



Fakultät für Technische  
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# **Parametric Modelling Workflows for Tunnel Information Modelling**

Comparison of Autodesk Revit® and Bentley OpenTunnel Designer®

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# Kurzfassung

Die Einführung der Building Information Modelling (BIM) Methode hat die Tunnelbauindustrie vor viele Herausforderungen gestellt. Beginnend mit der Fragestellung: Welche BIM-Software eignet sich am besten für die Erstellung von Tunnelbauwerken? Im Rahmen der vorliegenden Masterarbeit werden daher verschiedene Softwaretools und deren Erweiterungen zur automatisierten Erstellung von Betonkonstruktionen der Tunnelstrukturmodelle getestet und verglichen.

Tunnelbauwerke zeichnen sich durch die Anordnung von wiederkehrenden Bauteilen entlang einer Trasse aus. Diese langwierige und sich wiederholende Modellierungsaufgabe erfordert eine Automatisierung durch parametrisches Design. Ziel dieses Beitrages ist es, eine Bewertung von derzeit verwendeten Softwarelösungen und Marktentwicklungen im D-A-CH-Raum vorzustellen, die in der Lage sind, parametrische Modellierung über Erweiterungen oder Programmierung zu implementieren.

Um die Softwarelösungen zu testen und zu bewerten, wird ein Beispielprojekt durch eine Bestandsdokumentation eines bereits gebauten Tunnels erstellt. Dazu werden zwei Standardquerschnitte entlang einer zwei Kilometer langen Strecke parametrisch generiert und den erstellten Tunnelblöcken eine Reihe an Eigenschaften zugewiesen. Der Prozess, angefangen von den Vorbereitungen bis hin zu detaillierten Schritten, wird ausführlich dokumentiert.

Als Ergebnis wird für jede Software ein Modellierleitfaden entwickelt, der die Vorteile und Herausforderungen des Modellierungsprozesses beinhaltet. Auf der Grundlage dieser Arbeitsabläufe werden die verschiedenen Ergebnisse des Strukturmodells in jeder Software bewertet, verglichen und dargestellt. Darüber hinaus wird die Replizierbarkeit der entwickelten Arbeitsabläufe für zukünftige Projekte diskutiert.

Aufgrund der vielen Variablen, die bei der Suche nach der besten Software für die jeweilige Aufgabe und das jeweilige Unternehmen eine Rolle spielen, kann eine konkrete Empfehlung für eine Software schlussendlich nicht gegeben werden. Die Ergebnisse und der generierte Überblick sind jedoch besonders hilfreich für Unternehmen, welche die BIM-Methode noch nicht in ihre Praxis übernommen haben, aber darüber nachdenken, die Methode in Zukunft einzuführen.





# Abstract

The implementation of the Building Information Modelling (BIM) method has presented the tunnelling industry with many challenges. One leading question being: which BIM software fits best to generate tunnel structures? Therefore, as part of a master's thesis, different authoring software and extensions are tested and evaluated to automate the generation of the concrete cross-section components of the tunnel structure models.

Tunnel structures are characterised by the arrangement of recurring components along an alignment. This lengthy and repetitive modelling task requires automation through parametric design. The aim of this paper is, to present an evaluation of currently used software solutions and market developments in the D-A-CH area that are able to implement parametric modelling via extensions or scripting.

To test and evaluate the software solutions, a self-study is conducted, including a simplified example project based on the as-built documentation of an already constructed tunnel. For this, two standard cross sections are generated along a two-kilometre stretch, and a set of properties are implemented in each software. The process, beginning with preparation and leading to the specific steps, is well documented.

As a result, a modelling workflow was developed for each software and based on these workflows, the different outcomes of the structure model in each software were evaluated, compared and presented. In addition, the replicability of the developed workflows for future projects is discussed.

Due to many variables playing a factor in finding the best software for each task and company, it can be stated that a specific recommendation for one software cannot be made. However, the findings and overview are especially helpful for companies that have not yet adopted the BIM method or any of its software solutions into their practises but are thinking about doing so in the future.



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# Abbreviations

BEP	Building Information Modelling Execution Plan
BIM	Building Information Modelling
CAD	Computer Aided Design
D-A-CH	Synonym for the countries of Germany, Austria and Switzerland
DAUB	German Committee for Underground Constructions
EIR	Employer's Information Requirements
FIT	FIDES Infrastructure Toolbox ®
IFC	Industry Foundation Classes
UIBK	University of Innsbruck
TIM	Tunnel Information Modelling



# 1 Introduction

Building Information Modelling (BIM) is a widely used design, management, and maintenance process that models, organizes, and manages information throughout the design, construction, and tendering processes. One of the main goals of this method is to ensure the consistent and continuous use of digital information throughout the entire lifecycle. This is expected to increase productivity through real-time data exchange and the ability to identify design errors or conflicts through model checks. The main challenge is to generate a model that is as simple as possible while still being functional and containing all the necessary information. BIM-capable software is used to create three-dimensional, object-based geometric elements enriched with information. These tools allow for the planning, designing, and construction of a digital representation of a tunnel structure, commonly referred to as a digital twin. The method is intended to establish an efficient digital workflow that provides, utilizes, and stores data with as little loss as possible. [1, 2]

While BIM has been popular in the building industry for many years, the infrastructure field is slowly implementing this method into its processes. Similarly, Tunnel Information Modelling (TIM) is becoming more significant in the tunnelling industry. Various national and international companies and researchers are currently developing solutions and guidelines to implement TIM in the tunnelling field. For example, the German Committee for Underground Constructions (DAUB) has initiated a work group specifically designed to work on possible use cases and modelling guidelines for the use of TIM. Additionally, a team of buildingSMART International is developing a standard data exchange format, IFC-Tunnel, which will cover requirements for tunnel construction in particular. [3–5]

In addition, both clients and contractors have recognized the potential of the BIM method and are currently developing and implementing strategies and standards within their companies. Within the D-A-CH region, which refers to Germany, Austria, and Switzerland, several major infrastructure players such as the German federal railway Deutsche Bahn AG, the Austrian federal railway ÖBB-Infrastruktur AG, the Austrian highway and expressway company ASFINAG, and the Swiss railway company SBB have strategies to fully implement BIM by 2025 or 2030. To achieve this goal, all companies are gaining experience through the execution of different pilot projects to further improve workflows, processes, and strategies within their organizations.[6–9]

## 1.1 BIM in tunnel projects

The BIM method has been adopted by the building industry for many years, and as a result, this industry has developed field-specific BIM standards and guidelines. However, these guidelines, which were specifically formed for above-ground structures, are only partially applicable to the infrastructure field. Nonetheless, general topics such as BIM dimensions, level of detail, and terminologies may be applied to TIM as well. Tunnelling differs in many ways from the building industry due to the uncertainties of ground conditions and the complex and curved geometry of the alignment, as well as the tunnel structure. Consequently, these differences present additional challenges during the modelling process. [10, 11]

Traditionally, tunnel design involves the creation of many different documents by various stakeholders. Reports, technical specifications, drawings, and bills of quantities are usually produced independently, and in conventional design, the contained information is usually not linked to each other. This lack of coherence leads to information loss at worst. Tunnelling faces the challenge of many dependencies, which makes linking data even more important. Therefore, consistent and transparent data exchange is key to completing a tunnel project in a timely manner.

