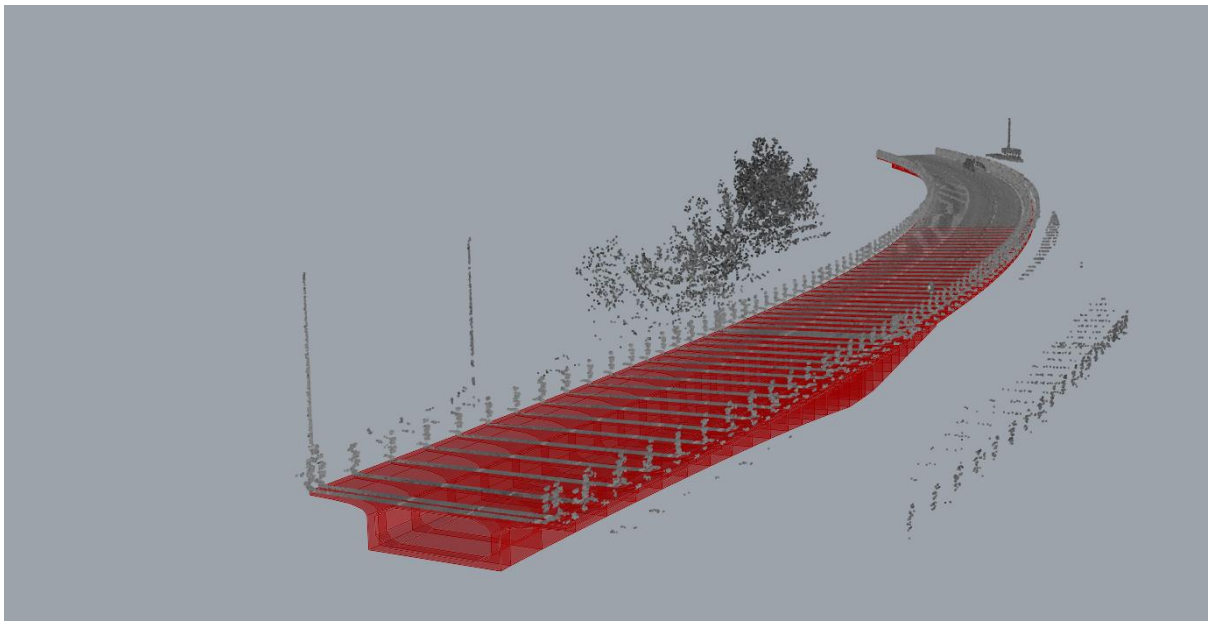


Figure 5. 54 Solid Bridge geometry

CHAPTER 5

6. Revit Interoperability and BIM model

6.1. Methodology

After creating the bridge model in Rhino using Grasshopper, the next step is to integrate this design into a Building Information Modelling (BIM) workflow using Rhino.Inside Revit. Rhino.Inside Revit is a powerful tool that allows for ideal interoperability between Rhino, Grasshopper, and Autodesk Revit. This integration enables to transfer complex geometry, such as the bridge model, from Rhino into Revit's BIM environment.

To begin the process, the Rhino bridge model is linked to Revit using Rhino.Inside. This tool converts the geometry into native Revit elements, such as walls, floors, or structural elements, depending on the bridge's design components. Through this process, the parametric and flexible nature of the Grasshopper-generated model is preserved while being transformed into a fully detailed BIM model that meets standards.

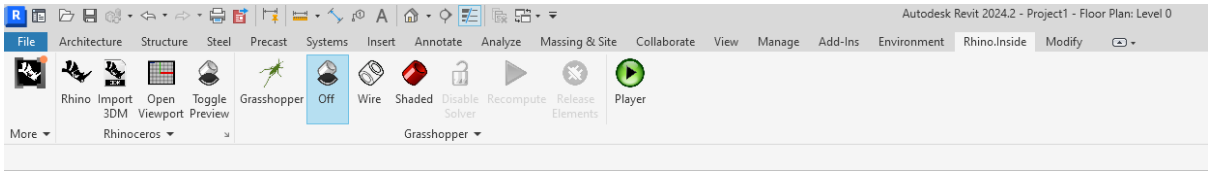


Figure 6. 1 Rhino Inside Revit

Rhino.Inside is a plugin we can download it for free. And we can open the rhino and grasshopper directly in Revit software.



Figure 6. 2 Rhino Inside Revit Components

Grasshopper's integration with Revit through **Rhino.Inside Revit** provides access to every Revit component, allowing manipulation of BIM elements within the Grasshopper environment. With this integration, parametric design workflows can drive Revit geometry and data, making it easier to automate complex tasks, maintain precision, and ensure that the design remains coordinated with Revit's BIM framework.

Once inside Revit, the bridge model can be further refined and integrated with other project data, such as terrain models, roads, and utility networks. Additionally, Revit's BIM capabilities

enable the inclusion of critical information like materials, structural specifications, and construction sequencing. By using Rhino.Inside Revit, the bridge design transitions from a conceptual model to a fully realized BIM model, allowing for accurate visualization, coordination, and planning in the construction.

6.1.1. Solid Geometry

We can import eh shape of the geometry as a line inside Revit from grasshopper. To perform this process GH component called “AddDirectShape (Curve)” is used.

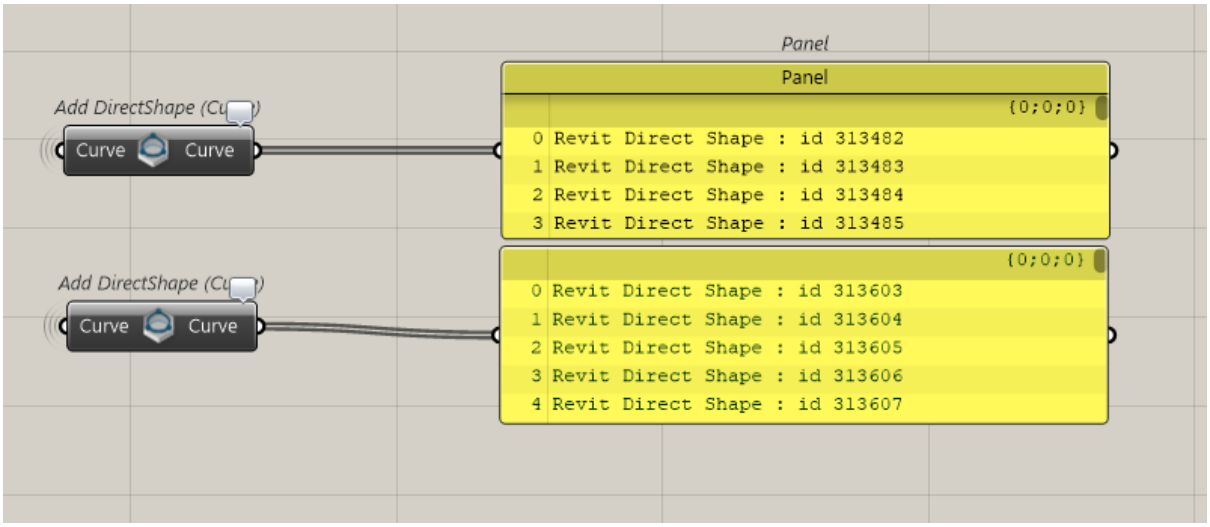


Figure 6. 3 GH Component for Curve

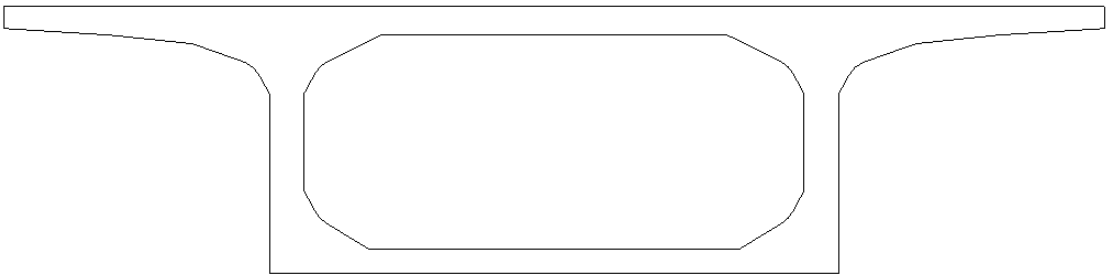


Figure 6. 4 Curve Inside Revit

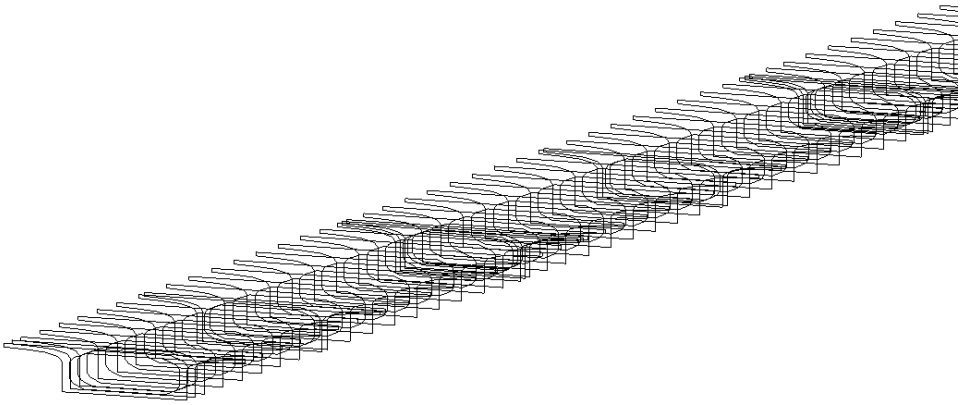


Figure 6. 5 Multiple Curve Inside Revit

Using a Grasshopper script, we created the complex geometry of the bridge, which was then imported into Revit. This process was facilitated by a Grasshopper component called "AddDirectShape (Brep)".

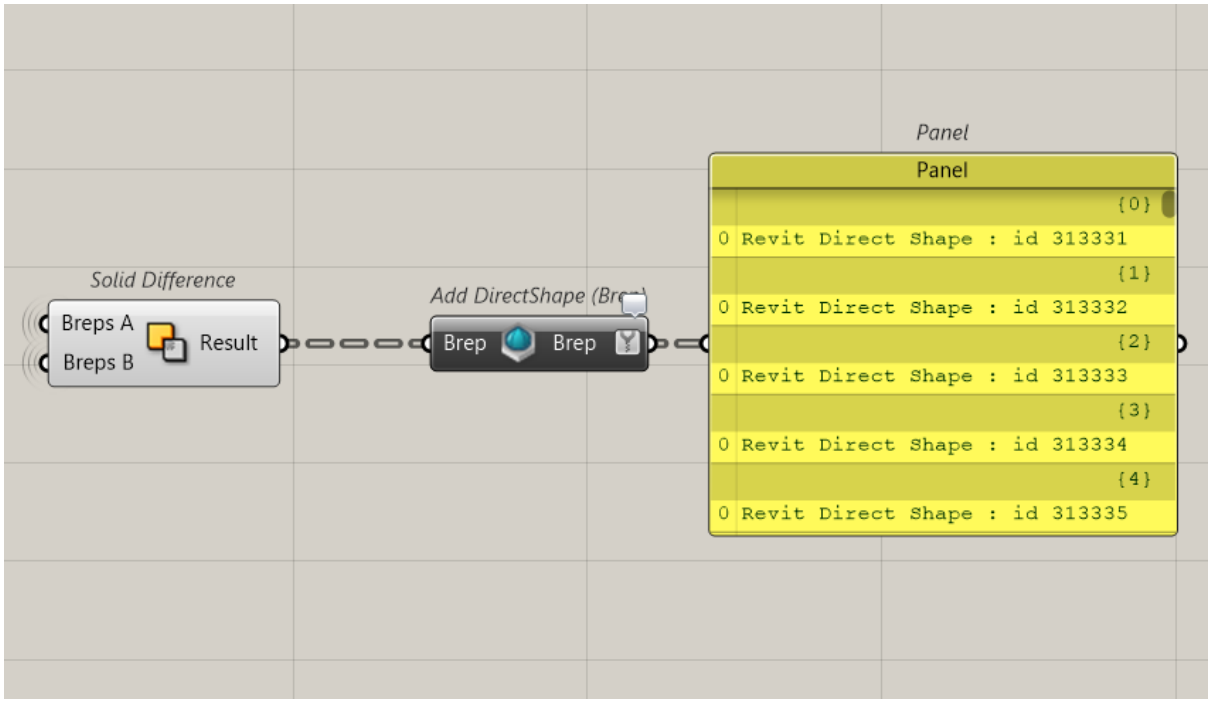


Figure 6. 6 GH Component for Solid Geometry

This component takes the solid geometry generated in Grasshopper and transfers it directly to Revit, enabling integration between the two platforms.

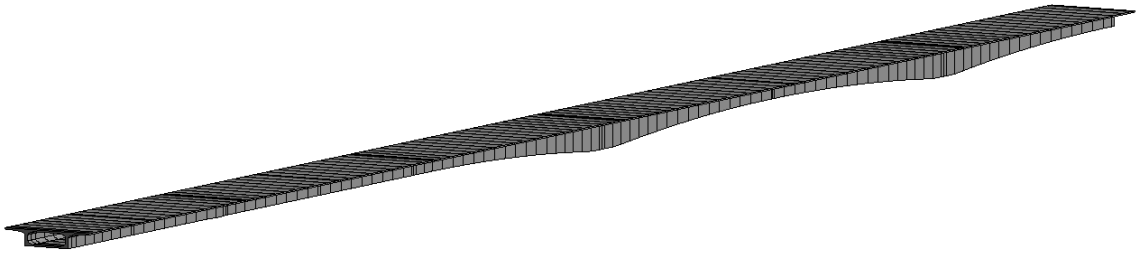


Figure 6. 7 Bridge Geometry in Revit (View 1)

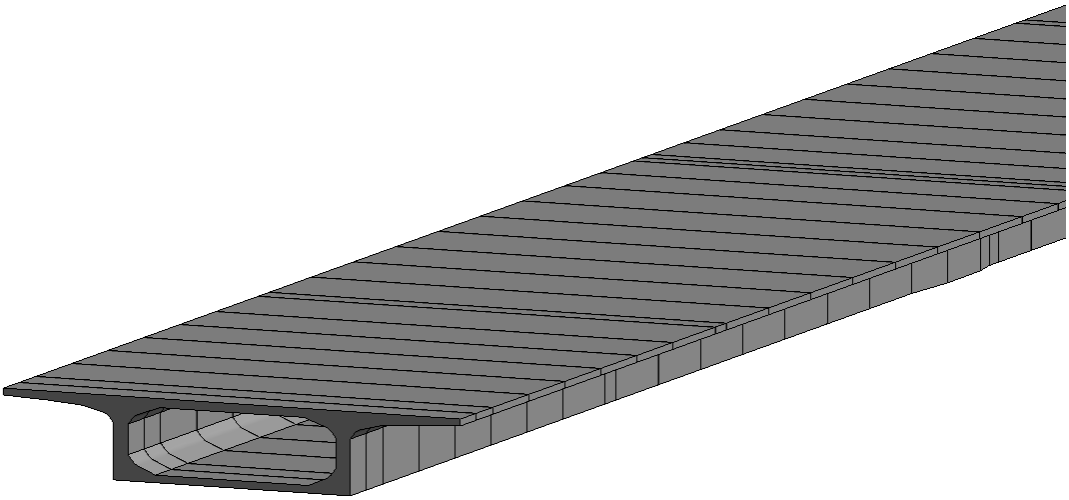


Figure 6. 8 Bridge Geometry in Revit (View 2)

While this method is effective for importing geometries into Revit, it has a significant limitation: the geometry cannot be edited directly within Revit. As a result, any future modifications to the model would require Grasshopper to adjust, rather than performing the changes directly in Revit. This limitation can pose challenges in terms of workflow efficiency, especially when multiple revisions are needed. In such cases, designers must return to Grasshopper for modifications.

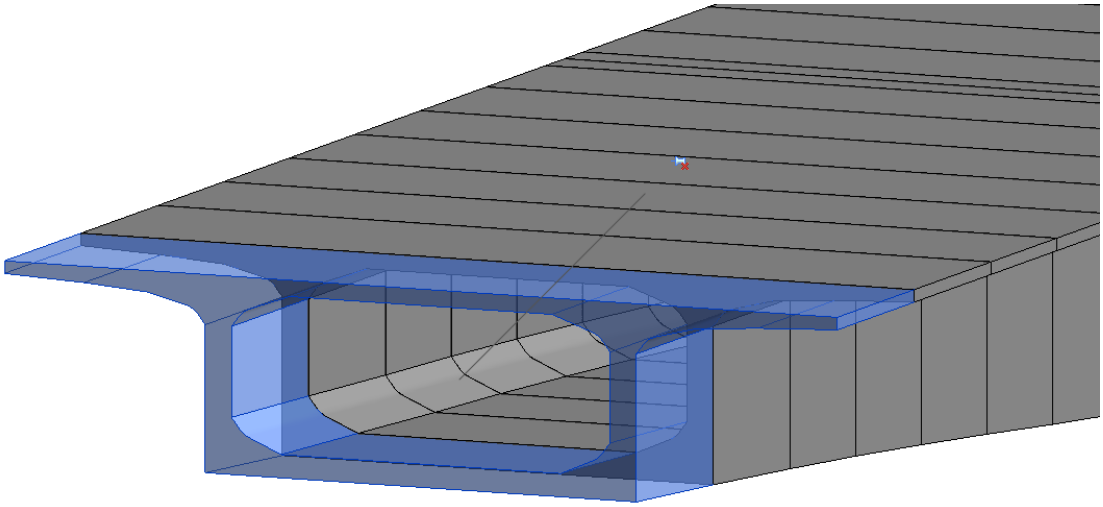


Figure 6. 9 Non-Modifiable elements

While this process ensures that the geometry remains accurate, it adds complexity to the revision process. Future improvements could focus on enhancing the ability to edit geometries within Revit or exploring better integration between Grasshopper and Revit for easier model adjustments and flexibility in future revisions.

6.1.2. Adaptive Family of Geometry

Adaptive families in Revit are highly versatile and powerful tools for modelling complex structures, particularly for intricate designs like bridges. These families allow for the creation of geometry that adapts to flexible points placed in the Revit model. Unlike traditional Revit families, adaptive families can adjust their shape and size dynamically based on the placement of key points, making them ideal for creating non-linear or irregular forms common in bridge design.

For complex bridge structures, adaptive families can accommodate varying cross sections, curves, and slopes by adjusting to the geometry's changing conditions. For instance, if a bridge has varying widths, elevations, or angles along its span, adaptive families will reshape accordingly as you move and place the adaptive points along the path. This flexibility allows for precise modelling that responds to the specific design needs of a bridge.

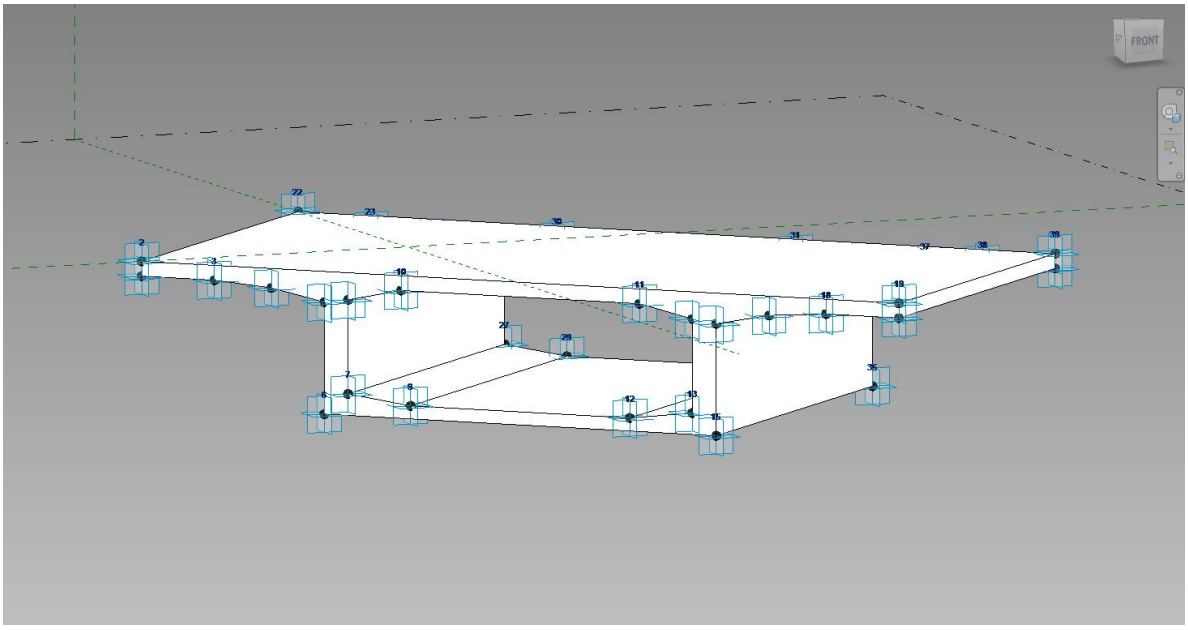


Figure 6. 10 Adaptive Family

As you can see in the above picture the adaptive family of the bridge has been created with points. Basically, I have created the cross section of the bridge with “24 Points”. Which means the dimensions and the position of the cross sections must need to be in perfect shape. So, each point indicates the position and moving the points create the complex geometry which can also editable.

For making the extrusion, two cross sections of the bridge have been made with “48 points”. This can bring the complex geometry of the bridge. After defining the adaptive family we have to load them to the model file, in this case we can be able to access the family in grasshopper.

6.1.3. Adaptative Component in Grasshopper

Each bridge cross section consists of 24 points that define its geometry. In Grasshopper, the points are indexed starting from zero, while in Revit, the points in adaptive families are numbered starting from one. To create a connection between Grasshopper and Revit, it is crucial to understand how the points are ordered in both platforms and ensure consistency when working between them.

Using the **Point List** component in Grasshopper, we can visualize the order of the 24 points in the cross section. Since Grasshopper’s numbering begins at zero, the first point is labelled as 0, the second as 1, and so on, up to 23 for the 24th point. In contrast, Revit’s adaptive families start numbering from 1, so the first point is 1, the second is 2, and the 24th is 24.

When creating the adaptive family for the bridge cross section in Revit, we need to ensure that the point numbers correspond to those generated in Grasshopper. This requires carefully cross-referencing the point numbers between Grasshopper and Revit to ensure that the positioning of points aligns correctly. Although the point numbers in Revit can be edited to match the Grasshopper numbering scheme, Grasshopper’s point order cannot be altered.

Therefore, it is essential to follow Grasshopper's point order when assigning points in Revit. This step ensures the bridge cross section is accurately modelled and behaves as intended when changes are made in the parametric Grasshopper model.

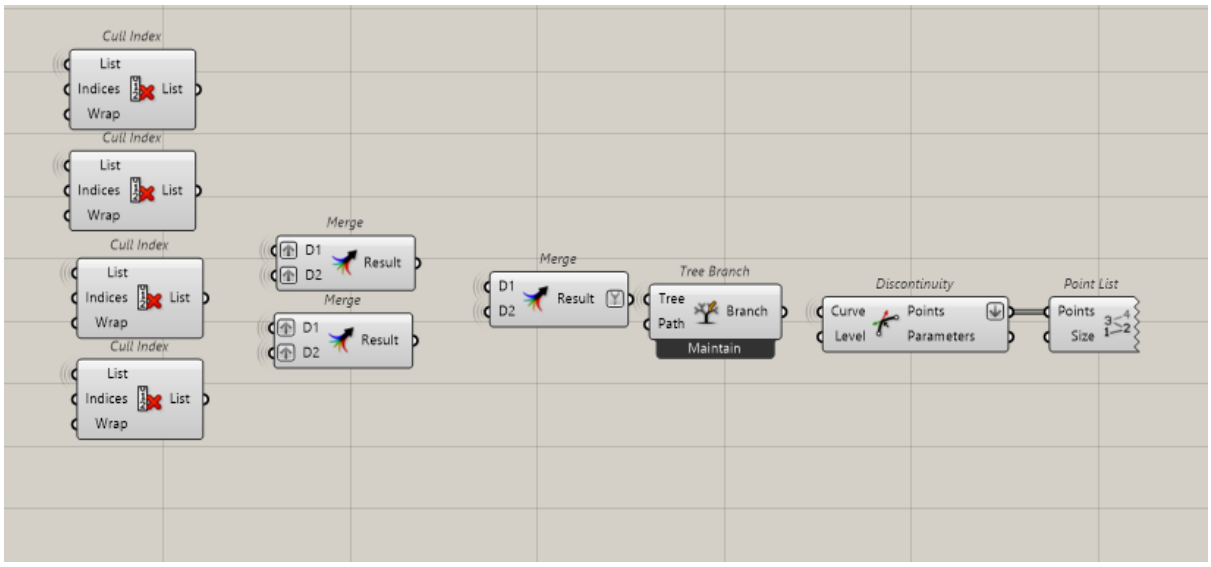


Figure 6. 11 creating the List of points

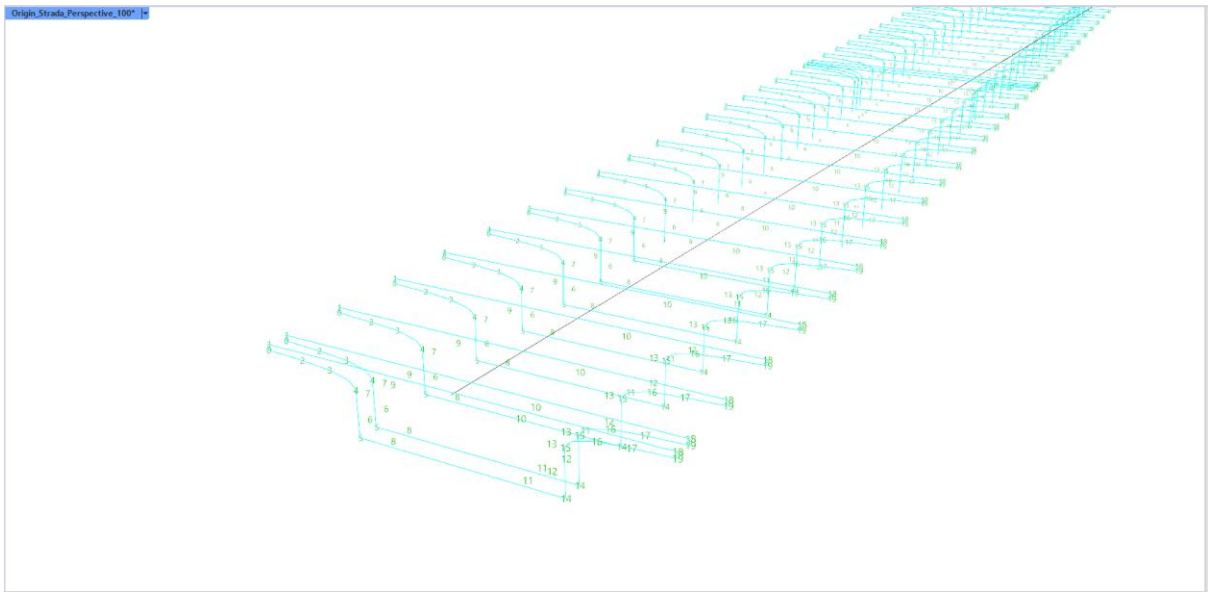


Figure 6. 12 List of points

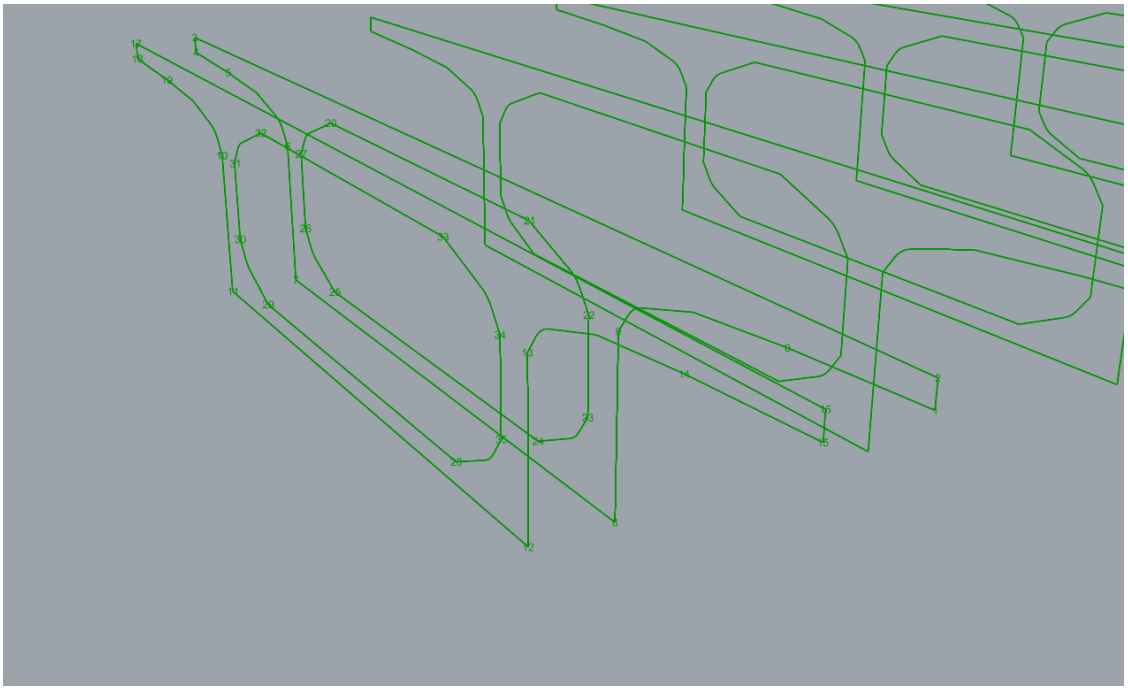


Figure 6. 13 Segment of the list of points

After defining the points for each bridge cross section in Grasshopper, the next step involves assigning the appropriate adaptive family in Revit. This is done using the **"Type"** component in Grasshopper, which allows you to select and apply a specific family type from Revit's adaptive geometry options.

