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Master in

Building Information Modelling



European Master in
Building Information Modelling

Optimizing tunnels modelling through visual programming

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SOMMARIO

Questa tesi mira a ottimizzare e automatizzare la modellazione delle gallerie in Revit tramite Dynamo. Un progetto esistente del tunnel di drenaggio già progettato in CAD e integrato da un modello BIM è stato preso come base. Il percorso del tunnel come input è stato ottenuto dal Civil 3D.

Il primo studio mirava ad ottimizzare il processo di modellazione delle principali strutture in calcestruzzo. Sono state analizzate varie sezioni del tunnel al fine di creare una componente adattiva parametrica. Sono stati creati diversi prototipi per ottenere il componente, in grado di seguire un percorso curvo con un'assenza o una bassa estensione della sovrapposizione tra due unità sequenziali a seconda del tipo di piegatura: piatta o spaziosa. Il posizionamento basato sul percorso con una regolazione dei giunti è stato effettuato tramite Dynamo.

Il secondo studio mirava ad ottimizzare il processo di modellazione delle nervature portanti in acciaio con giunti. Il componente adattivo composto da nervature radiali in acciaio è stato completato con dettagli di giunzione mediante Dynamo. Oltre che nell'unità di calcestruzzo, è stata implementata l'espansione del contorno esterno.

Il terzo studio mirava ad applicare un design generativo per ottimizzare lo spostamento dei fori di iniezione per la stuccatura per soddisfare la condizione dell'auto-intersezione minima per formare una barriera impermeabile.

Parole chiave: (BIM nelle infrastrutture, Tunnel, Componenti adattivi parametrici, Automazione, Programmazione visiva)

ABSTRACT

This thesis aims to optimise and automate the tunnel modelling in Revit by means of Dynamo. An existing project of the drainage tunnel already designed in CAD and supplemented by a BIM model was taken as a basis. The path of the tunnel as an input was obtained from the Civil 3D.

The first study aimed to optimize the process of modelling of the main concrete structures. Various sections of the tunnel were analyzed in order to create a parametric adaptive component. Several prototypes were created in order to get the component, capable of following a curved path with an absence or a low extent of the overlap between two sequential units depending on the type of the bending: flat or spacious. Placement based on the path with an adjustment of the joints was done by means of Dynamo.

The second study aimed to optimize the process of modelling of the steel supporting ribs with joints. Adaptive component comprised of radial steel ribs was complemented with joint details by means of Dynamo. As well as in the concrete unit, expansion of the external outline was implemented.

The third study aimed to apply a generative design to optimize the displacement of the injection holes for the grouting to meet the condition of the minimal self-intersection to form a waterproof barrier.

Keywords: (BIM in the Infrastructure, Tunnels, Parametric Adaptive components, Automation, Visual Programming)

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1. INTRODUCTION

1.1. Generalities and scope

Tunnel construction modelling involves creating digital representations of tunnels and their surrounding environments to aid in planning, design, simulation, and analysis. It encompasses various aspects, including geological conditions, structural integrity, construction processes, safety considerations, and more.

The creation process of the 3D-model of a tunnel can be committed once the path alignment as well as the geological data is present. The path is used as a starting point and represents one world with a large scale. Another world implies development of the structures with the details in a smaller scale. First challenge is to make ends meet through connecting these two worlds without loss of data and especially without exceeding tolerances in the geometrical representation of the future structure elements.

During the design phase, few variations of the tunnel must be provided and compared to choose the most optimal one, which meets all the requirements with minimization of the total cost. Once the tunnel is modeled and primary approximate cost based on the volume of materials can be calculated, the process might be done again with some alterations. The second aim is to automate the process of the modelling with ability to change initial parameters to obtain alternative versions of the tunnel faster without loss of the quality.

The tunnel can be roughly divided into three parts: an ingress, a main part and an egress. The scope of the study is limited to the main part, which unlike other ones is more prone to alterations and at the same time much more amenable to automation of the modeling. The main part of the tunnel lining usually can be divided into zones, depending on the functional purpose and the geological circumstances. In this study the functional purpose of the tunnel does not change along all the way – transportation of the floodwater with the constant capacity. Meanwhile zones are determined by the geological layers, changing along the lining and dictate the way of soil strengthening and the configuration of the inner lining.

Withing one zone the cross-section of the tunnel lining, its constitution and configuration remains the same or slightly expands with constancy of the geometrical proportions. Even though the configuration of the tunnel lining withing a zone remains the same, it may alter and serve as an input variable to obtain the variations of the final lining. A zone in its turn can be divided into parts in accordance with the advancement of the mining. The length of each advancement also may alter and influence the final lining and the total cost.

The study will be based on the existing project performed with the use of Civil 3D and Revit. Revit does not have a specialized functionality for tunnel modeling: neither for soil strengthening, nor for surrounding supports, nor for the inner lining. The core chapters will be devoted to the aforementioned use cases and based on the features of the project, selected for the study in the following order: the inner lining, excavation supports, grouting.

According to the hypotheses, the optimal way of the inner lining modelling is to create a parametric family with few types and place them along the path. Dynamo will be used to automate the process of displacement. Since the path from Civil 3D does not contain the geological information by itself, one of the challenges will be to provide the zoning as an input data. The main challenge and the main goal in this chapter will be: an absence or at least a low extent of the overlap between two sequential units on the curved section of the path.

The excavation supports will be modelled with a hybrid approach: the steel ribs supports will be enclosed in a compound parametric family and connective elements between the ribs will be placed by means of Dynamo. The main challenges would be: obtaining an expansion feature without overcomplicating of the family and a detailed table with arc lengths and angular dimensions of the connection points along the ribs.

In the chapter devoted to grouting, the capabilities of the Generative Design in Dynamo will be investigated. The aim would be to find an optimal displacement of the injection points based on the input requirements.

1.2. State of art

BIM has been actively and broadly implemented in the architectural projects for the past decade. The emerged standards and guides (ISO19650, EN 17412, Singapore VDC Guide, etc.) provide the evidence of the global purposeful changes. However, in construction and particularly in infrastructure digitalisation appeared relatively late (DAUB, “Bim in Tunnelling”, 2019). “Until 2015 almost no tunnels done in BIM anywhere” (Jure Česnik, BIM for Large High-Rise and Infrastructural Projects, 2023). For this reason, specific literature about BIM in tunnelling providing best practises based on the real projects experience relatively rare comparing to the residential buildings’ construction.

However, DAUB-Working Group elaborated a few guides sharing the best practices of the application of BIM in tunnelling. One of the most valuable suggestions was not to model all the details with numerous supports along all the tunnel as it would have “unnecessarily increase the data volume of the model” (DAUB, “Bim in Tunnelling”, 2019). On practice in means the lower level of detail (LOD) and in the main model and higher LOD in the auxiliary ones.

When it comes to the automation of the modelling, the literature is even more sparse. Nevertheless, there is a proposed methodology for TBM tunnels modelling with the usage of Revit adaptive family and Dynamo automation (Jelena Ninića, Hoang Giang Buib, Günther Meschke (2020). Even though the considered tunnel differs in terms of technology (TBM versus cast-in-place concrete) and shape of the alignment segments (circular rings versus non-circular expanding segments), the concept of the connections between subsequent segments may be applied in the current case study.

2. INNER LINING

The inner lining in a tunnel structure refers to the layer or layers of materials installed on the interior surface of the tunnel to provide structural support, protect against various forces, and ensure the safety and durability of the tunnel. The type of inner lining used in a tunnel depends on several factors, including the tunnel's purpose, geological conditions, and construction method. Common types of tunnel linings are listed below.

Shotcrete or Sprayed Concrete. This method involves spraying a layer of concrete onto the tunnel's surface, providing immediate support and sealing against water infiltration. Shotcrete is often used in mining tunnels and for initial support during tunnel excavation.

Concrete Segments. In tunnel boring machine (TBM) tunnels, precast concrete segments are commonly used. These segments are assembled to form a ring-like lining that provides structural support and stability to the tunnel walls.

Cast-in-Place Concrete. For larger tunnels or those requiring additional reinforcement, cast-in-place concrete may be used. In this method, concrete is poured and allowed to set in place to form the tunnel lining.

Steel Linings. In some cases, steel plates or liners may be used to provide structural support in tunnels, especially when facing challenging geological conditions or for temporary support during construction.

Segmental Linings. These are precast concrete or steel segments designed to interlock, creating a complete circular lining. Segmental linings are commonly used in metro and subway tunnels.

Fiber-Reinforced Polymer (FRP) Linings. FRP materials can be used as a lining to provide additional strength and protect against specific conditions like chemical exposure or seismic events.

Waterproof Membranes. For tunnels that may be exposed to water infiltration, waterproof membranes are used to prevent water ingress and protect the tunnel structure from moisture-related issues.

The choice of tunnel lining depends on various factors, including the geological conditions of the tunnel route, the anticipated loads and stresses on the tunnel, budget constraints, and local construction practices. Proper design and construction of the inner lining are essential to ensure the tunnel's long-term stability, safety, and performance.

In the study case the inner lining was constituted of a reinforced cast-in-place concrete and a waterproof membrane with an optional drainage system.

2.1. Methodology

In the parametric modelling of linear objects, such as railways and tunnels, the structure can be roughly represented by a sequence of identical units arranged along the given path. Looking more closely at a tunnel, the units may differ in terms of their geometric representation (dimensions, cross-section shape, etc.), material composition (e.x. with or without insulation) and future use. Nevertheless, they all have

enough common features to be represented with only a few parameterised units. With this in mind, the two main approaches to unit creation could be implemented:

- a) by means of the visual programming (Dynamo);
- b) as a parametric model (family).

Both approaches have their own advantages and disadvantages when compared with each other. The results of the comparative analysis based on key needs are presented in Table 1.

Table 1 – Unit creation: visual programming versus parametric models

Criterion	Visual programming (Dynamo)	Parametric component (Revit family)
Attributional information management	Only instance project parameters with a poor management through global parameters.	Centralized management outside of the main model, type and instance parameters, formulas, lookup tables and type catalogues.
	No dynamical linking to the geometry.	Dynamical linking to the geometry and nested families if necessary.
	Easier to change unintentionally by a user.	Values can be blocked.
Reliability	If any issues with Dynamo, the modelling can not be done	If any issues with Dynamo, components can still be placed manually.
Design changes	If any changes to the geometry applied, remodeling must be done from the scratch.	Any changes can be applied to all or only a few components through types and their update.
Seamless joints	More feasible (e.x. the tunnel can be sliced into segments as a last step after the extrusion).	Less feasible as a component has no dynamical link to the adjoining ones in the project.
One source of truth	Yes	No
Transferring to lower versions of the software	Most nodes can be transformed to Design Script code and copy-pasted.	No
Segregation potential for the 4D and 5D BIM (RIBA classification)	Low	High

It was decided to take the second approach and develop parametric families to create the units. The role assigned to the Dynamo: unit disposition and joint adjustment. The two main ways of disposition from the input point of view that have been studied in this work are:

1. by coordinates XYZ;
2. by CAD polyline.

2.2. Development of families

2.2.1. Analysis of the existing BIM model

One of the source files I was provided with in the beginning was a Revit BIM model of the tunnel with the ingress, the inner lining and the egress. The inner lining was modeled with a set of families of the category “Structural framing” and represented concrete structures, and waterproof layers with drainage pipes profiles. The profiles geometry of the families were not parametrized and for this reason did not imply scaling for the future usage.

The first step I decided to undertake was to analyze the existing types and identify unique cross-sections in order to understand how to decrease the amount of families and create parametric ones to make them scalable. A set of section views were created and placed on the sheet to see the whole picture.

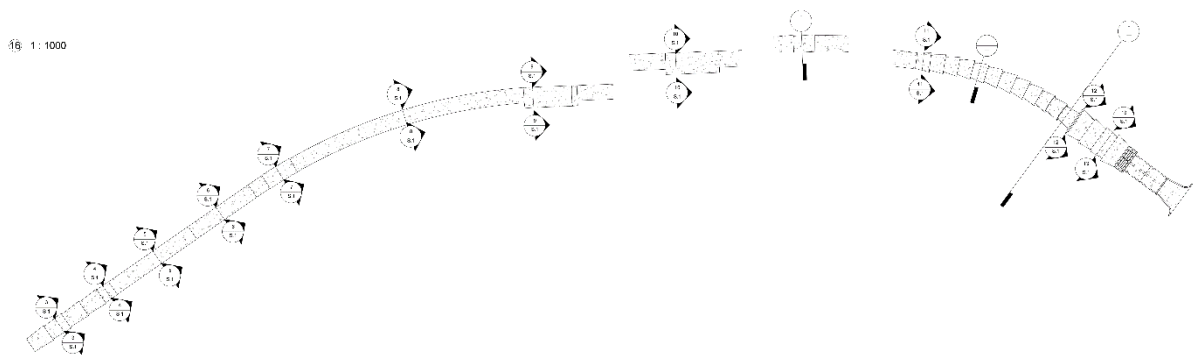


Figure 1 – A plan view with indicated section views

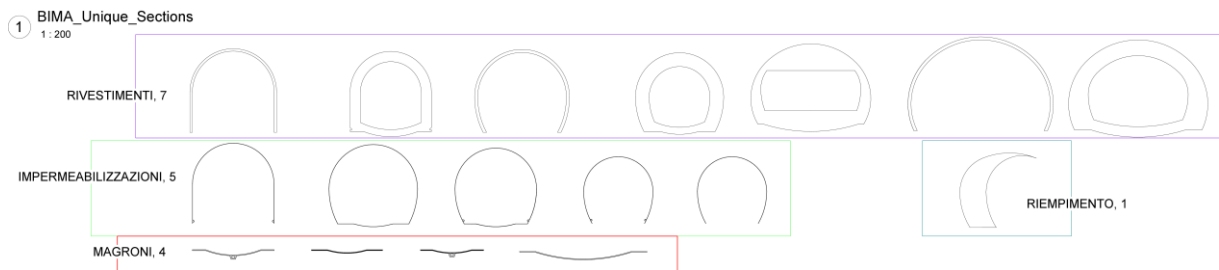


Figure 2 – A set of views with cross-sections of the unique profiles

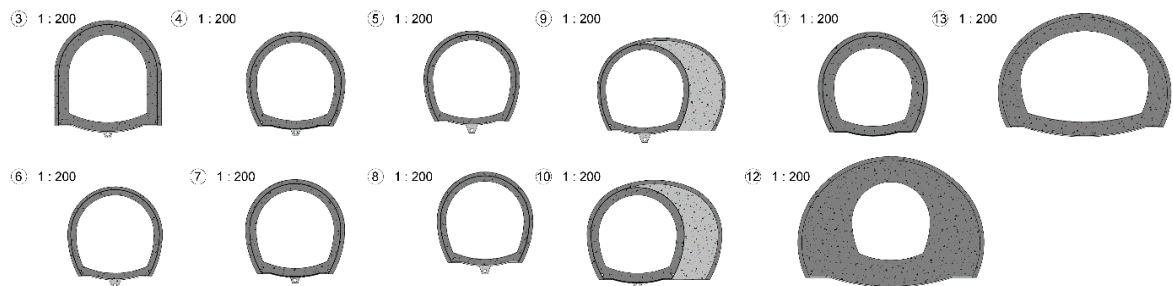


Figure 3 – A set of views with cross-sections of the unique compound profiles

The family development in Revit starts from a template choice. There is no any special one for the tunnel, thus a few were considered before the final choice.

2.2.2. Prototyping

2.2.2.1. The first prototype: Structural Framing

The first prototype of the family was created based on the existing approach – as a Structural Framing. One concrete layer was extruded with a parametrized profile. In order to get smooth connections between consequent segments two voids with faces able to rotate in both directions were added at the beginning and at the end. The rotation was driven by four angles between reference lines serving as a basement for voids at the beginning (“aXY1”, “aXZ1”) and at the end (“aXY2”, “aXZ2”).

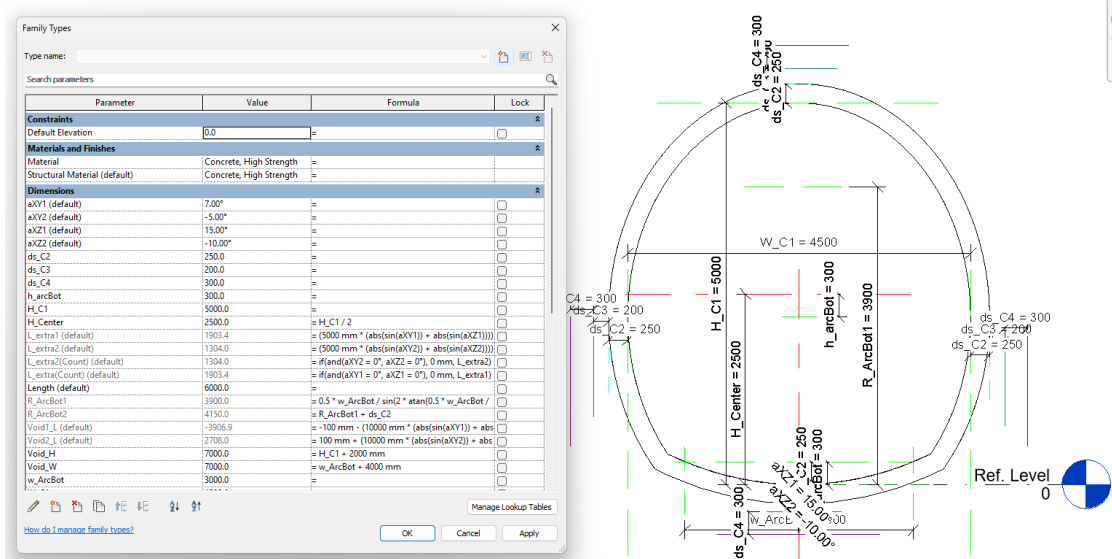


Figure 4 – The first prototype, inside the family: parameters and right elevation view

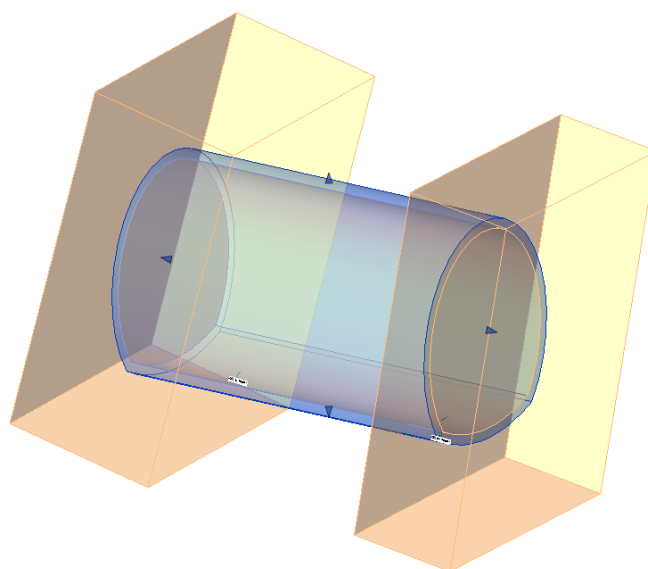


Figure 5 – The first prototype, inside the family: 3D view

The main upsides of the family based on the “Structural Framing” were the following: ability to set the elevation of the start and the end of the segment through instance parameters “Start Level Offset” and “End Level Offset”, ability to set rotation through “Cross-Section Rotation” and an ability to follow a curved path.

The main issue was caused by the principles any beam based on the structural framing template follows. It has predefined reference planes, such as “Left”, “Member Left”, “Stick Symbol Left”. The ends of the geometry are driven by “Member Left” and “Member Right” and make it hard to add a void cut with a surface, rotated in two planes without breaking the behavior of the beam. The result of the “broken behavior” is demonstrated in the figures 6 and 7: the segment does not change the real length.

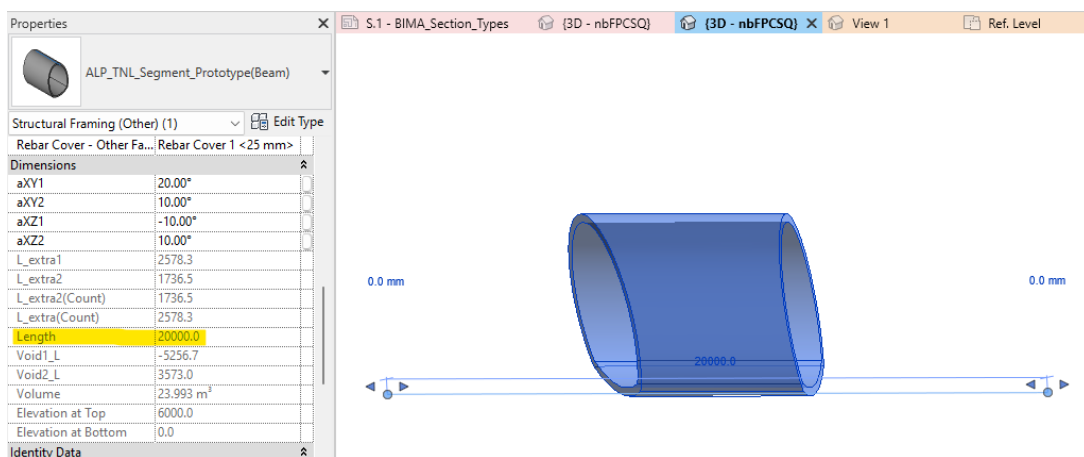


Figure 6 – The first prototype, the first instance in the project file: 3D view

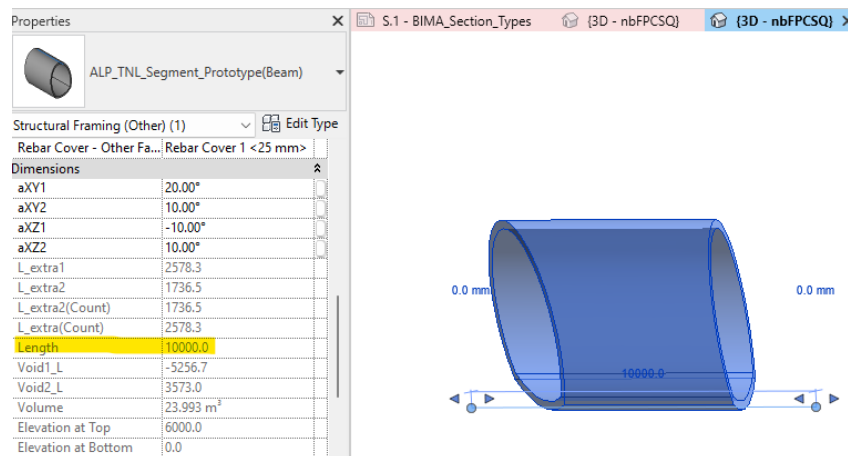


Figure 7 – The first prototype, the second instance in the project file: 3D view

This issue probably could have been resolved but even in that case, another one caused by the presence of the shape handles would have remained. Shape handles may change the geometry and lead to the failure of the family instance with such complex cuttings. In case handles do not influence the geometry, they would lead to the misconception of the user.

For these reasons the first prototype, based on the Structural Framing template was ruled out.

2.2.2.2. The second prototype: Adaptive Component, version 1

After some thoughts, the “Generic Model Adaptive” template was chosen as a base for the family development. Such template provides more tools comparing to the “Metric Structural Framing - Beams and Braces” or “Metric Generic Model” and considered to be an optimal choice when it comes to the development of the complex or nonconventional parametric models.

This time all three concrete layers were modeled: a footing, a coating and a main layer. The family had two placement points. The most complicated case of the tunnel segment was considered: with an expansion of the cross-section. The geometry of the segment had to start at the point 1 and end at the point 2. However, in order to provide the feature of inclined cuttings, the initial geometry had to be extended beyond the placing points. For this reason it was decided to place additional reference points (1' and 2' in the figures 8 and 9) and use their vertical planes for the profiles creation and parametrization.