Currently, because there is a lack of data linking and separate data integration by each stakeholder, changes that need to be implemented quickly may not be implemented in every single document produced. For this reason, one or more documents may be forgotten or not deemed necessary to revise at the point of change due to a lack of time. Furthermore, parties involved usually develop their own pool of information according to their needs. This information could be necessary or of value to other project members, but due to the lack of transparency, they might not even know this data exists. To illustrate the importance of data exchange, consider the comparison of a geologist and a geotechnical engineer. While both work in the field of ground conditions, they compile a different set of data to create their outputs. These two sets of properties go hand in hand with each other, due to both of them describing the same ground conditions and are further obviously related to each other. However, in the end, neither the geologist nor the geotechnical engineer will include the others' properties in their drawing or reports if it is not necessary. Therefore, if a third party gets involved and needs a combined set of properties, they would have to check both outputs and compare them against each other to make sure the information is coherent. However, if this additional party is only given one set of documents, they may not even know more data exists. If all of this data were stored within one database, one model, one object, or even one location and were automatically compared and evaluated against each other during its integration to verify its validity, it may not only be easier to access but also prevent the compilation of only fragments of information and misinterpretation of data. Overall, this would prevent incorrect decision-making as well as time losses due to limited access to or incomplete data. [12, 13]

Upon closer examination of the building industry's approach, almost every object is modelled with a high level of detail, and information is added as needed. Currently, the tunnelling industry is still determining the necessary level of detail, as well as the level of information. Since there are a lot of uncertainties in the design phase, field data, assumptions, and the previous experiences of involved experts form the basis of the design data. However, these assumptions may be wrong, and it is then essential to document and collect data during the tunnel drive to be able to compare and validate the data against each other once the tunnel is constructed. Especially for projects with little investigative data, the reality can differ significantly from the initial design. Therefore, on-site solutions and judgment calls are prevalent in tunnelling projects, and any changes, documentation, and decisions should be recorded in the models not only to be available during the operation and maintenance phases but also for similar future projects. [11, 14, 15]

## 1.2 Problem statement and aim

Even though Tunnel Information Modelling is still a developing field, many already believe that it will revolutionise the tunnel industry. Therefore, in the coming years, more and more infrastructure companies will have to implement TIM-capable software solutions into their practices. [12]

A series of interviews and a thorough literature review conducted in summer 2021 by a research team of the endowed chair on the shortcomings of BIM in infrastructure construction revealed, among other things, that current software products have not yet been extended to meet the needs of tunnel and infrastructure construction. [16]

Testing software solutions takes time and resources and is therefore very cost intensive. TIM is a rapidly developing field that confronts its line of business with several software choices as well as add on tools or “must have” packages. When researching possible software solutions, the literature provides its reader with a wide variety of tools, all promising to be leading in their industry. Hence, in the starting phase of implementing the TIM method, companies may be overwhelmed on their path of creating their personal workflows to apply the digital method.

Based on these findings and the lack of direct software comparisons, this thesis aims to test a number of these possible software solutions and extensions, especially those currently used by the tunnelling industry. It further emphasises the integration of changes based on properties, automation and replicability to generate a tunnel structure model with the help of parametric design. It will outline benefits, challenges, as well as differences of the used modelling tools and further document the tunnel modelling workflows as a step-by-step modelling guideline for each software.

Therefore, the overall output of this thesis is:

- Applied workflows for each software, useable as a step-by-step modelling guideline
- Overview, evaluation and comparison of the software and extensions used

### 1.3 Approach and method

The software and extensions were compared in a self-study through the implementation of an exemplary tunnel structure model. When imagining a tunnel structure model, possibly everyone envisions a different outcome based on their background, knowledge and experiences. Therefore, it is necessary to set an overall project baseline, which is to be realised in all software solutions. The baseline includes a rather detailed framework of what the resulting model should look like and furthermore, what the model should be capable of.

For this thesis, an already-built tunnel was chosen as an exemplary implementation project. Since tunnel projects and all their data are extensive and complex, the as-built tunnel documentation data was simplified to create a reasonable implementation framework. For this, two standard cross sections were selected, which will be placed as tunnel blocks with different lengths along the alignment. Furthermore, for a more structured comparison, the modelling process is broken down into several steps: alignment generation, automated object placement and arrangement along the alignment, attribute integration into these objects, and two-dimensional drawing derivation. These steps are supposed to be evaluated in terms of parameterisation, automation and replicability for future projects.

The following questions are supposed to be answered for each step:

1. *What are the benefits and advantages of the software or tool in this modelling step?*
2. *What are the challenges to be overcome in the software or tool in this modelling step?*

Ultimately, after implementing and documenting all modelling workflows in each software, the individual steps will be evaluated and compared, resulting in a summarised overview comparison table. This table may be used as a data sheet that gives a quick overview of the capabilities and limitations of each software used.

### 1.4 Limitation

Even though there are many benefits of comparing the software and extensions based on a self-study, there are limitations as well. Bias can be an issue, since personal preference and detailed experience influences objective assessment. Furthermore, the varying level of expertise influences the ease and range of use. However, despite these limitations, a self-study provides valuable insights into the range, flexibility and capability of the software and extensions. The comparison can assist in making comparisons to software solutions outside this framework and therefore helps in making informed decisions. It provides an insight into the level of expertise needed to be able to utilise each software and points out challenges that had to be overcome during their use. This can help readers achieve a better understanding of the software capabilities and potential limitations they may encounter. Overall, it will give an overview of the shortcomings as well as benefits of every software and tool used.