Once the points for each cross section are positioned correctly, the **"Type"** component helps in choosing the desired family that will form the adaptive geometry for the bridge structure. The adaptive family in Revit is crucial because it adjusts its form based on the placement and connection of these points, making it ideal for handling the complex, variable geometry of a bridge.

By linking Grasshopper to Revit through the **"Type"** component, you can easily manage the transition from a parametric model to a fully functional BIM model in Revit.

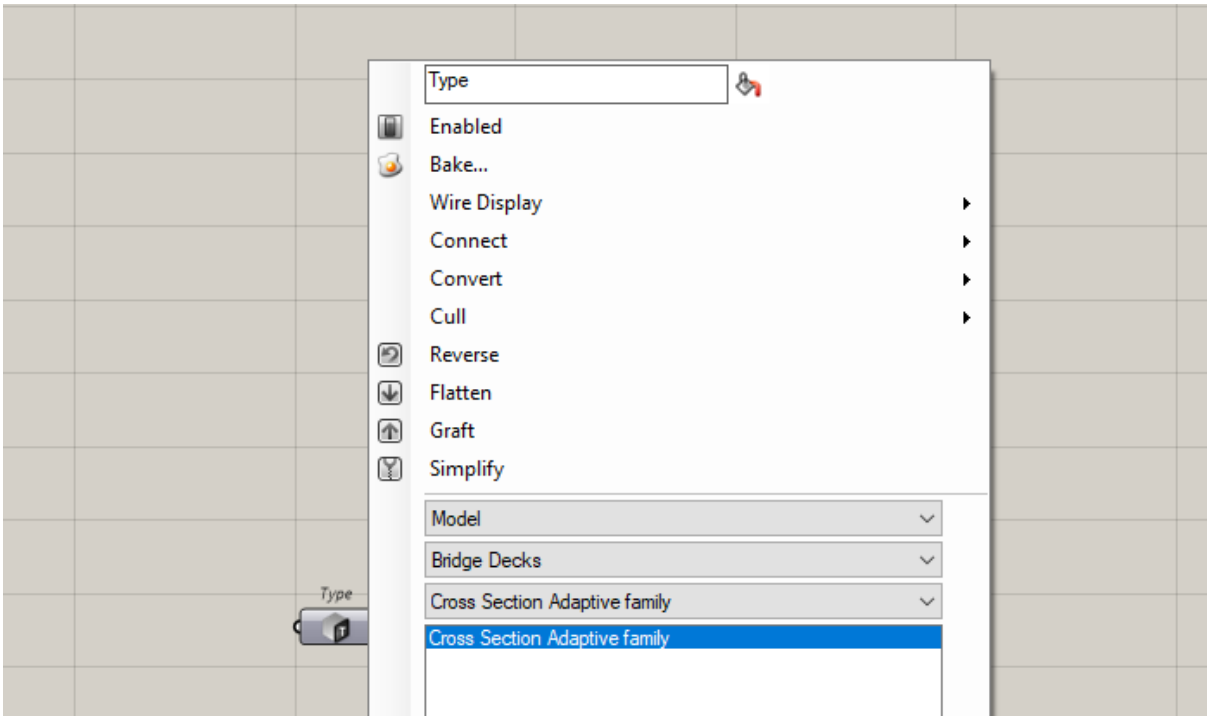


Figure 6. 14 Selection of Family in GH

Once the points are correctly aligned, we use the **"Type"** input to select the corresponding family from Revit's adaptive families. This family type governs how the geometry behaves and adapts as the points are manipulated.

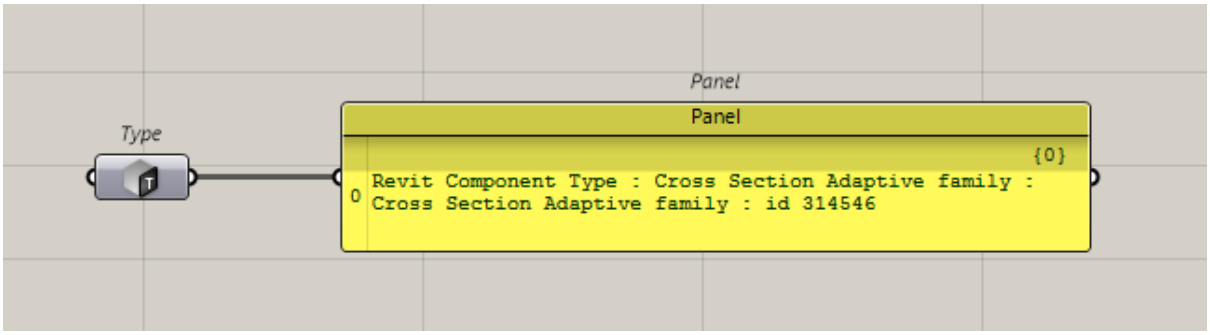


Figure 6. 15 Adaptive Family output

By adding the cross-section points and the family type, we can effectively create the BIM model of the bridge using Grasshopper's adaptive component. By serving as a link between the parametric design tools in Grasshopper and the BIM environment in Revit, the adaptive component makes it possible to create complex, flexible geometries that change dynamically in response to point data.

As the adaptive component processes both the point input and family type, it generates the BIM geometry of the bridge directly in Revit. The benefit of this method is that any changes to the points or family type in Grasshopper automatically update the Revit model, ensuring a dynamic and flexible workflow.

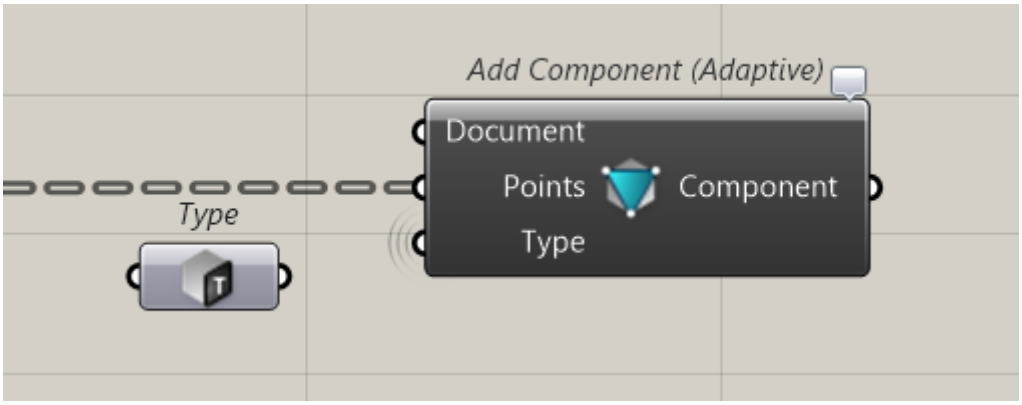


Figure 6. 16 Add Component (Adaptive)

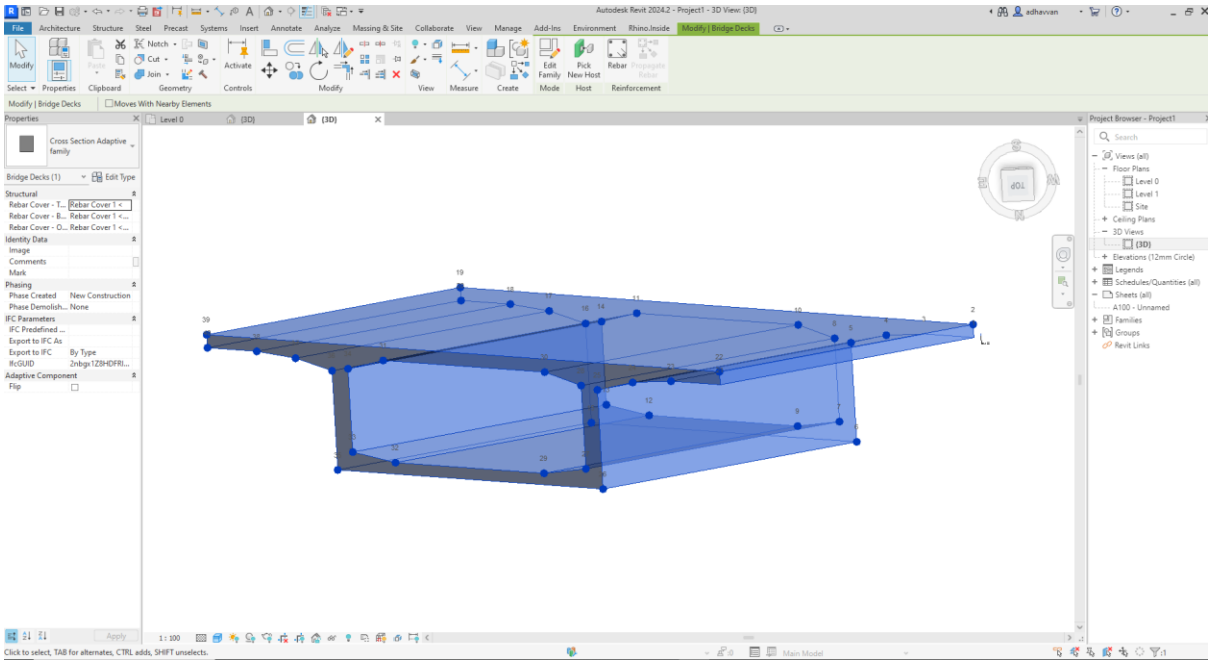


Figure 6. 17 Adaptive Family in Revit

When we connect all the points of cross section to the “Adaptive component” and its adaptive family type we can create the BIM model of bridge in Revit. This process is totally about automation, accuracy, time saving and easy to connect the bridge geometry software between grasshopper and Revit.

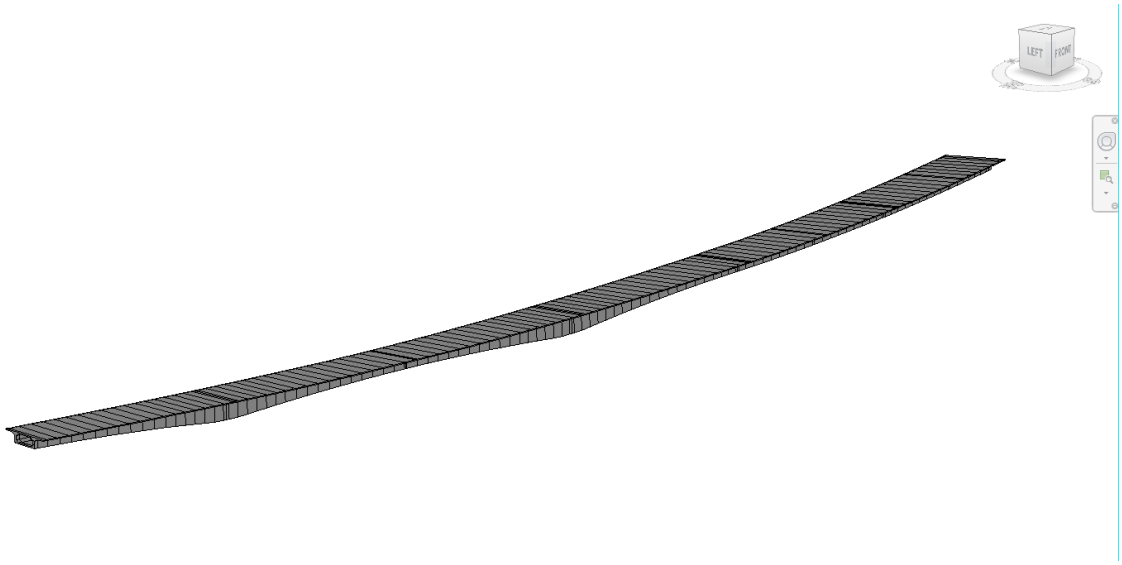


Figure 6. 18 Final Geometry of Bridge in Revit (View 1)

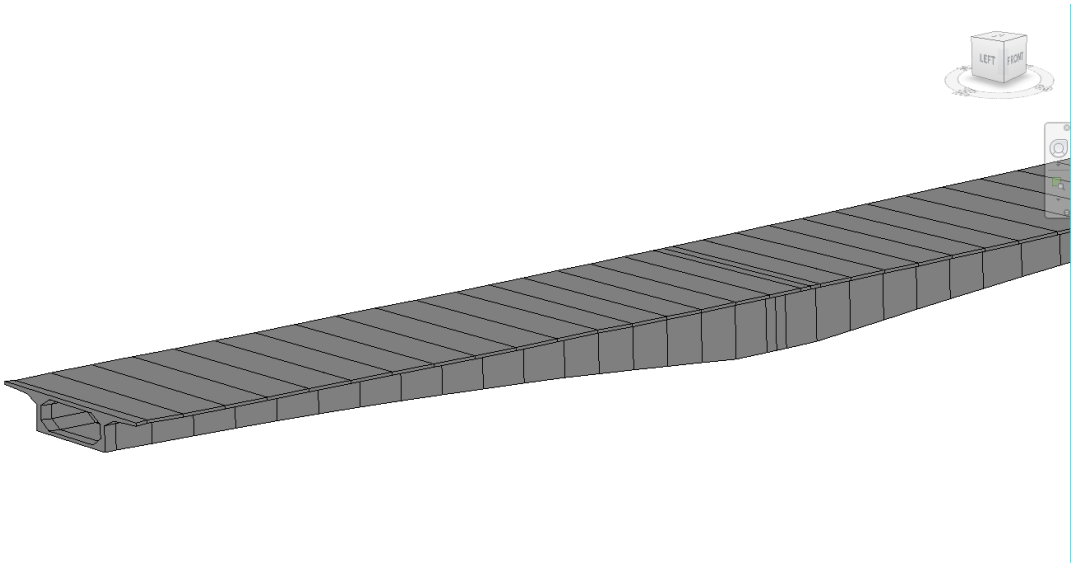


Figure 6. 19 Final Geometry of Bridge in Revit (View 2)

6.1.4. Creation of Curb

Utilizing the same method that was used to design the bridge geometry, we can now create the curb. Unlike the bridge structure, the curb's geometry remains constant, meaning it must maintain the same dimensions and shape along the entire span of the bridge. The curb does not require multiple varying cross sections, but it does need to be positioned correctly in relation to the bridge's altimetry and rotation.

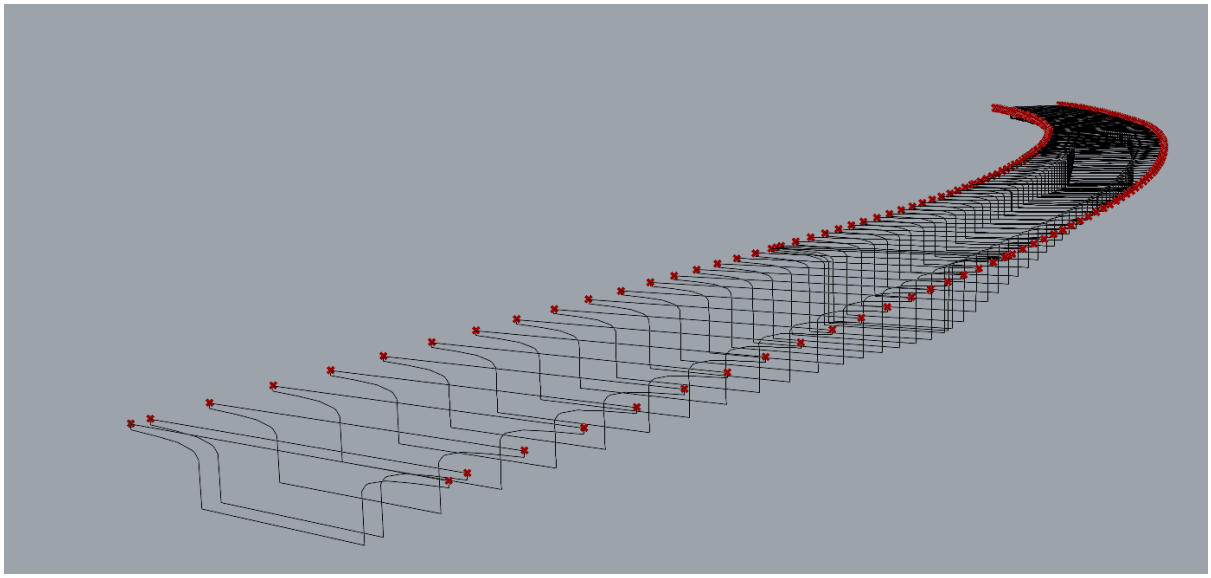


Figure 6. 20 Finding the Position of Curb

To achieve this, we first create an adaptive family for the curb in Revit. Since the curb's geometry remains uniform, we only need to set two point for its position.

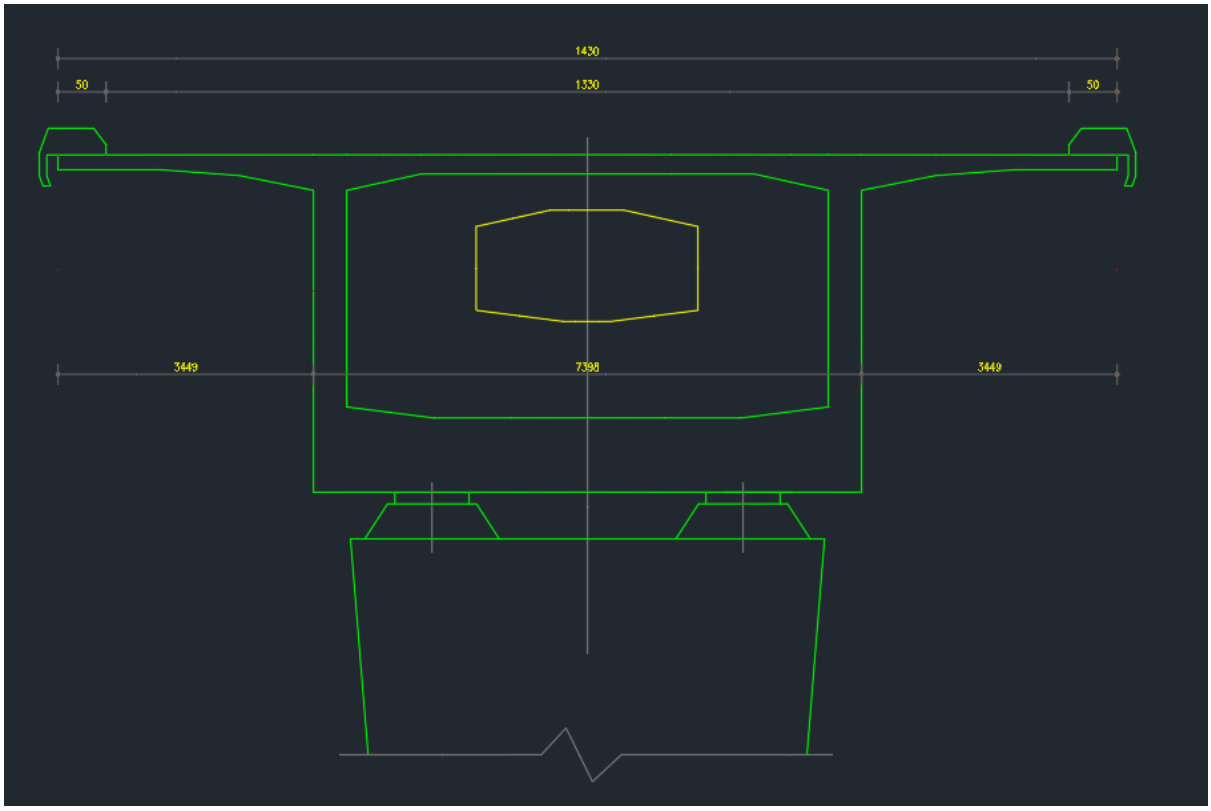


Figure 6. 21 Curb AutoCAD file

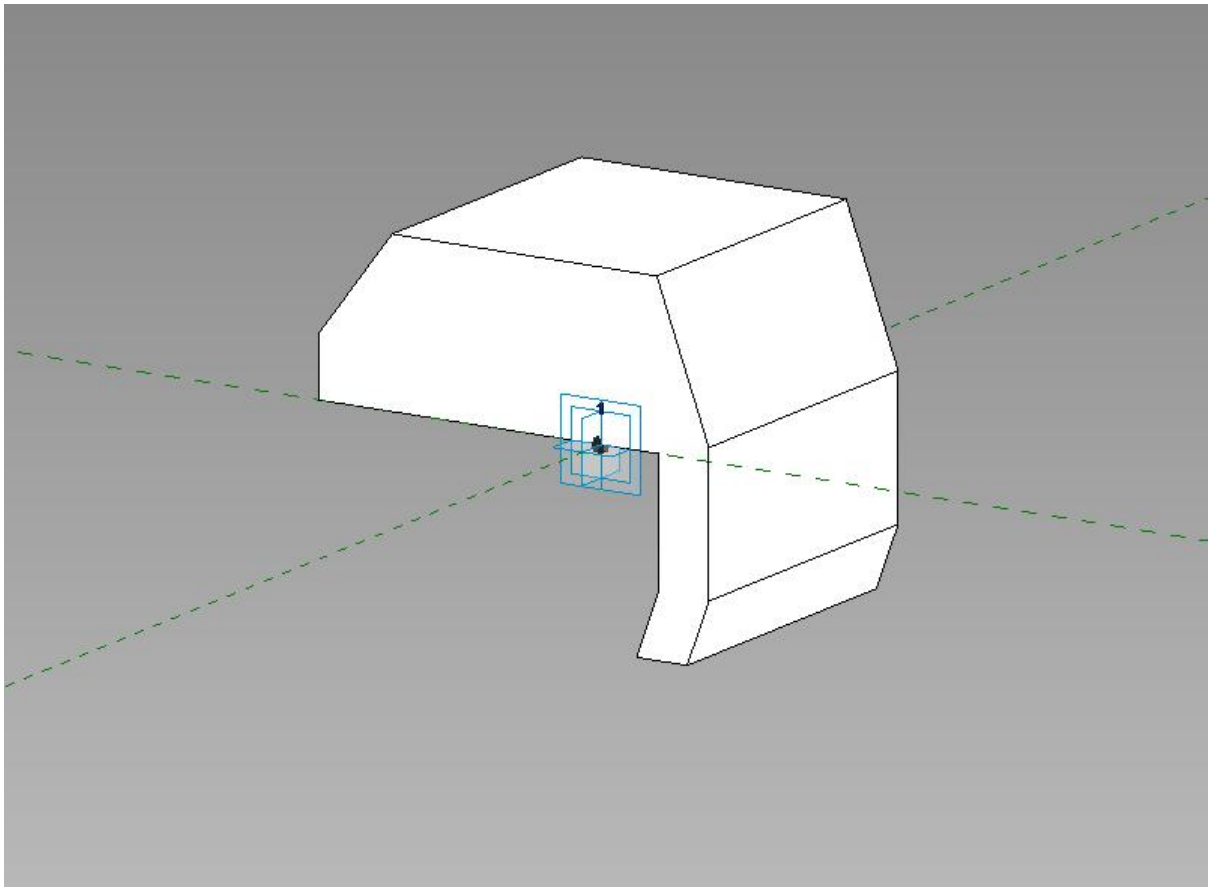


Figure 6. 22 Adaptive family of Curb

In Grasshopper, we define the position points for the curb by referencing the bridge's correct placement, altimetry, and rotation.

Using the **"Add Component"** in Grasshopper, we link the position points to the curb's location along the bridge. These points define where the curb will be placed across the entire structure.

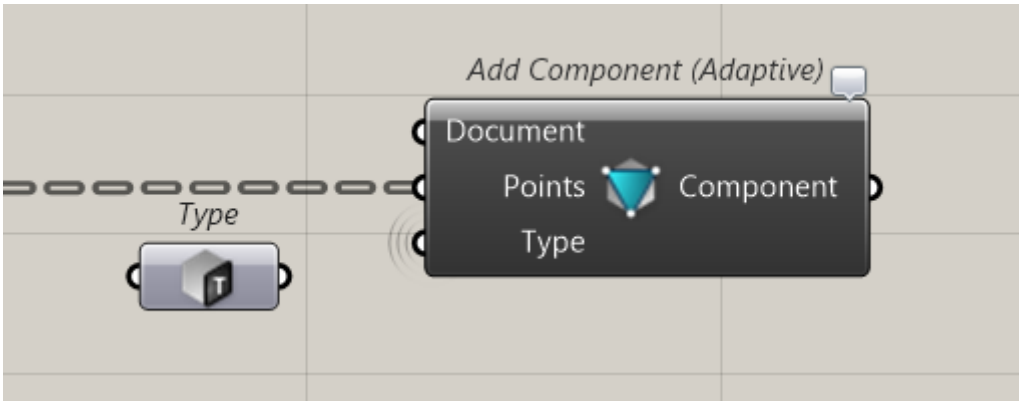


Figure 6. 23 GH Adaptive Component

Next, we use the **"Type"** component to select the adaptive family for the curb. This component ensures that the curb adapts to the correct positions and follows the bridge's path while maintaining its consistent dimensions.