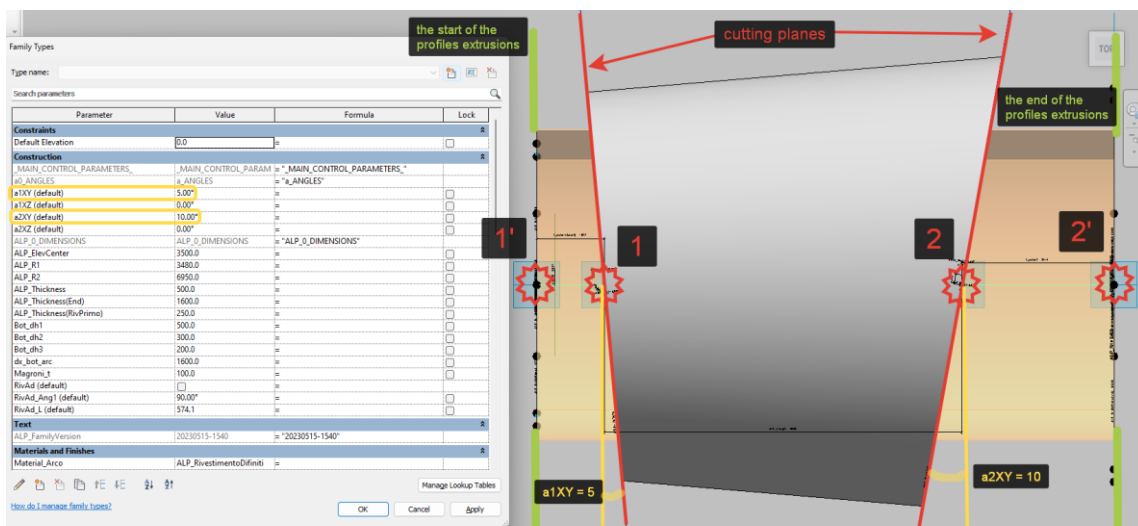


Figure 8 – The second prototype, inside the family: parameters and 3D top view

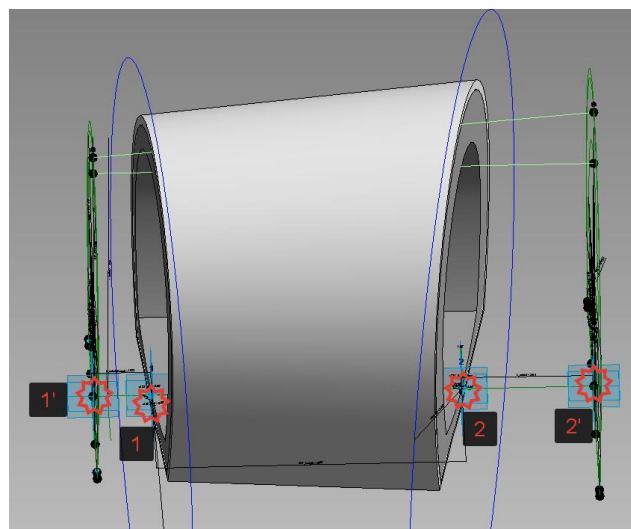


Figure 9 – The second prototype, inside the family: 3D view

Reference lines were used to form the outlines of the profiles. They are more reliable unlike model lines which disappear in case the 3D geometry based on them deleted.

2.2.2.3. The second prototype: displacement tests

After the creation of this prototype, a few tests of the sequential displacement were held. It was decided to use excel tables with coordinates as an input for the trajectory path. The workflow for the tests is presented in the figure 10. The Dynamo script will be explained in the [paragraph 2.3.1.](#)

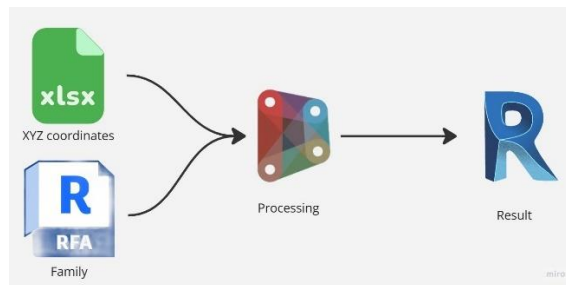


Figure 10 – Displacement tests workflow

Four cases of the path were considered to test the family: straight, curved in the plane XOY (horizontal), curved in the plane ZYO (vertical) and curved in both XOY and ZOY planes. The input coordinates are presented in the tables 1-4. The corresponding results are demonstrated in the figures 11 – 14.

Table 2 – Coordinates of the points for the displacement: straight

Coordinates values, m			Incrementation, m		
X	Y	Z	dX	dY	dZ
0	0	0			
5	0	0	5	0	0
15	0	0	10	0	0
30	0	0	15	0	0
34	0	0	4	0	0
44	0	0	10	0	0
49,5	0	0	5,5	0	0
56,2	0	0	6,7	0	0
59,9	0	0	3,7	0	0
64,9	0	0	5	0	0

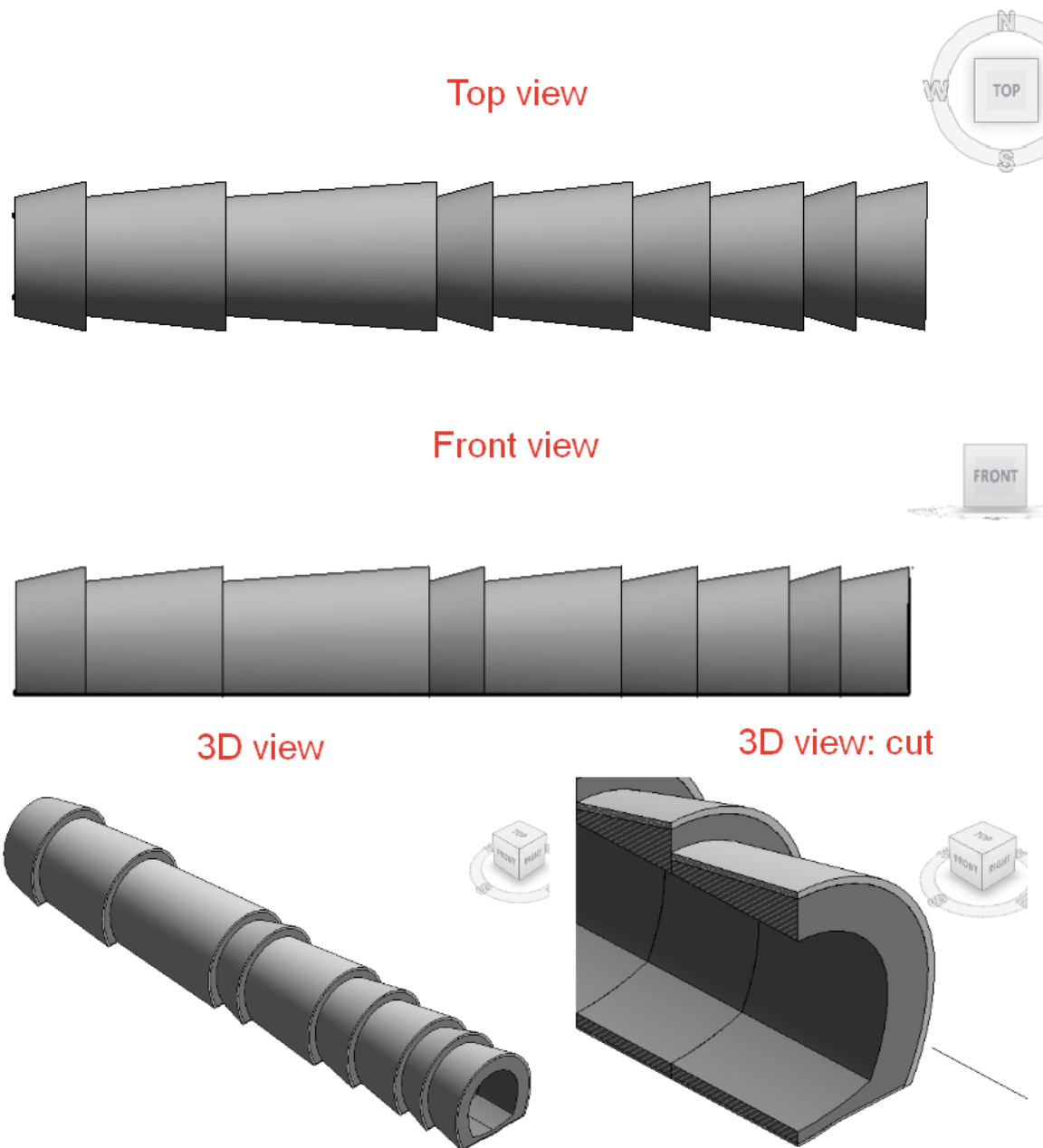


Figure 11 – Displacement results: straight

Table 3 – Coordinates of the points for the displacement: curved in the plane XOY

Coordinates values, m			Incrementation, m		
X	Y	Z	dX	dY	dZ
0	10	0			
8	11	0	8	1	0
20	12,2	0	12	1,2	0
30	13	0	10	0,8	0
38	13	0	8	0	0
48	13	0	10	0	0
54	12,5	0	6	-0,5	0

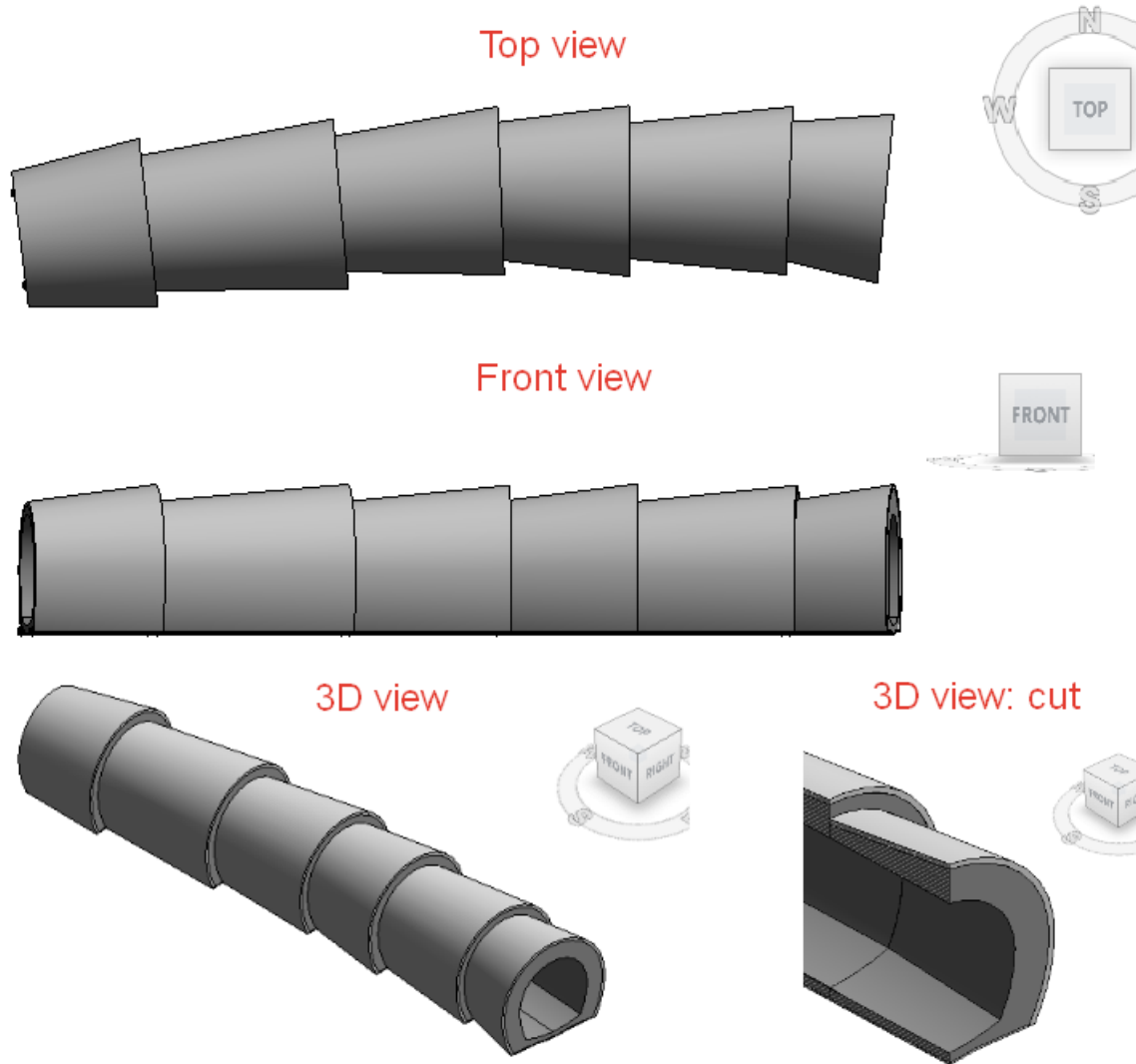


Figure 12 – Displacement results: curved in the plane XOY

Table 4 – Coordinates of the points for the displacement: curved in the plane ZOY

Coordinates values, m			Incrementation, m		
X	Y	Z	dX	dY	dZ
0	30	0			
10	30	0	10	0	0
20	30	-1	10	0	-1
30	30	-2	10	0	-1
40	30	-2	10	0	0
50	30	-1,5	10	0	0,5
60	30	-1	10	0	0,5
70	30	-1,52	10	0	-0,52
80	30	-2	10	0	-0,48
90	30	-2	10	0	0

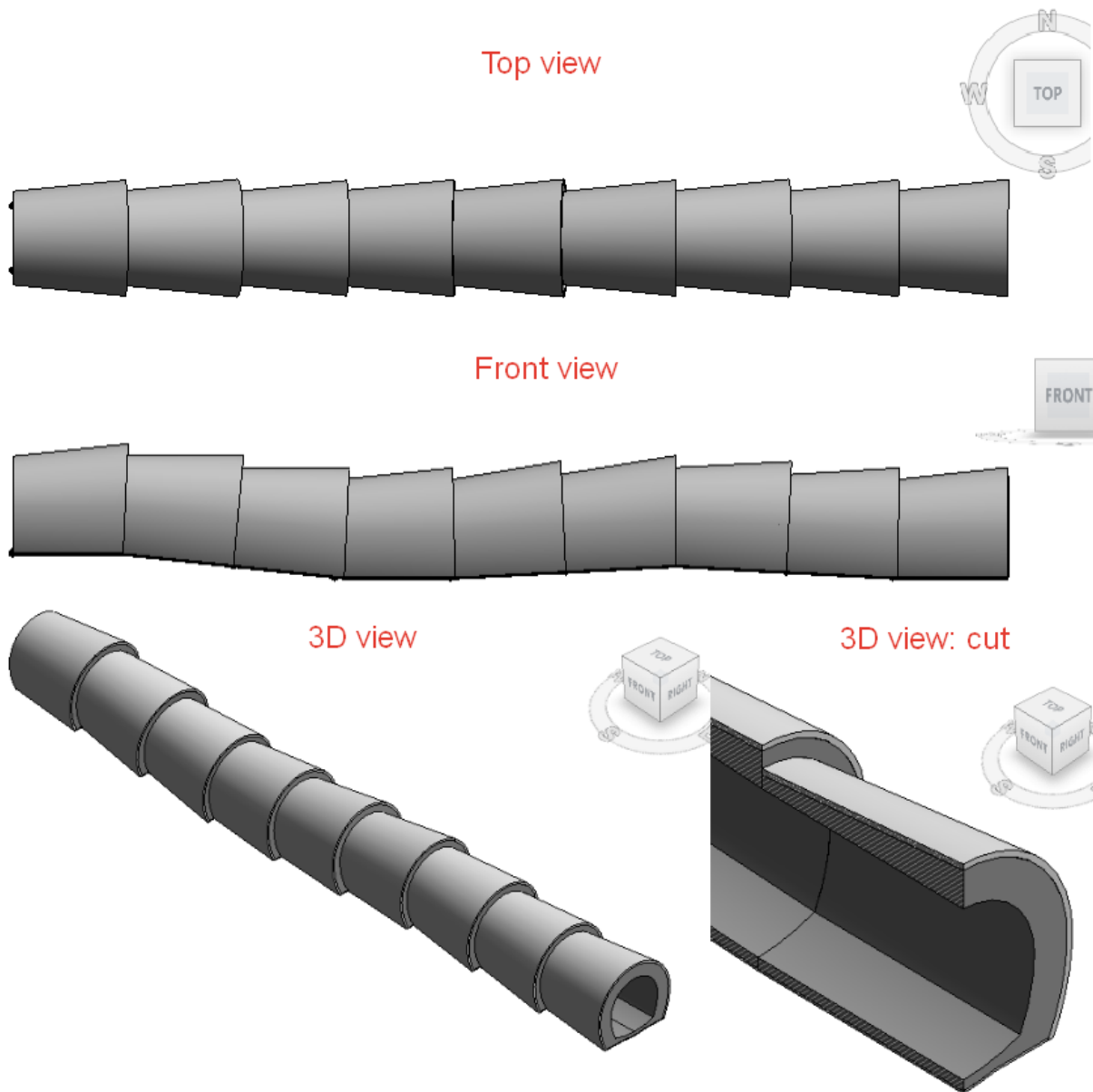


Figure 13 – Displacement results: curved in the plane ZOY

Table 5 – Coordinates of the points for the displacement: curved in both XOY and ZOY planes

Coordinates values, m			Incrementation, m		
X	Y	Z	dX	dY	dZ
0	45	0			
10	46	0	10	1	0
20	47,2	-1	10	1,2	-1
30	48	-2	10	0,8	-1
40	48	-2	10	0	0
50	48	-1,5	10	0	0,5
60	47,5	-1	10	-0,5	0,5

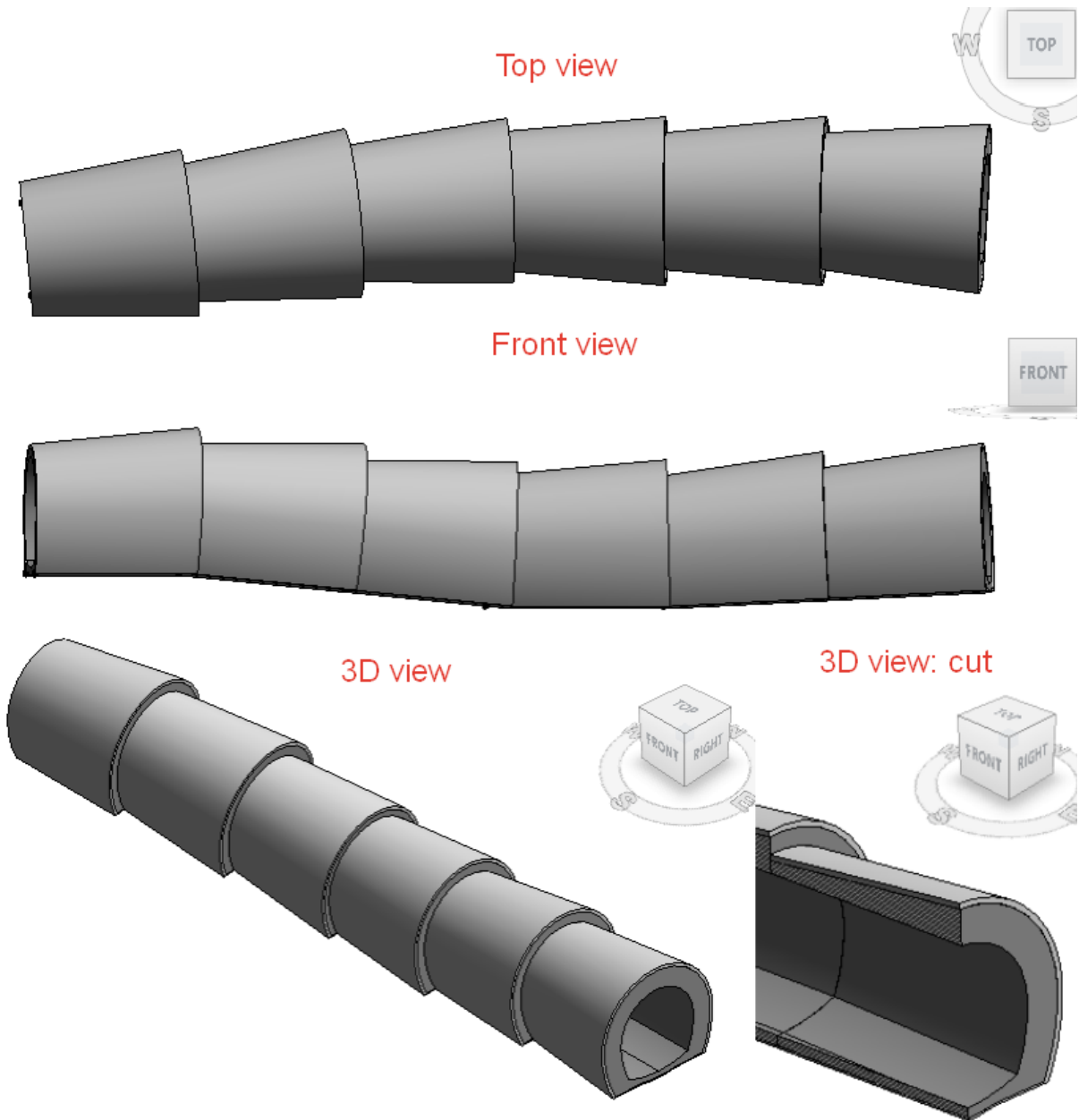


Figure 14 – Displacement results: curved in both XOY and ZOY planes

After a closer look at the connection areas, it was visible, that straight and curved in one plane cases had a fully smooth joints, while curved in two planes case showed minor inaccuracies with gaps and intersections which could be ignored due to their small size (2-3mm as a max) comparing to the segments size and a low influence on the final QTO. The joint areas with discrepancies are shown in the figures 15-16.

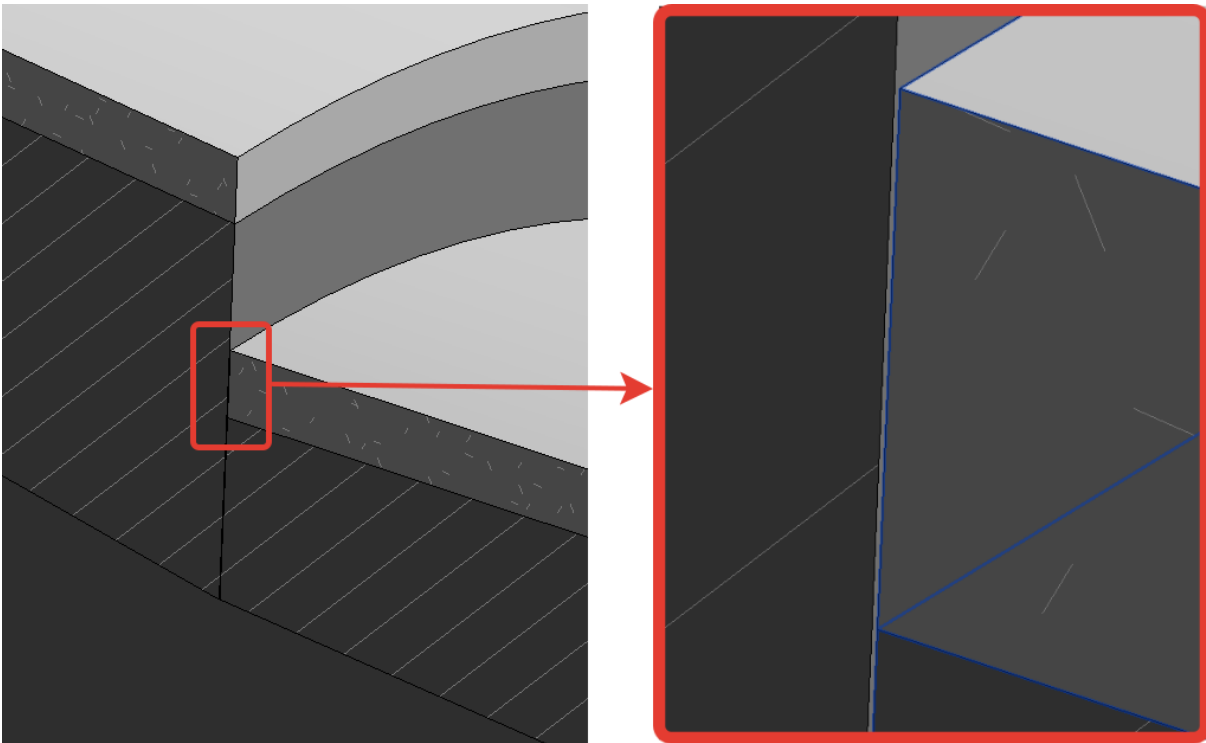


Figure 15 – Joint discrepancy, 3D views

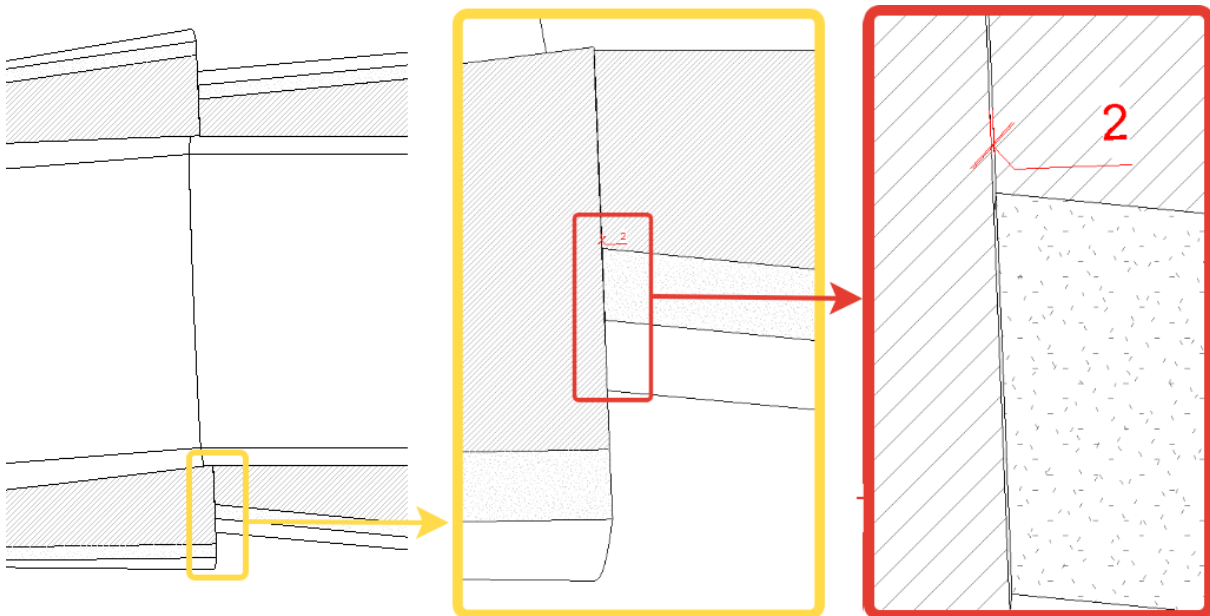


Figure 16 – Joint discrepancy, Top section views

The next step was to find a way to get a more realistic transition between segments without geometric simplification, in order to get more accurate results in the drawings and QTO in the future. The difference is shown in Figures 17 and 18.