## 2 Tunnel Information Modelling

### 2.1 Digital Twin and TIM

*“Digital Twin is a virtual model of a physical asset capable of fully mirroring its characteristic and functionalities during its entire lifecycle. It is an approach to manage all generated digital data of a component or system along its lifecycle and retrieve them as needed by simulation or optimisation functions to address any occurring challenges.” [17]*

The term digital twin was initially coined by Michael Grieves in 2010 to represent a product lifecycle management tool. Since then, the term has been used by many industries and fields, each following a different approach to use a digital twin to their advantage. Hereby, Grieves’ rather static use of the digital twin as a lifecycle management tool has in most cases evolved into a digital platform that includes real-time data integration through sensors as well as real-time changes. The main goal is to not only collect data, but instead envisage a feed-back and feed-forward loop between the virtual and physical products. A digital twin can be used to visualise, communicate and inform stakeholders such as contractors, regulators and the general public which helps generate an overall better understanding of the projects. [18–20]

TIM is a method used to help design, construct and manage a tunnel project over its entire life cycle. Therefore, TIM is used to create a digital twin, which will be further utilised to visualise, analyse and collect data from various components of tunnel projects and helps to identify time schedules, cost estimates, potential risks and challenges. It includes physical and functional characteristics such as dimensions, quantities, materials, location, sensor data, or any other information that is to be implemented into the various components modelled within the project as a single source of truth and makes the information available at any time and stage of the project. All this information assists project teams to coordinate and optimise various aspects of the project, including logistics and its potential issues. [11, 21]

#### 2.1.1 Model structure

A digital twin of a tunnel project, is broken down into several smaller sub-models. Project goals, size, number of stakeholders, number of companies, people involved and many more factors will influence the number of models created which, together, form the digital twin. While the field in general lacks official standards and codes in terms of Tunnel Information Modelling, the German Tunnelling Committee has published several guidelines, including a possible model

structure to follow. Based on these guidelines, each project will implement and adapt the structures to fit its needs and goals. [5, 22]

The endowed chair “Tunnel Information Modelling” at the University of Innsbruck has the ambition to create an integral digital twin for the field of tunnel construction. To achieve the set goal, three partial models were defined for tunnel projects: the subsoil model, the structure model and the construction site model. These models may be further divided and broken down into the smallest relevant component of each project, as seen in Figure 2-1. [4]

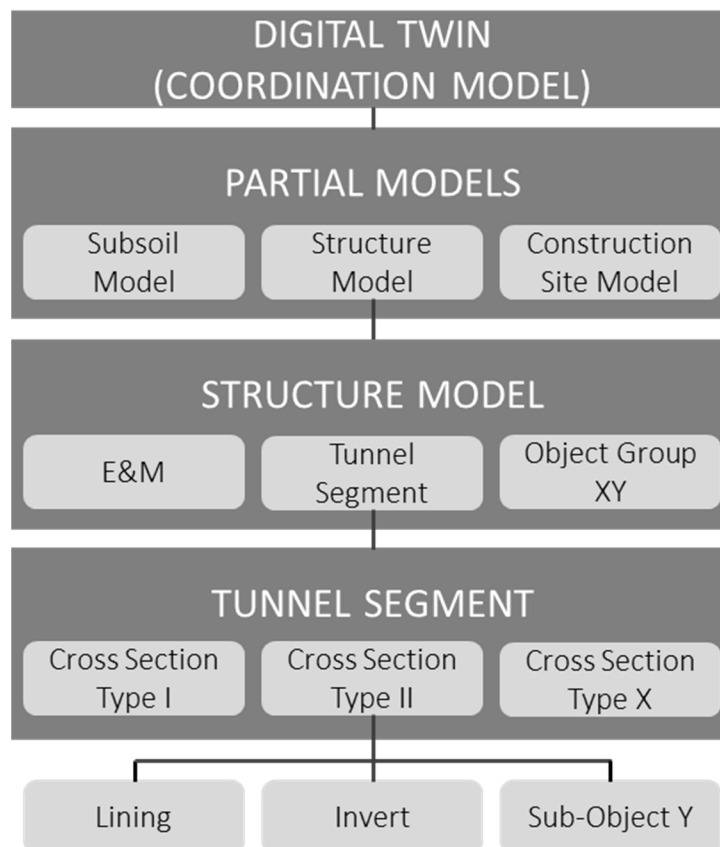


Figure 2-1: Model structure, based on DAUB and TIM models of the UIBK [4, 22]

### 2.1.2 The Structure Model

This thesis has set its focus on the exemplary implementation of the structure model. Currently, as mentioned before, there are no standards or codes that specifically define elements that have to be included in a tunnel structure model. However, there are several modelling approaches: some include a low level of geometry and a high level of information; others generate a high-detailed structure model including a high level of geometry and a high level of information. The chosen modelling approach should always be in direct correlation to the intended use of the model. For example, if it is not intended to derive drawings from the model, the detailed modelling of the structure may be a waste of time and resources while information integration

may be essential. In contrast, in the design phase, all necessary design attributes should be integrated and the geometry needs to be defined. In the construction phase, the design attributes need to be extended, revised, or updated and the model may be further used as a digital construction log. For this, sensors may also add another level of depth to the level of information and may be additionally integrated into the model. [5, 22, 23]

Even though details might differ from model to model and project to project, the general modelling process for each infrastructure and tunnel project stays the same: objects will always be arranged along an alignment. For this reason, the automated arrangement of objects along an alignment plays a big part in the modelling process of infrastructure and tunnel models. Consistently arranging blocks and objects is only a small part of the workflow. The variability of blocks and objects themselves, as well as the automated generation of a specific order of blocks, is one of the challenges within tunnel information modelling. [24]

## 2.2 Parametric Modelling

Parametric modelling, or parametric design, is a process in which constraints as well as variable parameters are defined for each object within a model. It eliminates the need for redrawing or manual adaptations due to the linkage and relationships of object components to design dimensions. Most design software include a wide variety of pre-programmed tools for parametric design, for example, an alignment tool. Further, visual scripting interfaces are often integrated into software packages, as they enable modellers with little to no coding experience to choose from a wide range of already predefined nodes to create their own scripts. A node is an already existing script that uses input attributes to automatically run its code and create the desired output. One of the simplest nodes is a point node, which demands an input for its coordinates X, Y and Z to place the point at its desired location. The output created by this node may be used for the next node, for example, to generate a line. Two point outputs are used as input for a line node to create the line output and so on and so forth. [25–27]

In Figure 2-2, an example of an automated arrangement of chairs is shown. Hereby, points are arranged at a certain distance up to a certain length and at each point generated, a chair is placed. The first two nodes, known as number sliders, provide the user with the flexibility to change the distance value as well as the length value, which further instantly arranges the chairs to the new input. For this, a function may be integrated as well; for example, it would be possible to feed an area to the programme and have it calculate the possible number of chairs that fit in this area.