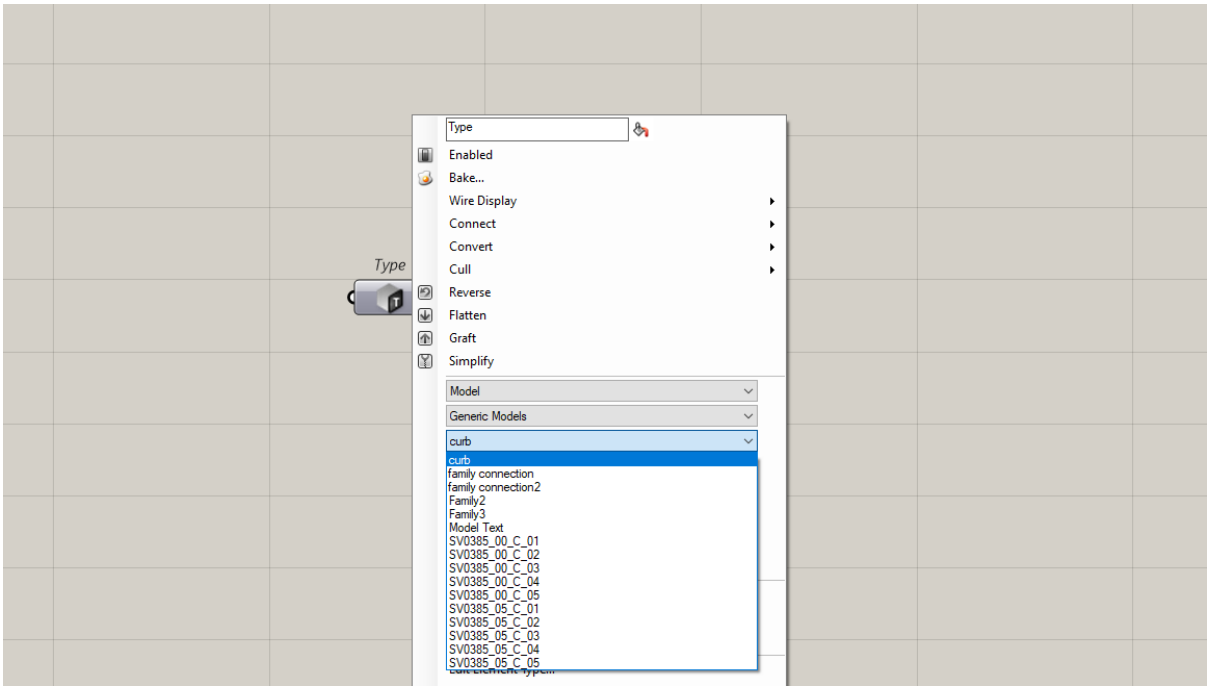


Figure 6. 24 Selection of Adaptive Family

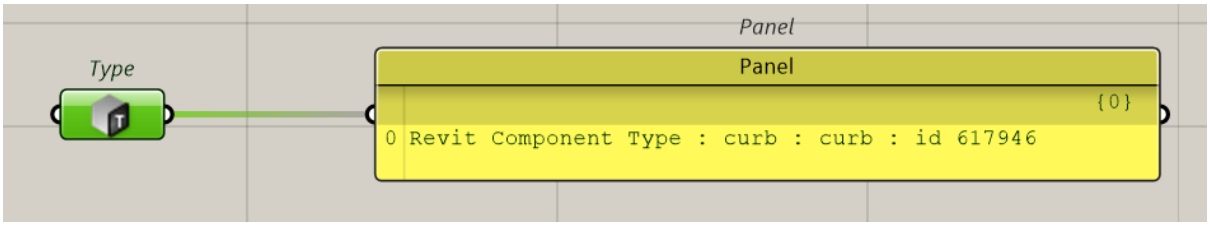


Figure 5. 55 GH Output of Family

Once connected, Grasshopper's output allows the curb to be placed accurately in Revit, ensuring it aligns perfectly with the bridge geometry, providing a complete and integrated design within the BIM model.

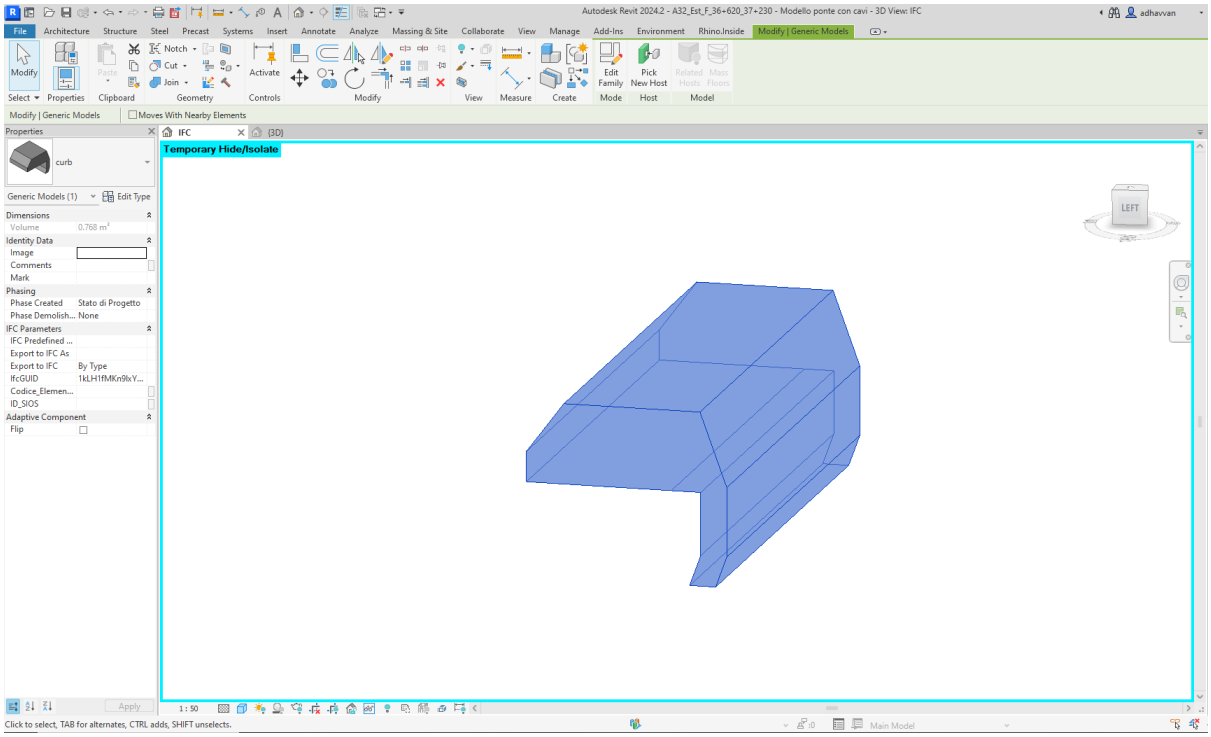


Figure 6. 25 Curb Geometry in Revit

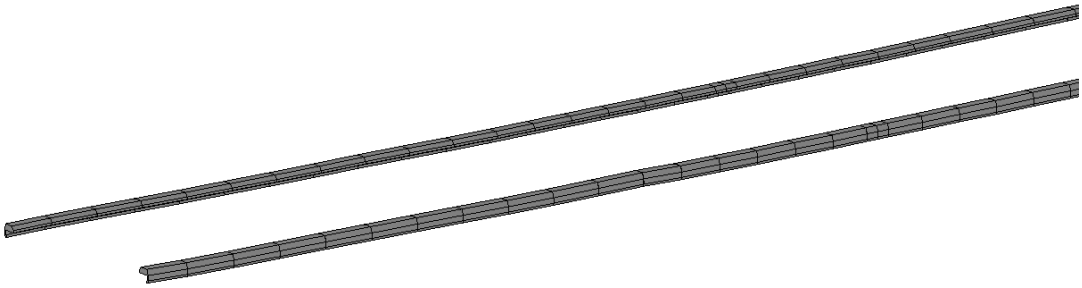


Figure 6. 26 Complete Curb Geometry

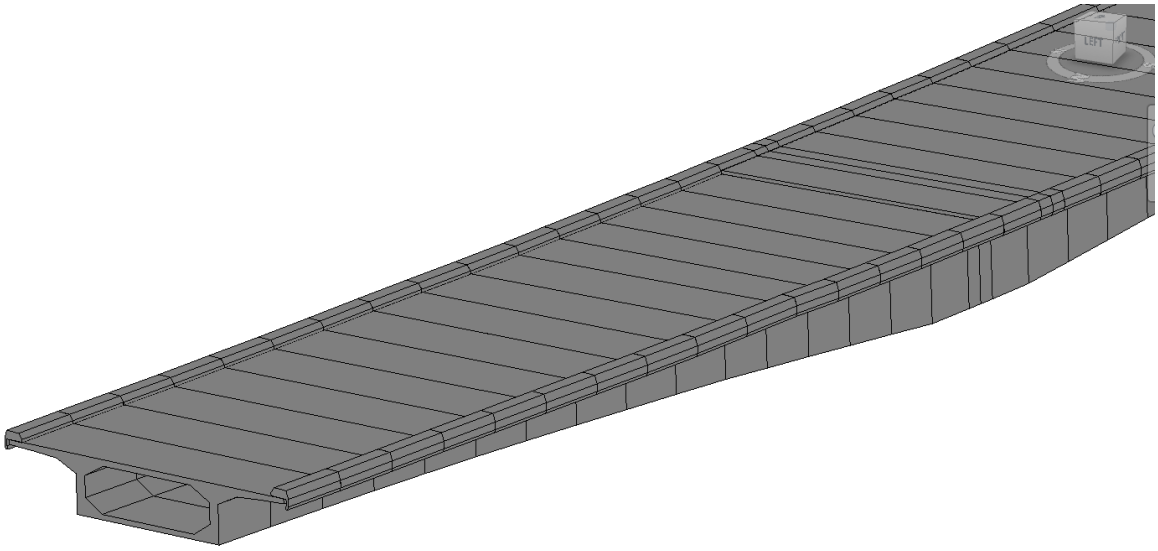


Figure 6. 27 Final Curb with Bridge Geometry 1

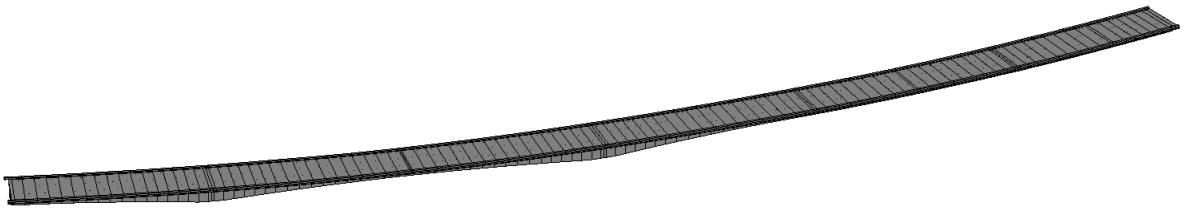


Figure 5. 56 Final Curb with Bridge Geometry 2

6.1.5. Creation of Pavement

The pavement of the bridge is created in Grasshopper, leveraging the precise position of the bridge that was defined using point cloud data. Since the point cloud provides an accurate representation of the bridge's geometry and location, it becomes straightforward to determine the dimensions and placement of the pavement. The bridge pavement, which is specified to be 15 cm thick.

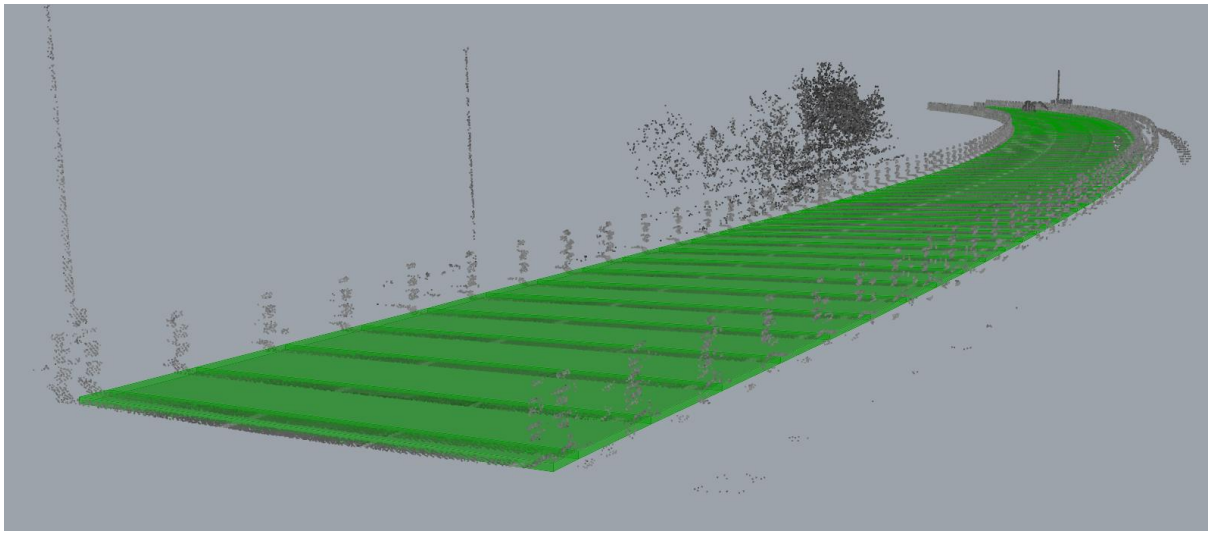


Figure 6. 28 Pavement Position

Using Grasshopper, we can generate the pavement by defining a uniform thickness of 15 cm along the entire span of the bridge. The pavement geometry is created by referencing the bridge's position, altimetry, and rotation derived from the point cloud.

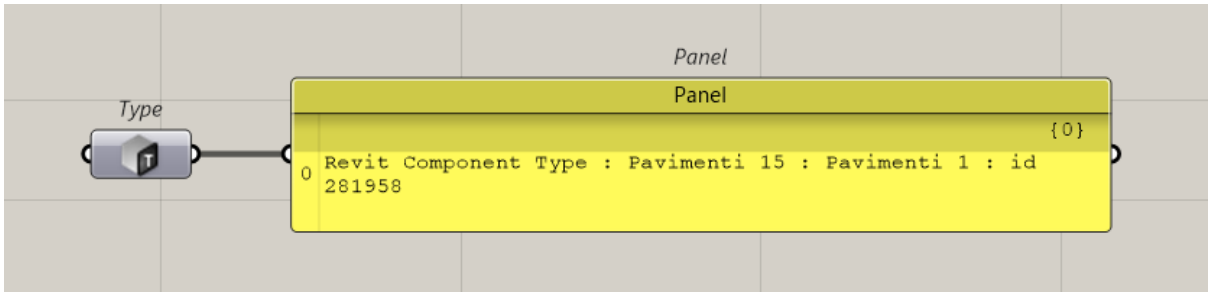


Figure 6. 29 Pavement Family output in Revit

Once the pavement position is determined using Grasshopper, it can be further refined or exported to Revit for inclusion in the full BIM model. This method can be utilized for defining the various geometry in automation way.

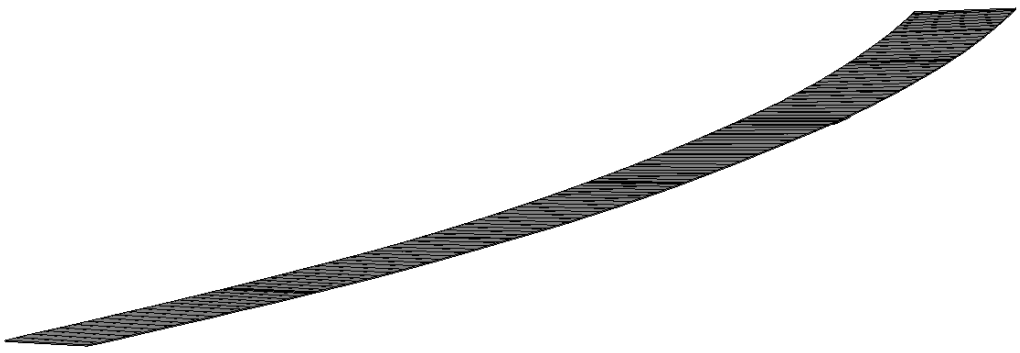


Figure 6. 30 Complete Pavement Placement

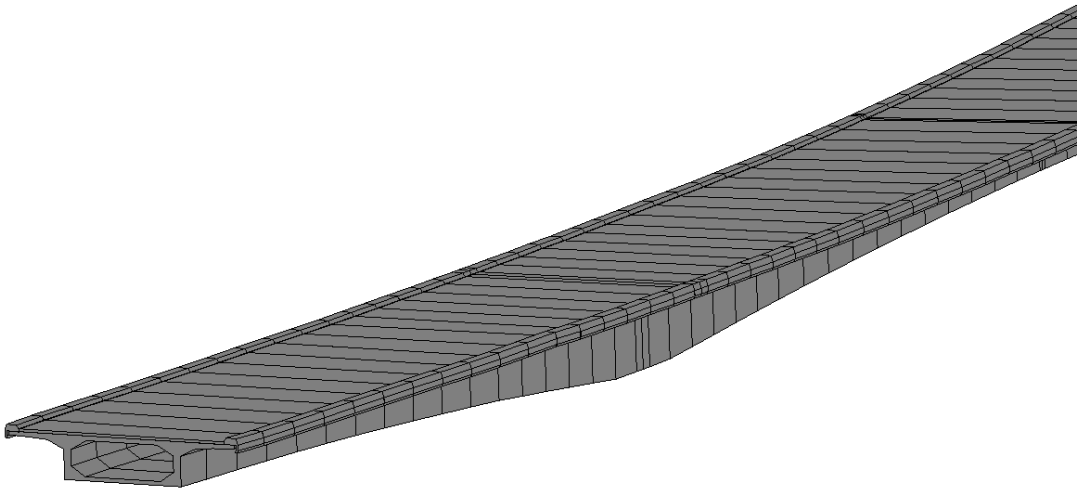


Figure 6. 31 Final Pavement with Geometry of the bridge in Revit

6.1.6. Pre-stressed Cables

Designing pre-stress cables in Revit can be challenging due to the complex nature of pre-stressed concrete structures and the software's limitations in handling detailed tensioning systems. Revit is primarily designed for BIM modelling, and while it can represent structural elements, it lacks built-in tools specifically for pre-stressing workflows. Custom families, parameters, and workflows often need to be developed to accurately model the pre-stress cables, their profiles, and tensioning forces. Integration with specialized software like Grasshopper or external analysis tools may be required to simulate the tensioning process, making the design process more time-consuming and intricate.

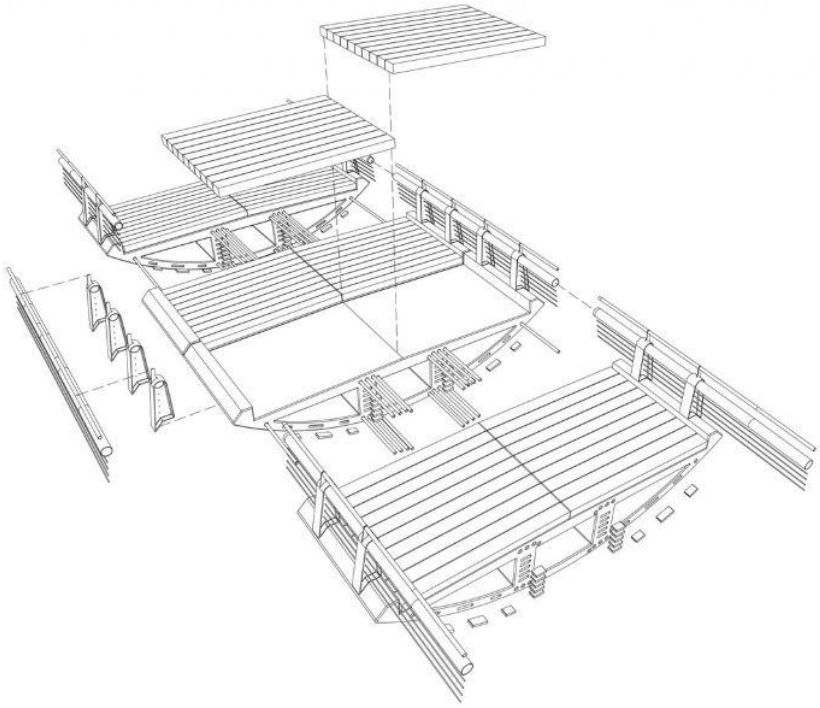


Figure 6. 32 Pre-Stressed Cable Of the bridge

Before designing pre-stress cables, it's essential to gather detailed information about them. Key data includes the **position of each cable**, the **total number of cables**, and the **exact location of each one within the structure**. Additionally, knowing the **length of each cable**, as well as its **starting and ending points**, is crucial for accurate placement and effective tensioning.

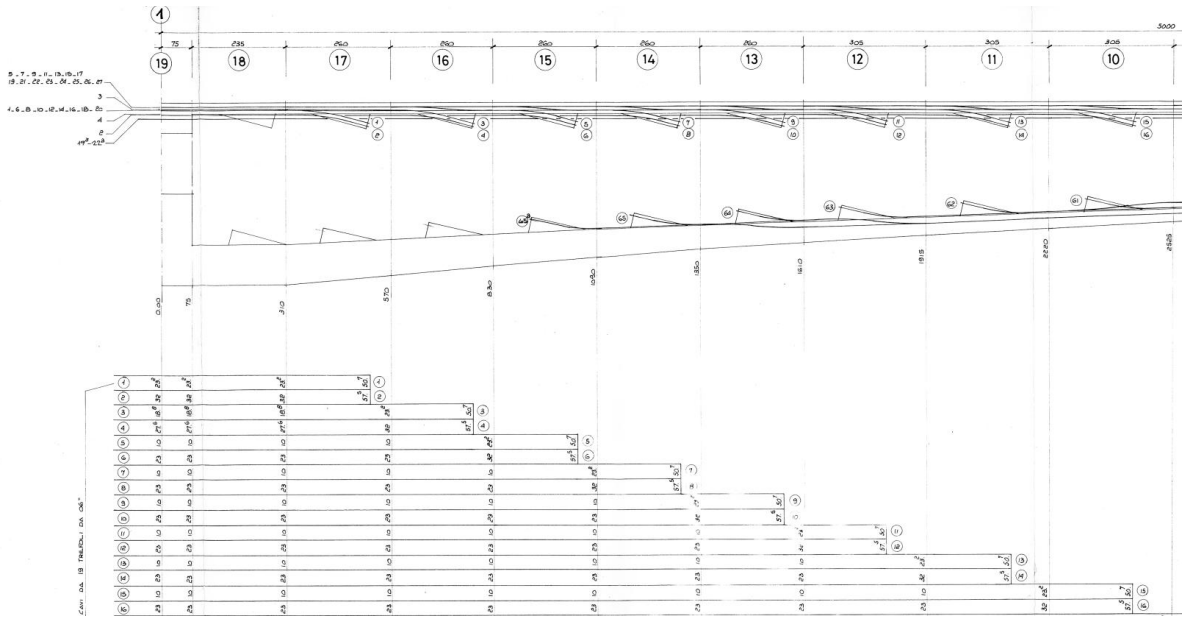


Figure 6. 33 Pre-Stressed Cable Of the bridge

Using the pre-stress cable information, I have developed a **cluster in Grasshopper** that automates the cable creation process.

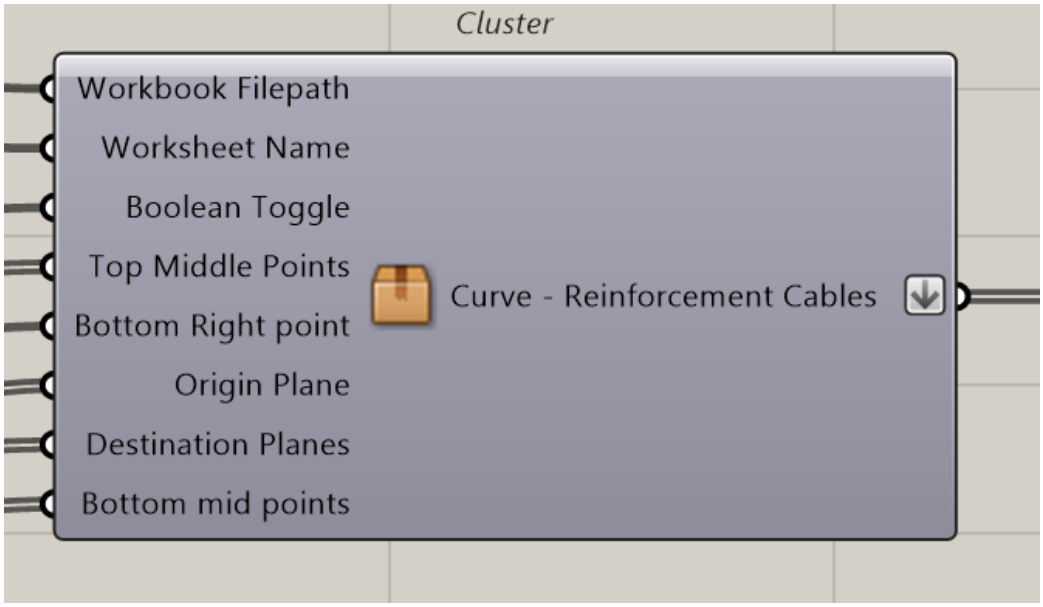


Figure 6. 34 Cluster for Pre-Stressed Cable

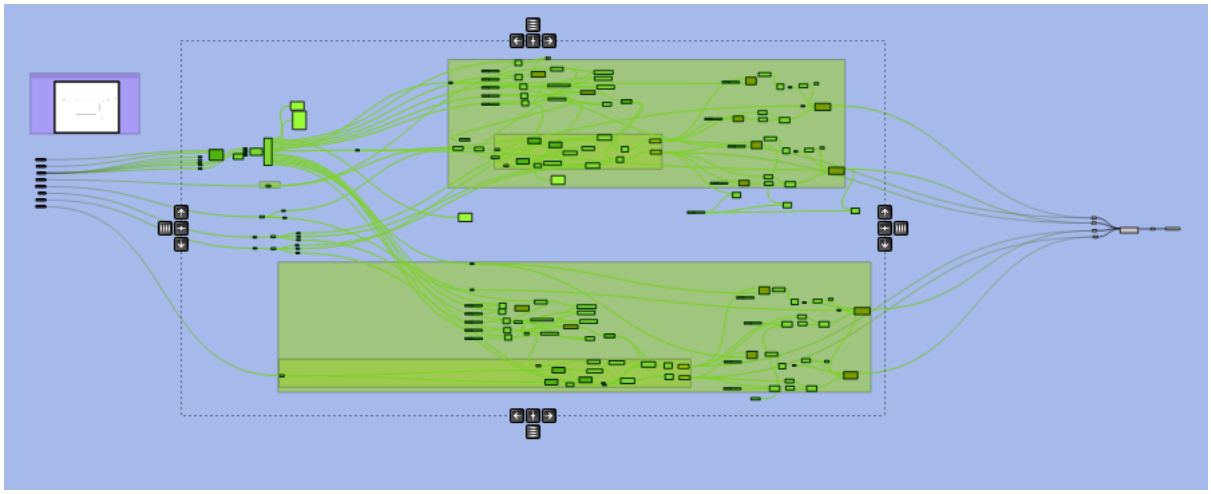


Figure 6. 35 GH Script for Pre-Stressed Cable

The cluster accepts inputs such as the **position** and **length** of the cables. An Excel file is used to provide the data, including which **sheet** to pull from, while a **Boolean toggle** component is added to activate the cluster. Once the inputs are defined, the cluster automatically generates the pre-stressed cable structure. This setup streamlines the design process, ensuring accurate placement and lengths of cables based on the given data, reducing manual effort and potential errors in the design.