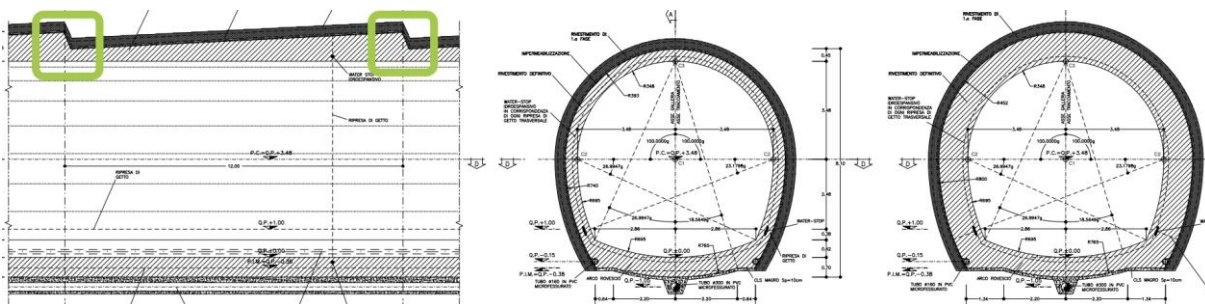


Figure 17 – Source CAD drawings

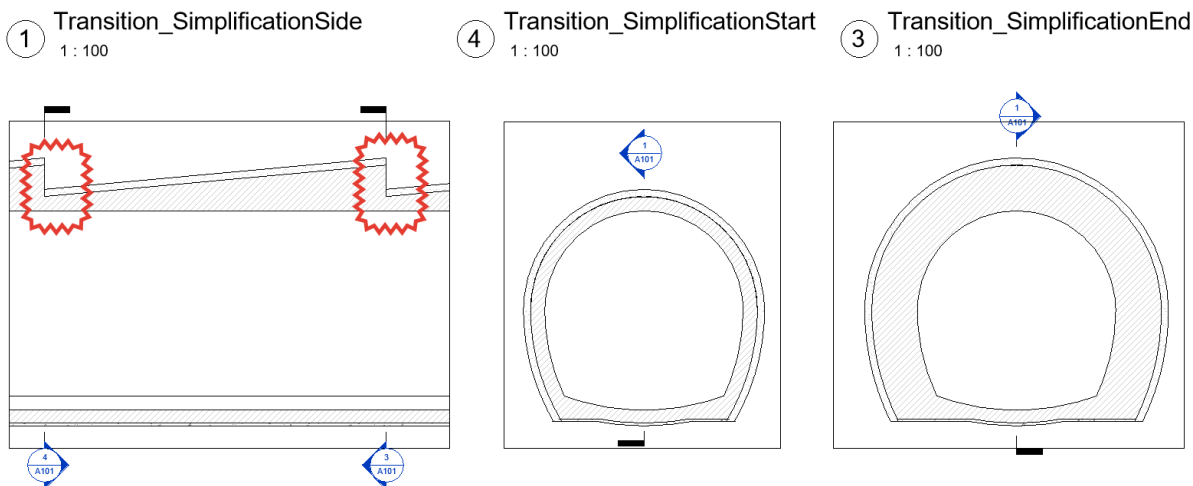


Figure 18 – Prototype sections in Revit

One of the easiest ways to achieve a smoother transition was to place an inverted short unit at the end. However, due to the geometric conditions, the thickness of the shotcrete layer will be three times less. The results of placing the double unit are shown in Figures 19 and 20.

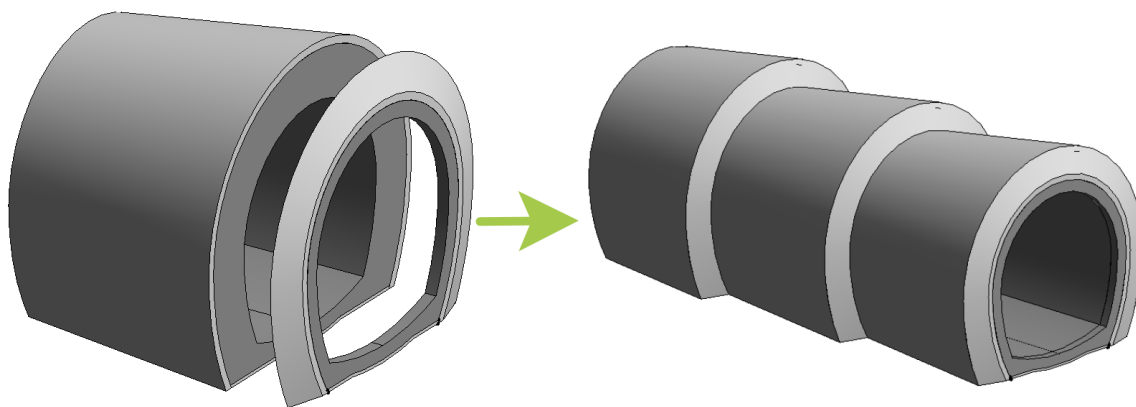


Figure 19 – Double unit, 3D

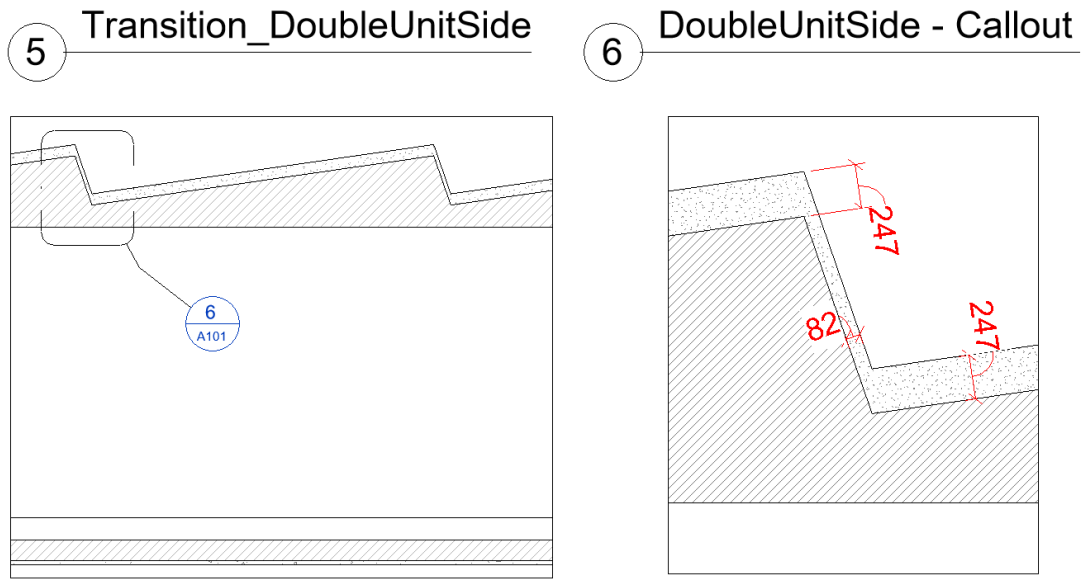


Figure 20 – Double unit, a section and a callout

To solve this problem, it was decided to add an additional solid to compensate for the lack of thickness. However, in order to obtain the required shape, an angle has to be measured and entered in the properties of the unit (manually or with Dynamo script). Furthermore, due to the complicity of the geometric interaction, Revit does not allow subsequent units to be joined. The result is superfluous lines on the sectional view. The results are shown in Figures 21, 22 and 23.

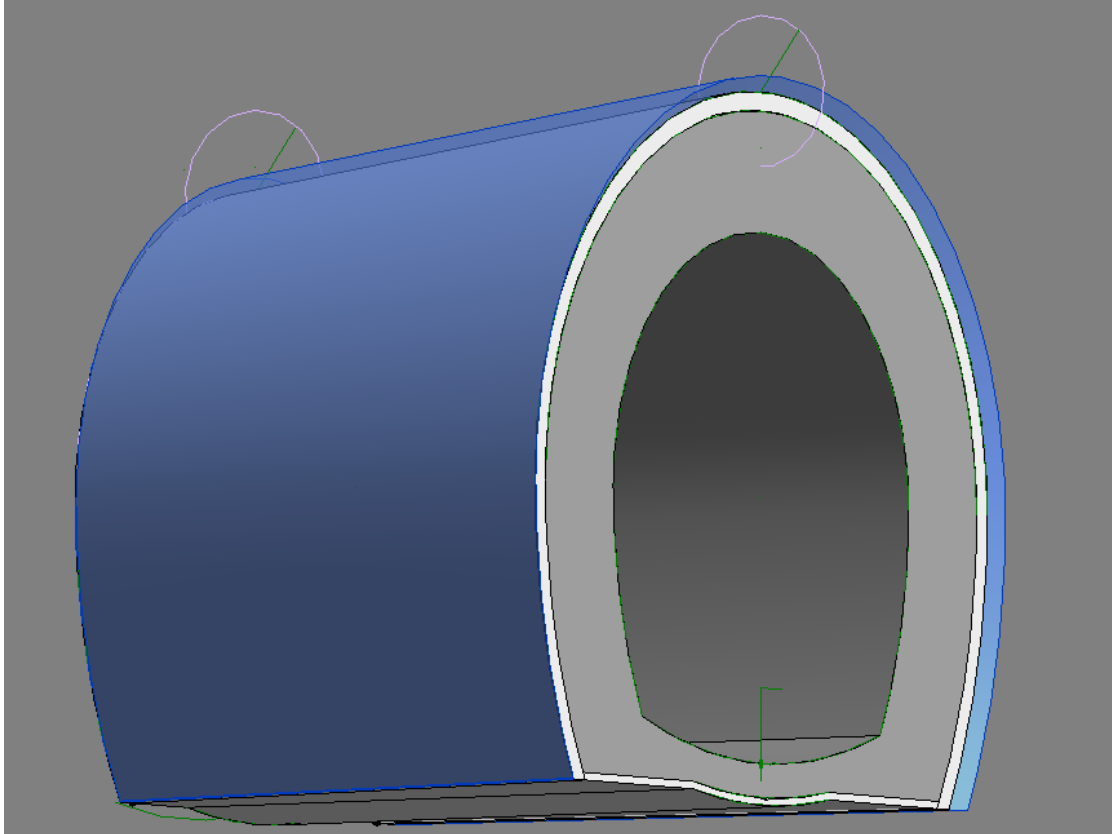


Figure 21 – Prototype with an additional layer, inside family 3D view

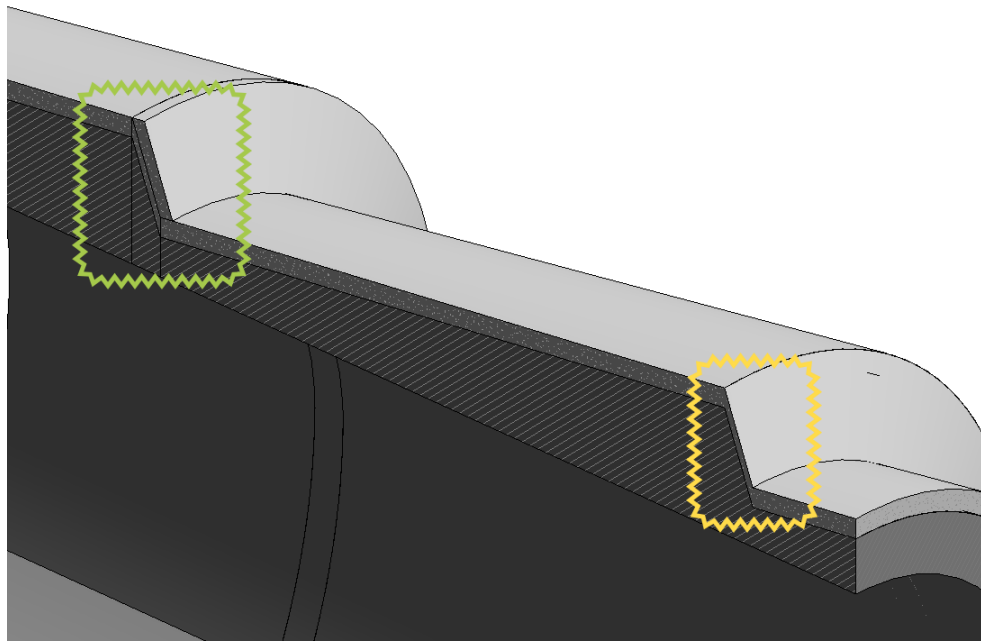


Figure 22 – Prototype with and without additional layer, 3D model view

- 7 Transition_DoubleUnitSideAdd 8 DoubleUnitSideAdd - Callout

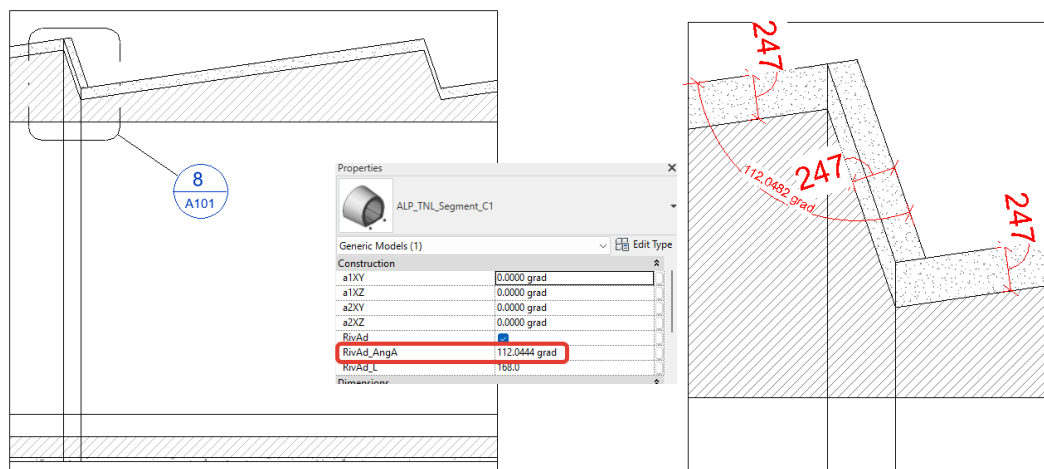


Figure 23 – Prototype with an additional layer, section views and properties

It was difficult to combine the additional layer with the ability to set inclined cuts at the beginning and at the end, which meant it could only be used properly in a straight section of the alignment. After some deliberation, it was decided to keep this prototype as one of the options and to create another family from scratch taking into account all the experience gained in the search for a more elegant and user-friendly model.

2.2.2.4. The final adaptive family

In the final family transition was added as a part of the component. A set of profile families were placed at the beginning, middle and end of the transition to make it work in both straight and concave cases. The shape of the transition was imperfect, with a slight loss of volume, but all other requirements were met, including: inclined cuts feature, both straight and expanding cases, inclusion of details such as tubes and insulation. The results are presented in the figures 23 and 24.

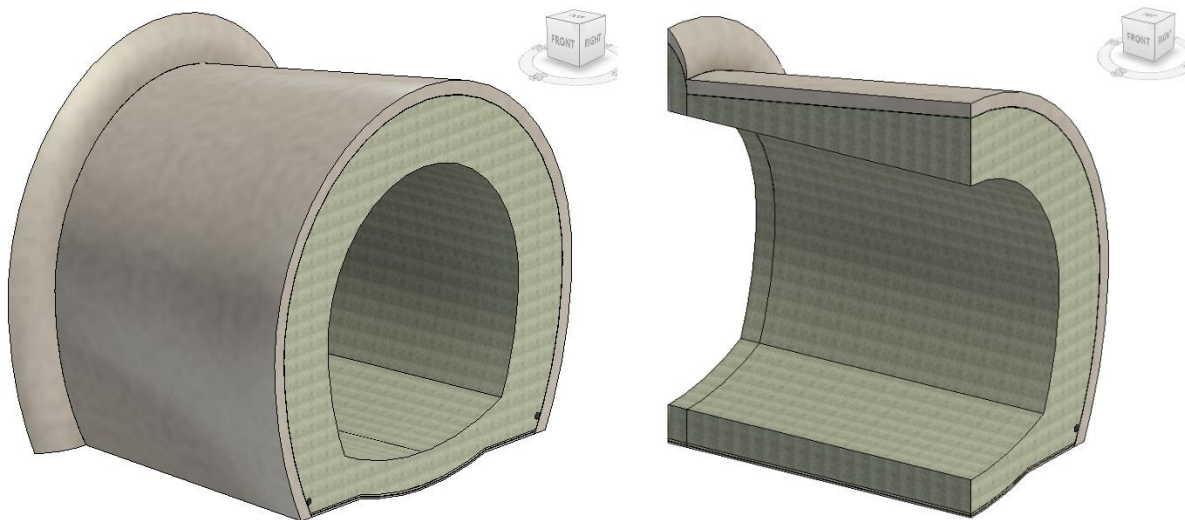


Figure 24 – Final prototype, 3D model view with a cut



Figure 25 – Main combinations of the final prototype, 3D model view

The drainage pipes were modelled mainly to cut the void in the concrete layer and obtain more precise volume. However, due to the distortion in the transition area they may not be suitable obtaining drainage drawings and quantities. The drainage discipline can be developed separately. It was also a challenge to

incorporate the insulation and cut it out of the concrete layers, so in the next version of the family it will be separated as an independent family: stand-alone or nested.

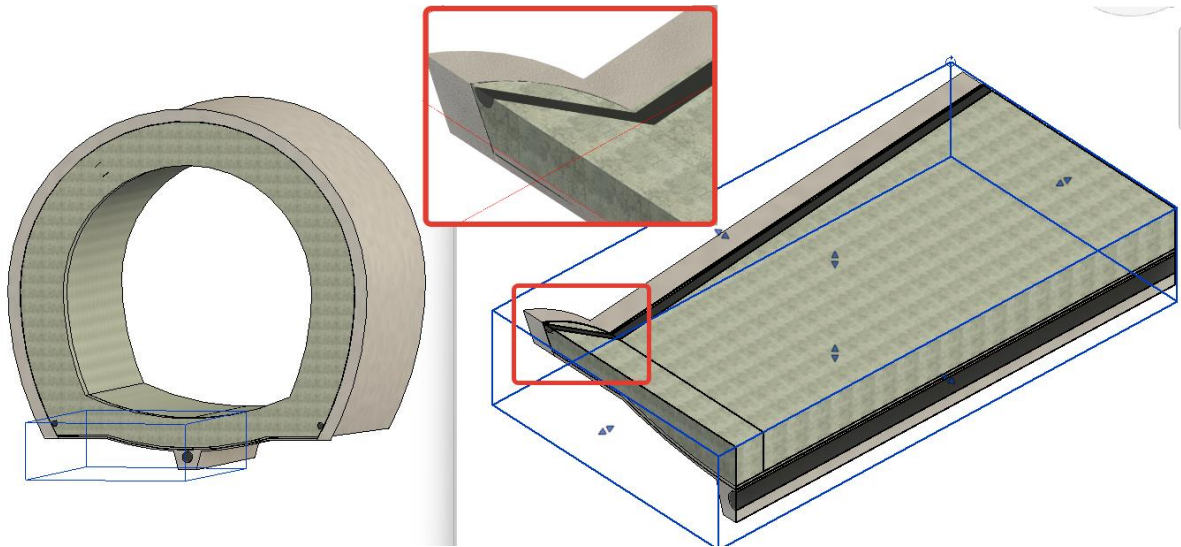


Figure 26 – Final prototype, 3D model view of a drainage with a cut

At the end of this paragraph, I must mention the main limitation of this family: the expansion with a transition area only works well with small cutting angles at the beginning ($<5^\circ$). However, the likelihood of using larger angles is low due to the large radius of the alignments in tunnelling.

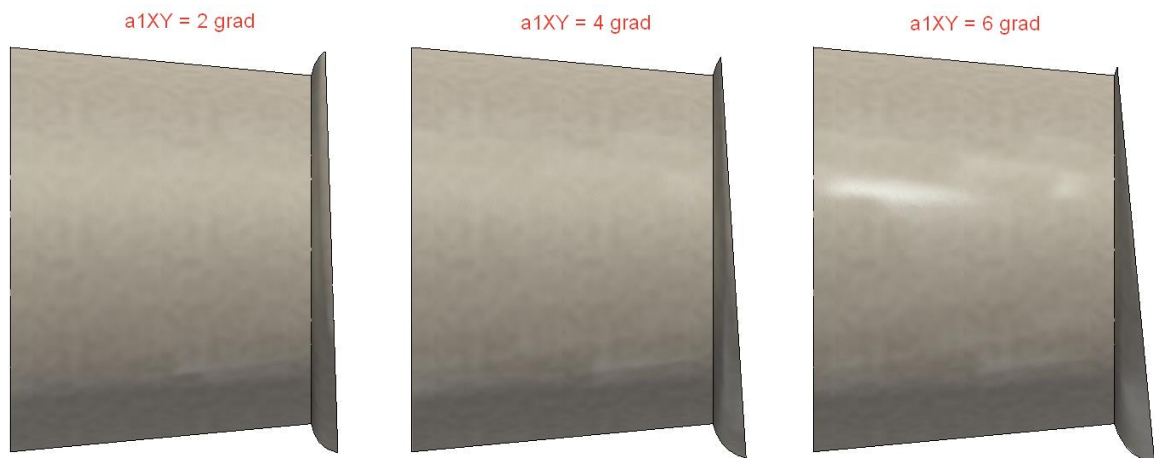


Figure 27 – Final prototype limitation, 3D model top view

2.3. Preparing alignment in Civil 3D

This research was not focused on providing a seamless link between Civil 3D and Revit, but one approach was proposed and tested. In Civil 3D the alignment is represented as a spatial polyline. This is shown in Figures 26 and 27.