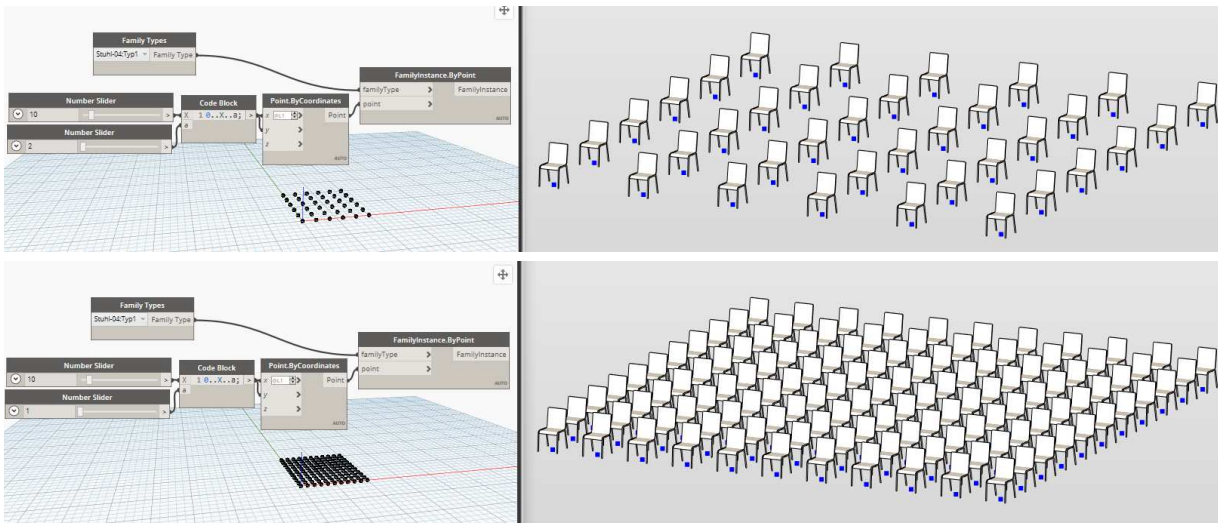


Figure 2-2: Example of basic parametric modelling

Obviously, the above shown example gives solely a small insight into the world of parametric modelling, it does not even come close to its full potential. Logical functions, algorithms and relationships between single attributes and / or objects which are either already integrated into the software or self-developed through coding make it easier and more automated to implement design changes or repetitive tasks. It allows for flexible and adaptive modelling and is supposed to save time during the design and therefore modelling stage of the project.

### 2.3 Parameter, Property, Attribute

According to the standard EN ISO 23386, a property defines the characteristics of an element and an attribute specifies one single detail of a property of an element. Therefore, each element in the model can have multiple properties and each property may have one or more attributes that can be used to describe physical and functional characteristics (see Figure 2-3). Properties and their attributes provide the basis for 4D, 5D and further dimension design and is thought to promote collaborative information exchange between stakeholders as a single source of truth. The number of properties and attributes varies based on the amount of data that is to be integrated. [22, 28, 29]

A parameter as defined by the oxford dictionary as

*“something that decides or limits the way in which something can be done.”*

[30]

Therefore, an attribute becomes a parameter as soon as it is used as a link between elements. For example, geometrical definitions, like dimensions, when integrated as parametric values are always considered a parameter, while the definition of the material is usually static and hereby considered an attribute. [31]

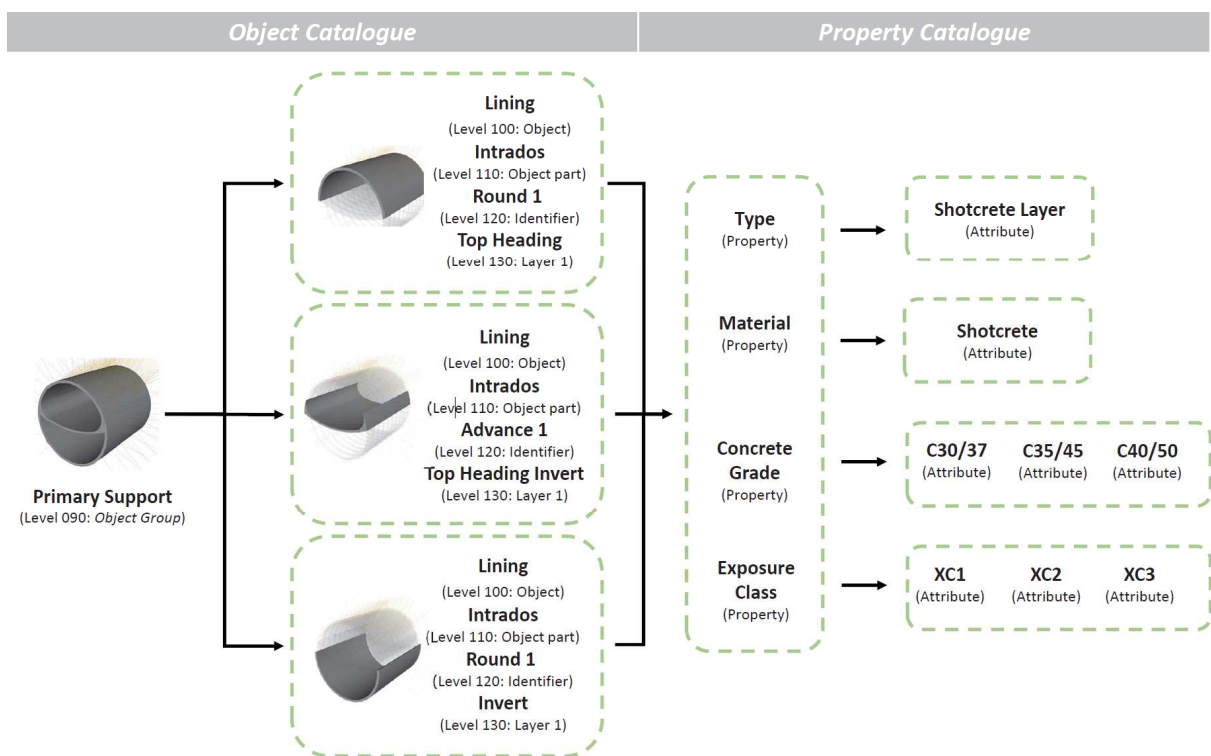


Figure 2-3: Example of property setup for elements of a tunnel structure by DAUB [22]

### 2.3.1 Industry Foundation Classes

The need for an overarching data exchange format was recognised as early as 1980. Back then, the idea of product modelling emerged, which is supposed to encompass both the geometry and semantics of a component as a comprehensive digital description. For this, a uniform interface between CAD systems is developed, which should allow an information exchange of geometric and semantic data without any data loss. While initially geometric data was solely being exported, Industry Foundation Classes (IFC) supports the exchange of information as attributes as well. [32]

IFC bases its data exchange on standardised property sets that are to be implemented by all users of the industry. Therefore, each IFC export-compatible software has to implement these IFC properties to further be able to export information as an overall data exchange. However, since a standard data set for tunnel modelling was not available when infrastructure modelling was taking its first steps, companies and projects have created their own attributes independent from the industry. Obviously, this works for individual projects, but it does not contribute to an overall information exchange. IFC-Tunnel, a project of buildingSMART, is supposed to provide a solution for the current lack of standardisation. [33, 34]

*“The ultimate goal of the project is to create and provide the engineering and construction industry with an open BIM data exchange standard capable to exchange & archive tunnel models in a neutral ISO format that is vendor-independent and persistent for the long run.” [33]*

These goals for the incorporation of tunnelling entities set by buildingSMART International are expected to be fully available with the release of IFC 4.4, while the overall infrastructure developments are included in IFC 4.3, as seen in Figure 2-4. [35]