Here the way to explain how the excel file must be,

We must give the input for the excel file such as position, from which section to which section the cables follow, extension of the cable and its angle

Table 1

TOP	Name of the Cable	1	2	3	4	5	6	7	8	9	10

	X-direction	2.715	3.115	2.915	3.185	3.345	3.605	3.765	6.4	2.715	2.755
	Z-Direction	0.232	0.32	0.1	0.1	0.1	0.1	0.1	0.1	0.232	0.1
	Cable Section From	0	1	2	3	4	5	6	7	8	9
	Cable Section TO	10	11	12	13	14	15	16	17	18	19
	Placement (Top o Bottom)	TOP	TOP	TOP	TOP	TOP	TOP	TOP	TOP	TOP	TOP
	Extension Length (x)	1	1	1	1	1	1	1	1	1	1
	Inclination Angle θ	20	20	20	20	20	20	20	20	20	20
BOT TOM	Name of the Cable	23	24	25	26	27	28	29	30	31	32
	X-direction	0.12	0.32	0.54	0.12	0.32	0.32	0.12	0.32	0.54	0.7
	Z-Direction	0.23	0.23	0.23	0.36	0.36	0.49	0.1	0.1	0.1	0.1
	Section From	0	1	2	3	4	5	6	7	8	9
	Section TO	10	11	12	13	14	15	16	17	18	19
	Placement (Top o Bottom)	BOT TOM	BOT TOM	BOT TOM	BOT TOM	BOT TOM	BOT TOM	BOT TOM	BOT TOM	BOT TOM	BOT TOM
	Extension Length (x)	1	1	1	1	1	1	1	1	1	1
	Inclination Angle θ	20	20	20	20	20	20	20	20	20	20

The below pictures can explain more about how the excel file inputs are created,

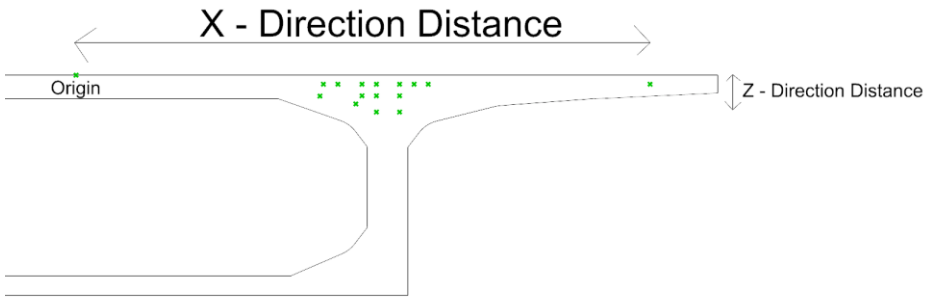


Figure 6. 36 Placement of Cable (X-Direction)

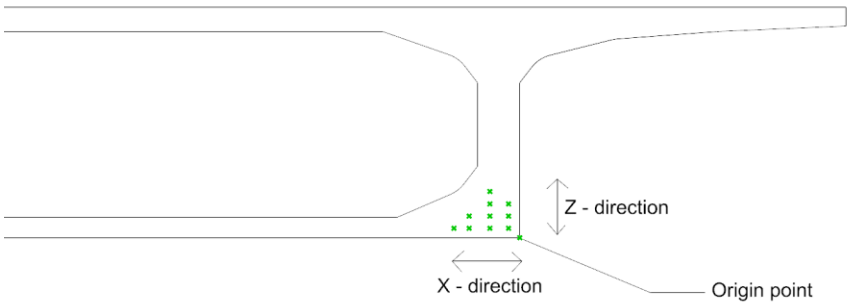


Figure 6. 37 Placement of Cable (z-Direction)

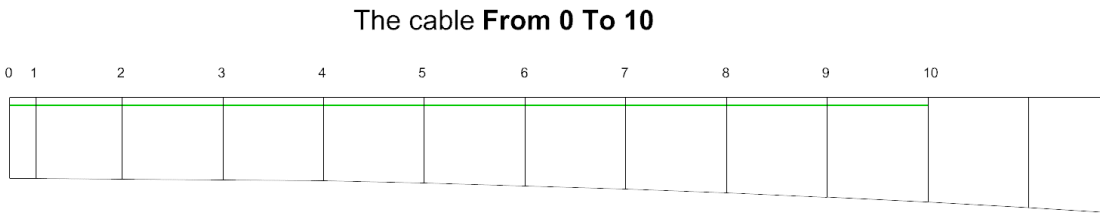


Figure 6. 38 Placement of Cable (From and TO)

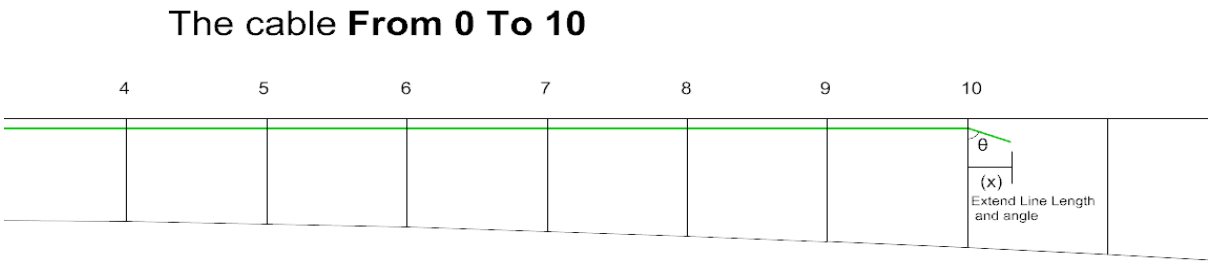


Figure 6. 39 Angle of the Cable

Using the Grasshopper cluster, we can input data from an Excel file and receive points as the output. This cluster is designed to adapt to the varying positions and curves of the bridge's cross sections. Since the bridge cross section changes along its length becoming narrower in

some areas and wider in others the pre-stress cables must adjust accordingly to maintain alignment with the structure. The Grasshopper cluster automates this adaptation process, ensuring that the cables follow the precise geometry of the bridge as it changes shape.

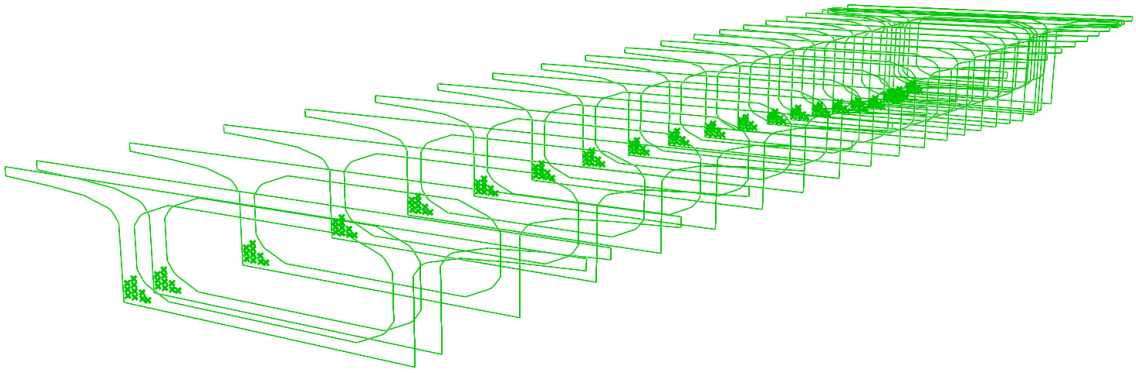


Figure 6. 40 Placement of Pre-Stressed Cable Points

By this cluster, the design process becomes far more efficient accurate. It eliminates the need for manual adjustments when the cross section of the bridge varies, reducing errors. The cables are automatically placed in accordance with the changing bridge profile, ensuring they provide optimal reinforcement throughout the structure. This automation not only saves time but also ensures the structural integrity of the bridge by maintaining consistent cable placement. The integration of data from Excel ensures flexibility and precision in managing various dimensions, making the entire process smoother and more reliable.

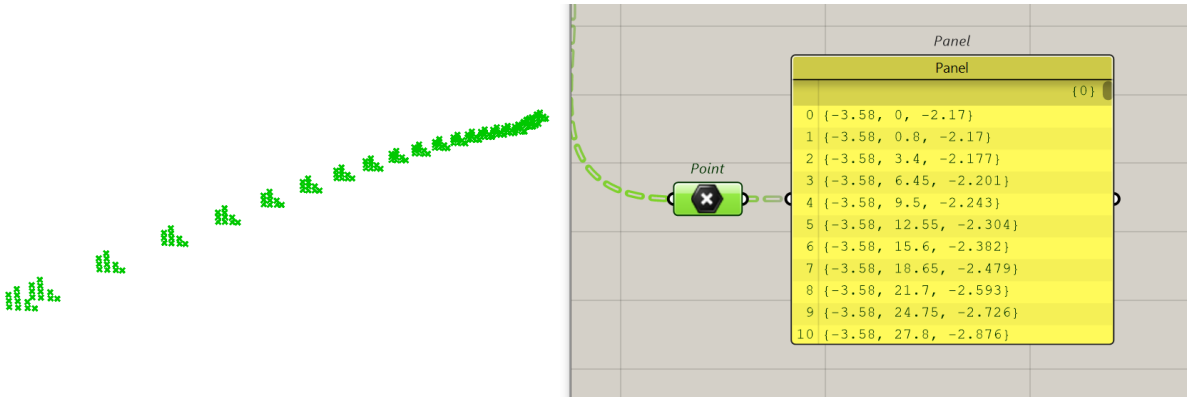


Figure 6. 41 Points (co-ordinates)

The output must be the points because when we have the bridge structure in 3d dimensional space it is difficult to move the cable from the origin to actual place. But if we have the output as points, we can move them and create the cable using the component called “Pipe “. This component used to define also the cable radius.

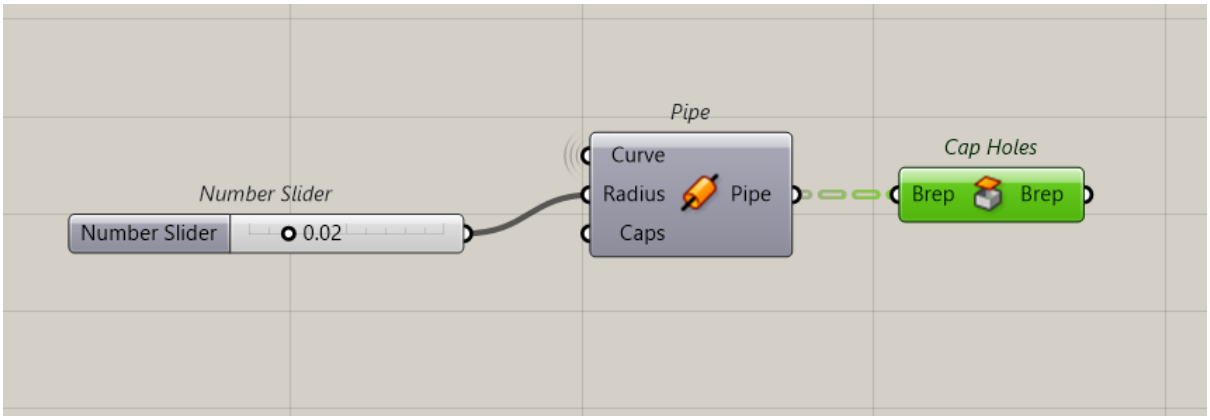


Figure 6. 42 Radius of the cables

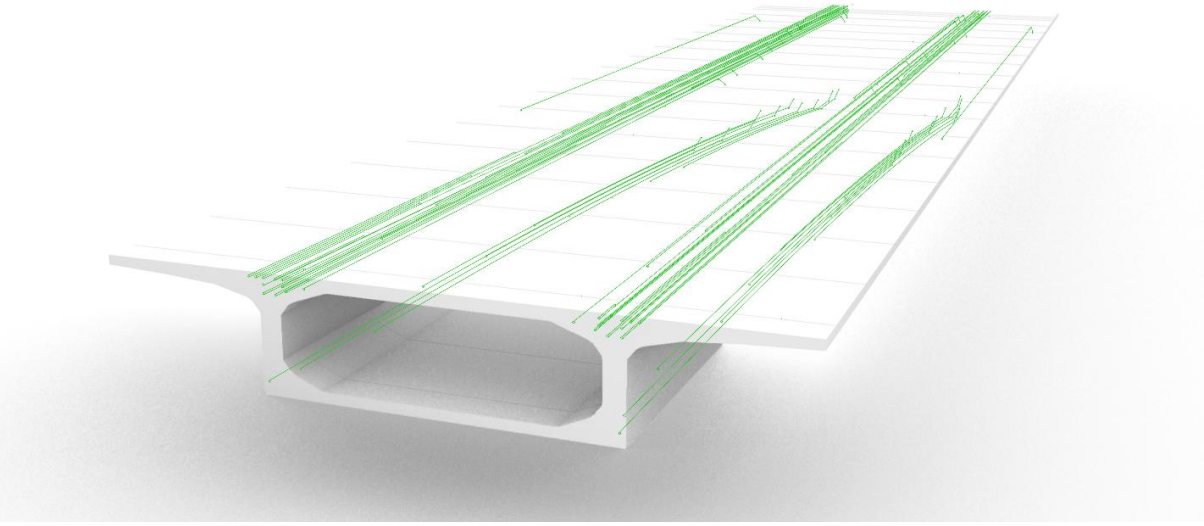


Figure 6. 43 Rendering of cables (View 1)

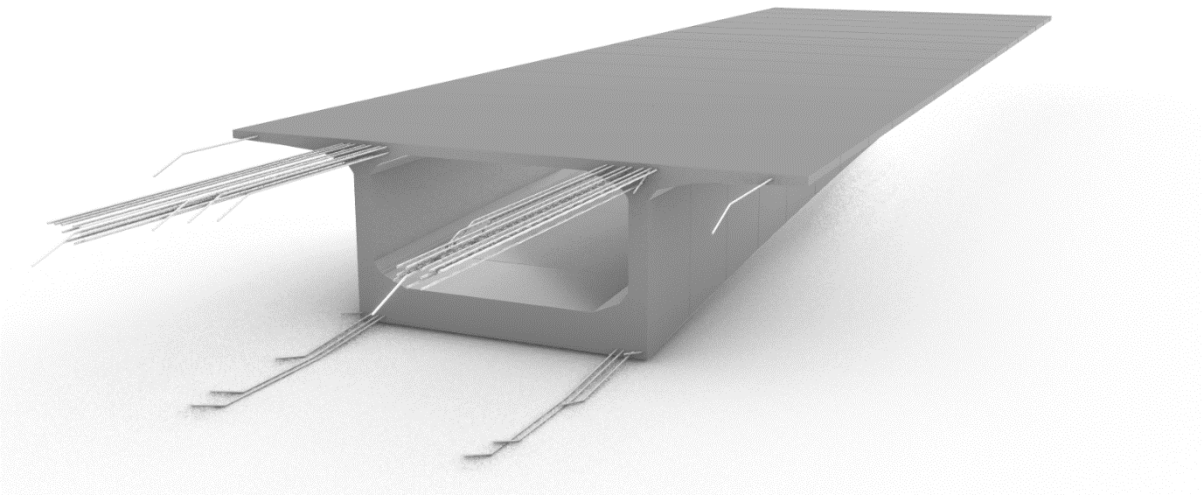


Figure 6. 44 Rendering of cables (View 2)

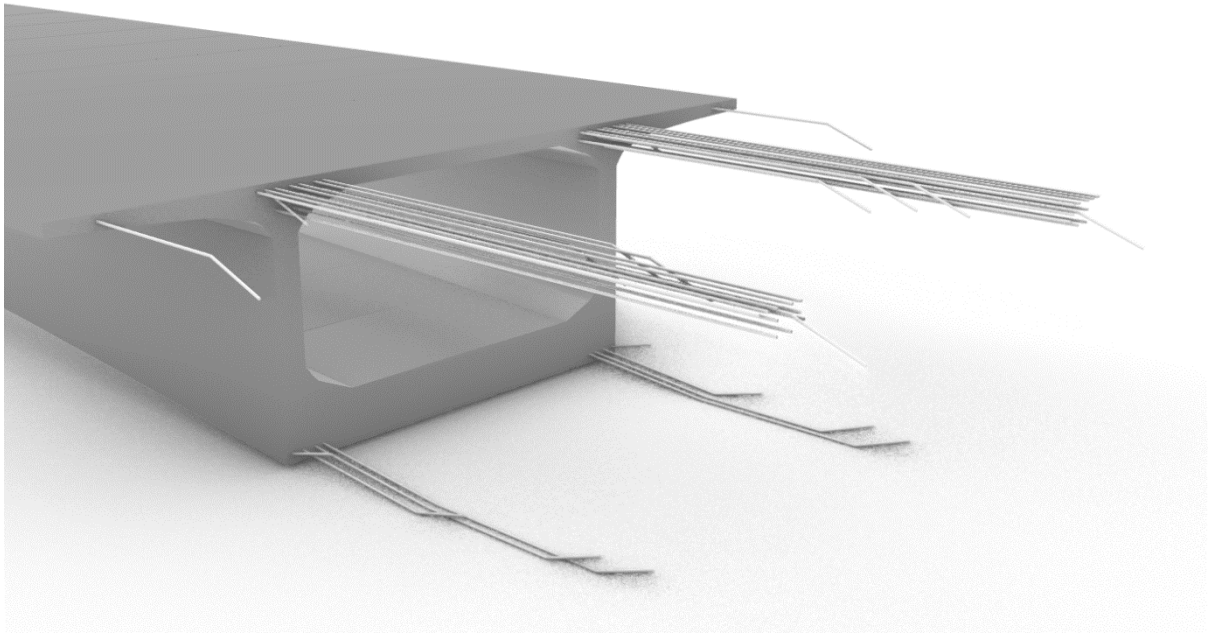


Figure 6. 45 Rendering of cables (View 3)

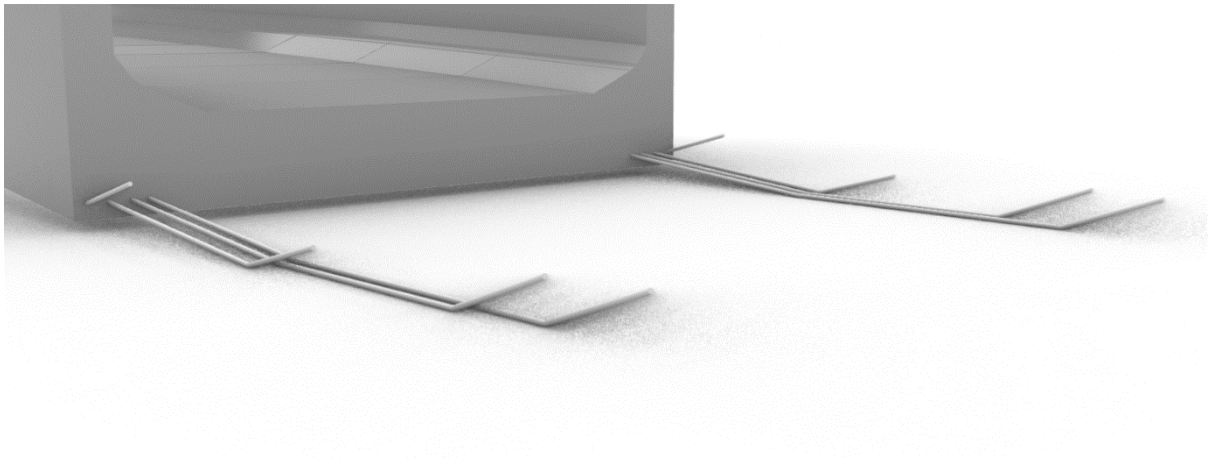


Figure 6. 46 Rendering of cables (View 4)

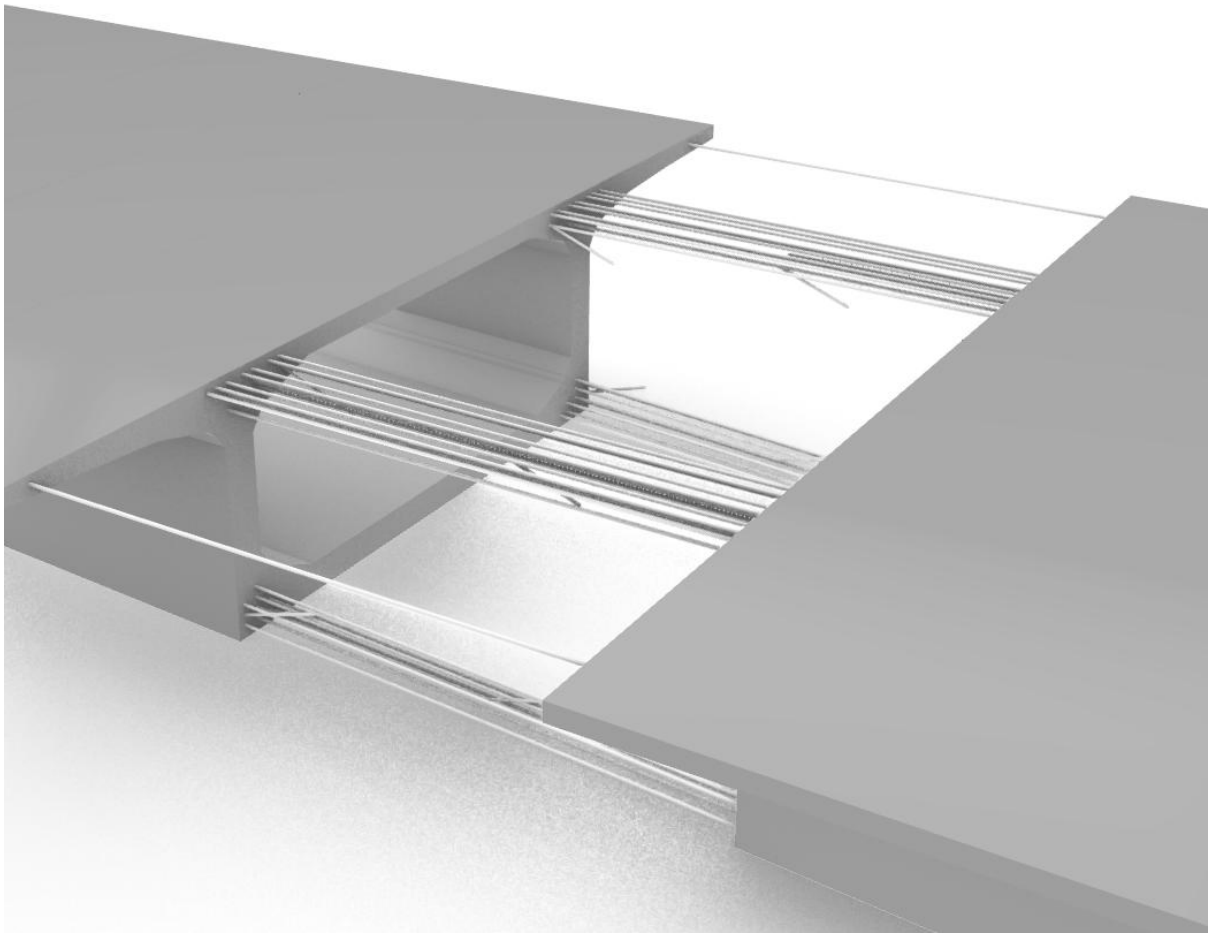


Figure 6. 47 Rendering of cables (View 5)

The complex process can be done in the automation way with accuracy of the position. And now to export the cables to Revit. There is component called “Add DirectShape (Brep)” which is used to import the solid shape geometry to Revit.

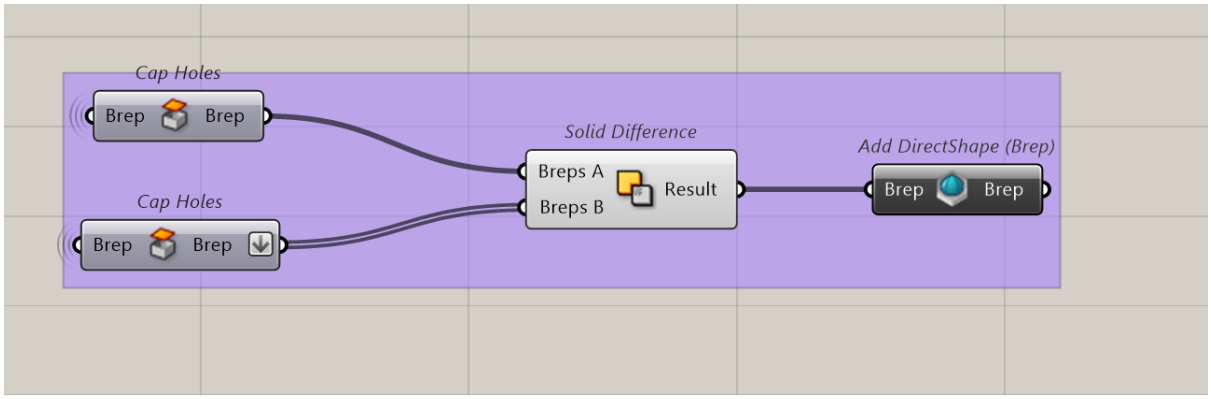


Figure 6. 48 Add Direct Shape of Cables



Figure 5. 57 Pre-Stressed Cable in Revit

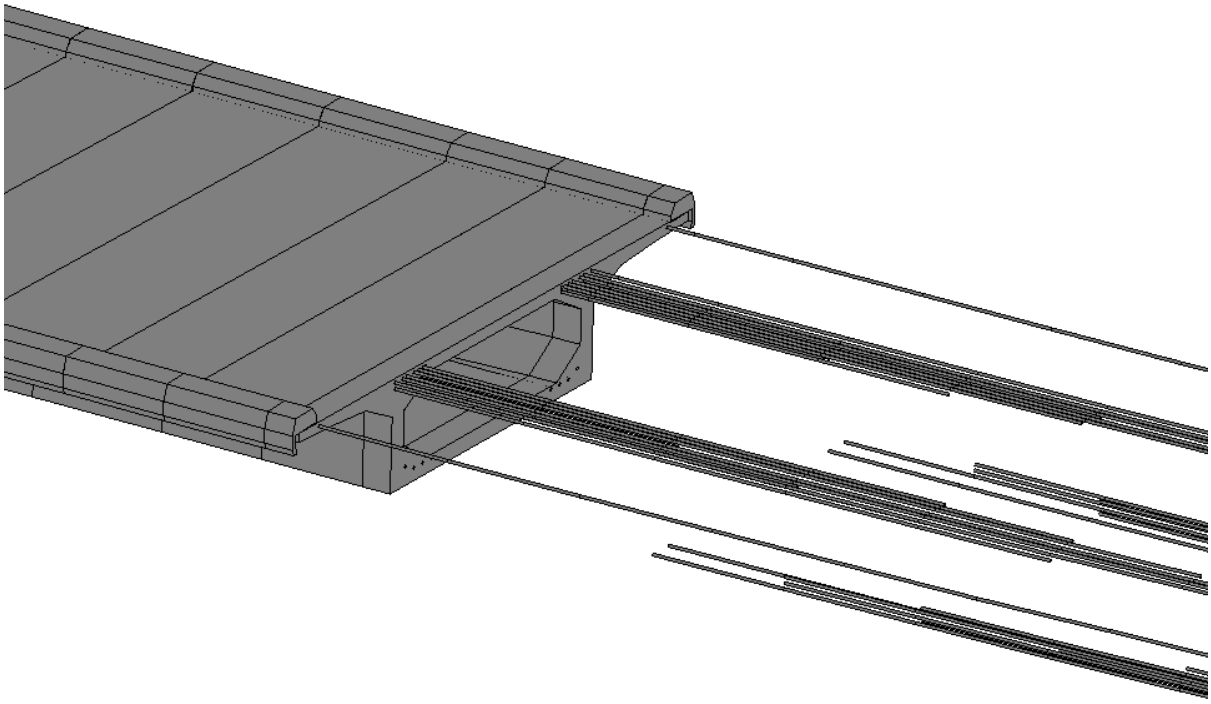


Figure 6. 49 Pre-Stressed Cable with Bridge geometry

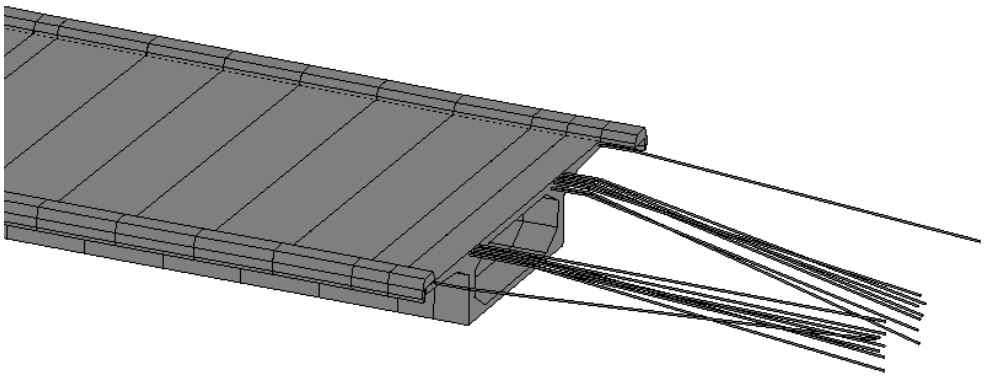


Figure 6. 50 Cables in Edge

CHAPTER 6

7. Tekla Structures Interoperability

7.1. Methodology

7.1.1. Tekla Live Link

Live Link is a plugin designed to enable live data exchange between Grasshopper and Tekla Structures, facilitating seamless integration for complex structural modelling. Unlike Revit, where Grasshopper can run inside the software through Rhino.Inside, Tekla requires a separate process. To establish the connection, you must first open Tekla Structures and then launch Grasshopper within Rhino. This setup allows both software platforms to communicate in real-time, with any updates or modifications made in Grasshopper reflected directly in Tekla.