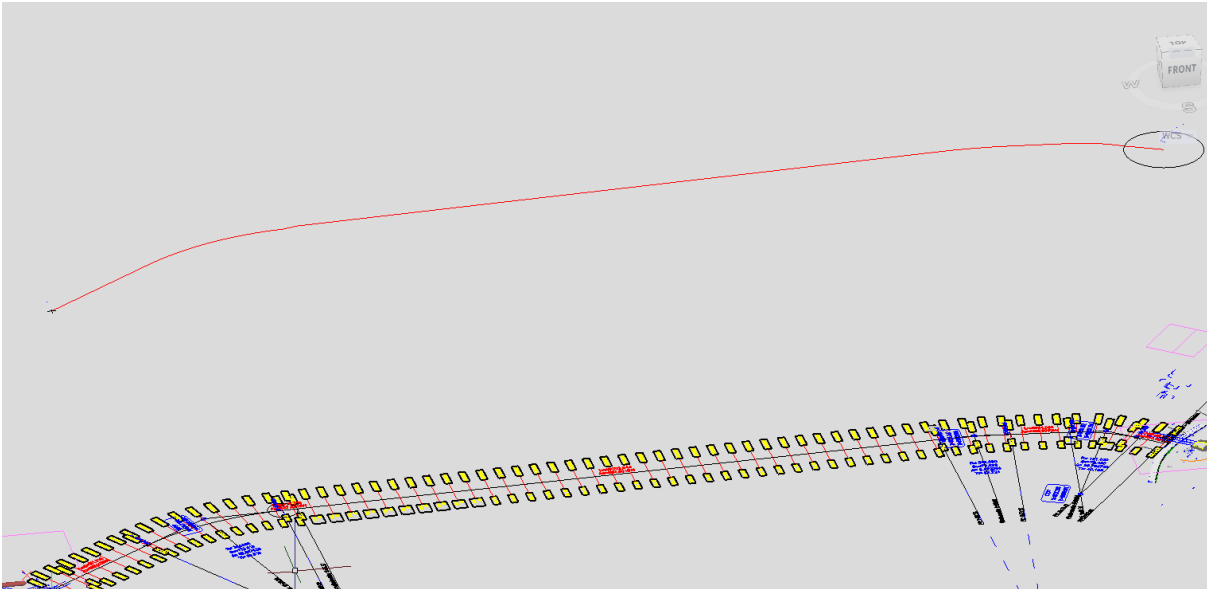


Figure 28 – Alignment in Civil 3D, 3D view

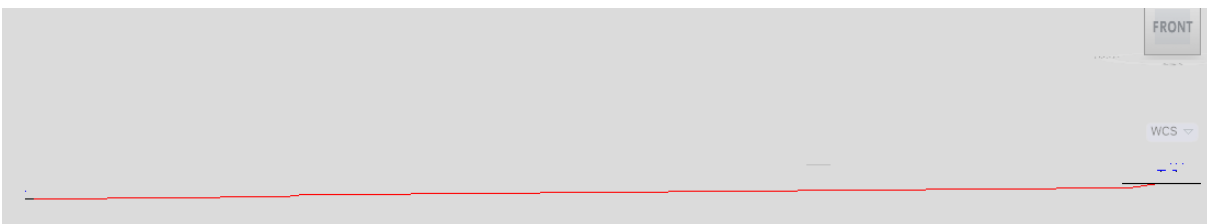


Figure 29 – Alignment in Civil 3D, front view

At the same time, a simple alignment is not enough for an input. Since the tunnel is not a set of segments with similar cross-sections and lengths, we need to explain to Revit where each segment starts, where it ends and what type it is. One way is to create a spreadsheet in Excel with the information we need. However, in this case we would have two sources of information. This means that if the length of the alignments is changed, we should not forget to update the lengths or numbers of the segments in Excel as well.

For this reason it was decided to use another approach of segments indication. In the “Layer Properties” manager in Civil 3D, a few layers were created. The name of each layer consisted of two parts by formula: RVT + _ + Family type name.



Figure 30 – Layer Properties in Civil 3D

After creating the layer, the alignment was exploded to get a set of lines. Some lines were replaced with one and finally some of them were assigned layers. The lengths were randomly assigned to test the workflow.



Figure 31 – Segmented alignment in Civil 3D, 3D view

Once the alignment is segmented it should be imported as a CAD link to Revit and positioned. If changes are made to the CAD file, it simply needs to be updated with a reload function. This can be done several times during the design variant phase.

2.4. Dynamo scripts

A Dynamo script was used to place tunnel segments of different types and lengths and to adjust the joints between them. As using an Excel spreadsheet as input for alignment segmentation has some advantages over using a CAD link (easier to modify and exchange, higher level of interoperability), both options were considered during development.

2.4.1. A prototype using an Excel spreadsheet as an input

The script consisted of two parts: placing the segments and setting the joints. The simplified scheme of the first and the second parts are shown in the figures 30 and 31.

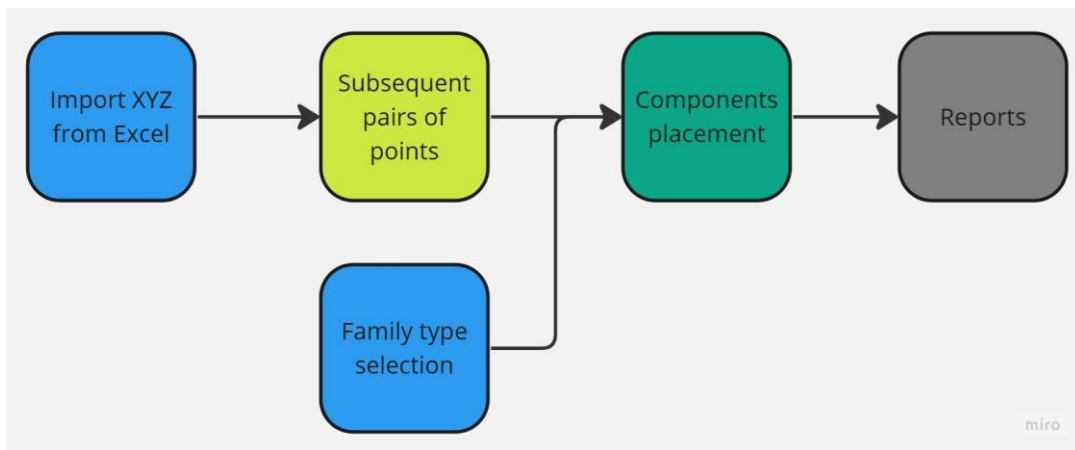


Figure 32 – First script, first part, simplified scheme

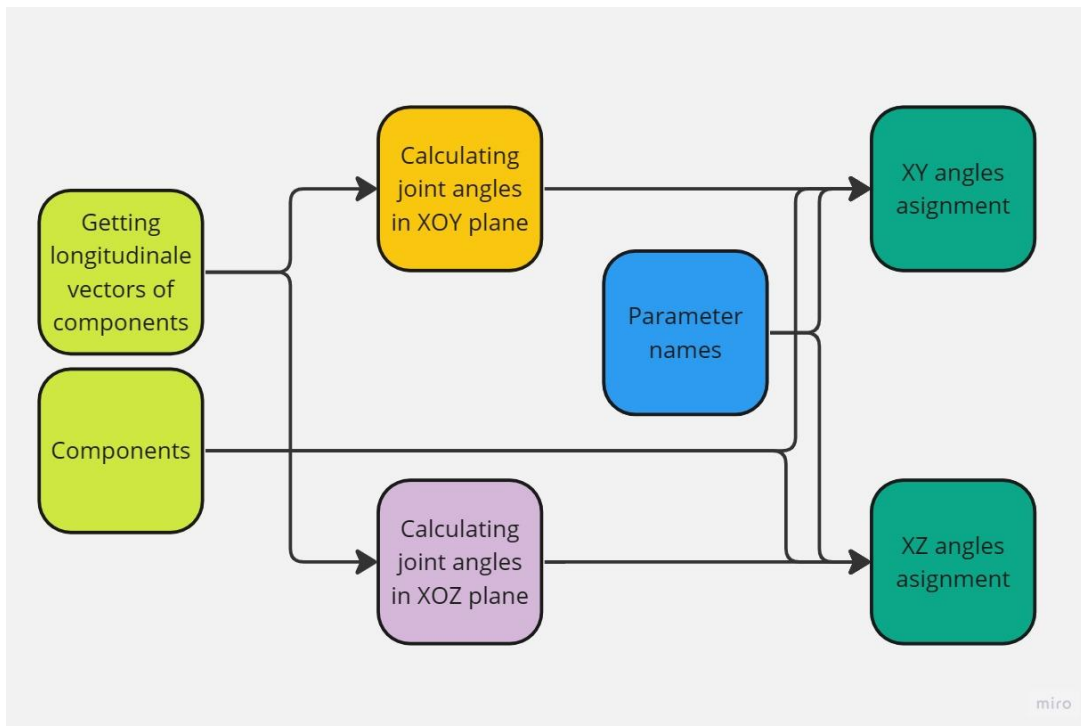


Figure 33 – First script, second part, simplified scheme

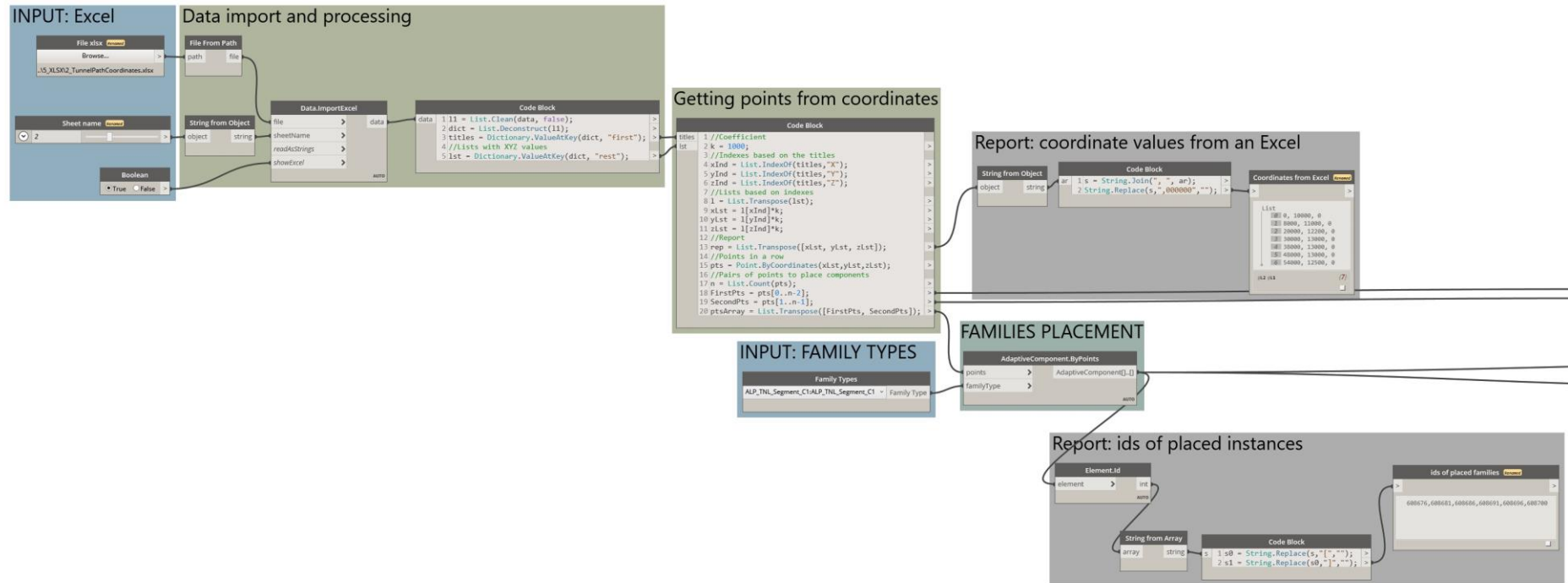


Figure 34 – Firs script, first part, Dynamo view

The second part contains the key process: calculating joint angles (in XOY and XYZ planes). In the example below, four segments bending in the XOY plane are shown in two states: before adjustment and after adjustment. Angle values are deliberately exaggerated and are given to 2 decimal places. Angles between subsequential segments are halved and assigned in the parameters a1XY at the start and a2XY at the end.

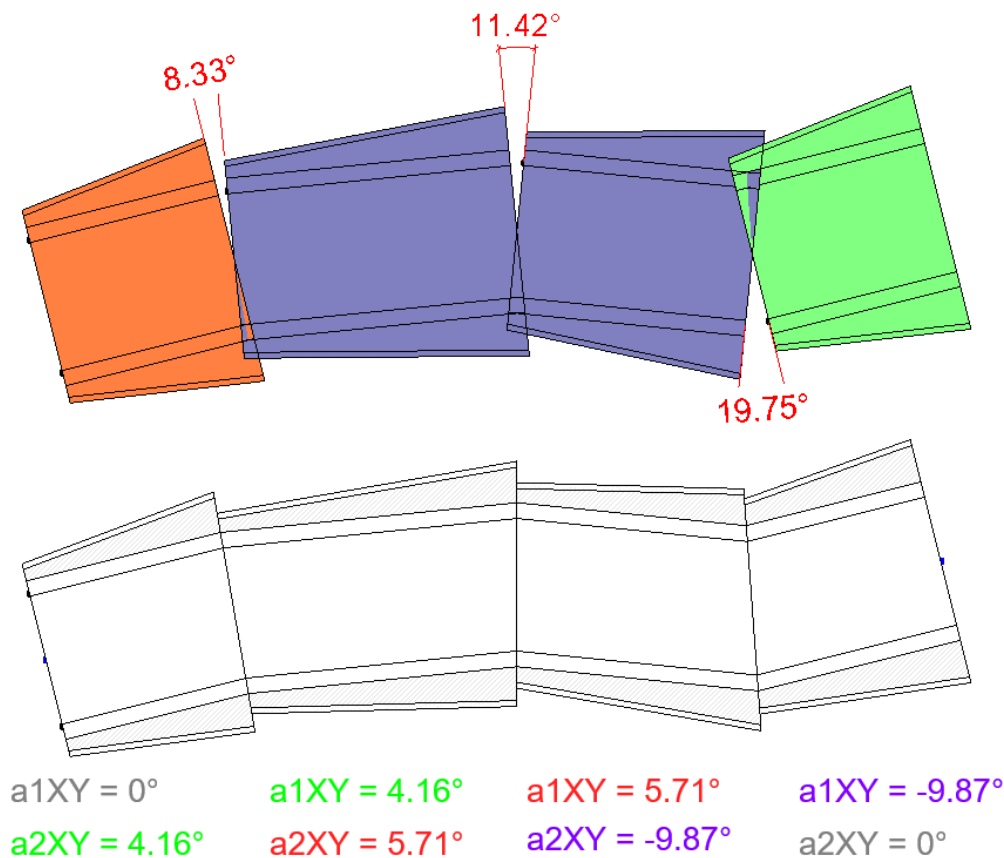


Figure 35 – Second prototype, top view, before adjustment and after adjustment

Depending on the direction of rotation (clockwise or counter-clockwise), the angles can have positive or negative values. To obtain the correct value, the rotation axis Z is provided as a reference for measuring the angle between two vectors. Before measuring, the vectors are projected onto the horizontal plane (just in case the segment is rotated in the vertical plane as well). The logic of the measurements is demonstrated in the figure 34. The second part of the script is presented in the figure 35.

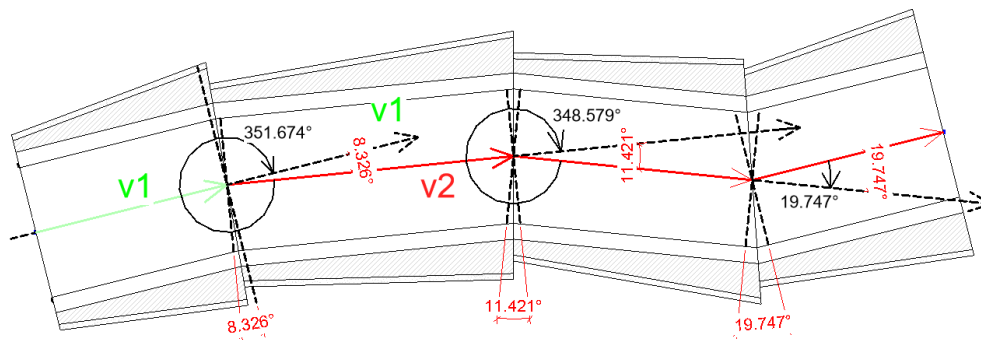


Figure 36 – Second prototype, top view, angle measurements

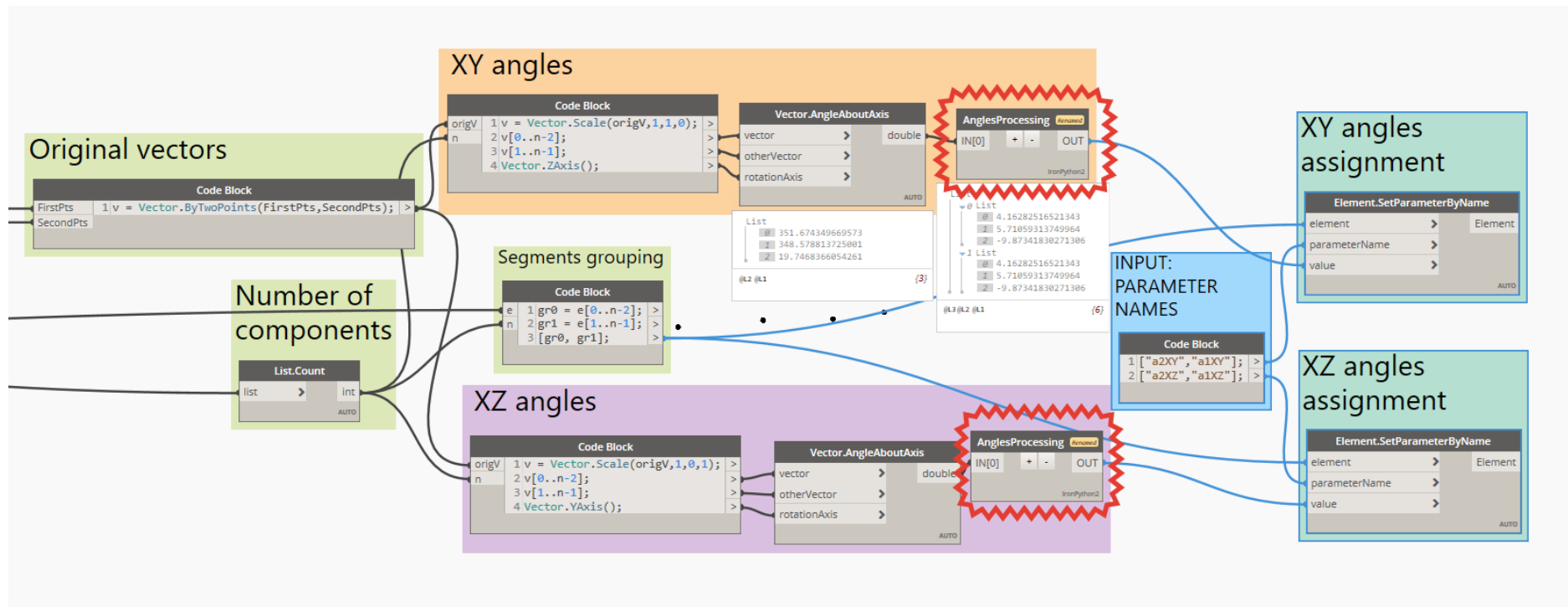


Figure 37 – First script, second part, Dynamo view

To process a set of angles, a small Python script was used within Dynamo, as this makes it easier to work with if-statements. The python script is presented below:

```

“import sys
import clr
clr.AddReference('ProtoGeometry')
from Autodesk.DesignScript.Geometry import *
angles = IN[0]

lst = []

for a in angles:
    if a==0:
        lst.append(0)
    elif a>300:
        lst.append(180-a/2)
    else:
        lst.append(-a/2)
OUT = [lst, lst]”

```

2.4.2. The main script using a CAD link as an input

This second script differs from the previous one in a first part. The second part is the same and its' simplified scheme is shown in figure 31.

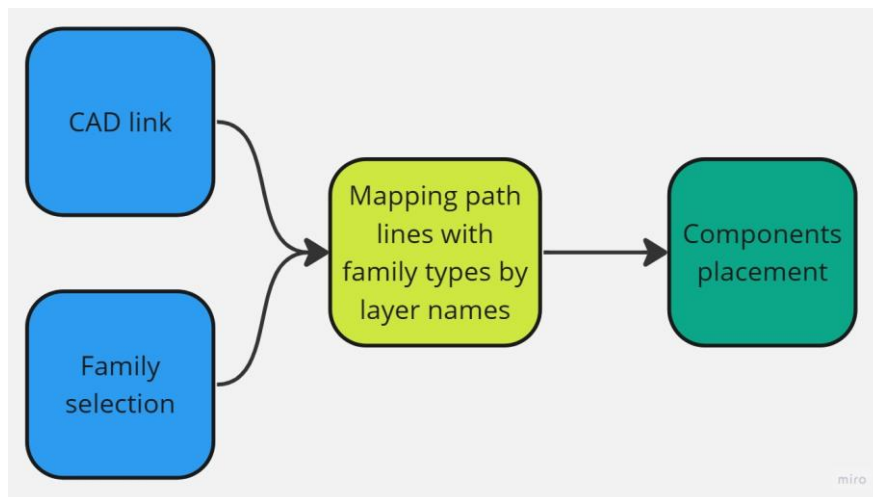


Figure 38 – Second script, first part, simplified scheme

One of the inputs was a family type from which all the types in the project could be found. A Python script was used to map layers with family types by name. As not all types can be displayed in the CAD link, an intersection function was added to avoid errors. A node “CAD.CurvesFromCADLayers” from the package “bimorphNodes (v4.2.4)” was used to obtain the lines of the path. A boolean input was provided in case lines from the link are reversed to change the directions. To make the script robust, the lines of the link were sorted by distance from the start by measuring the distance between the start point of the path and the midpoints of each line. The node “AdaptiveComponent.ByPoints” gave an error when multiple types were given as an input. Unfortunately, the lacing and “Use levels” features did not solve the problem. A different approach was used to solve this problem: place components of the same type and assign types afterwards.

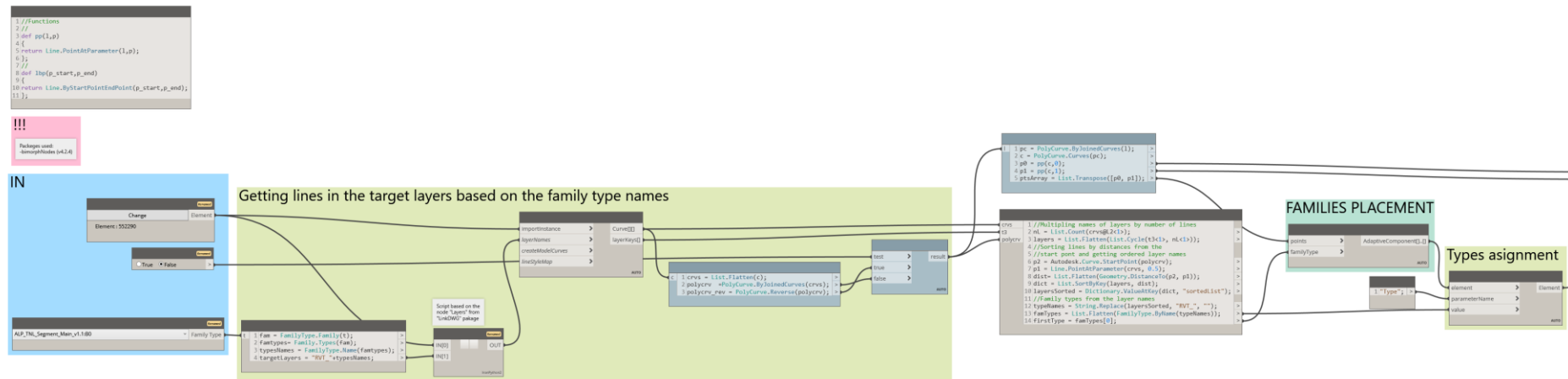


Figure 39 – Second script, first part, Dynamo view

The code used by the Python script node to get layers from CAD link and get target layers:

```

import clr
clr.AddReference("RevitAPI")
import Autodesk
from Autodesk.Revit.DB import *
def LinkDWG_LayersInImportInstance(obj):
    clr.AddReference("DSCoreNodes")
import DSCore
    rtn=[]
    cat=obj.Category.SubCategories.GetEnumerator()
    while cat.MoveNext():
        rtn.append(cat.Current.Name)
    
```

```

return DSCore.List.Sort(rtn)
DWG=UnwrapElement(IN[0])
targetLayers = IN[1]
allLayers=[]
if DWG:
    allLayers=LinkDWG_LayersInImportInstance(DWG)
    foundLayers = [x for x in targetLayers if x in allLayers]
    OUT=foundLayers
    
```

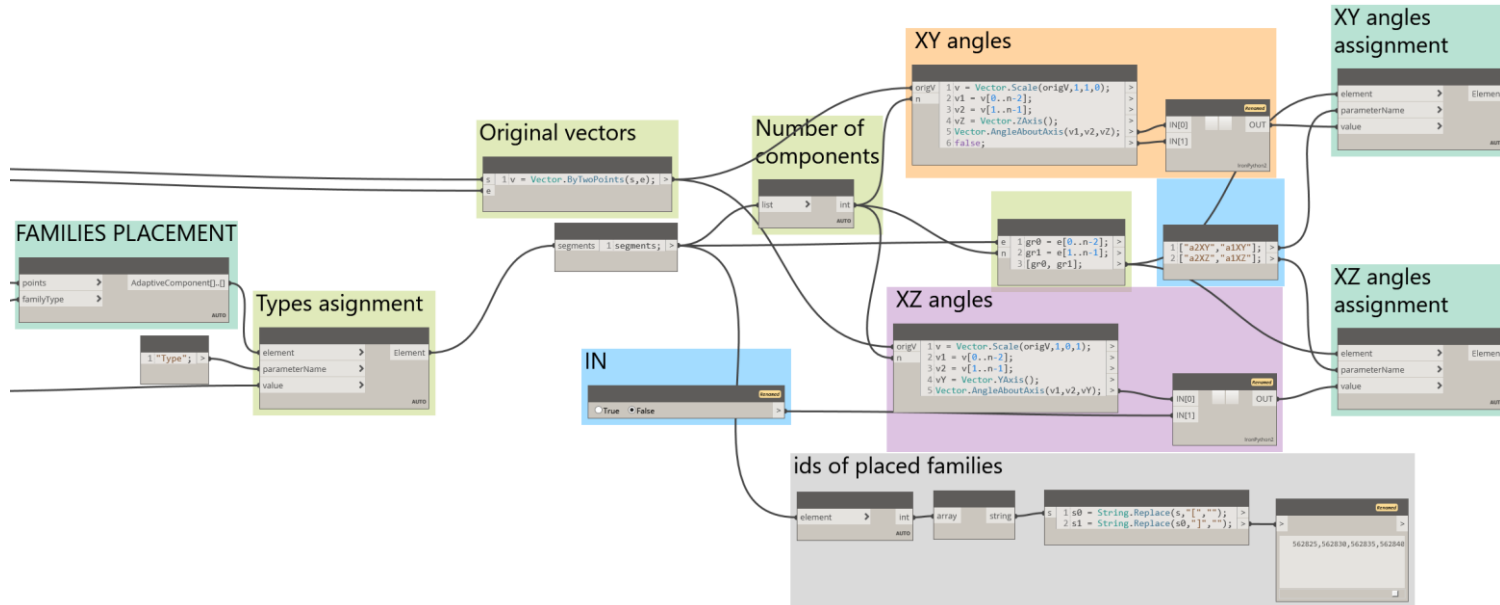


Figure 40 – Second script, second part, Dynamo view

The results of the work on the script are shown in Figures 39-42.