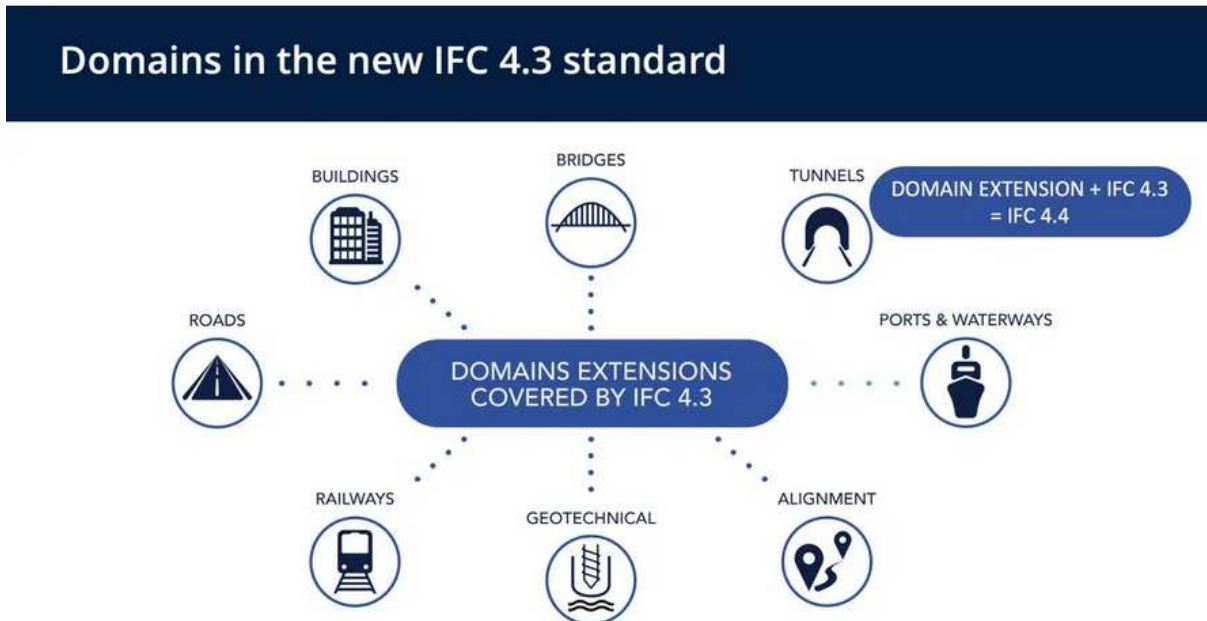


Figure 2-4: Infrastructure developments by buildingSMART International [35]

## 3 Software

While many software solutions are often referred to as BIM or TIM software, it is not strictly defined what such software must be capable of. This thesis considers a software to be capable of TIM if it can represent both the physical and intrinsic properties of a structure as an object-oriented model. Further, it especially focuses on software programmes that use parametric design as foundation of their modelling approach.

Cheng et al. (2016) have evaluated 171 industry cases and 62 academic papers on civil information modelling. In this research, a general overview of software used in the infrastructure field is given and the big market shares of Autodesk and Bentley Systems was mentioned. Due to rapid software and TIM development, a study conducted in 2016 may not represent the current state as of today. However, the mentioned authoring software, Autodesk Revit®, is still predominantly used in many case studies in the D-A-CH area, while Bentley Systems just released the first tunnel-specific software in 2022, the OpenTunnel Designer®. This indicates that these software families are still big players in the infrastructure field. Nevertheless, one has to keep in mind that Revit® was developed for the building industry and therefore needs some additional tools and extensions to be applicable for infrastructure modelling as well. [36–40]

Based on these findings, the newly introduced OpenTunnel Designer® by Bentley Systems and Revit® as authoring software with several extensions were chosen to be compared.

### 3.1 Autodesk Revit®

Autodesk Revit® is a well-known and widely used BIM software by architects and engineers to design, construct, analyse and manage models in the building industry. Hence, it may be surprising to find the application of Revit® for tunnel engineering. Civil3D®, which is Autodesk's infrastructure design software, was developed for linear structure and alignment design, would have been the more obvious choice as a tunnel software. Even though it is a three-dimensional modelling software, it mainly thrives on its derivation of two-dimensional drawings. Furthermore, the software often reaches its performance limits; for example, minor view changes requires several minutes to load, even when using high performance laptops and computers. Based on this, the software does not appeal to the TIM community as much and has not found its footing as the prominent TIM software within the industry. As a result, even though Revit® was specifically designed for above-ground structures, the software was one of the most used BIM tools in underground infrastructure modelling in 2017, according to an international review. [41, 42]

As mentioned before, due to its basis in the building industry, Revit® lacks tools specifically designed for the infrastructure field. Therefore, extensions like FIDES DV-Partner Infrastructure Toolbox “FIT®” or SOFiSTiK Bridge + Infrastructure Modeller® were developed to incorporate and generate tools for the infrastructure field. Another way to develop your own tools for infrastructure modelling tasks is to programme them yourself using Dynamo®, Revit®’s visual programming tool.

### **3.1.1 Dynamo®**

The visual programming tool Dynamo® allows modellers to further extend the functionality of Revit®. It runs as a plug-in within the Revit® environment and therefore allows modellers to customise workflows through a node-based interface. It is used to automate modelling or information integration tasks as well as to perform analyses. It may be used to calculate or even manipulate data within Revit®, which might not be accessible within the Revit® interface. Further, custom tools and add-ons may be developed with Dynamo® by programmers or developers.

### **3.1.2 FIDES Infrastructure Toolbox “FIT®”**

The FIT® tool, created by FIDES DV-Partner is a Revit® extension, which was especially created to design infrastructure projects. It includes functions to integrate the geology as well as create linear structures like roads, bridges, retaining walls and tunnels through the definition of an alignment. The alignment tool provides the possibility of placing the project at its true location and including chainage-based information. It further includes tools to flatten the tunnel into a straight line, which may be used to derive a true-length longitudinal section.

### **3.1.3 SOFiSTiK Bridge + Infrastructure Modeller®**

The Bridge and Infrastructure Modeller was specifically developed for bridge modelling, however, its alignment integration and variable arrangement of families along this alignment also make it a viable tool for tunnel design. With the help of parameterisation, variants and changes may be quickly integrated. Drawings may be directly derived using the longitudinal section or create sections function.

## **3.2 Bentley OpenTunnel Designer®**

Bentley Systems, a software development company based in America, provides software solutions for design, construction, operation and maintenance especially in the field of infrastructure projects. OpenTunnel Designer® is one of the newer developments by Bentley Systems and according to them, the first and only purpose-built software for tunnel modelling and design. Their incorporated tools are designed to increase productivity for automated modelling without the use of coding or scripting. Their direct exchange with other Bentley software programmes like Leapfrog®, PLAXIS®, OpenRoads®, OpenRail®, OpenBridge®



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and ProStructures® shall prevent errors, rework and delays and gather all information in a common data environment as a single source of truth. [40]

Even though OpenTunnel Designer® Release 1 was launched in 2022, it is not the first time Bentley Systems has been used for tunnel design. Different workflows may be found using a combination of OpenRail®, OpenRoads® and PLAXIS®, which have all been used in terms of tunnel design and calculation before.