The Tekla Live Link plugin enables dynamic collaboration between parametric modelling in Grasshopper and detailed structural design in Tekla Structures. Through this connection, you can generate and manipulate structural elements like beams, columns, and reinforcement directly from Grasshopper, while Tekla Structures updates the model accordingly.

This method enhances productivity and flexibility, as designers can take advantage of Grasshopper's parametric capabilities while maintaining precise, detailed control over structural components within Tekla. Although the workflow is not as integrated as with Revit, Tekla Live Link still offers a powerful way to connect these two programs for advanced structural modelling and analysis.

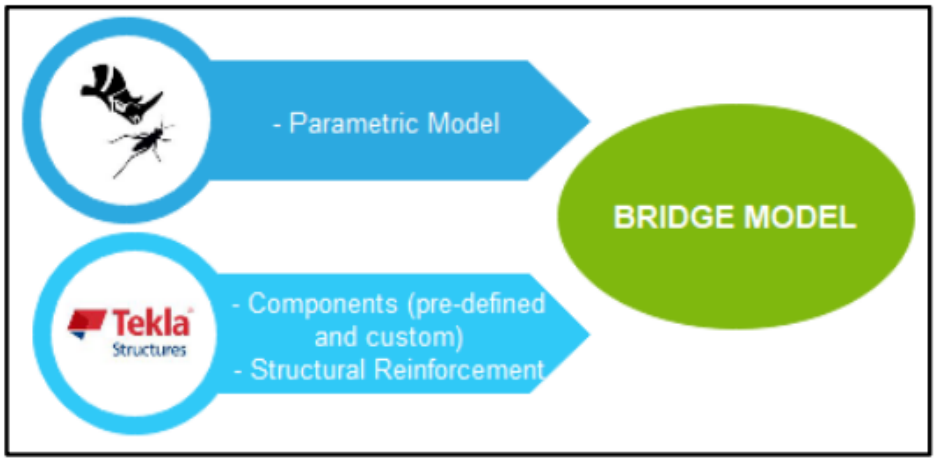


Figure 7. 1 Tekla workflow

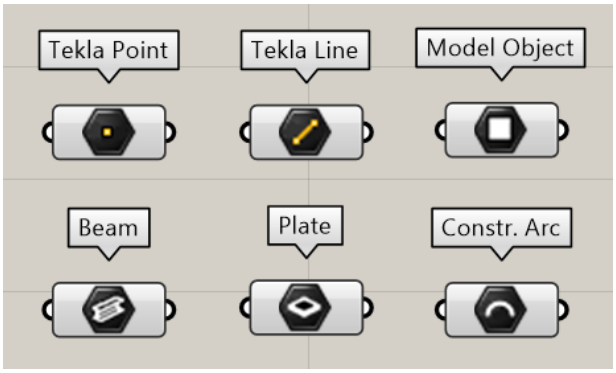


Figure 7. 2 Tekla GH components

In the Tekla Live Link plugin, we have complete access to control every aspect of Tekla Structures directly from Grasshopper. The components available in Tekla are transformed into Grasshopper components, allowing real-time manipulation and automation of structural elements. This enables users to create and customize structural models with precision while automating repetitive tasks. With this integration, it's easier to develop a detailed BIM model, as the connection allows seamless adjustments and updates to the design, ensuring that every aspect of the model is accurately reflected in Tekla, enhancing workflow efficiency and accuracy.

7.1.1. Create Profile

In the Tekla Live Link plugin, there is a component called **"Create Profile,"** which allows users to develop customized profiles within Grasshopper for automated design workflows. This tool is particularly useful when creating unique structural profiles, such as bridge dimensions. For example, when defining a bridge's profile, you can create the desired shape directly in Grasshopper and assign a specific profile name.

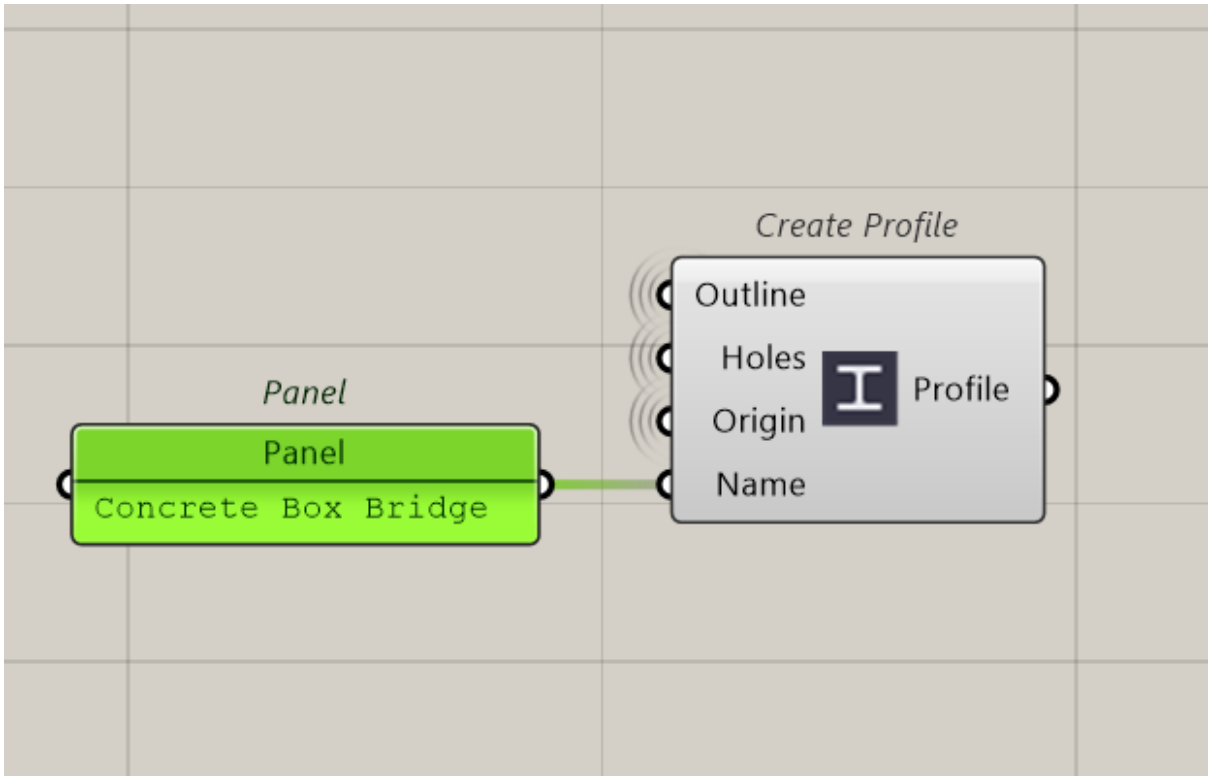


Figure 7. 3 Create Profile

Once the profile is defined, you can use another component, **"Profile Catalogue,"** to select and apply these custom profiles as needed.

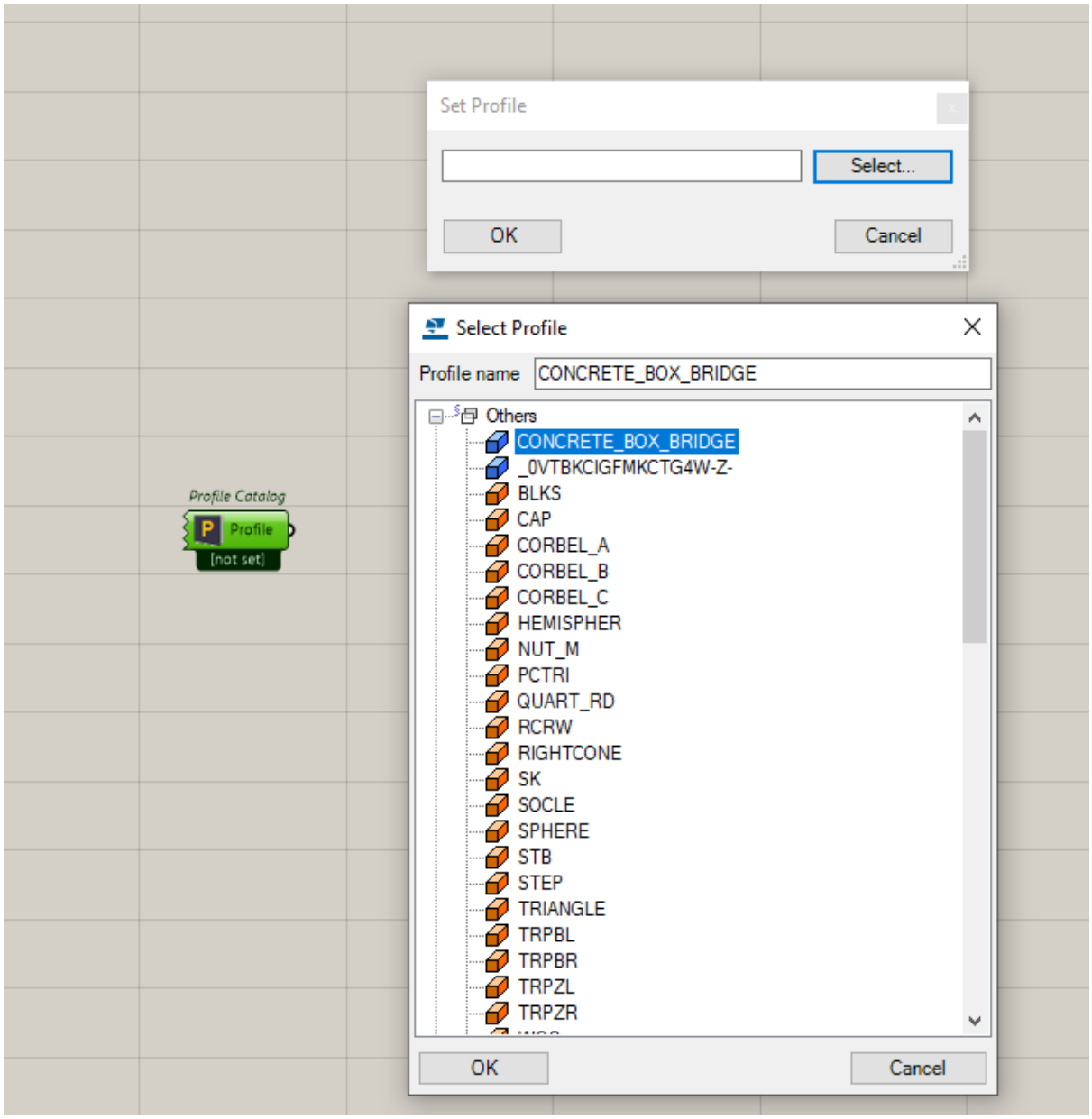


Figure 7. 4 Profile Catalogue

These two components, "Create Profile" and "Profile Catalogue," are essential when designing complex structures like bridges. After creating a line that represents the bridge's shape, you can assign your custom profile to that line, and Tekla Structures will generate the bridge profile accordingly. This level of customization and automation ensures that the bridge's cross sections and overall geometry are accurately based on the design inputs from Grasshopper.

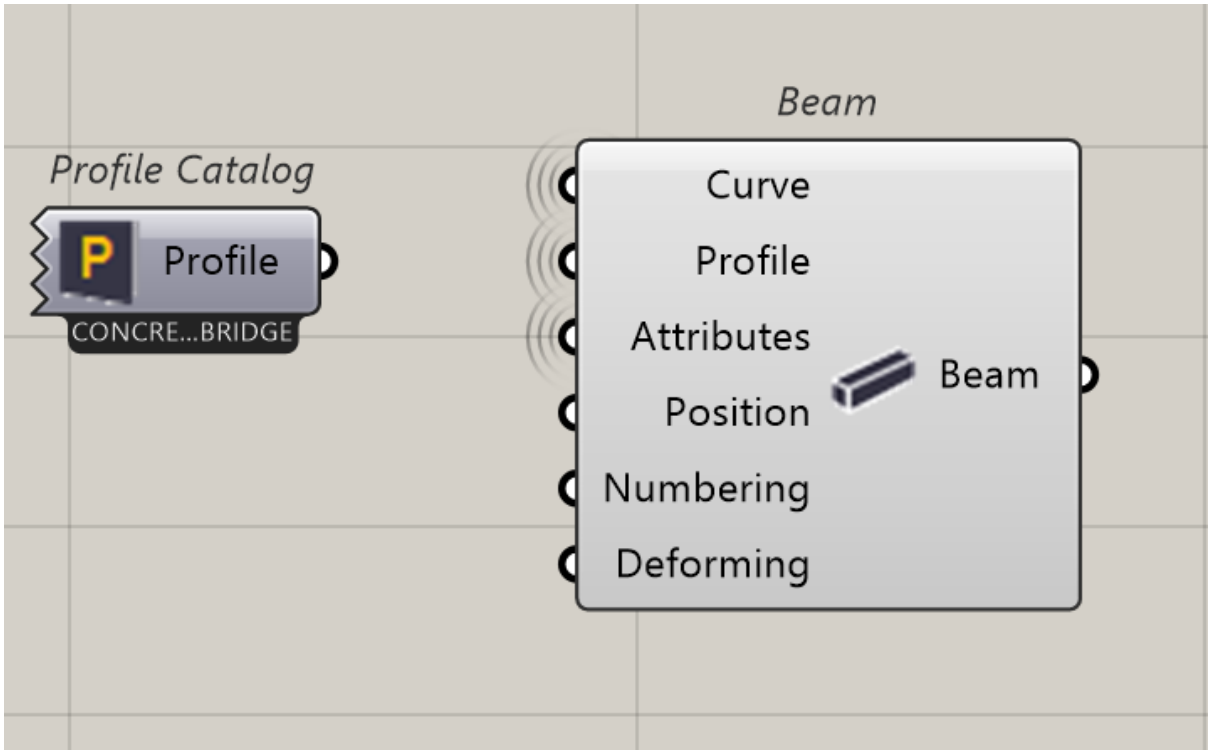


Figure 7. 5 Beam component

When we give the inputs such as the dimension length of the bridge and the profile we created using “create profile” component, it will create the bridge geometry inside Tekla Structures.

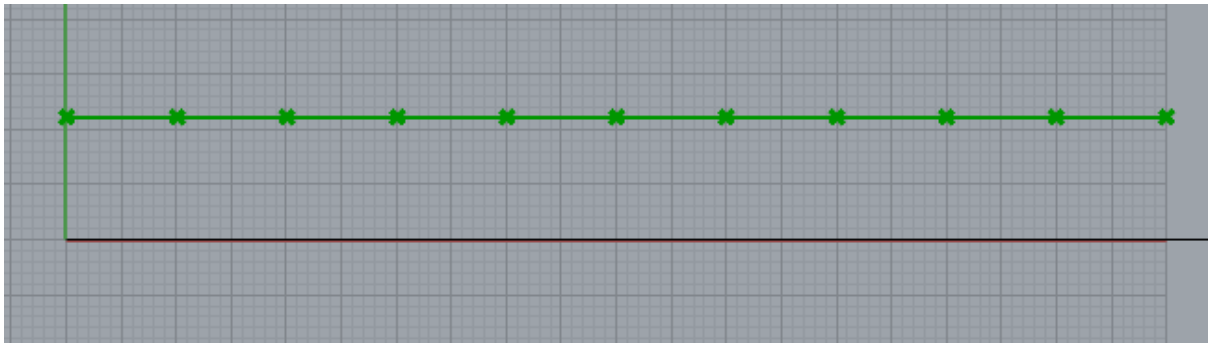


Figure 7. 6 Bridge Length with Segment of cross sections

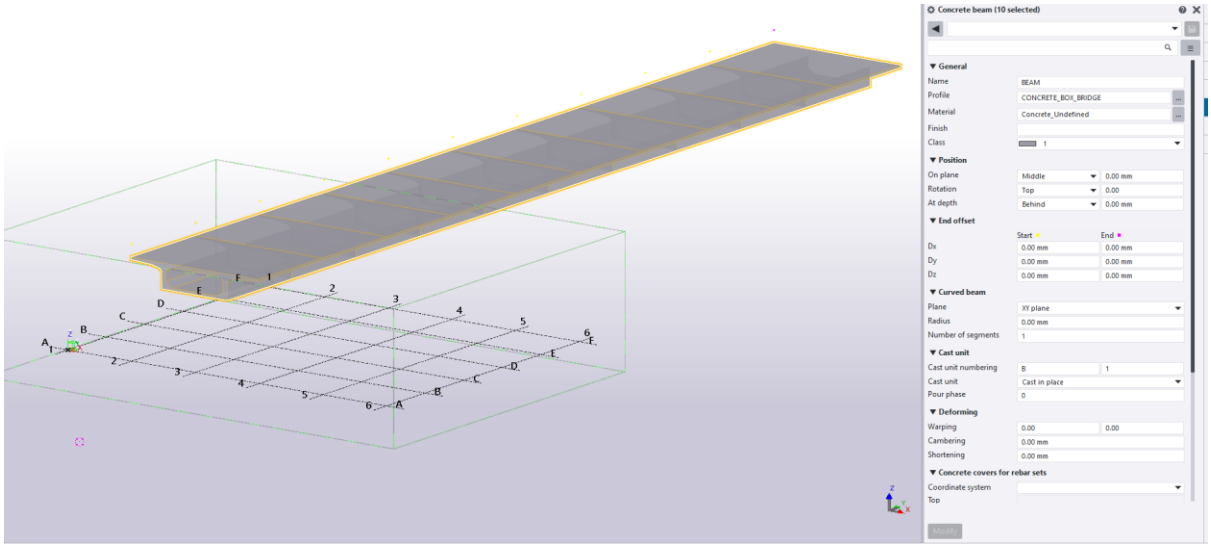


Figure 7. 7 Bridge Geometry in Tekla Structures

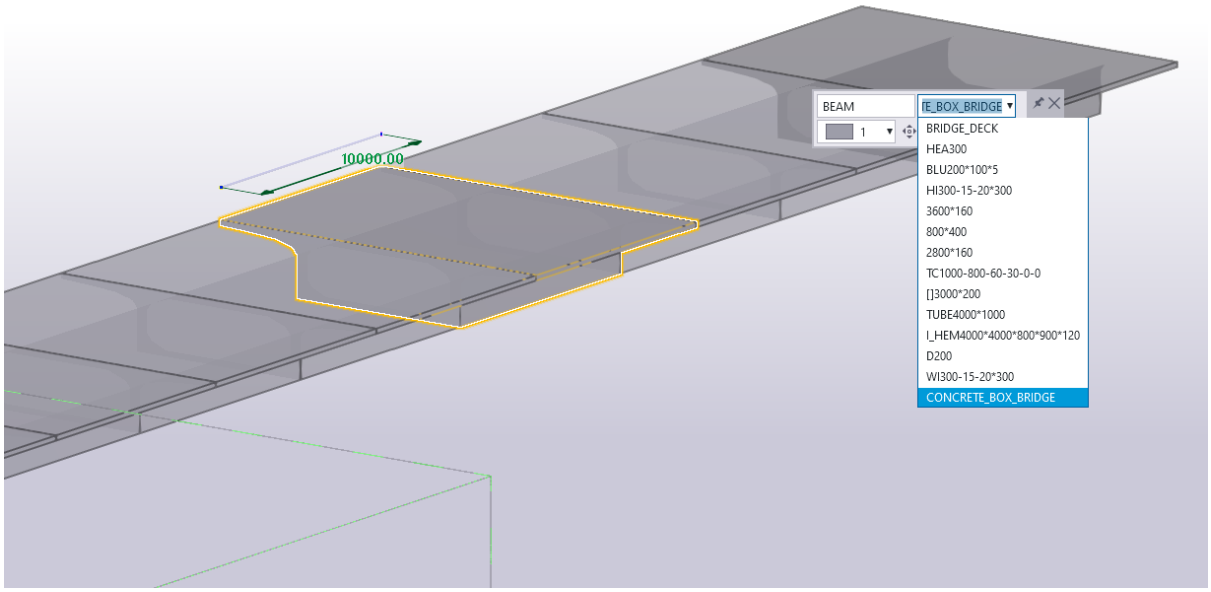


Figure 7. 8 Creation of geometry profile Inside Tekla Structures

This process is integral to creating a BIM bridge model inside Tekla Structures. By automating the creation of profiles and assigning them to structural lines, designers can streamline the process, improve accuracy and reducing time spent on manual adjustments. The result is a precise, data-driven bridge model that fits within the broader BIM framework in Tekla Structures.

7.1.1.1. Limitations

When dealing with different geometries for the bridge cross-section, we create individual profiles for each variation, which can be time-consuming. However, when the bridge cross-

section remains consistent along its length, this method becomes a highly automated and efficient way to generate the BIM model. By using this approach, the process of modelling becomes faster and more streamlined, significantly reducing manual effort. This automation not only accelerates the BIM creation process but also ensures accuracy and consistency in the model, making it an ideal solution for bridges with uniform cross-sectional geometry.

7.1.2. Bridge geometry

The process of defining the correct position of a bridge from point cloud data plays a crucial role in creating a precise BIM model in Tekla Structures. By using point cloud data, we can extract accurate measurements of the bridge's location, including its altimetry (elevation) and rotation. These details, already determined through Grasshopper

Once the altimetry and rotation data are established, the process to model the bridge in Tekla Structures. The integration between Grasshopper and Tekla allows for ideal data transfer, ensuring that the geometry created in Grasshopper and in Tekla.

By accurately positioning the bridge in Tekla using point cloud data, we ensure that the BIM model reflects the actual physical dimensions and orientations of the bridge. The automated workflow reduces the possibility of errors and allows for quick adjustments if needed, ensuring the bridge model in Tekla Structures is as accurate and reliable as possible.

Excel creating the geometry of the bridge by providing essential data points such as dimensions, positions, and other parameters. In the Revit workflow, we utilized the bridge geometry points, exporting them into Revit via the **adaptive component** method. This allowed the bridge's structural points to be connected and defined in Revit, where the geometry was built using these adaptive points.

However, in Tekla Structures, the process differs. Instead of exporting individual points, we directly export the **solid geometry** of the bridge. This solid geometry, created in Grasshopper using data from Excel, contains the complete form and shape of the bridge, including all its cross sections and curves. By exporting the direct solid geometry into Tekla, we streamline the modelling process, as Tekla is equipped to handle complex solid structures in BIM workflows.

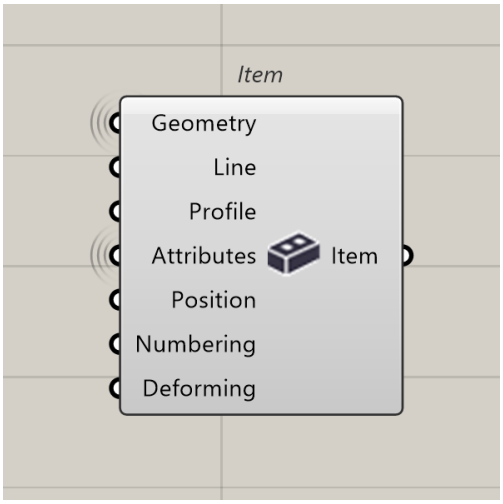


Figure 7. 9 Tekla GH "item" Component

The **“Item”** component in Grasshopper is key to exporting the direct shape of the bridge into Tekla Structures. This component allows several inputs to ensure the solid bridge geometry is accurately transferred. The **“geometry”** input is where the solid bridge model is provided. In cases where the geometry input fails to capture all the necessary data, the **“line”** input serves as a backup, helping Tekla recognize and process the geometry correctly. Additionally, the **“profile”** input lets you define the bridge profile used in the model.

Other inputs include **“attributes”**, **“position”**, **“numbering”**, and **“deforming”**, all which function similarly to the settings in Tekla Structures. These allow for more detailed customization, ensuring that the bridge geometry is fully aligned with Tekla’s structural requirements. The **“Item”** component, therefore, acts as a bridge between Grasshopper and Tekla, enabling the smooth export of complex solid geometries for further BIM modelling in Tekla Structures.

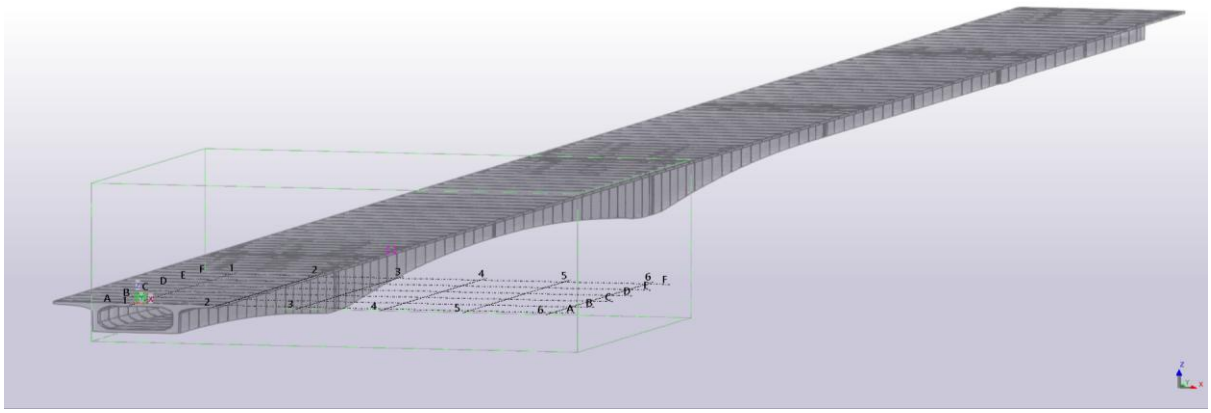


Figure 7. 10 Bridge Geometry in Tekla Structures

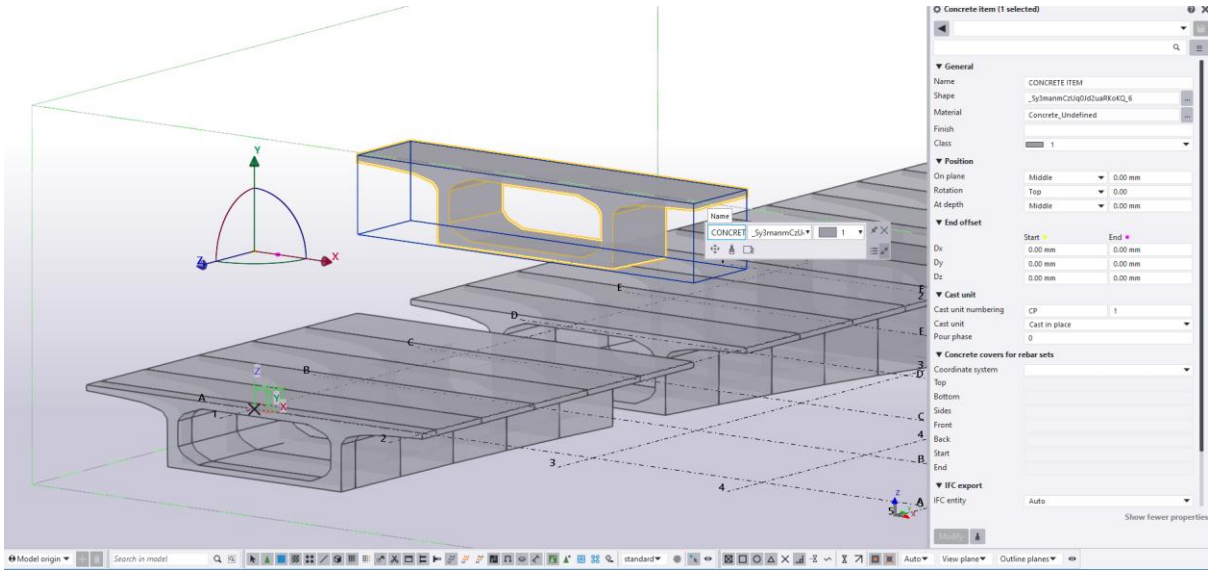


Figure 7. 11 Bridge section details

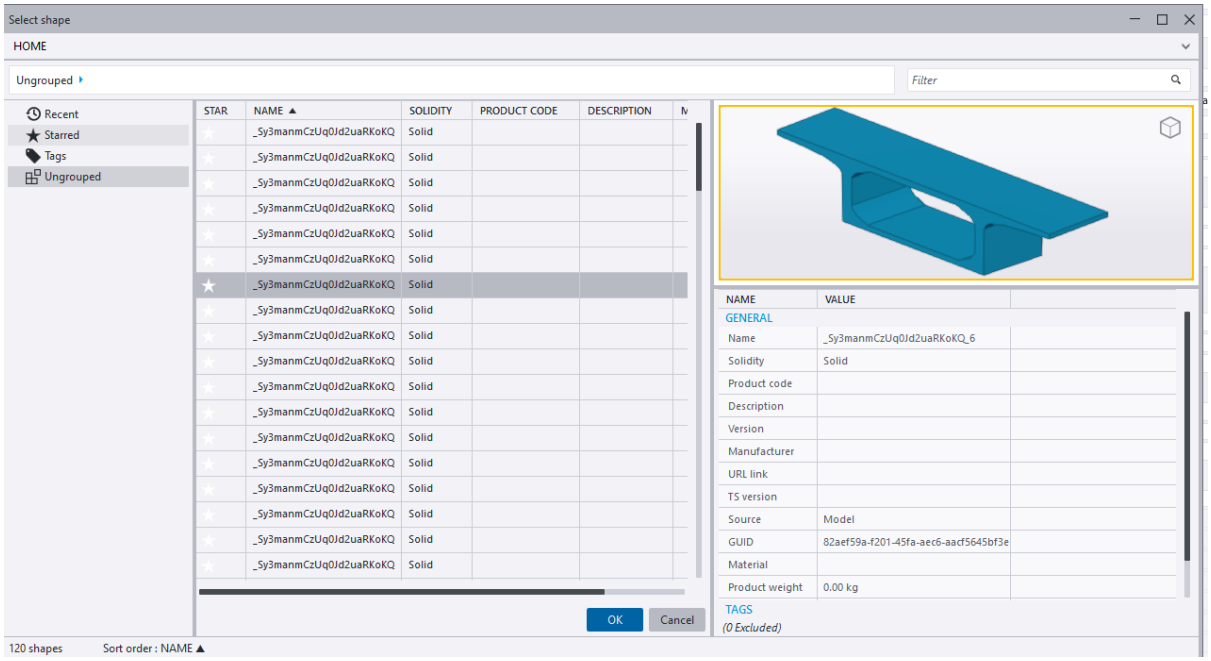


Figure 7. 12 Tekla Structures geometry individual profile name

7.1.3. Creation of pavement

Utilizing the same workflow, we can also create the pavement of the bridge. Knowing that the pavement has a thickness of 15 cm, we can generate a solid shape in Grasshopper to represent it. This solid geometry is then transferred to Tekla by connecting it to the "Item Geometry" component. This method ensures accurate representation of the pavement in the BIM model. By automating the process, we reduce manual work, streamline the design, and ensure consistency in the modelling of the pavement, like the approach used for the bridge structure.