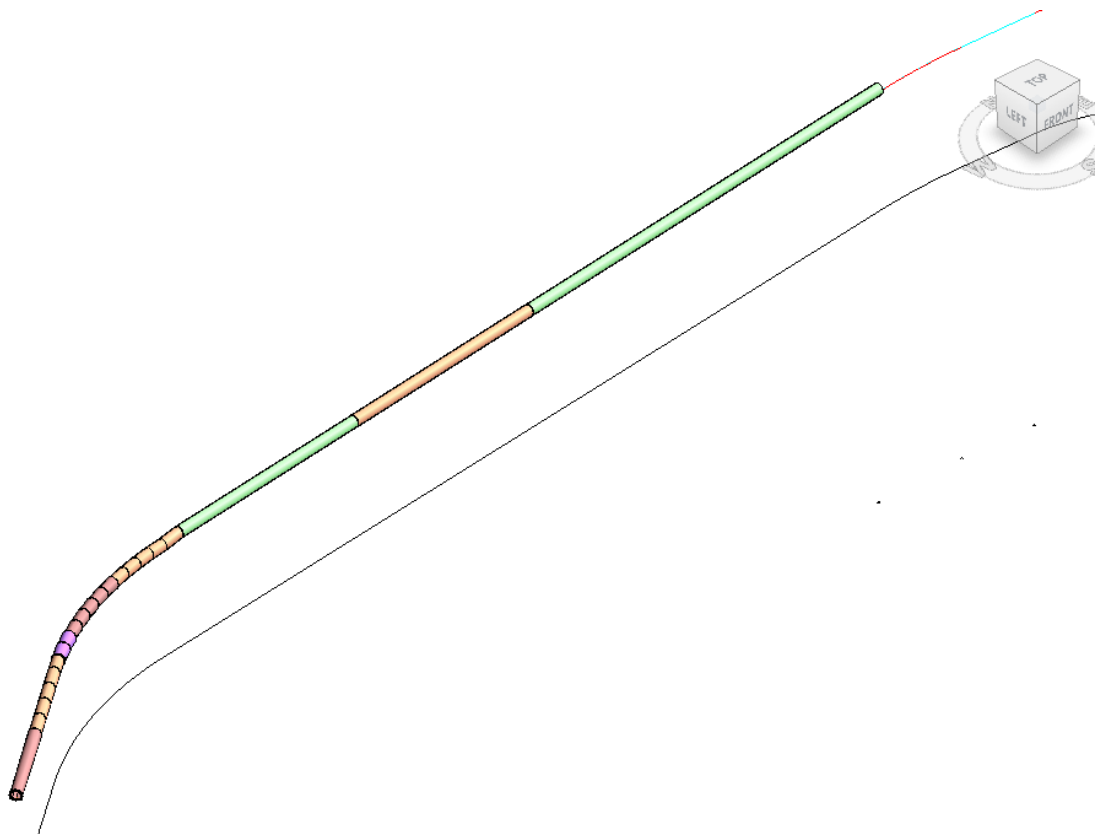


Figure 41 – Results, 3D model, general view

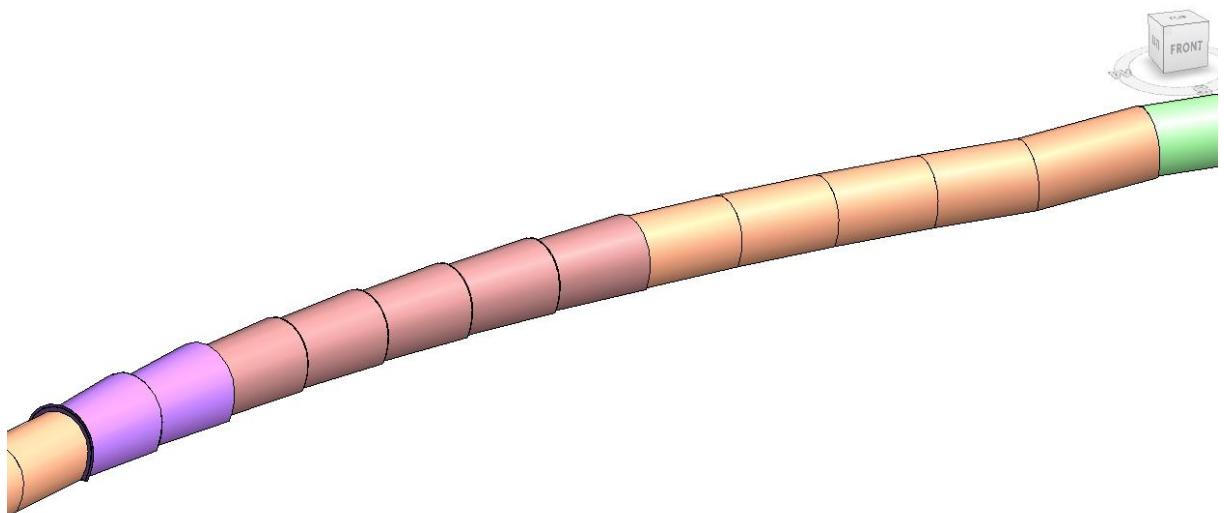


Figure 42 – Results, 3D model, closer look

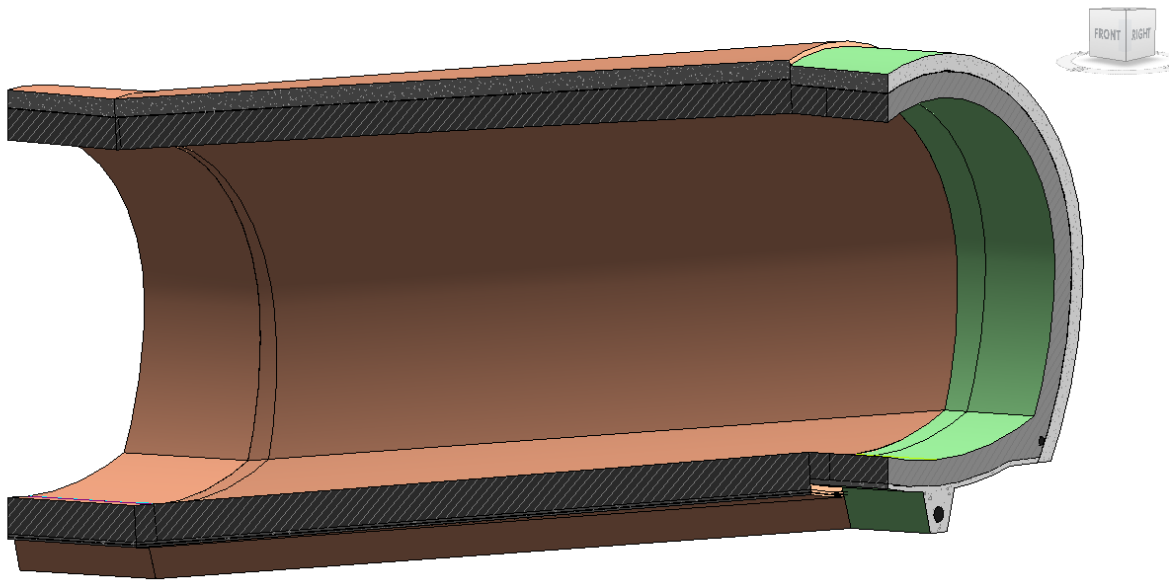


Figure 43 – Results, 3D model, section 1

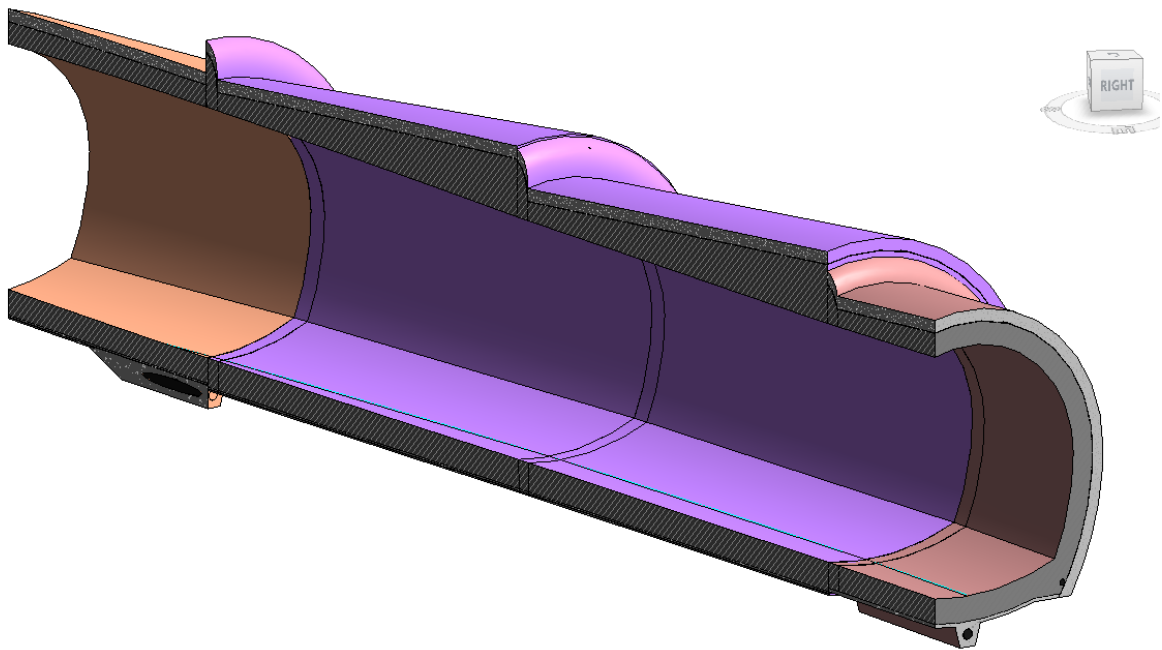


Figure 44 – Results, 3D model, section 2

3. EXCAVATION SUPPORTS

Excavation supports are crucial for guaranteeing the safety and stability of underground tunnels, both during and after the digging process. They furnish temporary structural reinforcement to prevent cave-ins, conserve the tunnel shape, and safeguard workers and equipment. The preferred excavation support approach relies on a range of factors, including geological circumstances, tunnel dimensions, construction techniques, and project stipulations. The following is a summary of the typical excavation support methods employed in tunnelling.

1. Rock Bolts and Rock Anchors:

- These are steel rods or cables installed into the tunnel walls to stabilize loose rock or soil.
- They help prevent collapses and maintain the integrity of the tunnel.
- Rock bolts are often used in conjunction with other support methods.
- Still, bolts improves the serviceability of segmental tunnel rings.

2. Shotcrete (Sprayed Concrete):

- Shotcrete is a mixture of concrete or mortar sprayed onto the tunnel walls.
- It forms a strong, durable lining that provides immediate support.
- Shotcrete can be reinforced with steel mesh or fibers for added strength.

3. Steel Ribs and Lagging:

- Steel ribs (often in the form of arches) are installed in the tunnel to provide structural support.
- Wooden or steel lagging boards are placed between the ribs to support loose or unstable ground.

4. Steel Sets or Frames:

- Steel sets consist of horizontal and vertical steel members assembled to create a frame-like structure within the tunnel.
- They provide support for the tunnel walls and roof.

5. Grouting:

- Grouting involves injecting a cement or chemical mixture into the surrounding ground to improve its stability.
- It can be used to fill voids, consolidate soil, or reduce water ingress.

6. Shield Tunneling:

- In tunnel boring machine (TBM) tunneling, a shield is used to protect the excavation face.
- The shield provides immediate support by preventing soil or rock from collapsing into the tunnel.

7. Segmental Linings:

- Commonly used in TBM tunneling, segments of precast concrete or other materials are assembled to form the tunnel lining.
- They create a smooth, structural surface that supports the tunnel.

8. Piles and Micro-Piles:

- Piles are driven or drilled into the ground to support the tunnel walls.
- Micro-piles are smaller, high-capacity piles used in limited space conditions.

9. Sheet Piles:

- Sheet piles are interlocking steel or concrete sheets driven into the ground to create retaining walls.

- They are used in soft or loose soil conditions to prevent soil from collapsing into the tunnel.

10. Crib Supports:

- Wooden cribs or boxes are stacked to support the tunnel walls.
- This method is used in loose or unstable ground conditions.

The selection of excavation support method relies on the geological conditions, project requirements, cost-effectiveness, and safety considerations. Tunnelling professionals and geotechnical experts conduct thorough assessments of these factors to determine the optimal support system for every tunnelling project. Appropriate design and execution of excavation supports are critical in guaranteeing the safety and durability of tunnels.

The project used for the study used steel ribs, shotcrete, rock bolts and grouting. The shotcrete layer was already included in the lining family. The focus of the study was limited to steel ribs and grouting.

3.1. Steel supporting ribs

The study aimed to speed up the modelling process for the design variants investigation. For this reason, the focus was on the elements with the highest material capacity and thus highest influence on the cost. It was decided to elaborate an adaptive family with steel ribs.

3.1.1. Development of families

According to the provided drawings, each supporting rib was a double I-section arch beam with two joints. The first attempt was to use the standard beam tool, but this did not give the desired shape at the base - an error occurred. It was also unclear how to get a solid beam from two arcs of different radii.

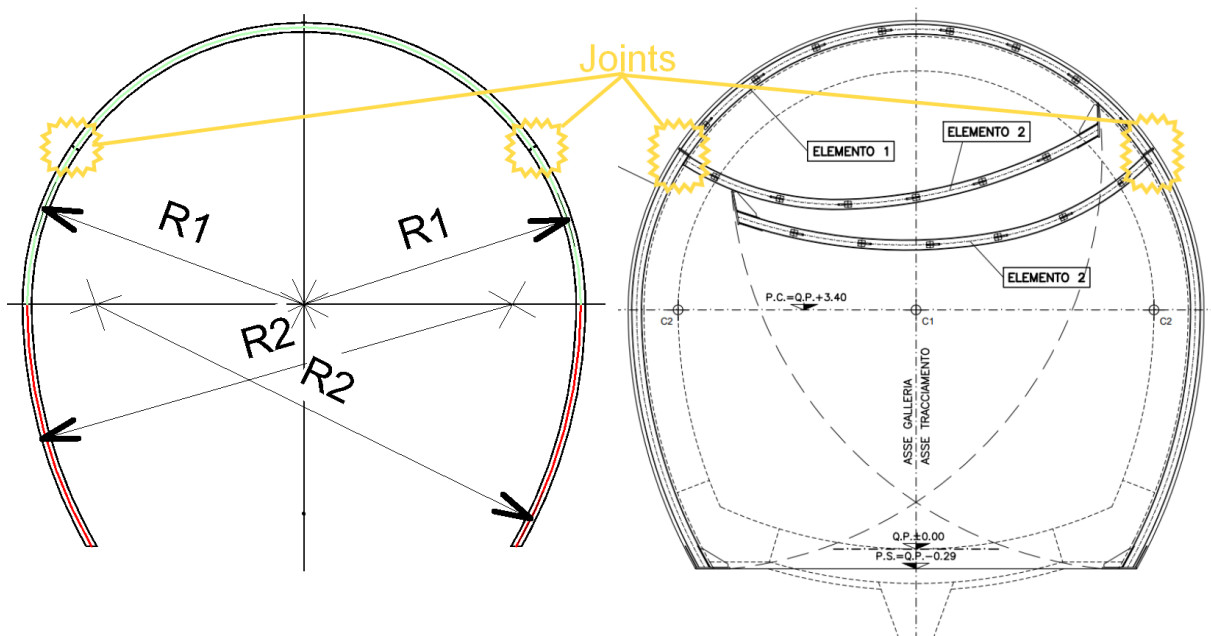


Figure 45 – Rib, required geometry

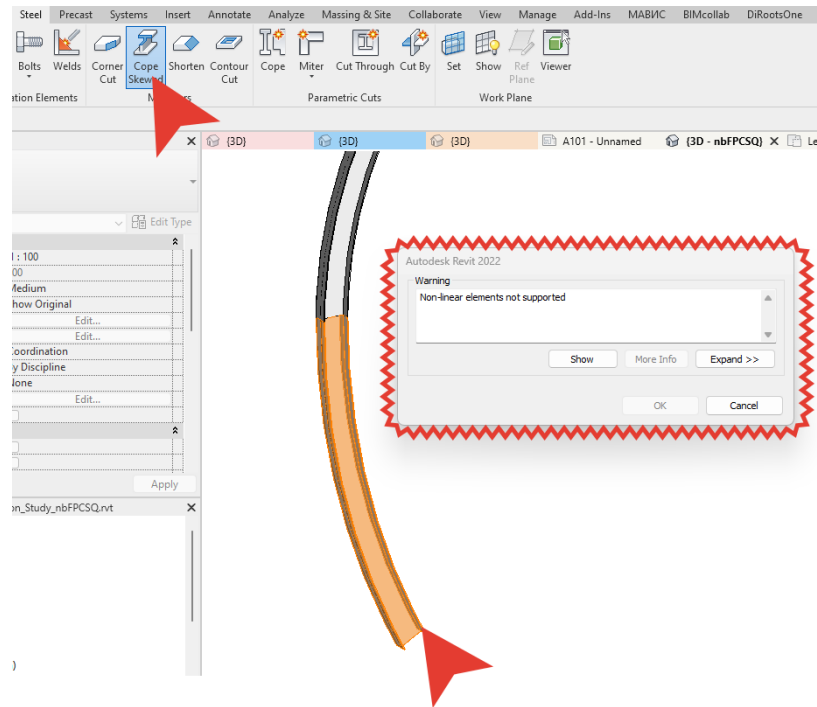


Figure 46 – Rib as beam, 3D model, error

For these reasons, it was decided to create a compound family that would meet all the geometric requirements.

The first parametric family was an I-section profile. It was used to extrude ribs in the second family.

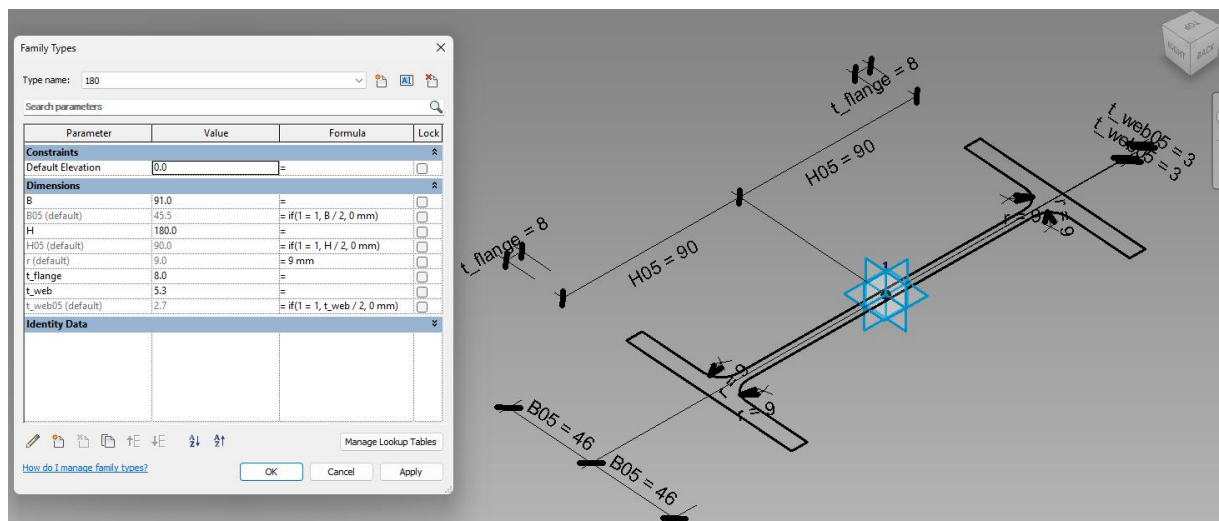


Figure 47 – I-section profile family, 3D view and parameters

The second parametric family consisted of two I-section arches. Each arch was divided into three parts by two joints. Each extrusion was based on the I-section family and reference arch lines. Such a structure provided the ability to define a section simply by selecting a type of nested family and controlling the radii as well as the position of the joints. The main feature of the family was the ability to expand according to its length. For this reason, two placement points were required.

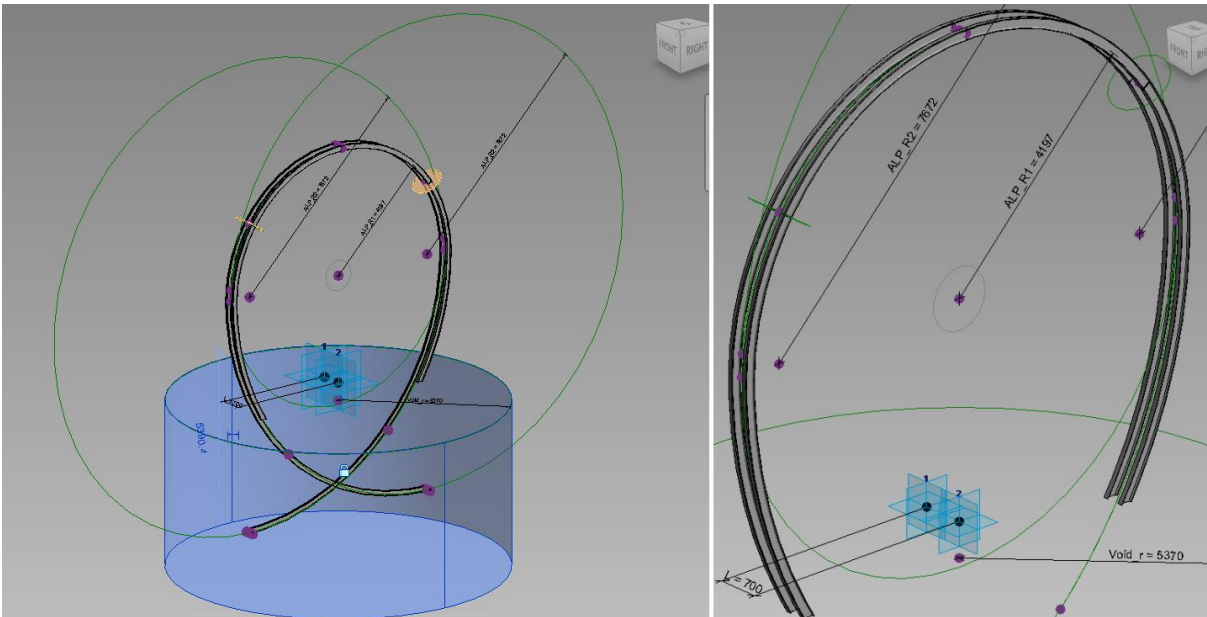


Figure 48 – Double rib family, 3D views: with voids and without

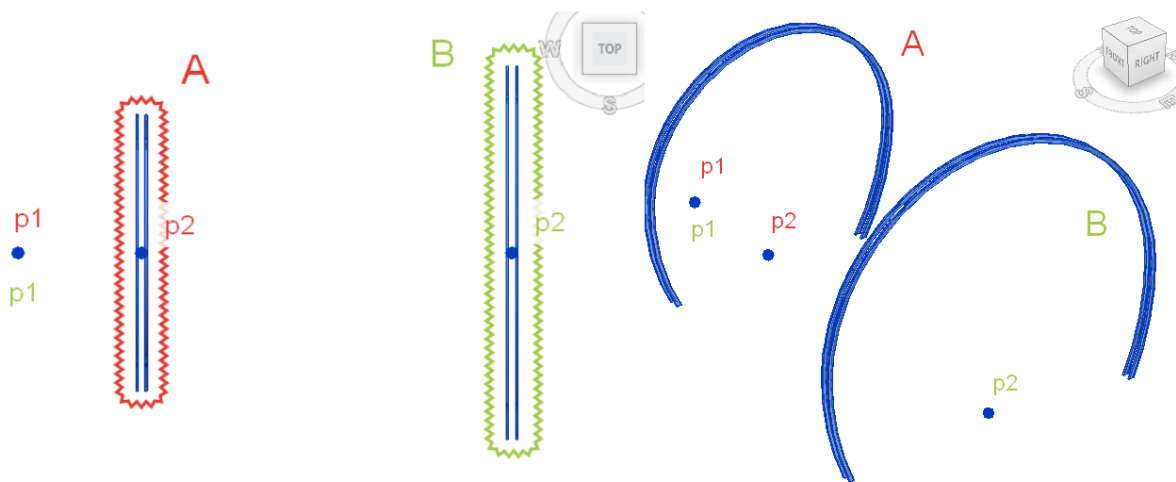


Figure 49 – Double rib family, expansion feature, 3D views: top and perspective

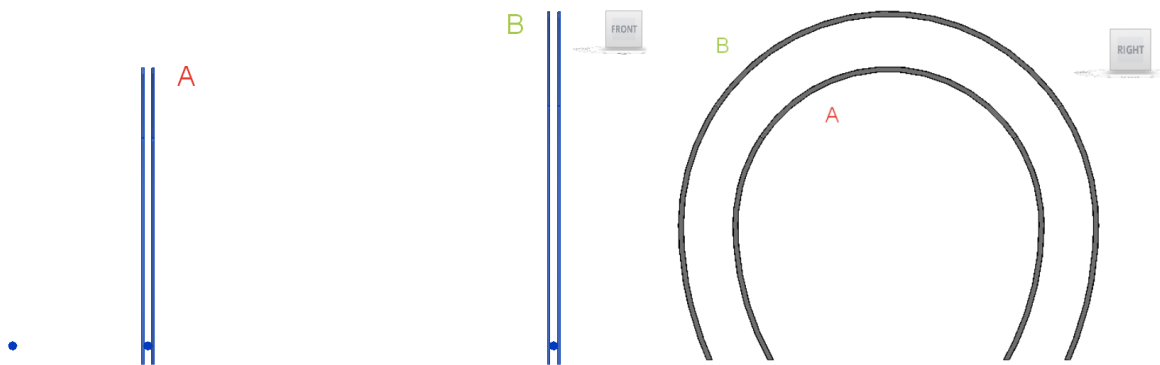


Figure 50 – Double rib family, expansion feature, 3D views: front and right

In order to fully define the supporting arch ribs for manufacture, a table of arch lengths and angles between longitudinal joints had to be provided. The required table is presented in the figure 50. Each longitudinal joint implied a short I-section between the ribs in a double ring and a strut between subsequent rings. At first it was unclear how to obtain all the numbers, but eventually logic was discovered and a set of formulas was obtained and added to the family.