## 4 Exemplary project

Based on the lack of case studies to compare, especially given that OpenTunnel Designer® was just introduced, the comparison will be done in a self-study. For this study and to objectively evaluate the chosen software in terms of general functions, parametric design and automated arrangement of objects along an alignment, a specific goal needs to be set. To form this framework, available data from one of the pilot projects at the University of Innsbruck was used as a reference. The aim is to design a workflow for each software that is not only capable of implementing the constructed framework but is flexible enough to be used for a variety of design and modelling tasks.

The data of the pilot project was hereby drastically reduced to ensure that it consists of a two-kilometre stretch and of two standard cross sections of the pilot project, which will be arranged along the alignment. The focus is on the overall parametric arrangement process, which should be applicable to further placing objects like niches, cross passages and other components.

The specific documents used for this thesis are:

- survey of the alignment
- two standard cross sections
- documentation of block separation (as list)

### 4.1 Alignment Data

The alignment was provided in several formats including landXML as well as a set of surveyed coordinates in the form of an Excel sheet. The first worksheet of the file, named alignment, comprises the coordinates of the alignment, the tunnel-meter and the overall kilometre chainage of the project location, as seen in Figure 4-1.

X (E/W)	Y (N/S)	Z (Elevation)	TM [m]	Stations
18093,2	224178,9	777,6	0,0	02+007,50
18092,2	224178,5	777,6	1,0	02+008,50
18091,3	224178,1	777,6	2,0	02+009,50
18090,4	224177,7	777,6	3,0	02+010,50
18089,5	224177,3	777,6	4,0	02+011,50
18088,6	224176,9	777,6	5,0	02+012,50
18087,7	224176,4	777,6	6,0	02+013,50
18086,8	224176,0	777,6	7,0	02+014,50
18085,9	224175,6	777,6	8,0	02+015,50
18085,0	224175,2	777,6	9,0	02+016,50

Figure 4-1: Excerpt of the alignment worksheet

The second and third worksheet, named 6700 and 6702, include information about the constructed block length of the two cross sections along the alignment. Hereby, the starting chainage of the block is included as well as a block name, the length of the block and the tunnelmeter at which the block starts. Each worksheet represents one cross section as seen in Figure 4-2.

Station	Block Name	Block Length [m]	Tunnelmeter [m]	Station	Block Name	Block Length [m]	Tunnelmeter [m]
02+007,50	012	12,50	0,00	03+035,75	096	12,50	1028,25
02+020,00	013	12,50	12,50	03+048,25	097	12,50	1040,75
02+032,50	014	12,50	25,00	03+060,75	098	12,50	1053,25
02+045,00	015	12,50	37,50	03+073,25	099	12,50	1065,75
02+057,50	016	4,25	50,00	03+085,75	100	12,50	1078,25
02+061,75	017	12,50	54,25	03+098,25	101	12,50	1090,75
02+074,25	018	12,50	66,75	03+110,75	102	12,50	1103,25
02+086,75	019	12,50	79,25	03+123,25	103	12,50	1115,75
02+099,25	020	12,50	91,75	03+135,75	104	12,50	1128,25
02+111,75	021	12,50	104,25	03+148,25	105	12,50	1140,75

Figure 4-2: Excerpt of the 6700 and 6702 worksheets

## 4.2 Cross Sections

The project originally consisted of a total of five cross sections. Three of which are standard cross sections that solely differ in the thickness of the inner lining, the amount of support elements which will be installed, as well as the construction of an invert and two regular cross sections for lay-bys. Out of these five, two standard sections were chosen to be implemented with the different software. These two cross sections can be seen in Figure 4-3 and Figure 4-4. Cross sections in general represent an element that can be defined using parametric design. To parameterise the cross section, in-depth knowledge is necessary to actually setup the dependencies between the single components. Whilst parametric design might be a valuable tool capable of helping, assisting and automating design challenges, it should be carefully evaluated as to what needs to be parameterised and what might actually be a static component. For example, a curb stone or a slot channel come in standard sizes, chosen from a catalogue and each parameter needs to be maintained and checked. More parameters might give more flexibility but they might also be a bigger source of errors.

For this thesis, the cross sections were not parameterised. The aspect was set on the longitudinal variability and implementation flexibility.



### 4.3 Block documentation

A tunnel block in this thesis is defined as one casting section in which the concrete is poured. In the project at hand, a standard block has a length of 12.5 meters, but this standard size cannot be constructed along the entire alignment, since cross passages, niches, or other elements also need to be placed along the alignment. Therefore, a drawing and a block separation list are generated, which are further used as the basis for time schedules, calculations and process logistics. The block documentation of the pilot project was used and implemented in the exemplary project. This way, the automated arrangement of blocks along the alignment, including varying lengths, may be tested.

Further, a list of attributes based on geological documentation was used to generate a set of properties to be included in the project. This is only an exemplary property implementation; in general, as many attributes as needed may be defined according to the project's needs and goals. For this project, all integrated attributes such as chainages, round of length, geological documentation number, number of rounds, advance class, etc. are presented in Figure 4-5.

Date	Time	Tunnelmeter from East	Round of Length	Geo Docu No.	No. of round	Docu in %	Docu from	Saved Server [A]	Saved [ÖBA]	Section	Advance class	Station	Section I	Rock Type I	I %	Section II	Rock Type II	II %	Rock behaviour
27.05.2016		9,40		1	1	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	9,40	A	GA-F01	90	B	GA-L06	10	3
27.05.2016		10,70	1,30	2	2	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	10,70	A	GA-F01	80	B	GA-L06	20	3
28.05.2016		12,00	1,30	3	3	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	12,00	A	GA-F01	50	B	GA-L06	50	3/11
28.05.2016		13,30	1,30	4	4	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	13,30	A	GA-F01	40	B	GA-L06	60	3/11
28.05.2016		14,60	1,30	5	5	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	14,60	A	GA-F01	40	B	GA-L06	60	3/11
29.05.2016		15,90	1,30	6	6	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	15,90	A	GA-L06	75	B	GA-F01	25	3/11
29.05.2016		17,20	1,30	7	7	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	17,20	A	GA-L06	60	B	GA-F01	40	3/11
30.05.2016		18,50	1,30	8	8	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	18,50	A	GA-L06	40	B	GA-F01	60	3/11
30.05.2016		19,80	1,30	9	9	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	19,80	A	GA-F01	60	B	GA-L06	40	3 (bzw. 3/11)
31.05.2016		21,10	1,30	10	10	100	IL	ja	ja	no docu	KF-6; (bis 1, 30)	21,10							3 (bzw. 3/11)
31.05.2016		22,40	1,30	11	11	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	22,40	A	GA-F01	70	B	GA-L06	30	3
01.06.2016		23,70	1,30	12	12	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	23,70	A	GA-F01	90	B	GA-L06	10	3
01.06.2016		25,00	1,30	13	13	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	25,00	A	GA-F01	100				3