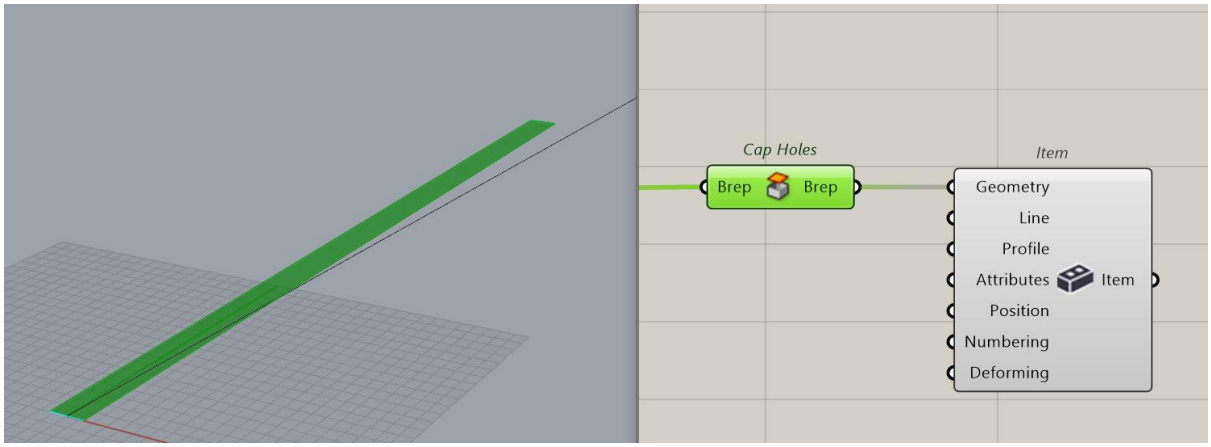


Figure 7. 13 GH Component to create Pavement

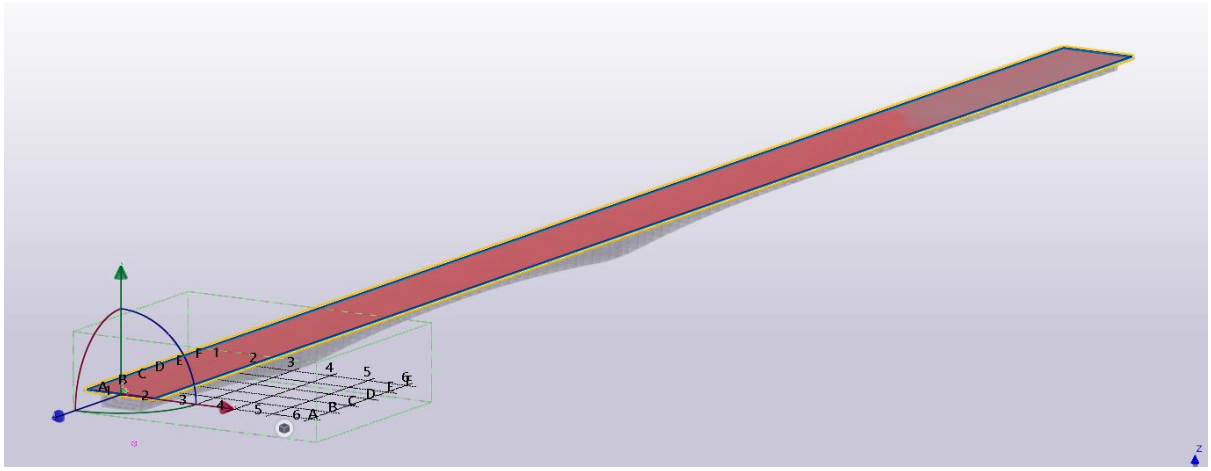


Figure 7. 14 Pavement in Tekla Structures (View 1)

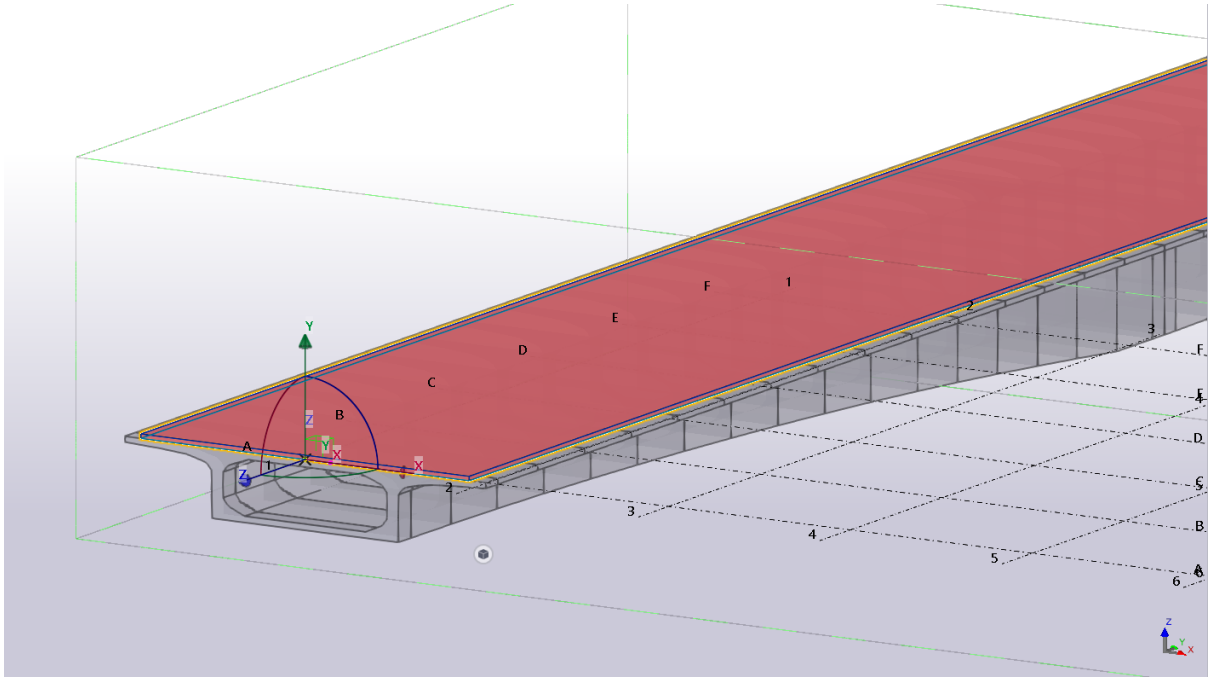


Figure 7. 15 Pavement in Tekla Structures (View 1)

7.1.4. Creation of curb

There are two methods to create the curb dimension in the bridge model. The first method involves using Grasshopper to create the curb geometry and extrude it along the bridge's length. The second method imports the curb's AutoCAD file into Rhino, where it can be extruded. Both methods are efficient and easy to execute within the Grasshopper interface. The choice between the two depends on the design workflow, but both ensure accuracy and integration with the overall model, making the curb creation process flexible and adaptable to different design inputs.

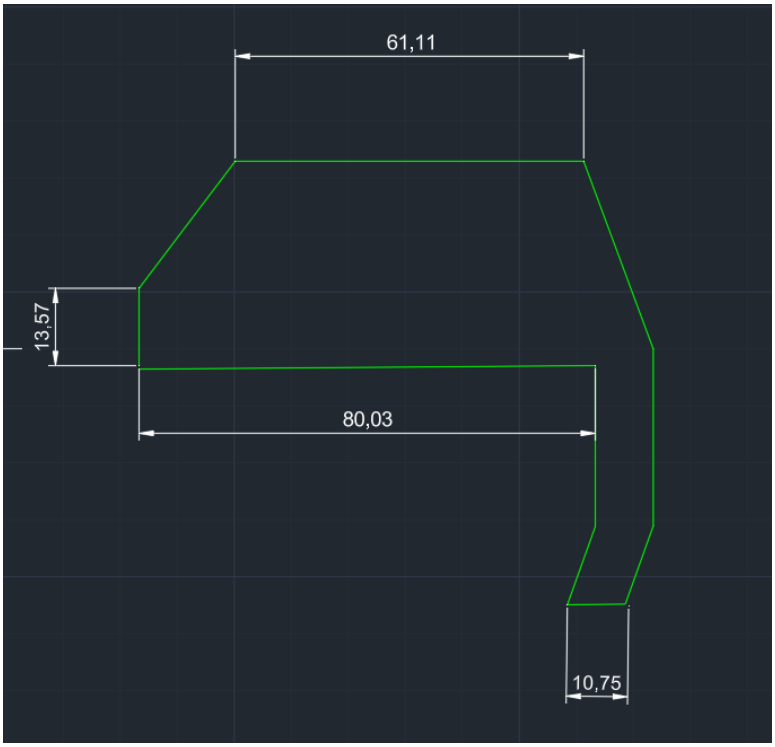


Figure 7. 16 Curb AutoCAD File

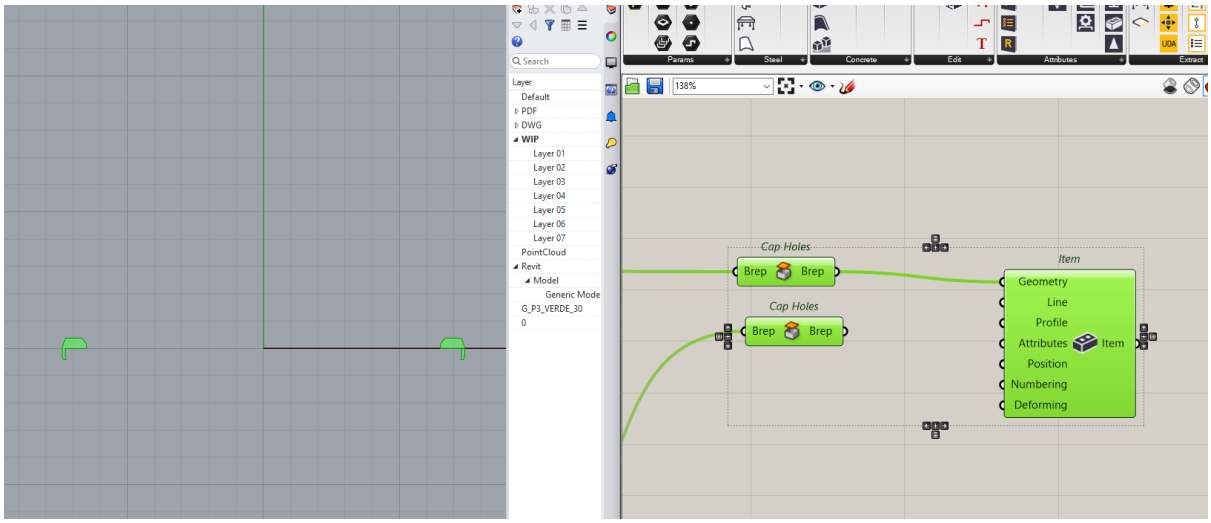


Figure 7. 17 Curb GH Script

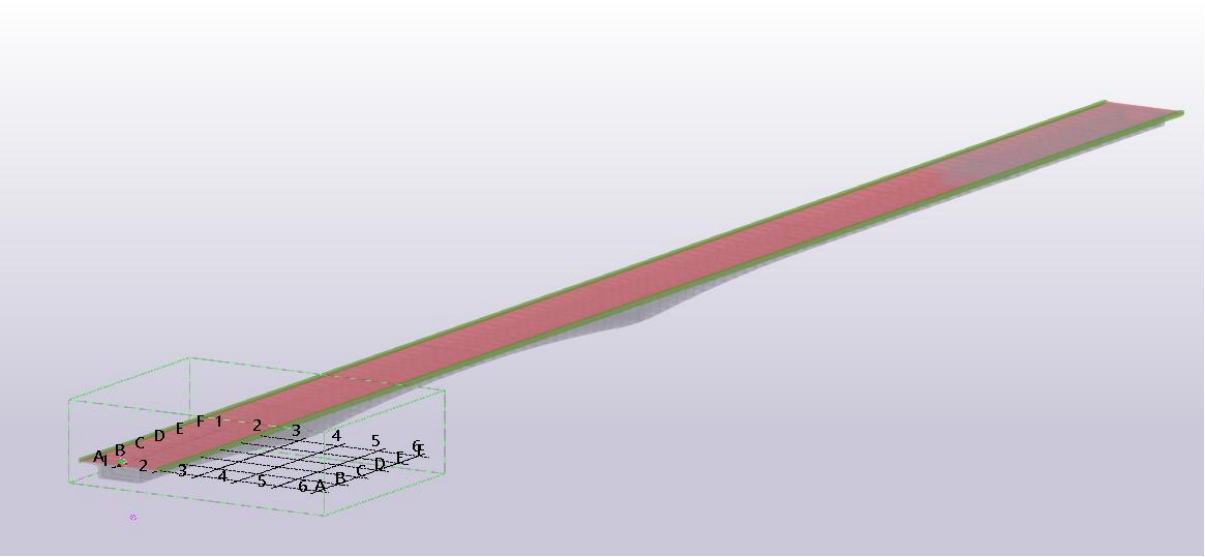


Figure 7. 18 Curb geometry inside Tekla Structures (View 1)

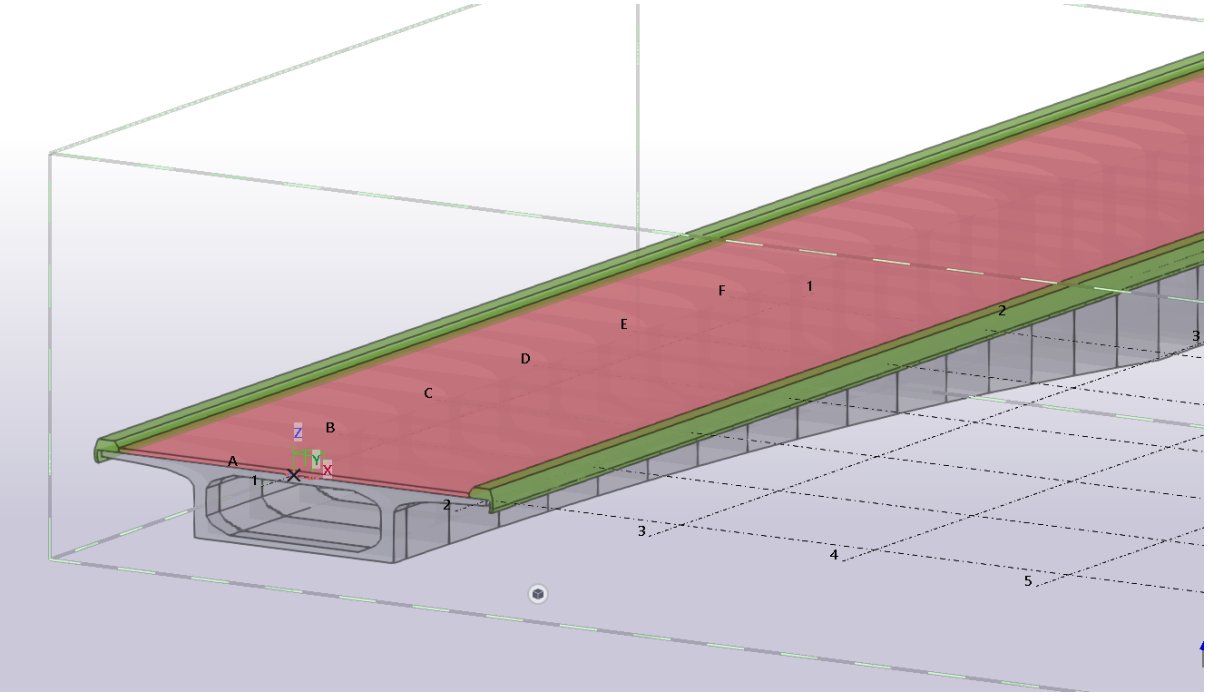


Figure 7. 19 Curb geometry inside Tekla Structures (View 1)

7.1.5. Pre-Stressed Cables

The same Grasshopper cluster can be used to create the position and exact length of the pre-stressed cables. In Revit, the cables are imported as solid shape geometries, ensuring accurate placement within the bridge model. Similarly, in Tekla Structures, the cables are also imported as solid shapes, with the input profile assigned its specific material properties. This method ensures consistency across both platforms and allows for precise modelling of pre-stressed cables. As you see in the below picture the cable radius has given as input.

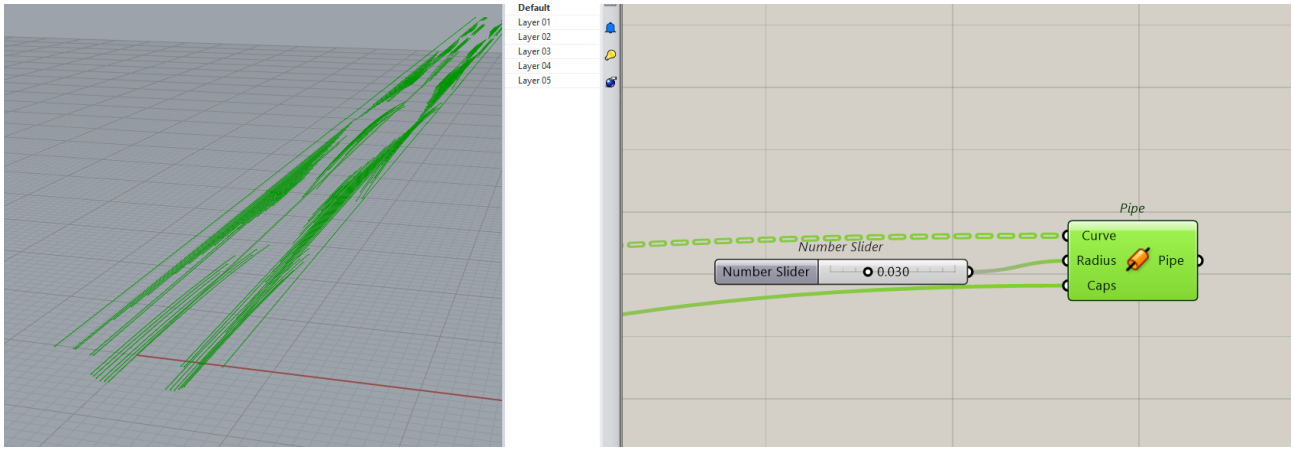


Figure 7. 20 Radius of the cables

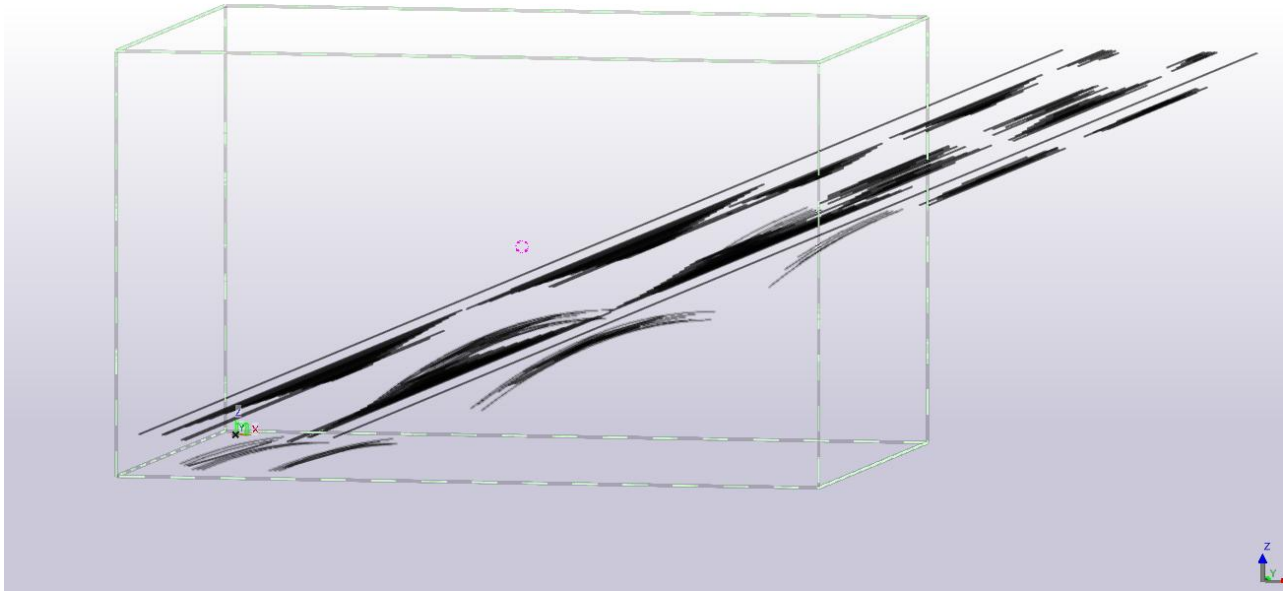


Figure 7. 21 Pre-Stressed Cables in Tekla Structures

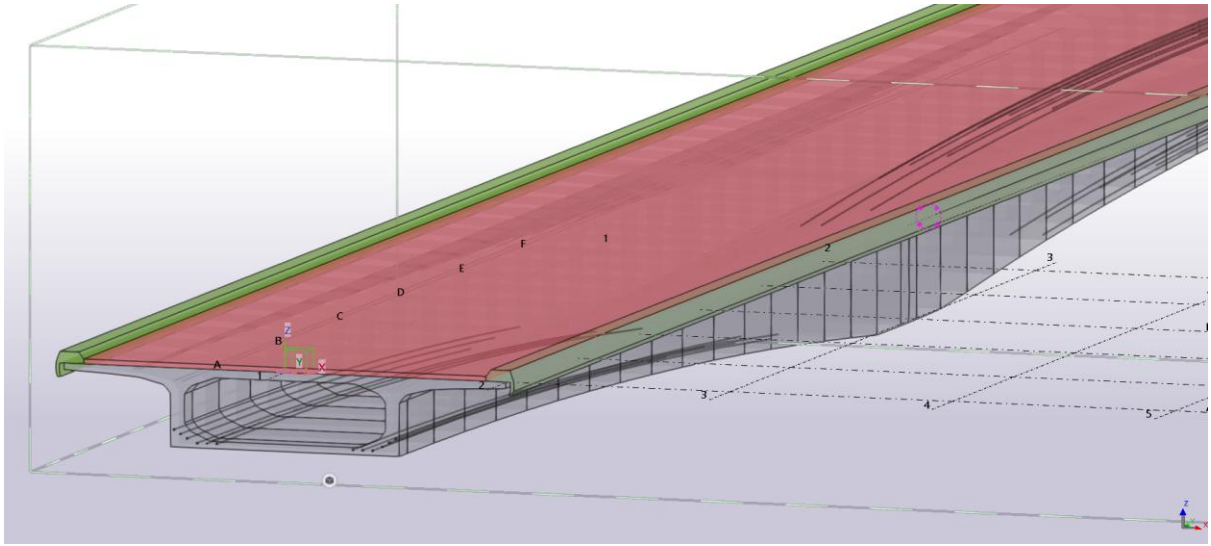


Figure 7. 22 Pre-Stressed Cables and bridge in Tekla Structures

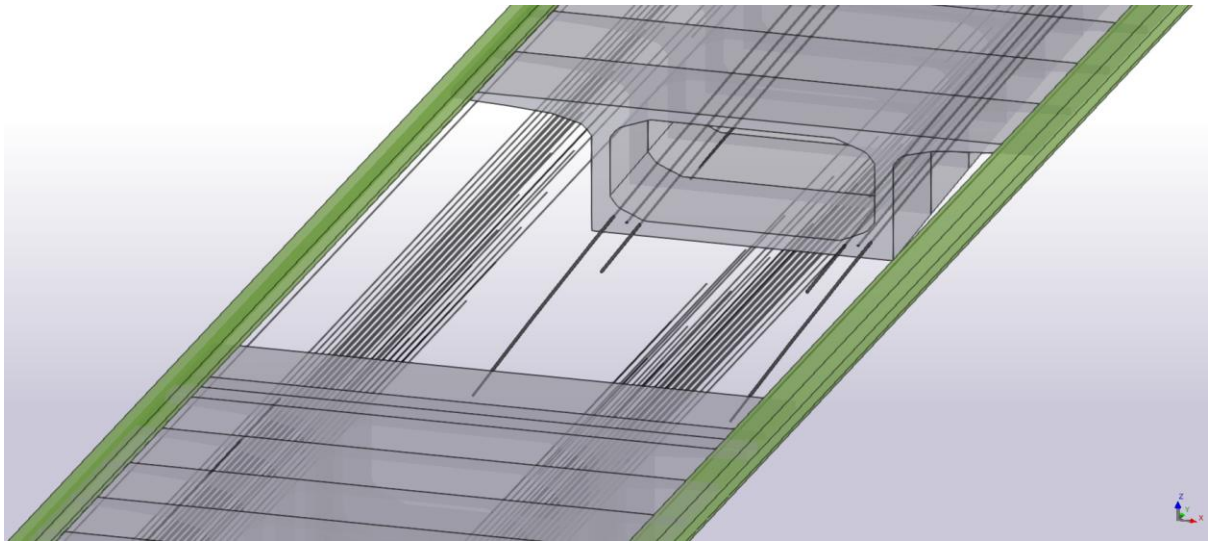


Figure 7. 23 Pre-Stressed Cables interior View

CHAPTER 8

8. Further Development and Automation

8.1. Automation Interface

As a further development of the parametric modelling workflow presented in this thesis, a dedicated graphical user interface (GUI) was developed using the **Human UI** plug-in for Grasshopper. The objective of the interface is to simplify interaction with the developed algorithms and make the modelling workflow accessible to users without requiring direct interaction with the underlying Grasshopper definition.