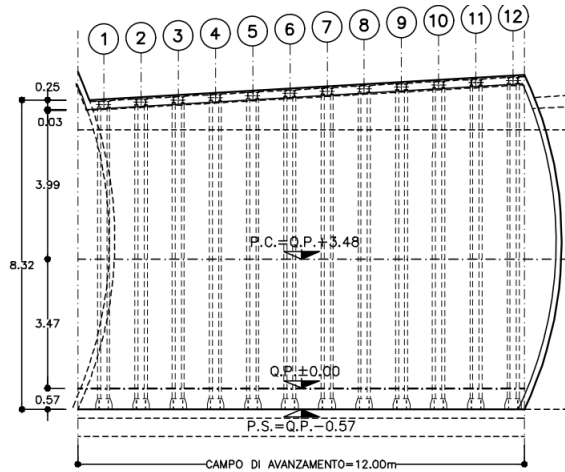


Figure 51 – Double ribs sequence from 1 to 12, source drawing

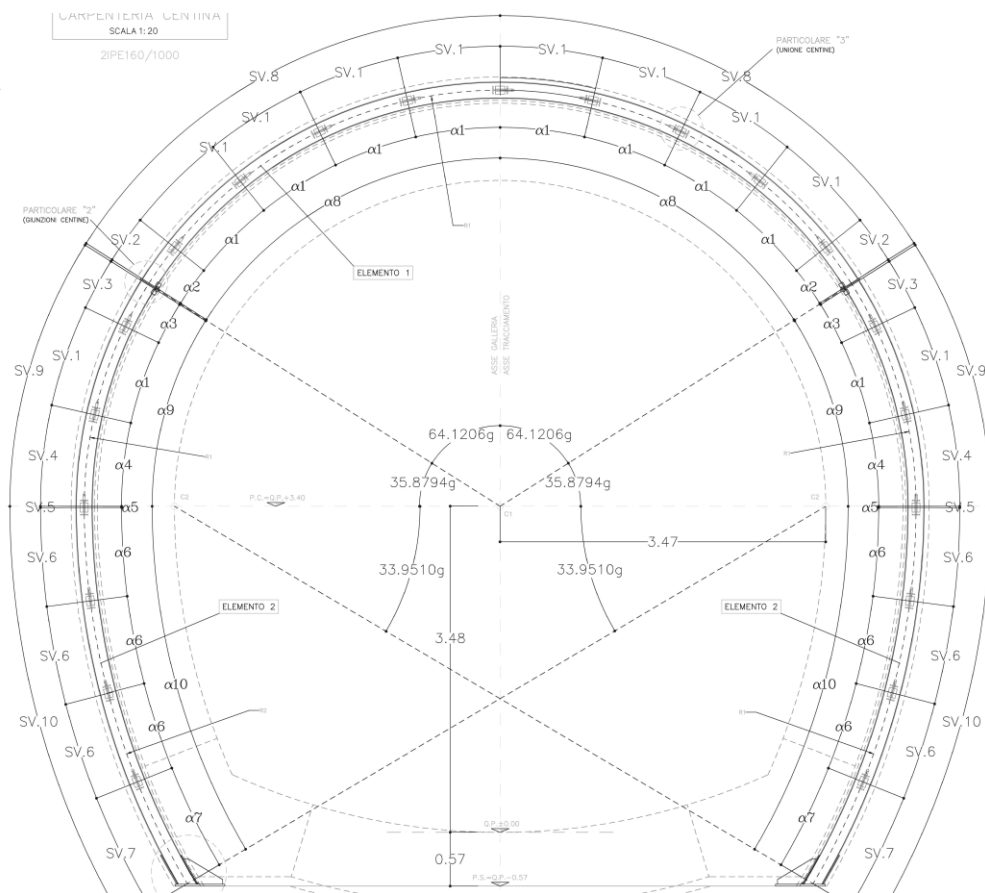


Figure 52 – Double rib with the variable's indication, source drawing

Variables ————— Lengths of the archs ————— Angles of the archs

ordinal numbers of the double ribs

reference double rib

reference values to calculate all the rest

CENTINA	TIPO	RAGGIO R1	RAGGIO R2	X	SV.1	SV.2	SV.3	SV.4	SV.5	SV.6	SV.7	SV.8	SV.9	SV.10	α1	α2	α3	α4	α5	α6	α7	α8	α9	α10
1		R4148	R7623	8176	933	438	475	920	13	962	1344	4168	2328	4244	14.3131g	6.7147g	7.2914g	14.1215g	0.1118g	8.0353g	11.2272g	63.9671g	35.7260g	35.4407g
2		R4208	R7683	8236	946	445	483	933	13	970	1318	4228	2362	4240	14.3131g	6.7169g	7.2936g	14.1215g	0.1109g	8.0353g	10.9182g	63.9693g	35.7281g	35.1317g
3		R4268	R7743	8296	960	451	489	947	13	977	1291	4289	2396	4236	14.3131g	6.7191g	7.2957g	14.1215g	0.1101g	8.0353g	10.6149g	63.9714g	35.7303g	34.8284g
4		R4328	R7803	8356	973	457	496	960	13	985	1265	4349	2429	4232	14.3131g	6.7211g	7.2978g	14.1215g	0.1092g	8.0353g	10.3172g	63.9735g	35.7323g	34.5307g
5		R4388	R7863	8416	987	464	503	973	13	992	1238	4409	2463	4229	14.3131g	6.7231g	7.2998g	14.1215g	0.1084g	8.0353g	10.0248g	63.9755g	35.7344g	34.2383g
6		R4448	R7923	8476	1000	470	510	987	13	1000	1212	4470	2497	4225	14.3131g	6.7251g	7.3017g	14.1215g	0.1076g	8.0353g	9.7376g	63.9774g	35.7363g	33.9511g
7		R4508	R7983	8536	1013	476	517	1000	13	1008	1186	4530	2530	4222	14.3131g	6.7270g	7.3017g	14.1215g	0.1068g	8.0353g	9.4555g	63.9793g	35.7382g	33.6690g
8		R4568	R8043	8596	1027	483	524	1013	13	1015	1160	4591	2564	4219	14.3131g	6.7288g	7.3055g	14.1215g	0.1060g	8.0353g	9.1783g	63.9812g	35.7401g	33.3918g
9		R4628	R8103	8656	1040	489	531	1027	13	1023	1134	4651	2598	4215	14.3131g	6.7307g	7.3017g	14.1215g	0.1052g	8.0353g	8.9059g	63.9830g	35.7419g	33.1194g
10		R4688	R8163	8716	1054	495	538	1040	13	1030	1108	4712	2631	4212	14.3131g	6.7324g	7.3091g	14.1215g	0.1044g	8.0353g	8.6382g	63.9848g	32.7926g	32.8516g
11		R4748	R8223	8776	1067	502	545	1053	13	1038	1082	4772	2665	4209	14.3131g	6.7341g	7.3108g	14.1215g	0.1036g	8.0353g	8.3749g	63.9865g	35.7454g	32.5884g
12		R4808	R8283	8836	1081	508	551	1066	13	1045	1056	4832	2699	4206	14.3131g	6.7358g	7.3108g	14.1215g	0.1029g	8.0353g	8.1161g	63.9865g	35.7470g	32.3296g

Figure 53 – Table with variable values for double ribs from 1 to 12, source table

As we can see from the source table: some of the variables are constant (α_1 and α_6), the incrementation of the radii R1 and R2 is linear. Each arch length variable SV.i has a corresponding arch angle variable α_i , where i varies from 1 to 10. The sequence of calculations is presented below.

- 1) SV.8, SV.9 and SV.10 can be obtained from R1, R2 and the given angles (in the example: 64.1206, 35.8794 and 33.9510) of the arches;
- 2) $SV.2 = SV.8 - n \cdot SV.1$, where n is a max number of SV.1 arches able to fit along SV.8 arch;
- 3) $SV.3 = SV.1 - 2 \cdot t - SV.2$, where t is a thickness of the plates in the joint;
- 4) $SV.4 = SV.8 + SV.9 - SV.1 \cdot N1$, where N1 is a full number of SV.1 arches;
- 5) $SV.5 = SV.1 - SV.4$
- 6) $SV.7 = SV.10 - SV.5 - SV.6 \cdot N2$, where N2 is a max number of SV.6 arches able to fit along SV.10 arch after SV.5 calculation;

To obtain these formulas for the parametrization, one simplification was applied:

- α_8 and α_9 are constant (in fact they slightly differ), so that the radial position of the joint is the same in all the double ribs.

In the last compound family, a sequence of double ribs was placed. Each rib started from the same point at the beginning, while the second points were placed with a step. The compound family also had two placement points. Moving the second point away from the first triggered the generation of new double ribs. If the expansion feature was required, a special bool parameter was set to true and each subsequent rib appeared with an incremented value of the radii. The expansion feature is shown in figure 51 with an example of a non-existent frame using the radius increment of 300mm to make it more visible.

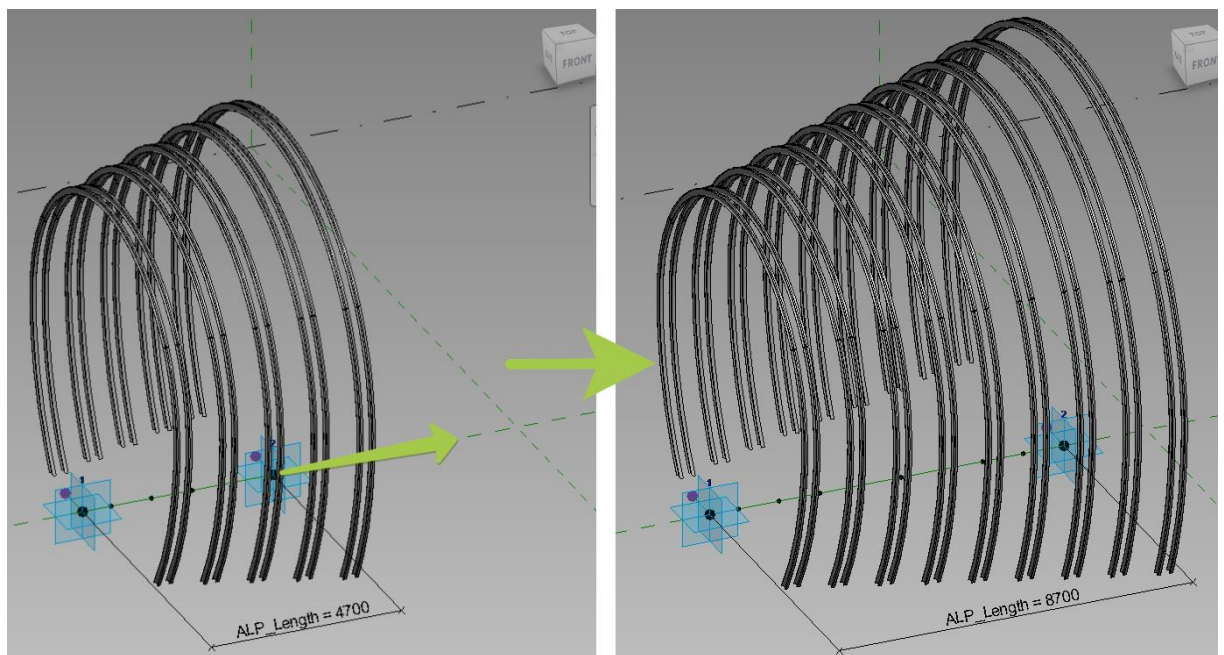


Figure 54 – Compound family with double ribs, expansion feature demonstration

The values of the variables to form the geometry of the ribs were transferred from the parent family. In order to make it work in combination with the “Repeated component” feature, the procedure was the following:

1. create a divided path;
2. place the first component;
3. link parameter values;
4. repeat the component.

With such an approach any new generated component kept the link between parameters with the parent family.

Parameter	Value	Formula
Constraints		
Default Elevation	0.0	=
Construction		
ALP_ElevCenter	3480.0	=
ALP_R1	4148.0	=
ALP_R2	7623.0	=
ALP_Rib_SV01	933.0	=
ALP_Rib_SV06	962.0	=
FirstRib_Distance	700.0	=
IPE_Type<Generic Models>	ALP_TNL_Rib_Double_v4 : IPE_180	=
SV7_bigger_than_SV6	<input checked="" type="checkbox"/>	=
bot_dh	570.0	=
Elem1_ang1	35.8794 grad	=
PlateBotBase_t	20.0	=
PlateJoint_t	10.0	=
Radius_Increment_PerMeter	300.0	=
Text		
ALP_FamilyVersion	20230725-1740	= "20230725-1740"
ALP_HostMark	B2V*	=
Dimensions		
ALP_Length (report)	5700.0	=
AngArc2	35.4613 grad	= 200 grad - 2 * (atan(H_Arc2 / (ALP_R2 - (ALP_R2 ^ 2 - H_Arc2 ^ 2) ^ 0.5)))
H_Arc2	4030.0	= ALP_ElevCenter + bot_dh - PlateBotBase_t
R1	3938.0	= ALP_R1 - k * FirstRib_Distance
R2	7413.0	= ALP_R2 - k * FirstRib_Distance
a07	3.1974 grad	= AngArc2 - ALP_Rib_a05 - ALP_Rib_a06 * seq2_SV6_1stApprox
Other		
ALP_Rib_a01	14.3193 grad	= 200 grad * ALP_Rib_SV01 / (ALP_R1 * pi())
ALP_Rib_a04	14.0840 grad	= 100 grad - seq1_SV1 * ALP_Rib_a01
ALP_Rib_a05	0.1281 grad	= (ALP_Rib_a01 - ALP_Rib_a04) / ALP_R2 * ALP_R1
ALP_Rib_a06	8.0340 grad	= 200 grad * ALP_Rib_SV06 / (ALP_R2 * pi())
k	0.300000	= if(1 = 1, Radius_Increment_PerMeter / 1000 mm, 0)
seq1_SV1	6	= rounddown(100 grad / ALP_Rib_a01)
seq2_SV6	3	= if(and(SV7_bigger_than_SV6, a07 > ALP_Rib_a06), seq2_SV6_1stApprox, seq2_SV6_1stApprox - 1)
seq2_SV6_1stApprox	4	= rounddown((AngArc2 - ALP_Rib_a05) / ALP_Rib_a06)

Figure 55 – Compound family with double ribs, parameters

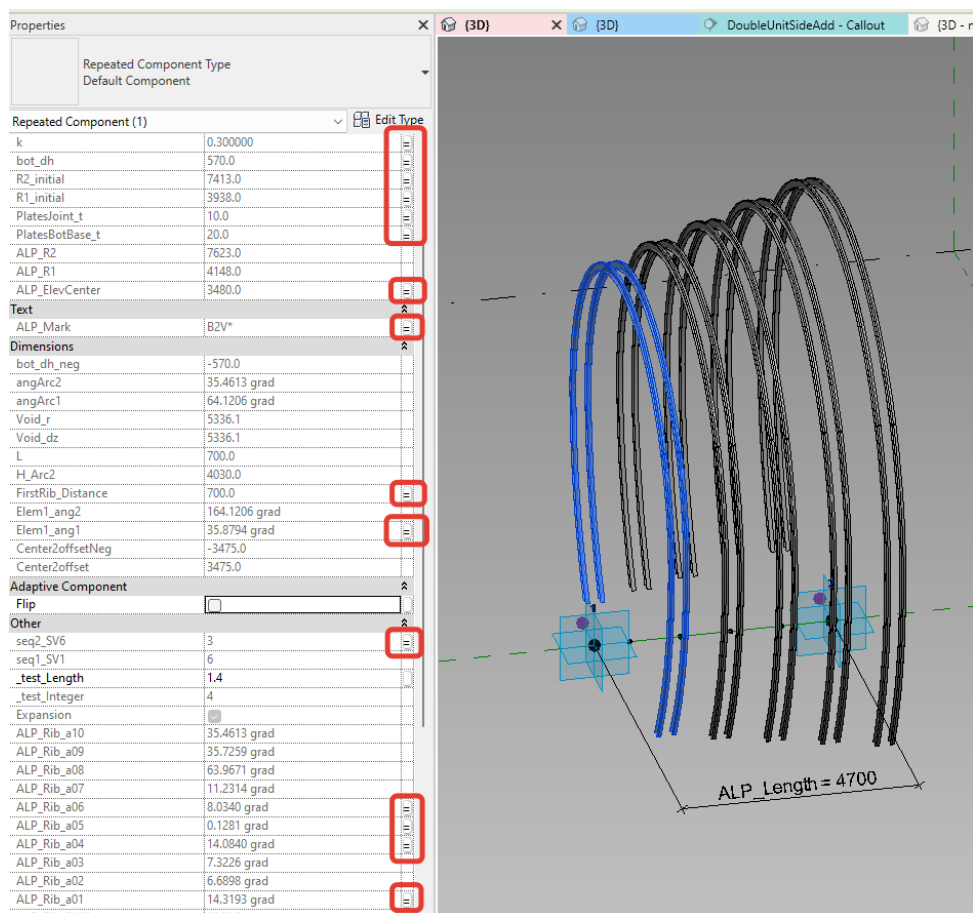


Figure 56 – Compound family with double ribs, linked parameters in the repeated component

Once the values are transferred to the nested family, the derivatives are calculated according to the formulas presented earlier.

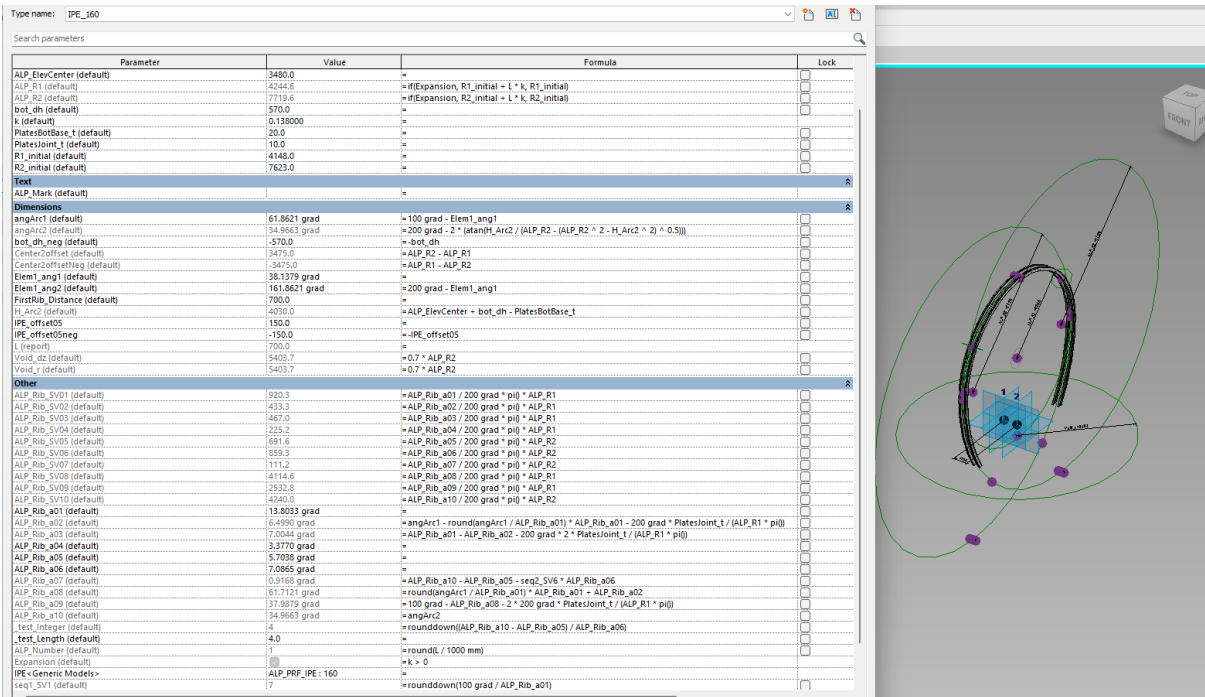


Figure 57 – Double rib family, parameters and 3D view

The automatically generated Revit schedule dynamically linked to the model elements is shown in Figure 55. Both CAD source and Revit schedule tables are shown in Figure 56 to illustrate the differences.