Figure 4-5: Excerpt of project attribute, which are to be implemented into the model

The documentation is defined by the round of excavation lengths, which are between 1,30 and 2,20 meters, since the tunnel face is documented by the geologist after almost every blast cycle. Therefore, data of roughly 5-9 documentation cycles would have to be included in one tunnel block. For this, data may either be averaged over a tunnel block and implemented into the tunnel block, or an encasing element, like an excavation volume in the size of the round of length, is integrated carrying these attributes as a single source of information. The latter approach has been followed by a team of researchers at the University of Innsbruck in terms of possible sensor data integration into a so-called process model. [43]

Since the attribute for the exemplary projects stays mostly consistent over a tunnel block, the data will be integrated as an aggregated value. This data is further attached to the inner lining of the project as the most obvious stand-alone component of the cross section that may be easily selected in any model view. The properties could also be linked to all elements of one tunnel block, which is not recommended due to duplicate data being a large source of inconsistent data as well as increase of the file size.

# 5 Modelling Process

The following chapter describes and summarises the development of the different workflows for each software. While the step-by-step modelling approaches, which can be found in the appendix in chapter 9, may be used as follow-along guides to create similar projects, this section points out the different choices and paths that may be taken during the modelling process of the self-study. Furthermore, these paths are evaluated with respect to their functionality and automation, including a focus on the benefits and challenges of the integrated tunnel-specific tools. It is important to keep in mind that, depending on in-depth knowledge of each software, even more modelling approaches may be attained. Years of experience are needed to create, optimise and perfect workflows. Therefore, the limitation of this thesis and every project will always be the experience and knowledge of the users generating the models.

## 5.1 Autodesk Revit ®

### 5.1.1 General Setup

As mentioned in previous chapters, Autodesk Revit® was initially developed for the building industry. Therefore, the whole interface, including all ribbons and tools, focuses on elements of buildings or above-ground structures. Every volume, object and element created in Revit® is called a family. These families are already pre-classified and additional categories cannot be created, nor can existing ones be deleted or renamed. An example for these categories may be an annotation, door, wall, floor, beam, etc. Based on this, the only applicable existing category used for tunnel components will currently be the generic family. More on the families and their setup will be found in chapter 5.1.1.2.

Another limitation of Revit® is its internal modelling boundary, which is set to a diameter of 32 kilometres. All objects of a model must be placed within this constraint. Unfortunately, even though 32 kilometres should be enough length for most tunnel projects, the further away an object is placed from the base points, the worse its illustrated geometry gets. Therefore, it is recommended to keep models as compact as possible and to split the project into several segment models, which will be coordinated in a model coordination software. Due to the boundary, the coordinate integration logic is different, as known, for example, in GIS software products, which will be discussed in more detail in the following chapter.

### 5.1.1.1 Coordinates

The Revit® template includes two project coordination points and setting these points at the right location is crucial for accurate illustration of the geometry and real-world project location. The Survey Base Point identifies the real-world location, while the Project Base Point defines the origin of the internal project coordinate system and the origin of the modelling boundary. To model in the centre of this boundary, the location of the Project Base Point should always be set close to the modelled elements. Moreover, all elements are placed in reference to the Project Base Point and its project coordinate system.

In tunnelling, survey data plays an important role in the orientation and coordination of projects. Since all elements are placed in relative distance to the Project Base Point, placement points have to be transformed. If both points are moved to one Project Coordination Point, the northing and easting values of the Survey Base Point, which will reflect the world coordinates, can be subtracted from the integrated real-coordinates to become project coordinates. This transformation may be done prior to the import of survey data or based on functions during the import included in the extensions.

The base points are often hidden in views and not integrated as objects in exported files. For this, a Project Coordination Marker is created to make project coordination simpler. This way, the correct placement of models can be immediately confirmed when coordinated and viewed together.

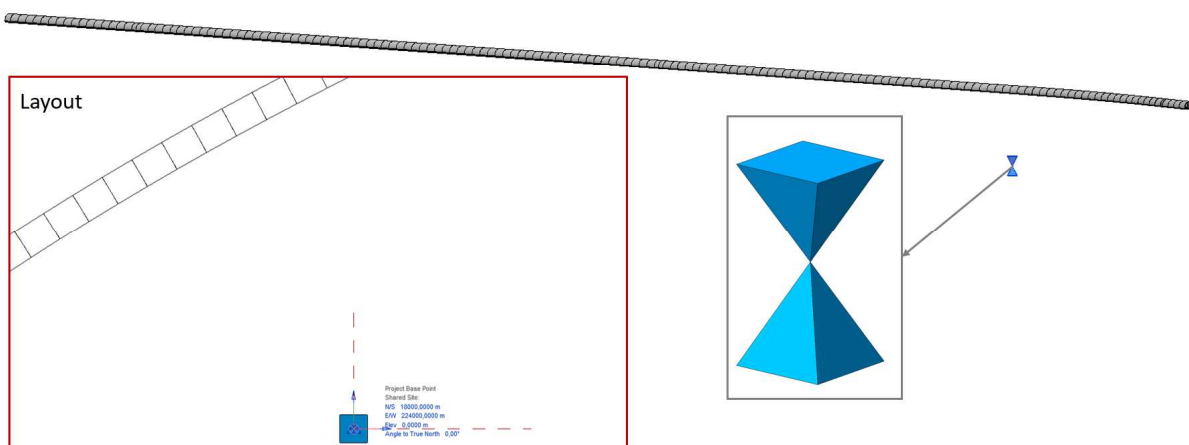


Figure 5-1: Project Coordination Marker in layout and three-dimensional view

### 5.1.1.2 Families

A Revit® family is a group of elements with common properties, divided into properties. The individual elements of a family can have different values for some or all of the properties, but the composition of the parameter group (i.e., name and meaning) remains the same. These variants within the family are called family types, or simply types.

For example, a window in the building industry will always have the same functions, but they differ in terms of size, material and other minor changes. Geometry-wise there are only basic



changes like size, the way of opening and the depth of the window in between the walls. These geometric changes are all implemented with parameters. On top of these parameters, there are attributes, which do not change the families in size but may change important inputs like material, energy efficiency, etc. For the building industry, a wide catalog of families already exists and is extended every year, including different wall types, stairs, windows, doors, furniture, flooring amongst others. Since Revit® is not yet commonly used for tunnel design, the catalog for infrastructure families is very little to none. This implies that for the infrastructure field, families have to be specifically designed and developed.