Human UI enables the creation of customized graphical components, such as panels, sliders, buttons, checkboxes, and input fields, which can be directly connected to Grasshopper parameters. These components were used to provide an intuitive environment for controlling the principal inputs required for bridge modelling.



Figure 8. 1 Human UI Logo

The interface is organized according to the main stages of the modelling process. Users can select the geometric input method, including **point-cloud data or an alignment curve**, and define the parameters required for bridge generation. External data can also be imported from **Excel files**, allowing geometric and dimensional information to be read directly by the

Grasshopper algorithms and reducing repetitive manual input.

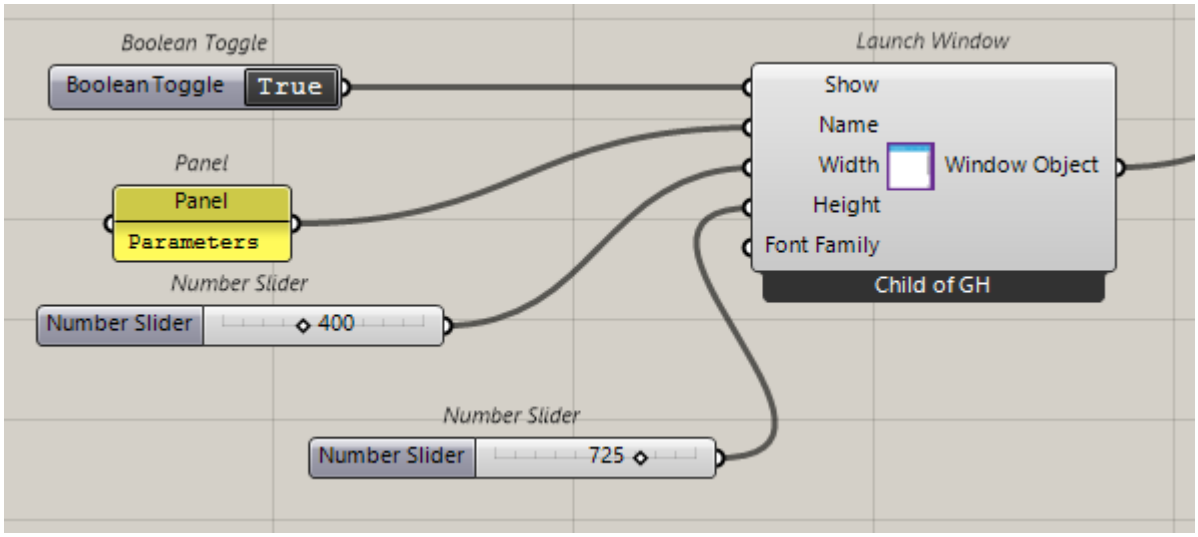


Figure 8. 2 Human UI GH component

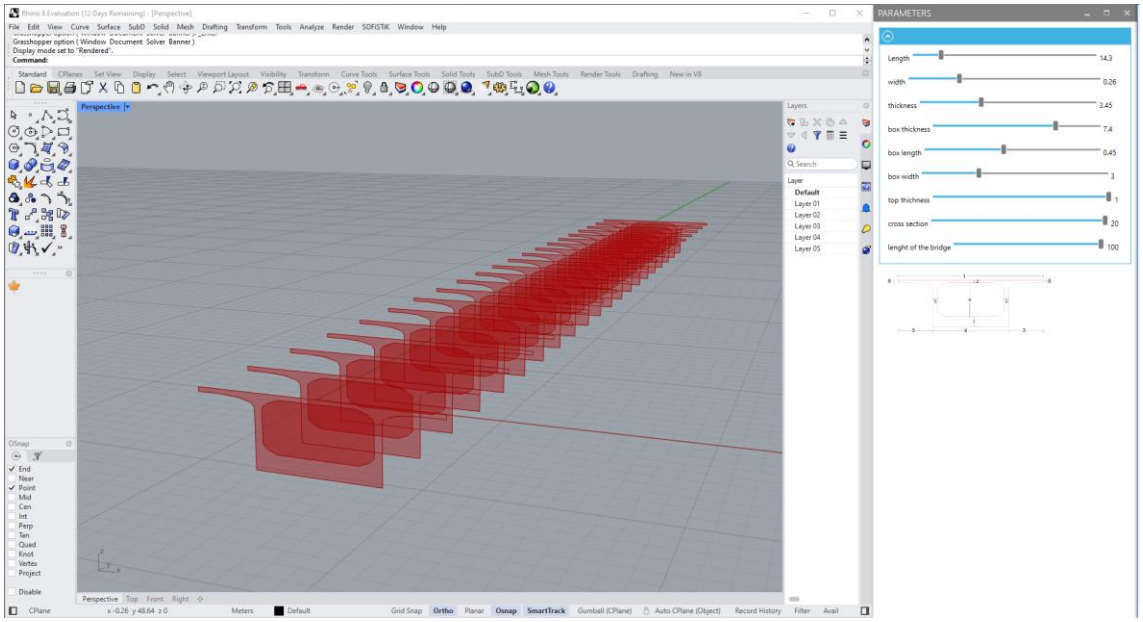


Figure 8.3 Interface method

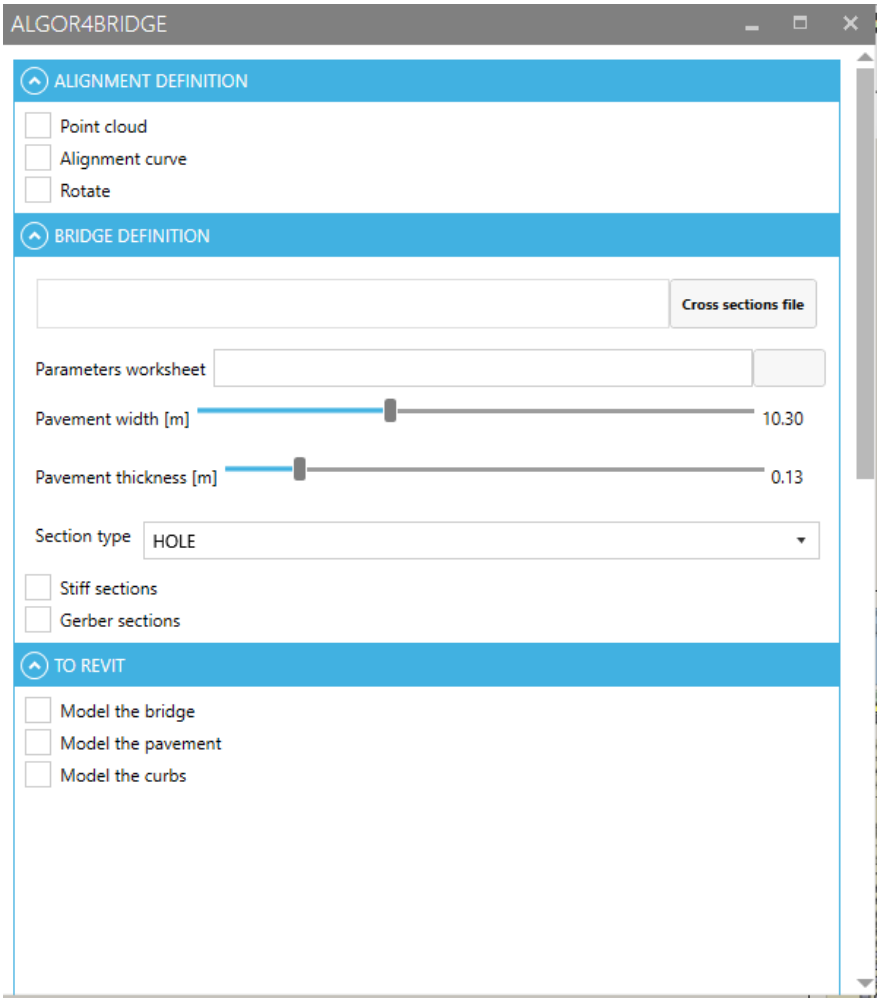


Figure 8.4 Interface Slider

To ensure that the developed set of algorithms is accessible and easy to use for a wide range of users, a dedicated interface was created using the Grasshopper plug-in Human UI. The primary goal of this interface is to provide a user-friendly environment that removes unnecessary complexity from the modelling process, allowing designers and engineers to focus on inputs and results rather than technical implementation details.

Through this intuitive interface, users are required only to provide the necessary input parameters, such as structural dimensions or material specifications. In addition, the system allows the integration of optional data, including point clouds and alignment curves, which can further refine the accuracy and realism of the generated bridge model. Once the input is provided, the underlying algorithm automatically processes the data to generate a complete geometric representation of the bridge.

A key feature of the interface is the integrated preview window. This function enables users to visually inspect the model in real time, ensuring that the geometry meets the design requirements before any data is exported. By offering a direct visual check, the system reduces potential errors and increases confidence in the results, which is particularly important for large-scale infrastructure projects where accuracy is crucial.

Beyond visualization, the algorithm also performs automatic calculations of the bridge's coordinates and spatial position. This capability is essential for ensuring that the model can be properly georeferenced when imported into Building Information Modelling (BIM) environments. Accurate georeferencing guarantees consistency between the digital model and the physical project site, facilitating collaboration across disciplines and supporting the integration of the bridge model into broader project workflows.

In summary, the combination of Human UI and automated algorithms provides an efficient, reliable, and user-centred approach for generating bridge models, significantly improving usability within the BIM context.

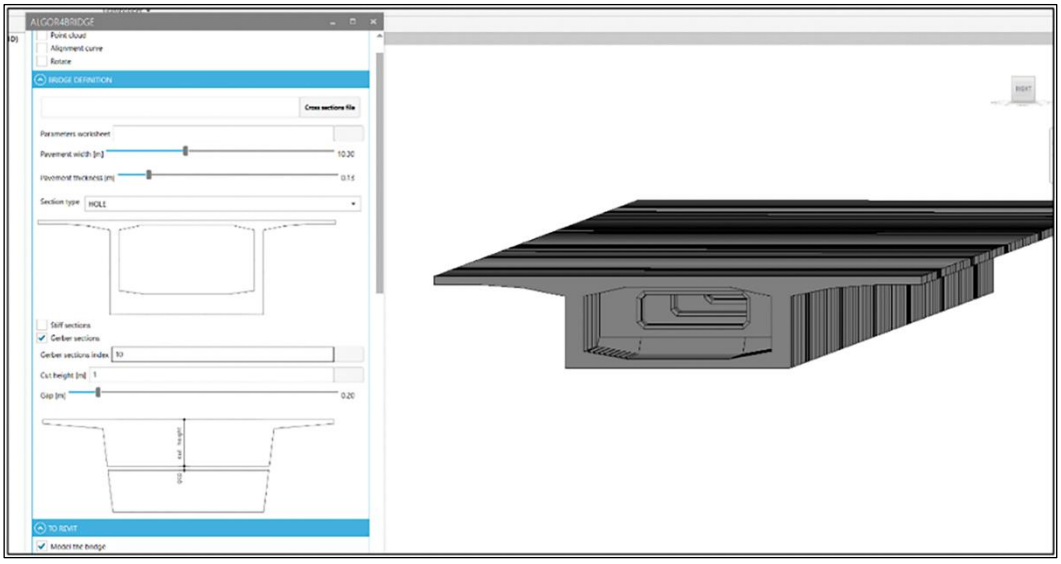


Figure 8.5 Interface Slider

The interface developed through Human UI provides users with full control over all aspects of the bridge model, ensuring flexibility and ease of use. One of its key advantages is the ability to directly connect with Excel files, allowing the system to read parameters straight from the spreadsheet without requiring additional operations within Grasshopper. This streamlined process reduces manual input and speeds up the modelling workflow.

In addition, the interface supports the import of point cloud data files, which can be seamlessly integrated to enhance the accuracy and realism of the geometric model. Users also have the option to define and modify the bridge's section type directly within the interface, enabling quick adjustments to design alternatives. By combining parameter control, data integration, and flexible section management, the tool offers a comprehensive and efficient environment for bridge modelling, simplifying complex processes into an intuitive and user-friendly workflow.

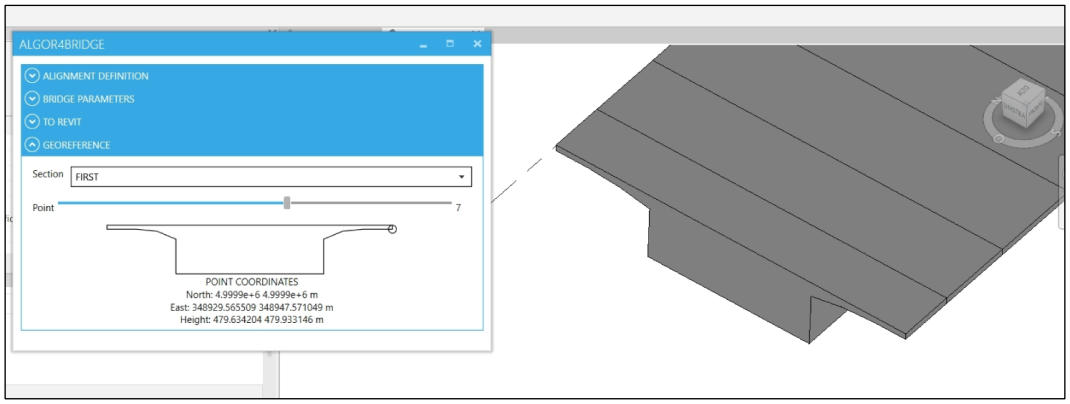


Figure 8.6 Georeferencing operation

The interface also supports georeferencing of the bridge model, ensuring accurate placement within its real-world context. By automatically calculating coordinates and spatial positioning, it guarantees seamless integration into BIM environments. This functionality enhances collaboration, accuracy, and consistency across disciplines, aligning the digital model with the actual project site.

CHAPTER 9

9. Aspects to Continue developing

9.1.1. Create Sheet

The grasshopper automation can also create the sheet detailing in Tekla structures. Using the plugin called “Tekla Drawing” we can also access the sheet work of the bridge.

There is automation for everything even for the easy work to make easiest and fastest. For example, creating the sheet. We know that for creating the new sheet in Tekla structure we have the option called create GA drawing and when we click that the sheet will be created and opened.

There is component called “create GA Drawing” in grasshopper which allows to create the sheet from grasshopper. We can also give the name of sheet as input from the grasshopper. Also, we can create the multiple number of sheets in the automation way with individual name of sheets.

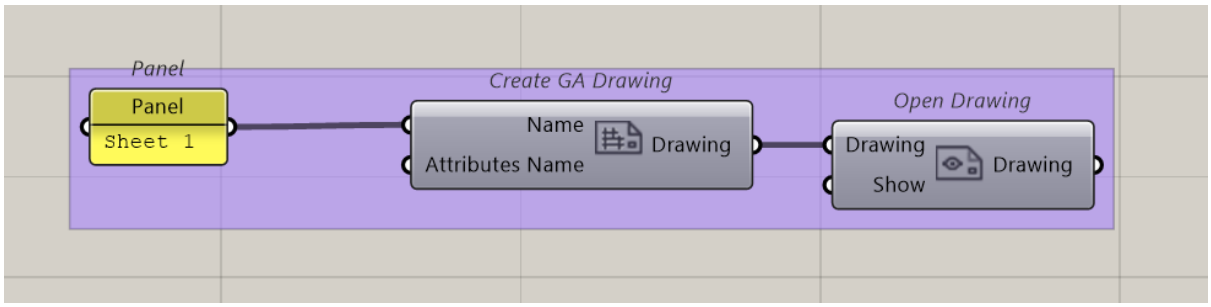


Figure 9. 1 Create GA Drawing

As we know the sheet making is an easy process but takes more time. When we can to create the detail like dimensions, length, width, making section throughout the bridge and making the cross section dimensioning of it. using the Tekla drawing plugin, we can create everything with automation process. It is the best way to reduce the time and make the accuracy of the detailing in the sheet.

9.1.2. Activate Sheet

After creating a sheet, it's crucial to gain access to it to manage and automate tasks effectively. This becomes even more important when multiple sheets are created for the same drawing. Accessing each individual sheet allows for precise control and specific operations, ensuring the correct data or functions are applied to the intended sheet. Without accessing the

individual sheets, automation processes could become inefficient or inaccurate. Therefore, it's necessary to establish access to each sheet to perform the required automation, ensuring accuracy and functionality across all sheets in a drawing.

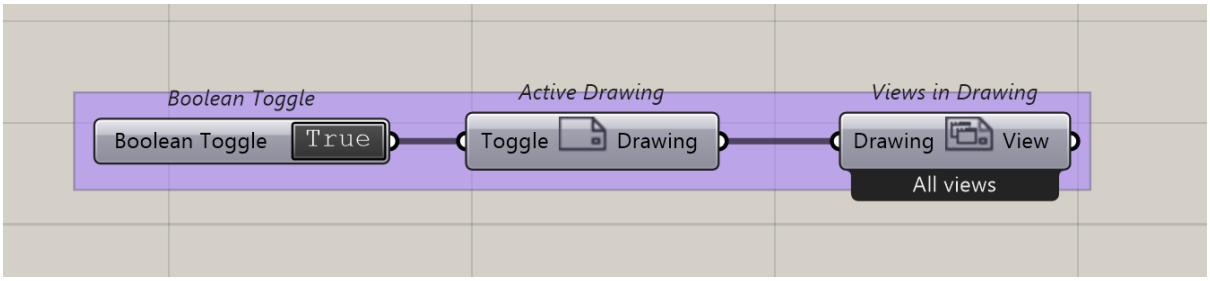


Figure 9.2 View Drawing

Activate drawing component is used to get the access of each Sheet



Figure 9.3 Tekla Structure Sheet

To open individual drawings straight from Tekla Structures in Grasshopper, utilize the "View Drawing" component from the Grasshopper-Tekla Live Link. This makes it possible for users to interact and view drawings inside the Grasshopper environment. The Boolean Toggle component must be connected to the "View Drawing" component's drawing input to use this feature. The toggle offers a smooth method to see and manage design documents immediately within the parametric modelling workflow when it is set to "True," which causes Tekla Structures to launch the specified drawing.

9.1.3. Drawing to sheet

When the sheet is activated, the drawing of the bridge is automatically displayed on the sheet. This process allows for the bridge design to be instantly transferred, streamlining documentation and presentation.

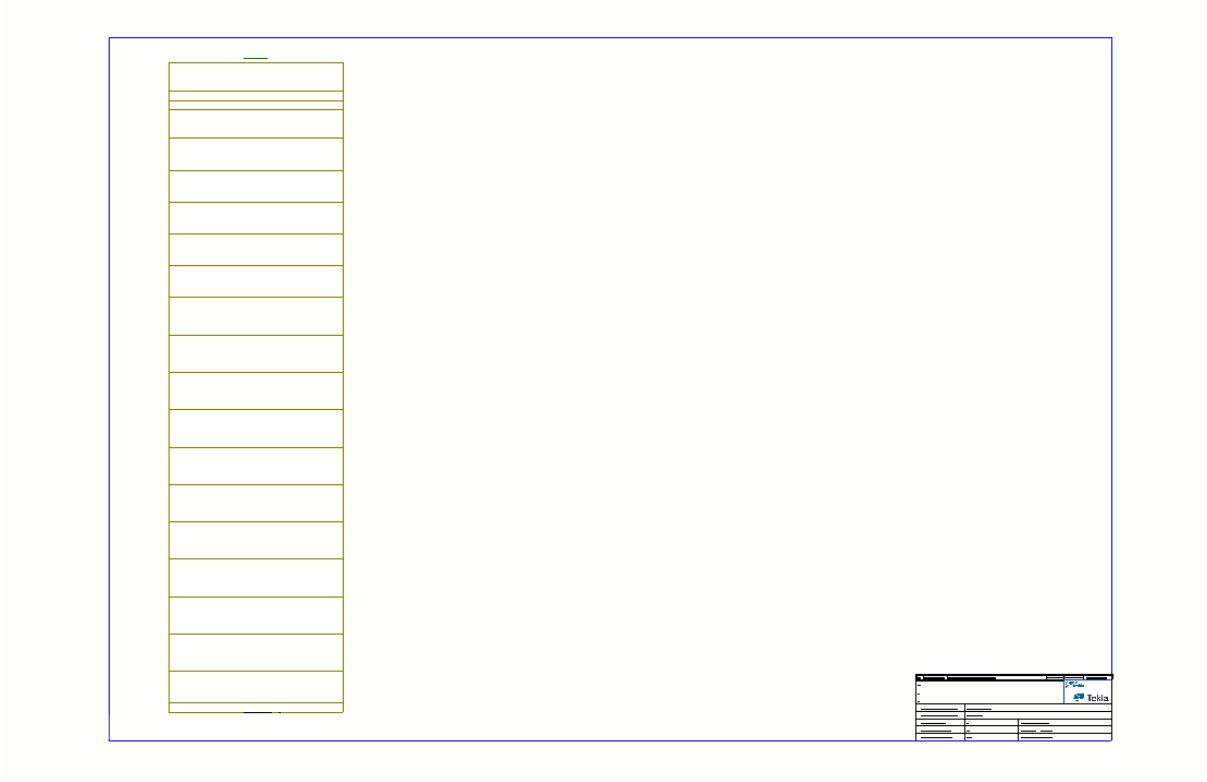


Figure 9.4 Bridge view in sheet

9.1.4. Section mask and view

To create sectional cuts of a 3D model, utilize Grasshopper's Section View component. It lets you specify a plane that divides across your geometry and shows the cross-sectional profile or intersection where the cut happens. This is especially helpful for deciphering and displaying internal features of intricate models or architectural components, such as the cross-section of a bridge.

A 3D geometry (such as a solid or surface) and a cutting plane typically created using a plane component are required to use the Section View component. You are left with an accurate sectional picture, along with a collection of curves that indicate the points on the geometry where the plane intersects.

When the "Section View" component is activated in Grasshopper for a bridge cross-section, it not only generates the section cut but also automatically creates section annotations. Each cross-section receives its unique identifier or mark, allowing for organized documentation. For example, the first cross-section will be labelled "Section 1," followed by "Section 2," and so on throughout the length of the bridge. This annotation ensures that every section is clearly distinguished and easy to reference in drawings, simplifying communication, documentation, and construction workflows, especially for complex structural designs like bridges.

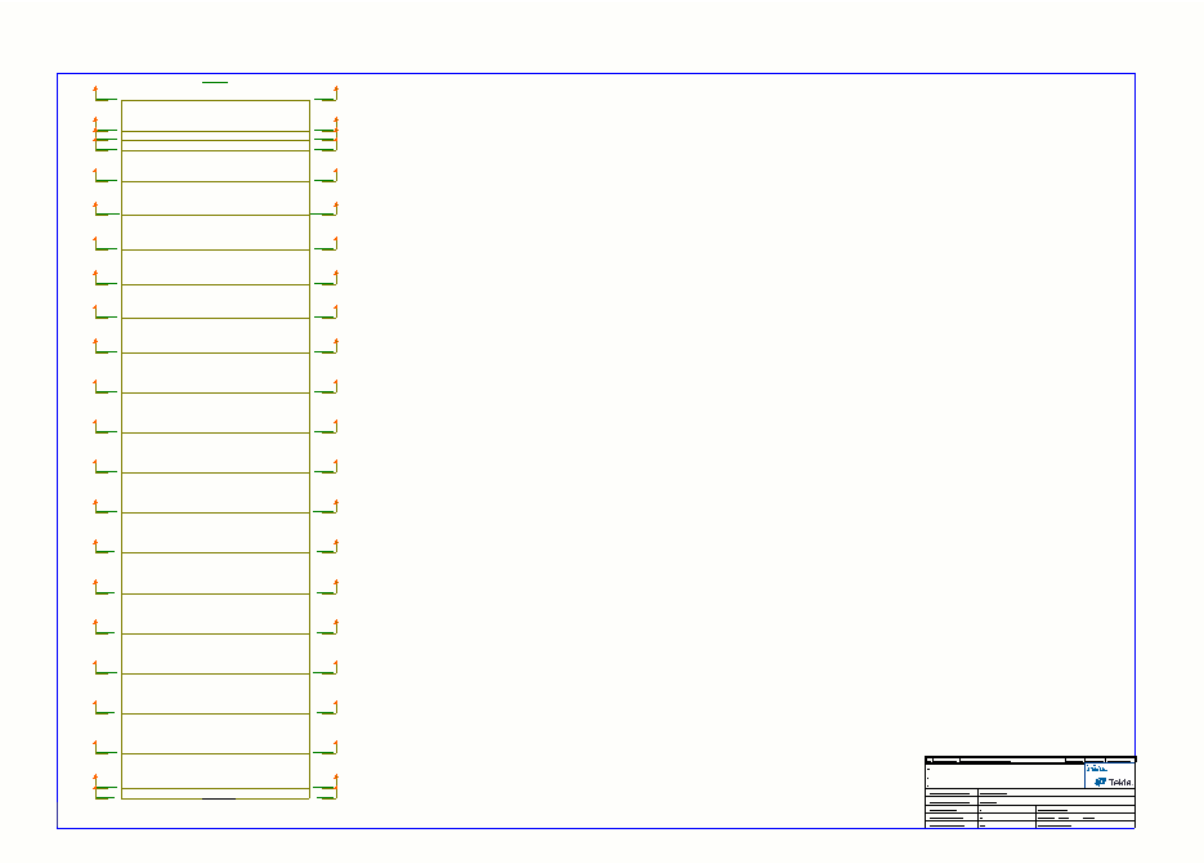


Figure 9.5 Section mask of the bridge (View 1)

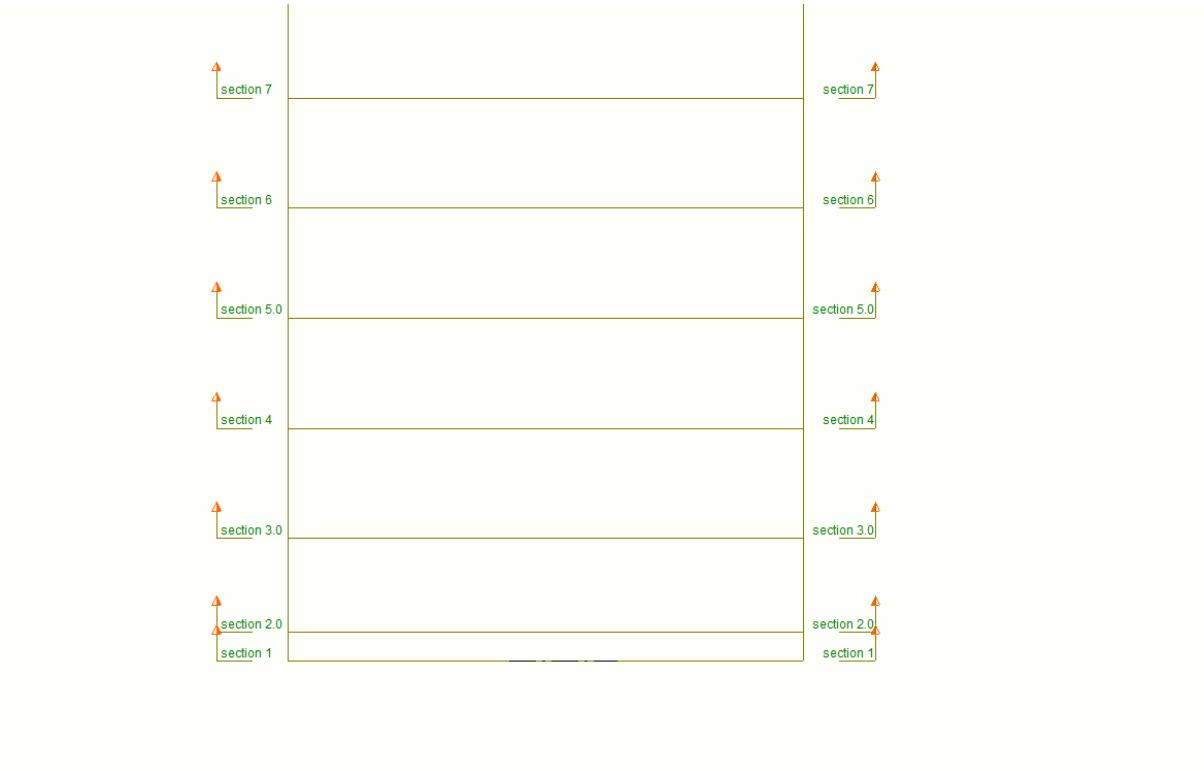


Figure 9.6 Section mask of the bridge (View 2)

A Grasshopper component can be used to generate a bridge's cross-section. The bridge geometry is determined by its specific measurements, as indicated in the image, and matching cross-sections are automatically generated along its length. Grasshopper outputs each cross-section as a separate frame during this procedure. For example, if a bridge needs 120 cross-sections, the component will automatically create all 120 sections, which conserves an endless amount of time and work.