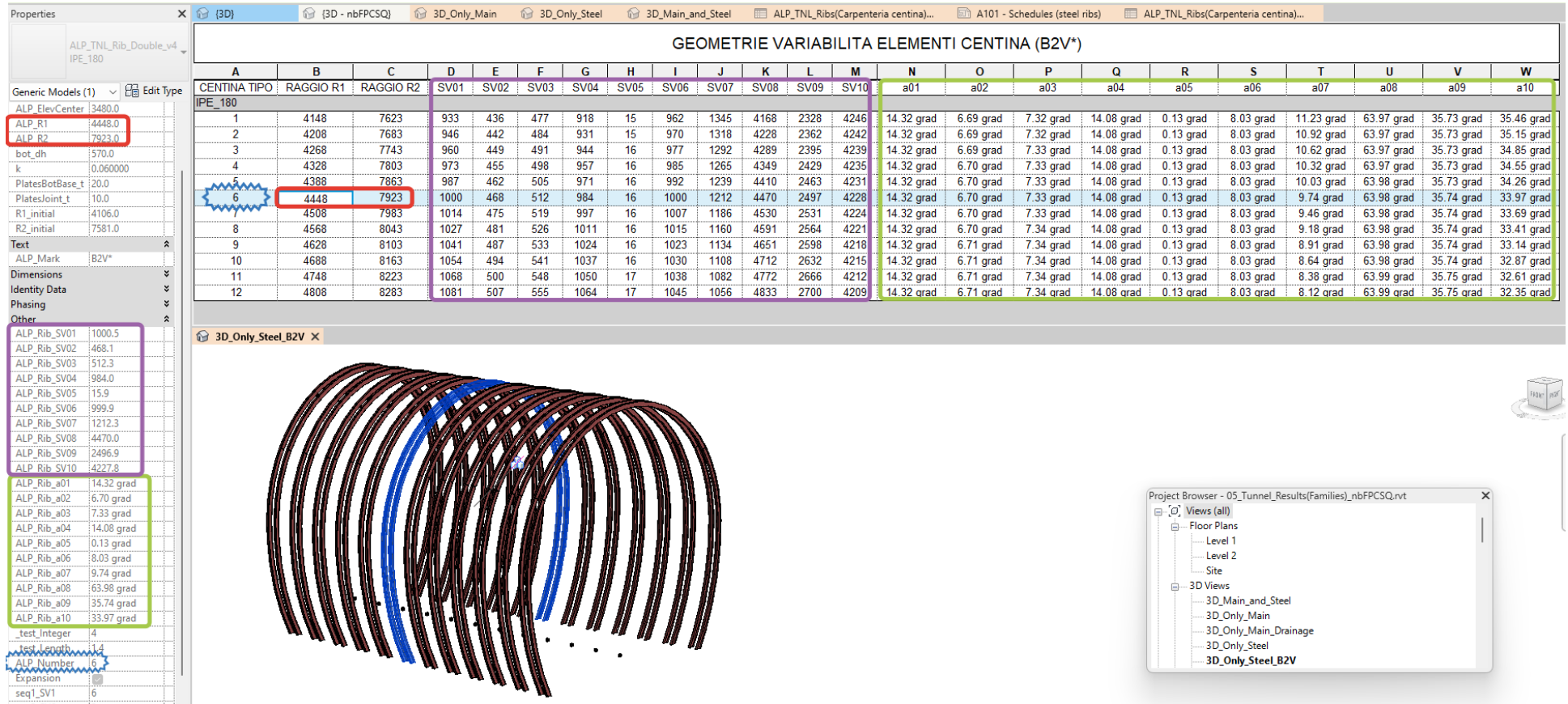


Figure 58 – Compound family in the project, automatically generated schedule

CAD source table

CENTINA TIPO	RAGGIO R1	RAGGIO R2	X	SV.1	SV.2	SV.3	SV.4	SV.5	SV.6	SV.7	SV.8	SV.9	SV.10	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10
1	R4148	R7623	8176	933	438	475	920	13	962	1344	4168	2328	4244	14.3131g	6.7147g	7.2914g	14.1215g	0.1118g	8.0353g	11.2272g	63.9671g	35.7260g	35.4407g
2	R4208	R7683	8236	946	445	483	933	13	970	1318	4228	2362	4240	14.3131g	6.7169g	7.2936g	14.1215g	0.1109g	8.0353g	10.9182g	63.9693g	35.7281g	35.1317g
3	R4268	R7743	8296	960	451	489	947	13	977	1291	4289	2396	4236	14.3131g	6.7191g	7.2957g	14.1215g	0.1101g	8.0353g	10.6149g	63.9714g	35.7303g	34.8284g
4	R4328	R7803	8356	973	457	496	960	13	985	1265	4349	2429	4232	14.3131g	6.7211g	7.2978g	14.1215g	0.1092g	8.0353g	10.3172g	63.9735g	35.7323g	34.5307g
5	R4388	R7863	8416	987	464	503	973	13	992	1238	4409	2463	4229	14.3131g	6.7231g	7.2998g	14.1215g	0.1084g	8.0353g	10.0248g	63.9755g	35.7344g	34.2383g
6	R4448	R7923	8476	1000	470	510	987	13	1000	1212	4470	2497	4225	14.3131g	6.7251g	7.3017g	14.1215g	0.1076g	8.0353g	9.7376g	63.9774g	35.7363g	33.9511g
7	R4508	R7983	8536	1013	476	517	1000	13	1008	1186	4530	2530	4222	14.3131g	6.7270g	7.3017g	14.1215g	0.1068g	8.0353g	9.4555g	63.9793g	35.7382g	33.6690g
8	R4568	R8043	8596	1027	483	524	1013	13	1015	1160	4591	2564	4219	14.3131g	6.7288g	7.3055g	14.1215g	0.1060g	8.0353g	9.1783g	63.9812g	35.7401g	33.3918g
9	R4628	R8103	8656	1040	489	531	1027	13	1023	1134	4651	2598	4215	14.3131g	6.7307g	7.3017g	14.1215g	0.1052g	8.0353g	8.9059g	63.9830g	35.7419g	33.1194g
10	R4688	R8163	8716	1054	495	538	1040	13	1030	1108	4712	2631	4212	14.3131g	6.7324g	7.3091g	14.1215g	0.1044g	8.0353g	8.6382g	63.9848g	35.7429g	32.8516g
11	R4748	R8223	8776	1067	502	545	1053	13	1038	1082	4772	2665	4209	14.3131g	6.7341g	7.3108g	14.1215g	0.1036g	8.0353g	8.3749g	63.9865g	35.7454g	32.5884g
12	R4808	R8283	8836	1081	508	551	1066	13	1045	1056	4832	2699	4206	14.3131g	6.7358g	7.3108g	14.1215g	0.1028g	8.0353g	8.1161g	63.9865g	35.7470g	32.3296g

Revit schedule

CENTINA TIPO	RAGGIO R1	RAGGIO R2	X	SV01	SV02	SV03	SV04	SV05	SV06	SV07	SV08	SV09	SV10	a01	a02	a03	a04	a05	a06	a07	a08	a09	a10
IPE_180																							
1	4148	7623	8176	933	436	477	918	15	962	1345	4168	2328	4246	14.3193	6.6998	7.3226	14.0840	0.1281	8.0340	11.2314	63.9671	35.7259	35.4613
2	4208	7683	8236	946	442	484	931	15	970	1318	4228	2362	4242	14.3193	6.6919	7.3248	14.0840	0.1281	8.0340	10.9222	63.9693	35.7281	35.1521
3	4268	7743	8296	960	449	491	944	16	977	1292	4289	2395	4239	14.3193	6.6941	7.3269	14.0840	0.1281	8.0340	10.6187	63.9714	35.7302	34.8487
4	4328	7803	8356	973	455	498	957	16	985	1265	4349	2429	4235	14.3193	6.6961	7.3290	14.0840	0.1281	8.0340	10.3208	63.9735	35.7323	34.5607
5	4388	7863	8416	987	462	505	971	16	992	1239	4410	2463	4231	14.3193	6.6982	7.3310	14.0840	0.1281	8.0340	10.0282	63.9755	35.7343	34.2681
6	4448	7923	8476	1000	468	512	984	16	1000	1212	4470	2497	4228	14.3193	6.7001	7.3330	14.0840	0.1281	8.0340	9.7408	63.9775	35.7363	33.9707
7	4508	7983	8536	1014	475	519	997	16	1007	1186	4530	2531	4224	14.3193	6.7020	7.3349	14.0840	0.1281	8.0340	9.4585	63.9794	35.7382	33.6884
8	4568	8043	8596	1027	481	526	1011	16	1015	1160	4591	2564	4221	14.3193	6.7039	7.3367	14.0840	0.1281	8.0340	9.1811	63.9812	35.7400	33.4110
9	4628	8103	8656	1041	487	533	1024	16	1023	1134	4651	2598	4218	14.3193	6.7057	7.3385	14.0840	0.1281	8.0340	8.9085	63.9830	35.7418	33.1385
10	4688	8163	8716	1054	494	541	1037	16	1030	1108	4712	2632	4215	14.3193	6.7074	7.3403	14.0840	0.1281	8.0340	8.6406	63.9848	35.7436	32.8705
11	4748	8223	8776	1068	500	548	1050	17	1038	1082	4772	2666	4212	14.3193	6.7092	7.3420	14.0840	0.1281	8.0340	8.3772	63.9865	35.7453	32.6071
12	4808	8283	8836	1081	507	555	1064	17	1045	1056	4833	2700	4209	14.3193	6.7108	7.3437	14.0840	0.1281	8.0340	8.1182	63.9882	35.7470	32.3481

Figure 59 – Steel ribs geometrical manufacturing data, CAD source table and Revit schedule

As we can see from the figures, the formulas used for the calculation were correctly identified. The small differences are mainly due to the simplification mentioned above.

Two simple families were created to model the most material consuming details:

- I-section straight beam based on the I-section profile discussed above;
- Brace.

Both families were provided with a rotation feature. The families are presented in the figures 57 and 58.

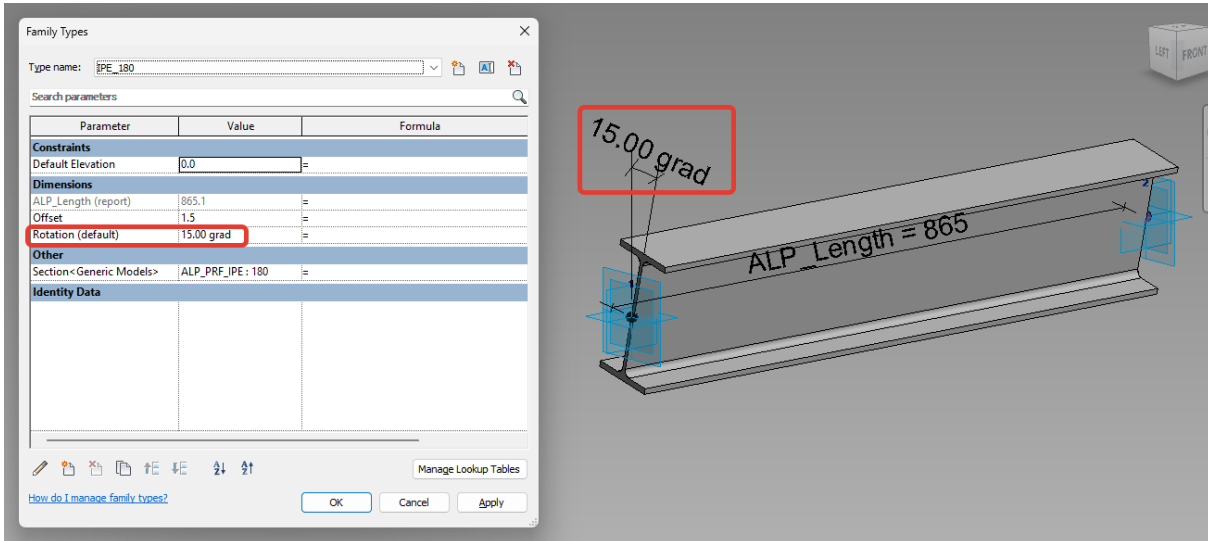


Figure 60 – Connection rib, parameters and 3D view

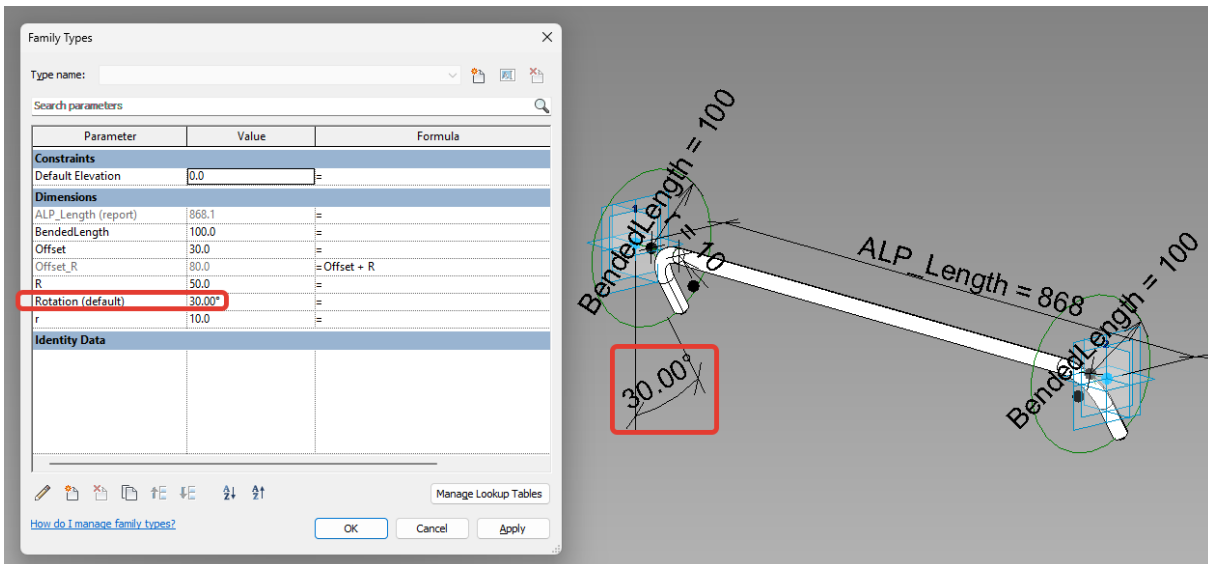


Figure 61 – Connection brace, parameters and 3D view

3.1.2. Dynamo script

In order to automate the placing of I-section ribs and braces at joints and calculation of the rotation angles, a script was created. As an input there must be provided:

- family instance of the steel ribs compound family

- values of the SV.1 and SV.6
- family type of the I-section connection rib and family type of the brace

At first, the geometry of the reference lines and parameter values from the double rib families were used to reconstruct the centerlines.

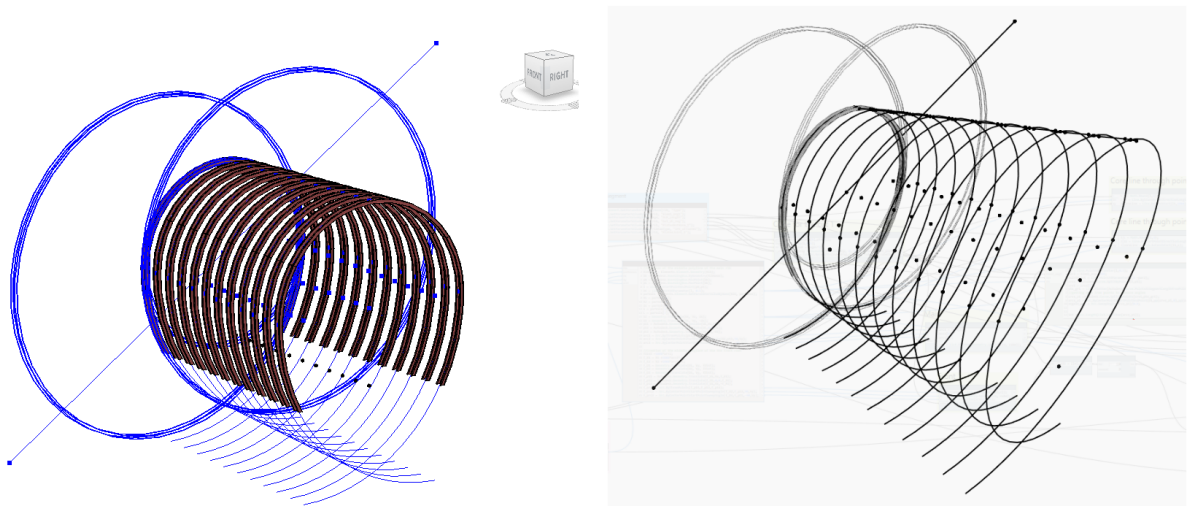


Figure 62 – Compound family in the project and Dynamo preview, reconstruction of the centerlines

The next step was to use these centerlines to obtain the core lines of the steel arch ribs. At the same time, radial surfaces were created based on values SV.1 and SV.2. As a result, intersection points were obtained.

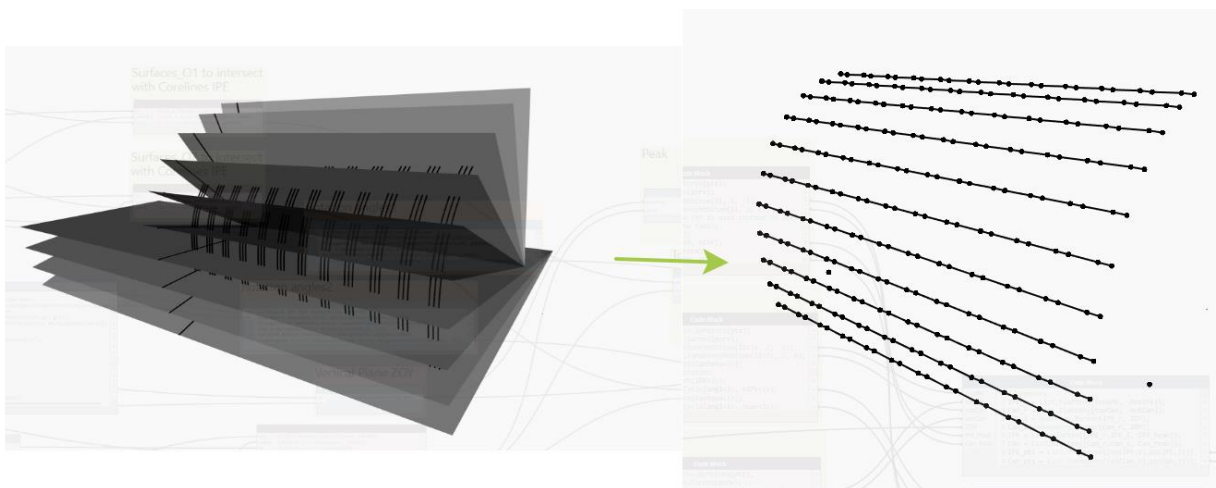


Figure 63 – Dynamo preview, getting the intersection with the radial surfaces

Once the placement points were obtained in the correct order for one half, they were mirrored. After the families placement the rotation was set in accordance with special position.

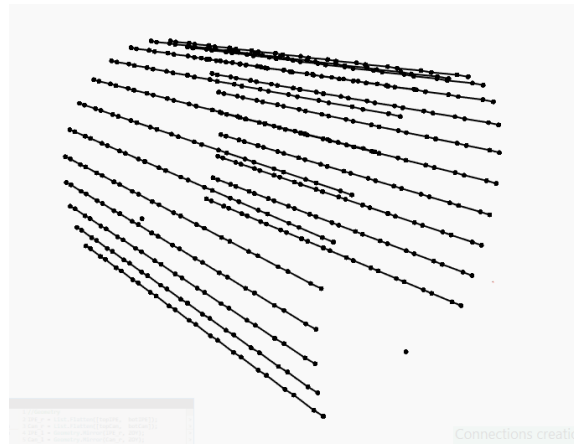


Figure 64 – Dynamo preview, all the necessary point for families placement

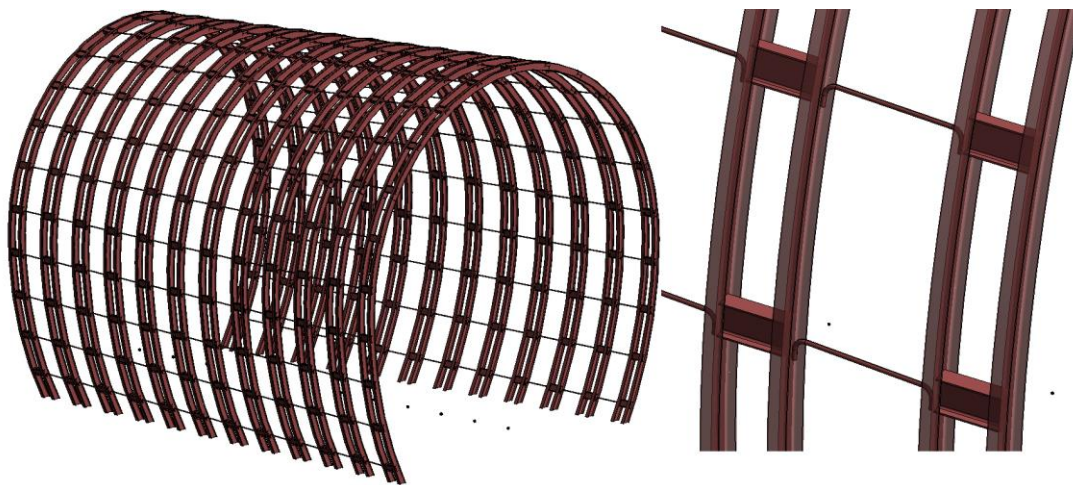


Figure 65 – Project 3D view, the result, only steel elements visible

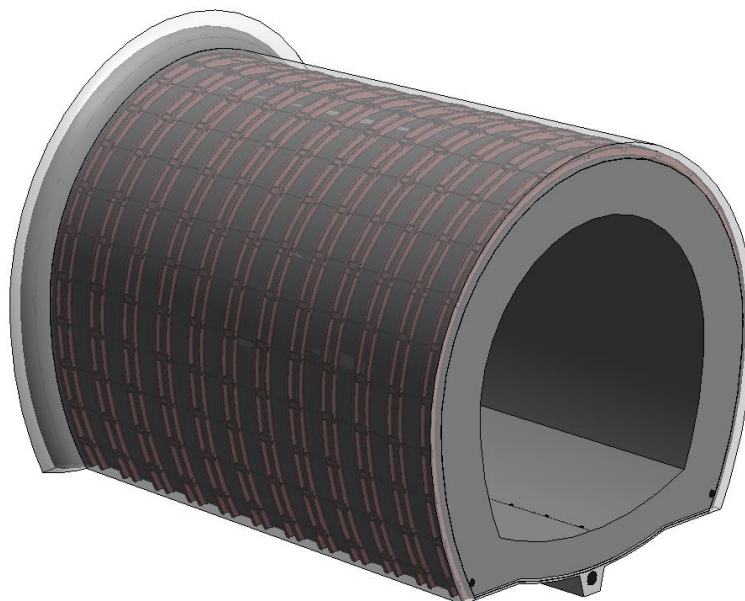
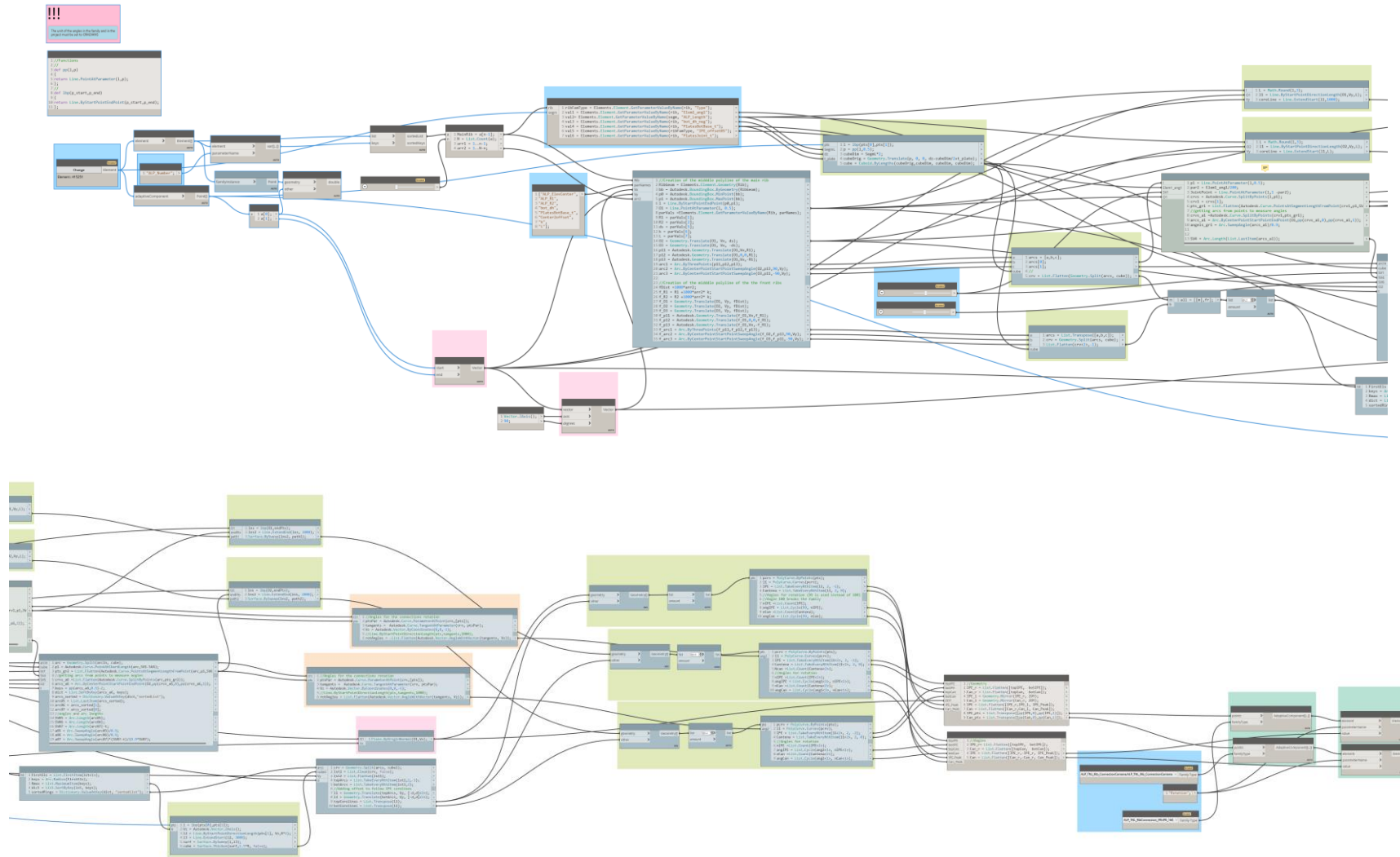


Figure 66 – Project 3D view, the result, a full tunnel segment assembly



Figures 67 and 68 – Dynamo script for joint details placement and rotation

3.2. Grouting

3.2.1. Introducing the issue

Grouting involves injecting a cement or chemical mixture into the surrounding soil to improve its stability. In the source project, this technology was used to consolidate the ground and reduce water ingress. Grouting requires large quantities of material, as the aim is to create a large concrete shield around the tunnel and in front of each advance during excavation. The aim is to minimise quantities without compromising the durability of the structure. Dynamo Generative Design was chosen to optimize the process of finding the optimal solution.