With the help of this automation, the cross-sections distribute uniformly according to the bridge's structure, and every section may be specifically identified for further study or archiving. Additionally, because Grasshopper makes it simple to parametrize and modify the design, each cross-section may be controlled and altered in the future. This implies that any cross-section can be edited in the future without having to reassemble the complete set.

More effective design workflows are made possible by this technique, particularly for large-scale infrastructure projects like bridges, where accurate cross-sectional details are essential for construction documentation. Throughout the bridge design and detailing stages, designers and engineers can guarantee accuracy, preserve flexibility, and drastically minimize manual drawing work by utilizing parametric modelling.

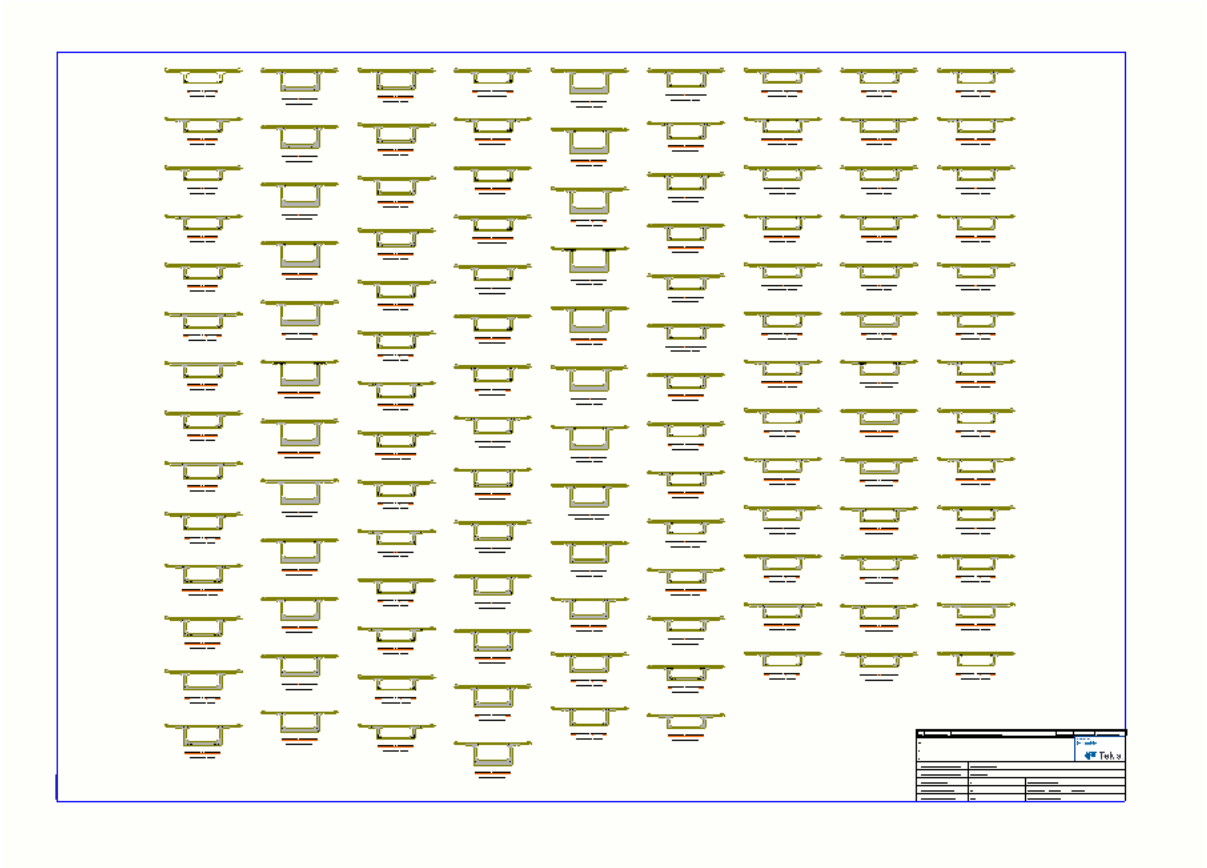


Figure 9.7 Cross Section of the bridge (View 1)



Figure 9.8 Cross Section of the bridge (View 2)

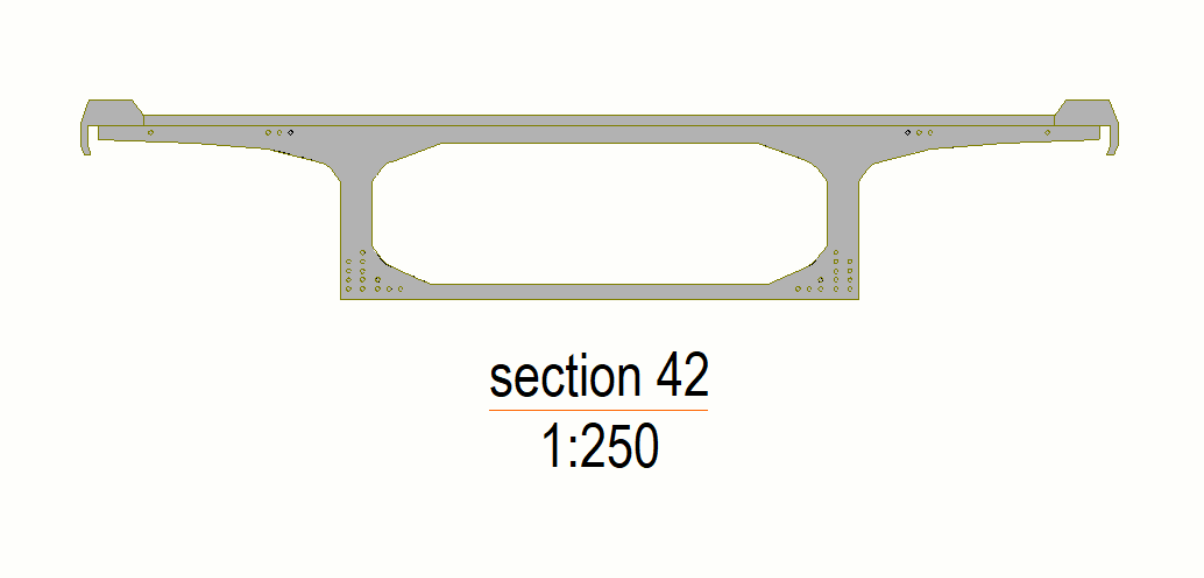


Figure 9.9 Individual Cross Section of the bridge

9.1.5. Automation in Dimension

Dimension lines in Tekla Structures drawings can be automatically created with Grasshopper's Dimension Line component, especially when used in conjunction with the Grasshopper-Tekla Live Link. This part aids in producing precise and parametric dimensions for the several Tekla model elements, including the lengths, widths, and distances in a building project or bridge.

You can add dimension lines to particular views or areas of your Tekla Structures model by defining important items or reference points in the Grasshopper script. For instance, you may specify a beam's or cross-section's endpoints and have Tekla automatically create dimension annotations for those components.

This is particularly helpful for producing parametric, automatically updated drawings, providing that any modifications made to the Grasshopper model will be mirrored in the dimensions of the Tekla drawing. As the design changes, it enables dynamic control over the presentation of dimensions, preserving efficiency and accuracy in documentation.

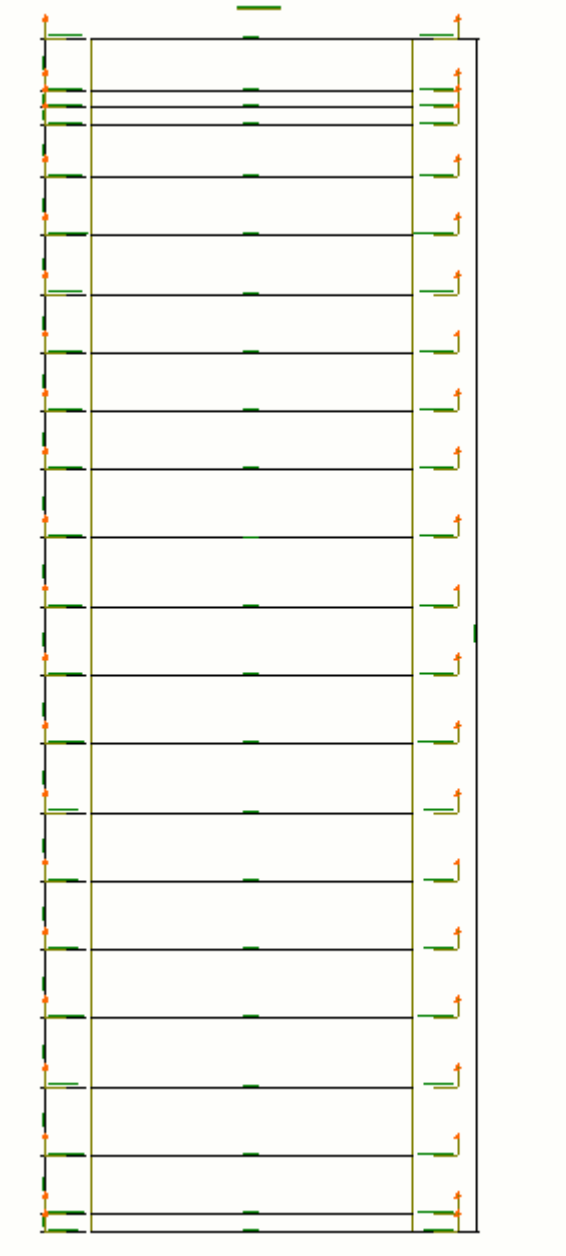


Figure 9.10 Dimension of the bridge (View 1)

We have created the geometry of the bridge using data from an Excel file, where the dimensions of various elements are already defined. These dimensions include key measurements such as the length, width, and height of the bridge components, which are

essential for creating accurate drawings. By leveraging Grasshopper's **Dimension Line** component, we can automatically generate dimension annotations for the bridge within Tekla Structures.

The process begins by importing the Excel data into Grasshopper. Each line or part of the geometry is defined based on the coordinates and dimensions stored in the Excel file. Once the geometry is created, the **Dimension Line** component is used to translate these lines into dimension annotations. You simply input the lines or points representing the bridge's geometry into the **Dimension Line** component, and it converts them into dimension data suitable for Tekla Structures.

This parametric workflow allows for the automatic generation of dimension lines on Tekla's drawing sheets, ensuring that every part of the bridge is accurately documented. Any modifications to the Excel file, such as changes in the bridge's dimensions, will automatically update the corresponding dimensions in the Tekla drawings, providing flexibility for future edits and maintaining consistency throughout the design

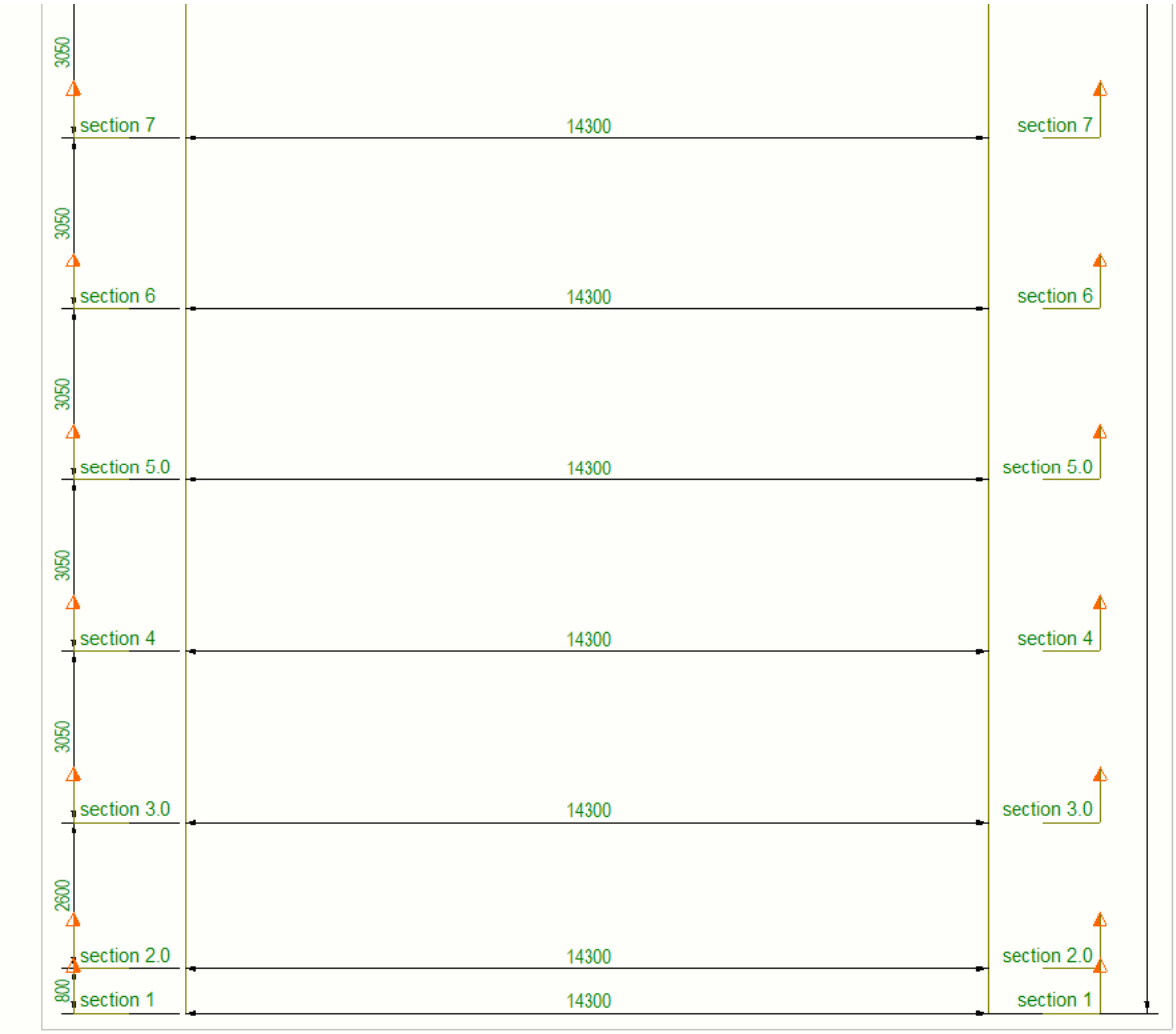


Figure 9.11 Dimension of the bridge (View 1)

9.2. Two cell concrete box bridge

A reinforced concrete structure with two parallel hollow cells or voids forming the deck makes up a two-cell concrete box bridge. Concrete is poured around internal forms to produce these cells, leaving an empty space within each one that lowers the bridge's overall weight without compromising its structural integrity. This kind of bridge is frequently employed for medium- to long-span constructions, where the twin-cell design facilitates effective weight distribution over the deck.

It is also necessary to precisely state the two cells' dimensions and spacing geometrically. Accurate measurements are required to guarantee both structural soundness and interoperability with current infrastructure. Further complicating the design are variations in bridge lengths, lane widths, and approaches.

Another level of difficulty is added by interaction with the current utilities and roads, since correct alignment and functionality must be preserved. Advanced modelling programs such as Rhino and Grasshopper speed up the design process, but handling the complex interrelationships between parts requires a high degree of skill.

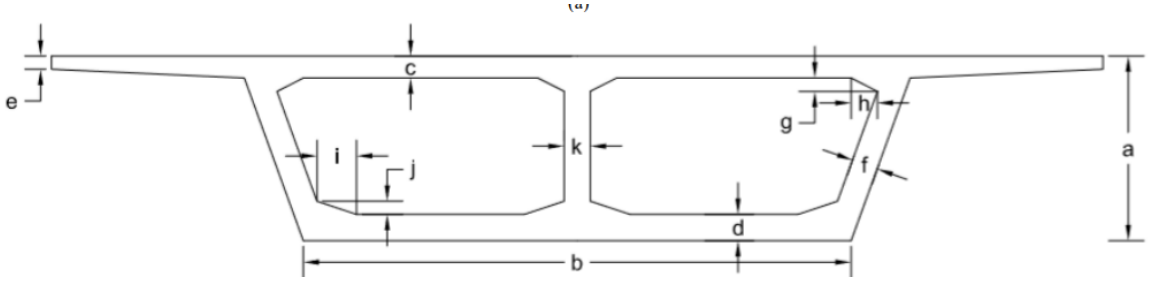


Figure 9.12 Two cell Concrete Box Bridge

In my research, I developed a cluster for the geometry of a single-cell concrete box bridge, which is now extended to accommodate a two-cell concrete box bridge as well. The figure below illustrates the cross-section geometry of the two-cell concrete box bridge, created directly from the input parameters specified in Grasshopper. This design process allows for a dynamic and flexible modelling approach, where each aspect of the bridge's geometry is influenced by user-defined inputs.

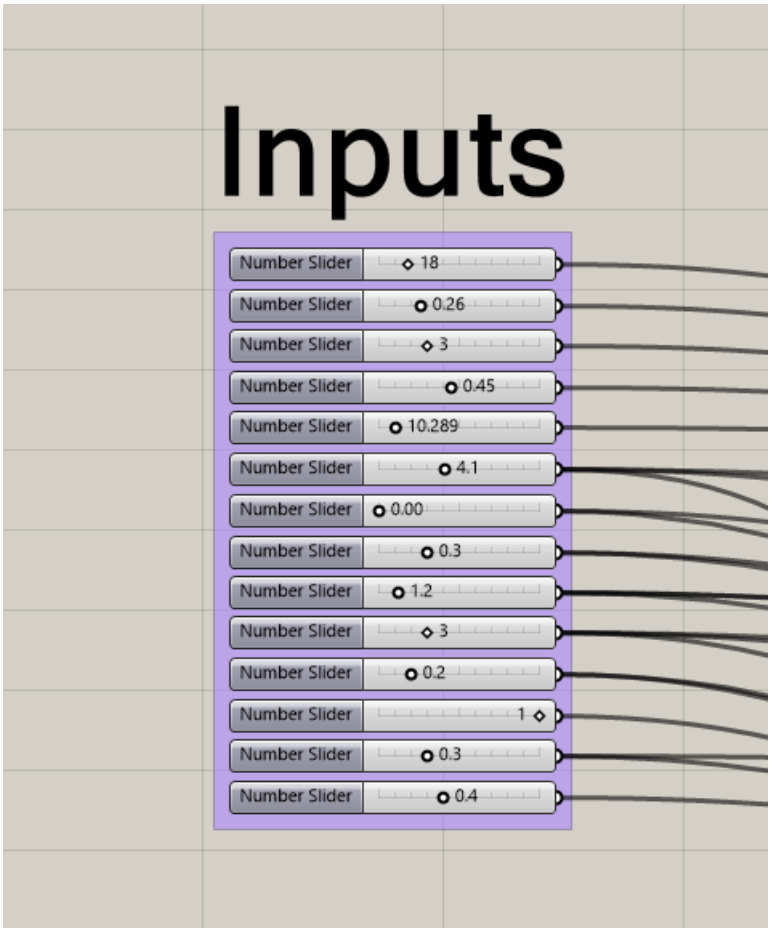


Figure 9.13 Two cell Concrete Box Bridge input example 1

By incorporating input sliders in Grasshopper, users can easily modify parameters such as width, height, and spacing of the cells. When adjustments are made to these sliders, the geometry updates in real time, reflecting the changes in the cross-section of the bridge. This interactivity not only enhances the design experience but also facilitates rapid prototyping and exploration of different design options.



Figure 9. 14 Two cell Concrete Box Bridge output example 1

Another example of the slider will give the different input to create another geometry of the shape

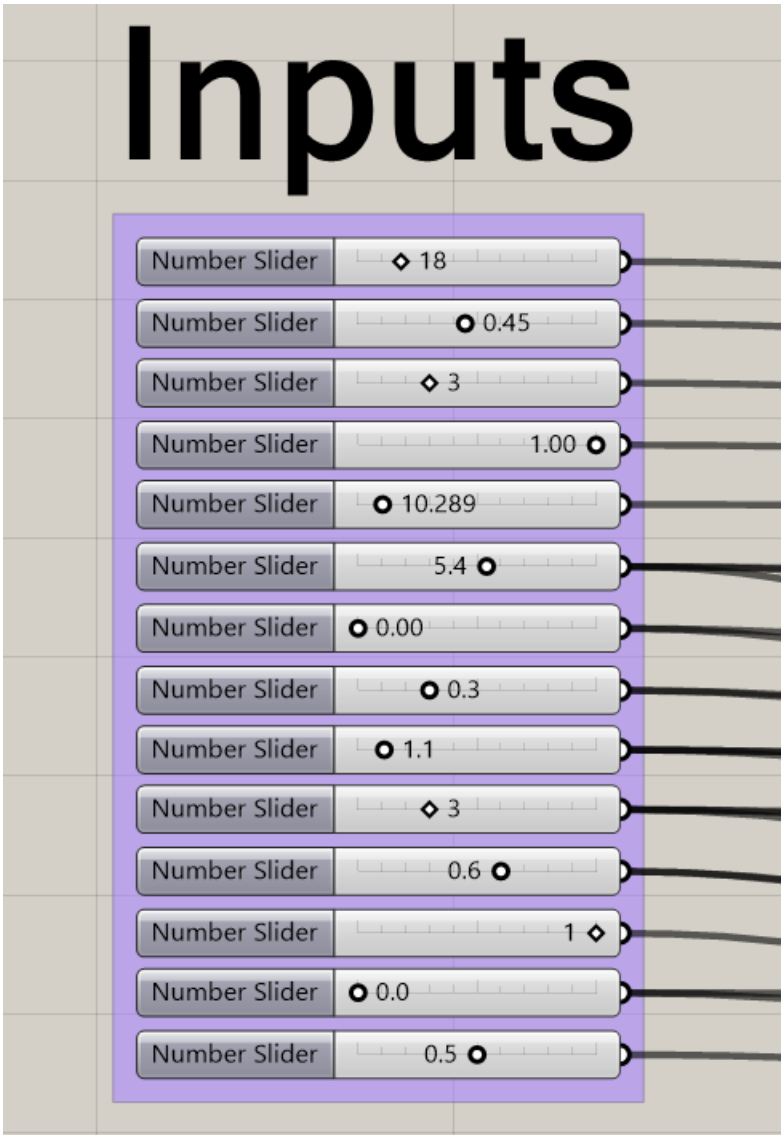


Figure 9.15 Two cell Concrete Box Bridge input example 2



Figure 9.16 Two cell Concrete Box Bridge output example 2

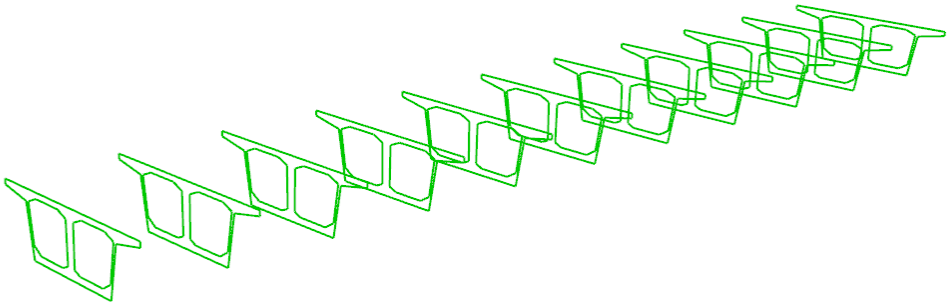


Figure 9.17 Two cell Concrete Box Bridge cross section



Figure 9.18 Two cell Concrete Box Bridge rendering 1

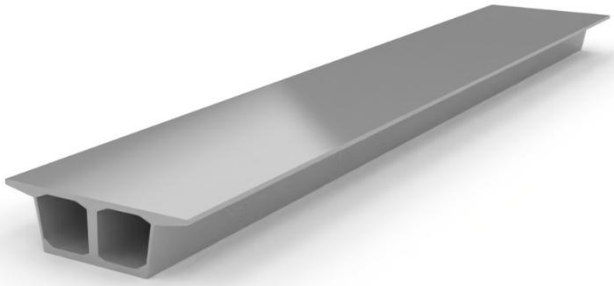


Figure 9.19 Two cell Concrete Box Bridge rendering 2

CHAPTER 10

10. Conclusion

This thesis demonstrates the implementation of parametric modelling using Grasshopper for the development of flexible 3D bridge models and their integration with Tekla Structures and Autodesk Revit. The developed workflow enables point-cloud data representing an existing bridge to be processed and transformed into the geometric information required for the parametric reconstruction of a concrete box-girder bridge. Despite the challenges encountered during the development process, Grasshopper proved to be an effective environment for managing complex bridge geometries and automating repetitive modelling operations. The use of external Excel-based input data further simplifies the modification of geometric parameters without requiring users to directly modify the underlying Grasshopper definition.

For the integration with **Autodesk Revit**, adaptive families were used to generate BIM components while maintaining parametric control over the bridge geometry, including the deck, curbs, and pavement. Compared with the direct import of solid geometry, the adaptive-family approach provides greater flexibility for subsequent geometric modifications, making it particularly suitable for bridge components that may require adjustments during the modelling process.

In **Tekla Structures**, the developed workflow supports the generation of the BIM model of the concrete box-girder bridge and the automation of selected modelling and documentation operations. The connection with Grasshopper improves the efficiency of transferring and generating complex bridge geometry while reducing repetitive manual operations, particularly when dealing with large structures and numerous cross-sections.

The modelling of **prestressing cables**, characterized by variations in position, length, geometry, and inclination, was also addressed through a dedicated parametric workflow. The developed algorithm uses data stored in Excel to control the geometry and positioning of the cables along the bridge, allowing modifications to be introduced efficiently by updating the corresponding input values.

Finally, the implementation of a dedicated graphical user interface using the **Human UI** plug-in further improves the accessibility and usability of the developed parametric framework. The interface allows users to manage the principal modelling parameters and incorporate external inputs, including point-cloud data and alignment curves, without directly interacting

with the complete Grasshopper definition. An integrated model preview provides visual verification of the generated geometry before its transfer to the BIM environment.

The workflow was further extended through the implementation of **automatic coordinate management and georeferencing**. By determining the spatial position of the bridge and assigning the corresponding coordinates to the generated model, the system maintains consistency between the original survey data, the parametric geometry, and the resulting BIM model. This reduces manual positioning operations and facilitates the integration of the model within its real-world spatial context.

Overall, the research demonstrates how **point-cloud processing, parametric modelling, BIM interoperability, external data management, automation, and user-interface development** can be integrated into a unified workflow for the digital reconstruction of existing concrete box-girder bridges. The proposed methodology reduces repetitive modelling operations, maintains flexibility in geometric modifications, and improves the connection between survey data and BIM environments, providing a structured approach for the development and management of complex bridge models.

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