The case study focused on the surrounding row of injection piles (coloured yellow in the source drawings). It can be seen that the injection points follow the perimeter of the tunnel cross-section with a certain step. Due to the inclination of the piles, the distance between the centre lines decreases along the shield and reaches a minimum value at the end. In order to act as a robust waterproofing layer, the piles must overlap.

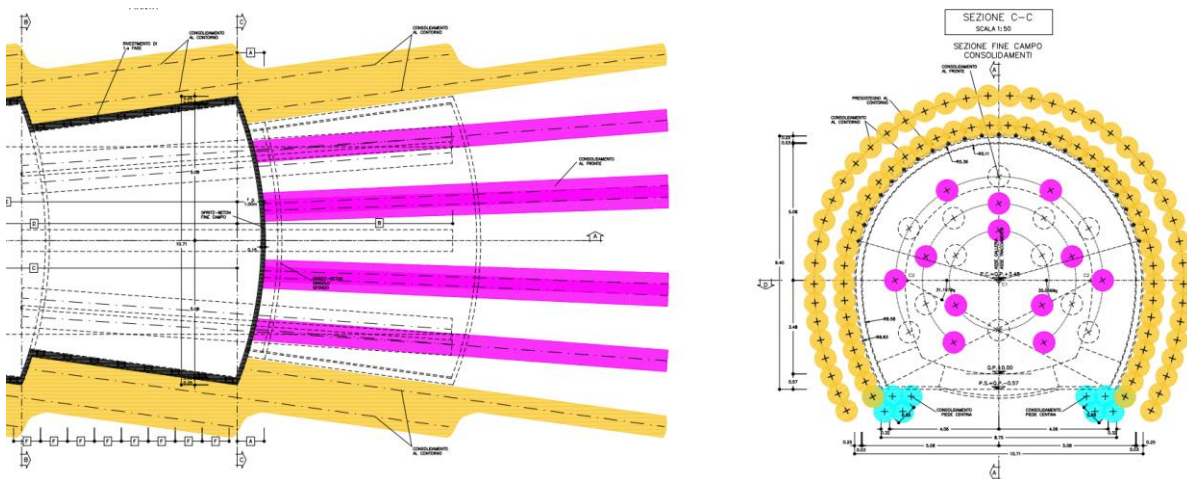


Figure 69 – Grouting, source drawings

3.2.2. Dynamo script

3.2.2.1. The body

The geometrical analysis is based on the existing parametric family of the segment lining. In order to simplify the process of injection points placement, the nested family with the profiles were set to visible (highlighted with red dashed lines in the figure 66). In order to make the script robust, it was decided to start the flow with the retrieval of the smallest profile (in case a few of them are unintentionally set to visible). After that, the profile geometry was projected on the vertical plane at the start of the segment, where injection points must be allocated. The points were spread and circles were created using an input data: step and radius (figure 67). The next step was to extrude the piles along the vectors (figure 68).

Once the shield was formed, three types of measurement could be taken as a target value: overlap distance, overlap area or overlap volume. Overlap distance was chosen as the main objective. Another

objective was to minimize the volume of the pile geometry. For visualization purposes and further QTO, the shield could be modelled as a direct shape with a desired material once the optimal design was found.

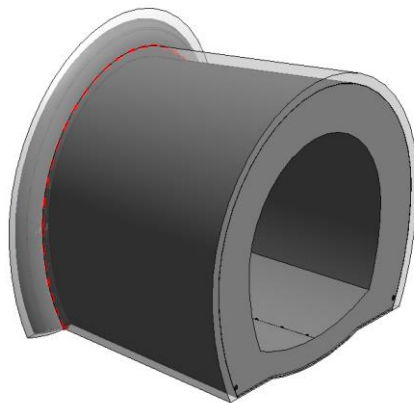


Figure 70 – Segment family, profile highlighting

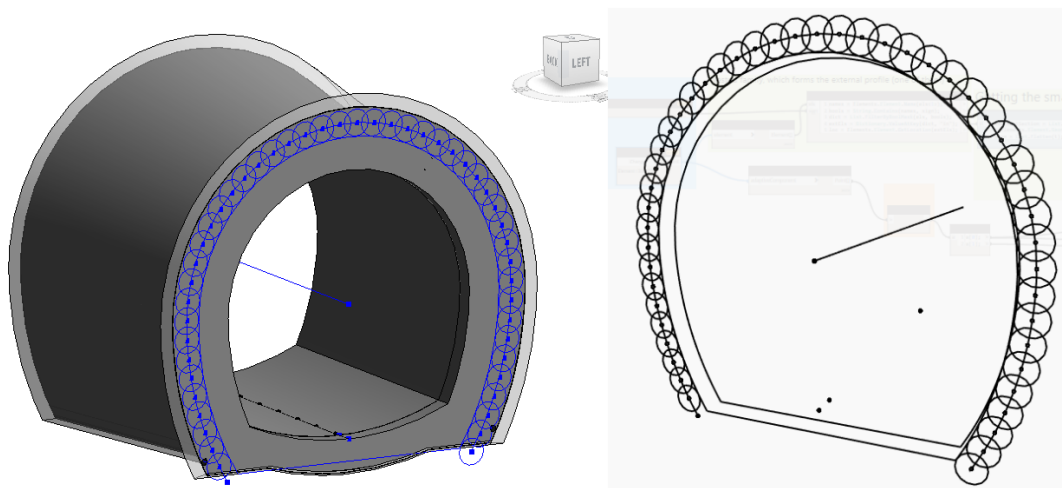


Figure 71 – Allocation of injection points and pile profiles, 3D project and Dynamo view

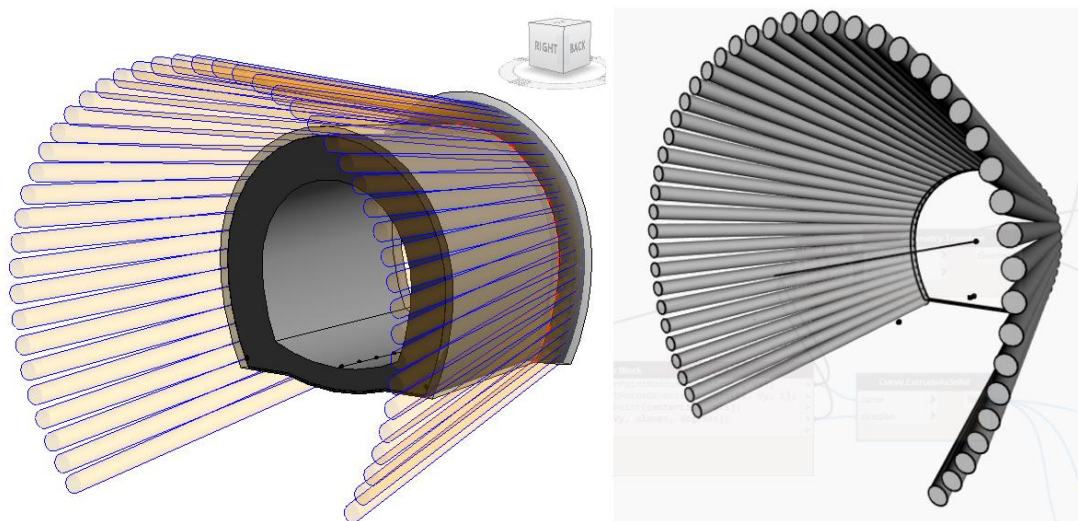
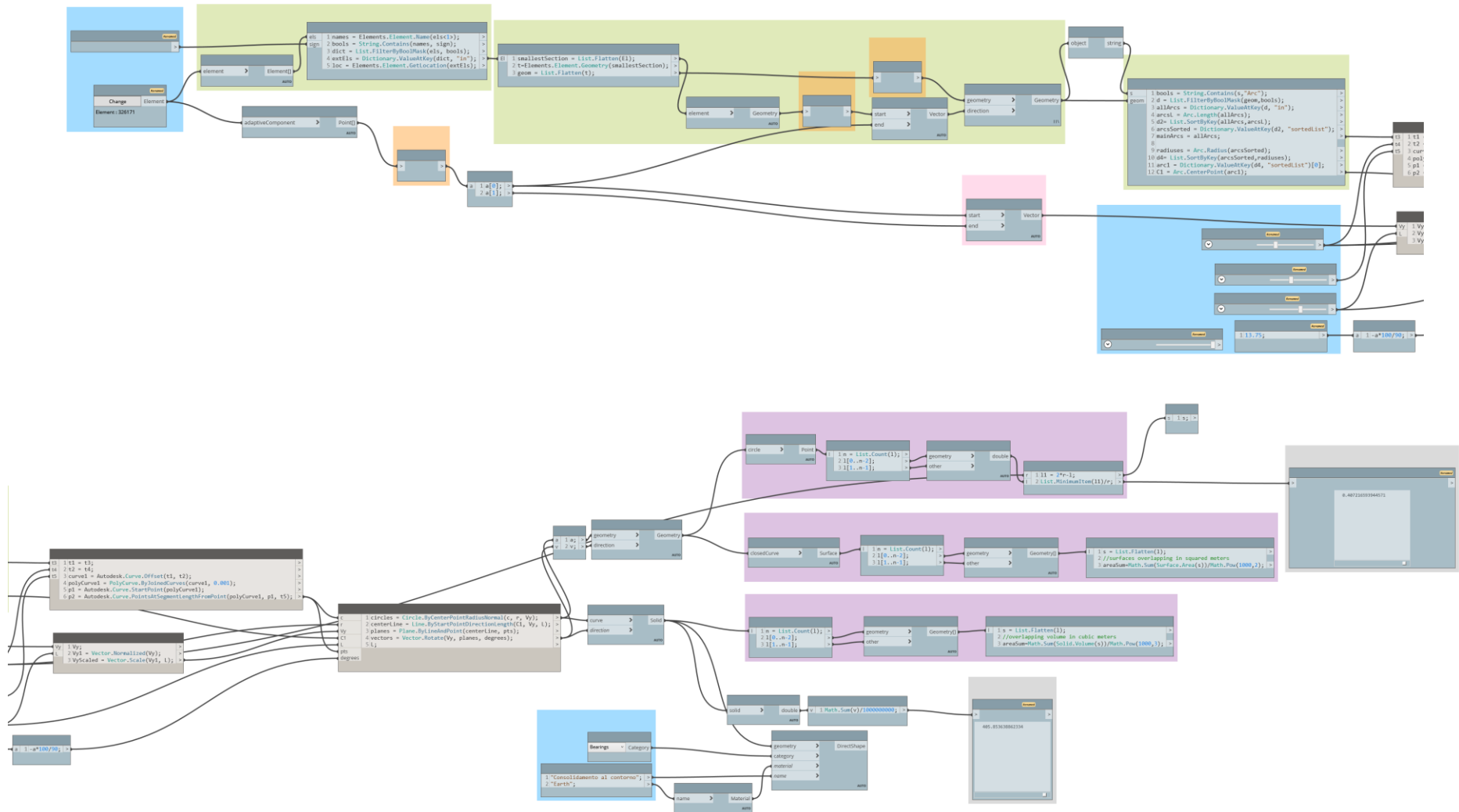


Figure 72 – Pile extrusion, 3D project and Dynamo view



Figures 73 and 74 – Dynamo script for grouting optimization

3.2.2.2. Exploring outcomes with Generative Design

Two studies were run to find the optimal radius and step of the injections. Due to the simplicity of the task, varying the constraints and generation settings after the first study did not change the results in the second study. The constraints set with the range of values and minimisation objective of the studies and the corresponding results are shown in the figures below.

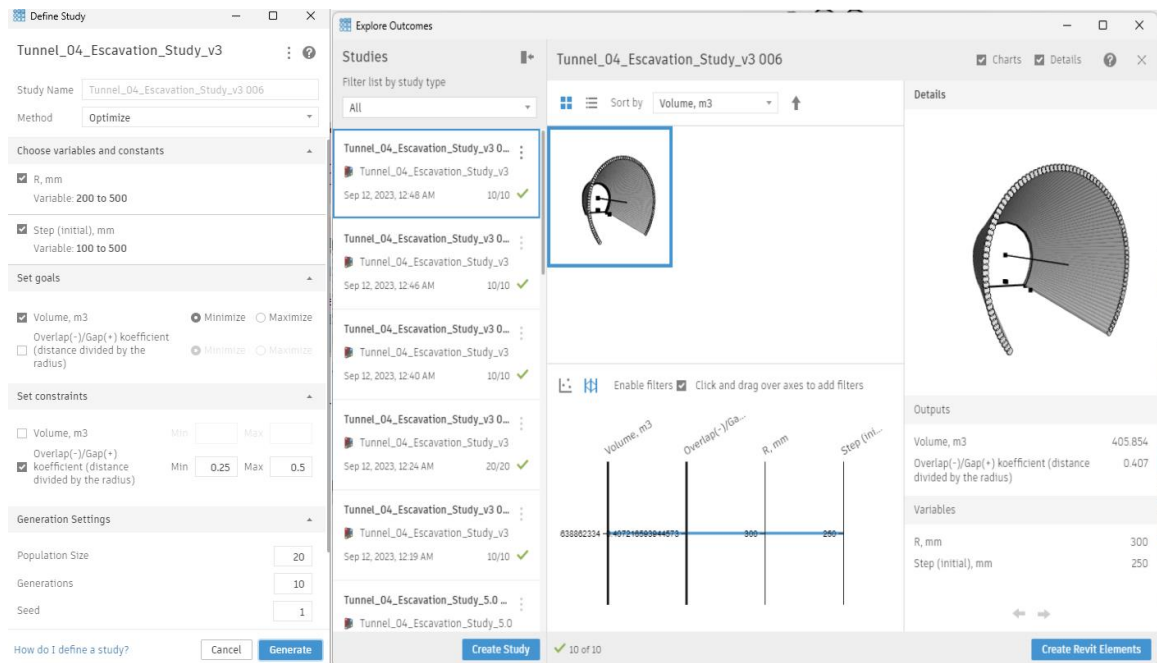


Figure 75 – Exploring outcomes with Generative Design, first study

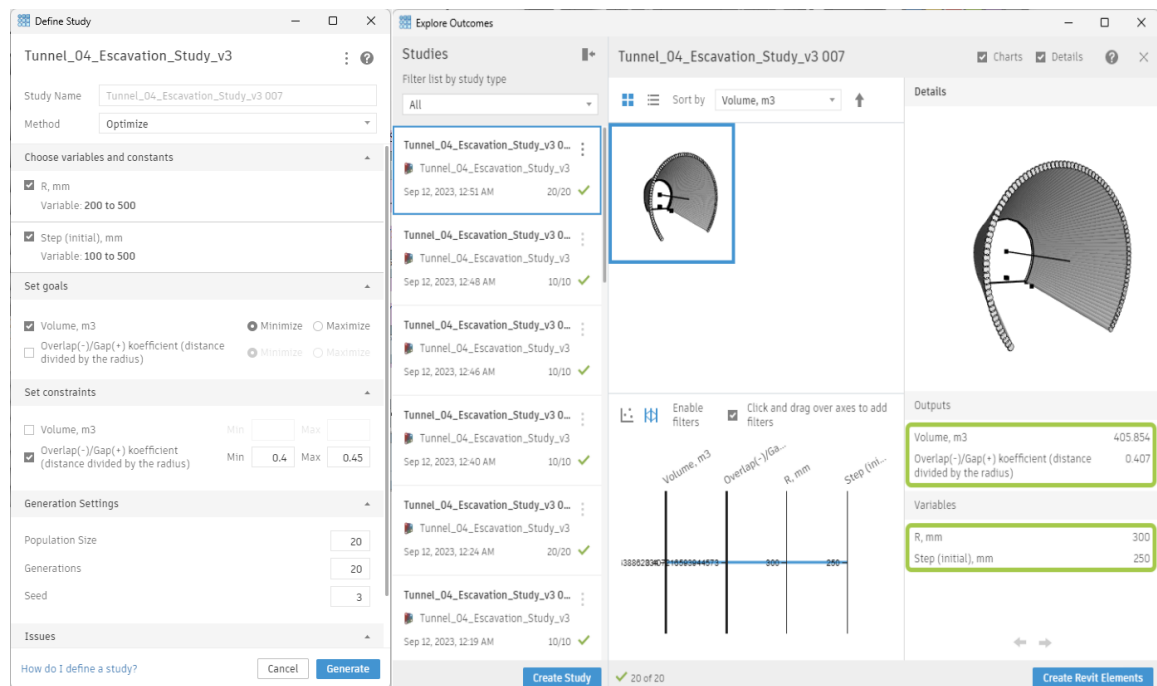


Figure 76 – Exploring outcomes with Generative Design, second study

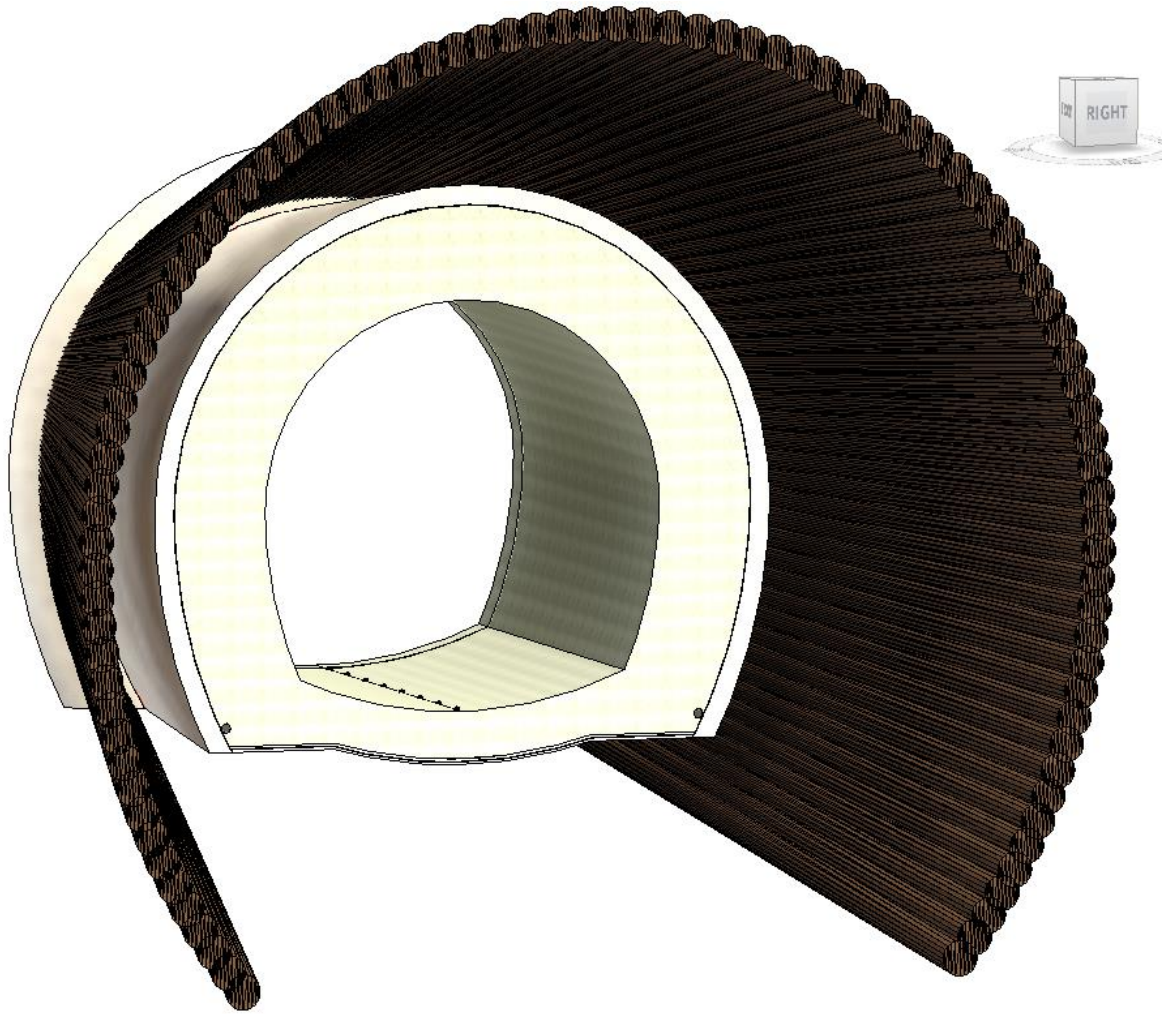


Figure 77 – Model created based on the outcome results

4. CONCLUSIONS

This dissertation had the objective of automation of the tunnel design process with the use of Dynamo. Since automation should be applied to the optimized manual process, the first step was the optimization of the modeling.

After creation of a few prototypes of the inner lining family, the adaptive component template was chosen as a preferable one. The structural framing option was rejected as it was hard to get a component with a desirable geometrical parametrization at the start and at the end for the inclined joint, since Revit automatically cut geometry by the Member Left and the Member Right planes. However, it should be noted, that Beam is a powerful tool and may be appropriate in case of simplified modelling with an admission of slight collisions or without sectioning of the tunnel. Moreover, it may be appropriate for a road modelling inside a tunnel as it has a built-in parameter Cross-Section Rotation in addition to vertical alignment parameters at the beginning and at the end.

Adaptive component template in its turn provides more flexibility and an additional functionality for the complex geometry modelling. With an adaptive component, the main goal of the elimination of the overlap with “joint to joint” connection between sequential units was completely reached in case of the flat bending of the tunnel and partly done in case of the spacious one. One of the serious limitations is an inability to use nested families based on another templates.

Dynamo script was created and performs a few actions. First, the sequential placement of the units, based on the CAD link from the Civil 3D in accordance with the path and its zoning. Zoning information is provided by names of the layers in accordance with the types of the inner lining family. Secondly, the adjustment of the joints between the sequential units is proceeded, based on the angles between them. Depending on the orientation of the path in coordinates (ascending or descending of X and Y values from the beginning to the end) and the direction of the bending (clockwise or counterclockwise), a toggle might be used to set a correct sign to the adjusting angles at the joints: positive or negative. The final workflow of the lining creation is presented in the Appendix 1.

Two approaches of the excavation supports modeling were tested: using native Revit tools or with a parametric families. The main elements were the steel arch ribs with an I-section. The first option was to model ribs using a Beam and tools from the steel tab. Such approach was rejected since Revit does not allow to use steel connections functionality with non-linear objects.

As a result, the expanding steel frame constituted of double I-section ribs was modelled as an adaptive family constituted. The data for the final detailed table with arc lengths and angular dimensions of the connection points along the ribs was formed through formulas. To make it happen this way, a geometrical simplification was applied to the ribs.

Connections between double ribs could not be placed in the family as they must be located between adjacent nested families with different radial dimensions due to the expansion. For this reason, Dynamo script was developed to place them. Two values of the step were used as an input with ability to apply the script to a frame with any number of the ribs of any radial dimensions. As envisioned by the design, table with dimensions for the fabrication and the numeric data for the cost estimation of connections

must be done for each unique frame. For this reason, the workflow implies the placement of connections only per one unique unit.

The last study showed that Generative Design is applicable for finding an optimal solutions in the grouting works. It facilitates the process and once the optimal distance between the injection points is found can be easily modelled as direct shapes with the desirable material and the category for the visualization and cost estimation.

Even though Revit was not designed for infrastructural projects such as tunnel, with aid of the Dynamo and a set of smart families the process of modelling may be automated. At least, modelling of the main part. In addition, some engineering tasks (solution finding) can be eased by means of Generative Design.

REFERENCES

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LIST OF ACRONYMS AND ABBREVIATIONS

BIM	Building Information Modelling
LOD	Level of Detail /Level of Development
CAD	Computer-Aided Design/Drawing/Drafting
QTO	Quantity Take-Off
TBM	Tunnel boring machine

APPENDICES

APPENDIX 1: TUNNEL LINING MODELLING, WORKFLOW FOR THE VARIANT INVESTIGATION