### 5.1.1.3 Project Specific Families

While there should eventually be a wide range of general infrastructure families, such as standard niche blocks, ventilation units, signs and other standard components that will be transferred from project to project, there will always be a certain amount of project-specific families, like the cross-section type and sizes, that will need to be implemented. For this project, two standard cross sections from the original design were modelled as tunnel blocks. Due to their setup as a generic family with adaptive points and voids at both ends, they can be flexibly placed in the project. The two placement points are the main reference for the location and they define the start and the end of each tunnel block. The voids can be rotated in the xy-plane as well as the xz-plane to fit the alignment gradient horizontally as well as vertically, as can be seen in Figure 5-2.

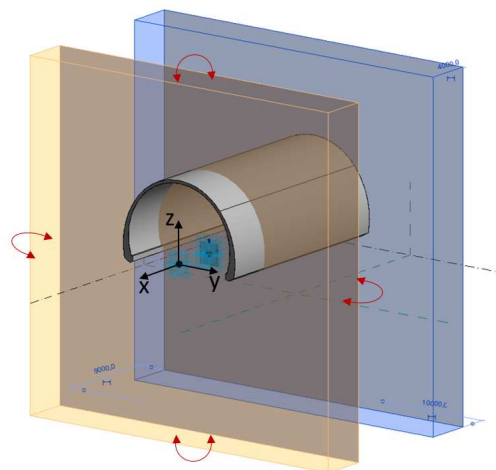


Figure 5-2: Adaptive family setup

A family setup may be project-specific depending on further use. Every component of the cross sections can either be modelled as individual family or, if the properties are the same, several elements can be combined into one family. However, if the properties differ, a family within family composition is possible as well, but due to performance degradation, it is not recommended. For the project at hand, components were modelled individually to ensure flexible use.

Each individual family may include a set of properties. The number of included attributes and parameters is again project-specific. At this point, it should be said that the inclusion and

generation of parameters make modelling more flexible but can also create a lot of work in terms of maintenance and parameter handling. Overall, there should be a specific idea of which properties want to be included and what will be modelled as a static component.

Once the general setup is concluded, the integration of an alignment and arrangement of the families is started in each extension.

### 5.1.2 Dynamo®

*“Dynamo® is, quite literally, what you make it.” [44]*

This is the answer to the question “What is Dynamo®?” given by Matt Jezyk and the Dynamo® development team at Autodesk via the Dynamo Primer. Dynamo® is the first extension used for this thesis and can be run either as stand-alone software or as a plug-in for Revit® and other software. Within Revit®, Dynamo® is split into the programming interface and the Dynamo Player.

If the Dynamo® interface is started within Revit®, a new window appears in which scripts can be generated or edited. This is done either by visual scripting through linking of nodes, as seen in Figure 5-3, or through direct coding. To get started and be able to generate scripts, a general knowledge of the possible workflows and capabilities of Dynamo® and Revit® are needed, as well as a basic coding knowledge is necessary. A very useful introduction and a structured guide into Dynamo®, and visual programming in general, may be found on the Dynamo Primer, an online site setup run by Autodesk. [44]

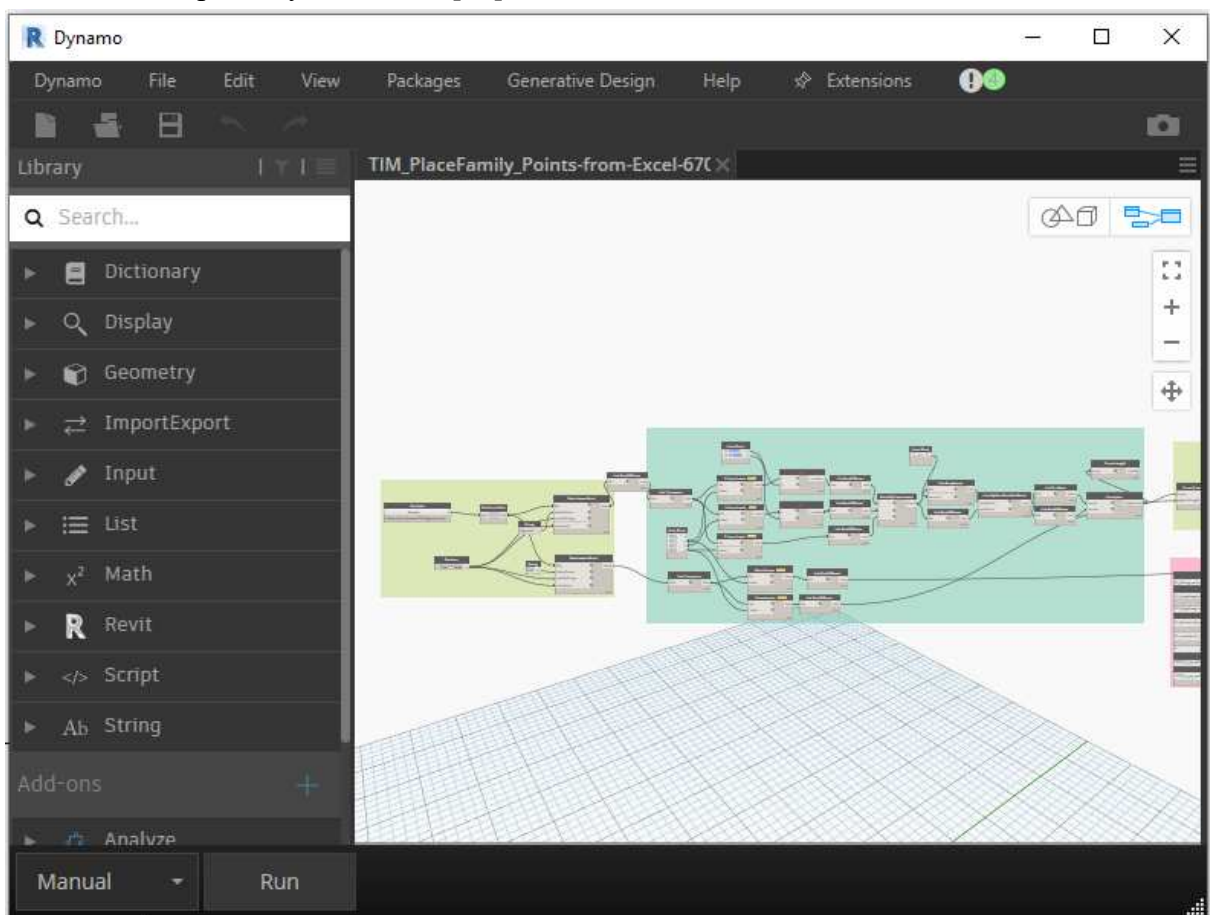


Figure 5-3: Dynamo® interface with script

The Dynamo® Player, in contrast to the Dynamo® interface, is solely used to run finished or pre-existing scripts. Figure 5-4 illustrates an example. Hereby, inputs that are defined within the script need to be added manually before initiating the script’s run. Through the Dynamo®

Player, users who are not familiar with coding and scripting are able to run scripted tasks by simple mask inputs without having to be confronted with the code or nodes themselves.

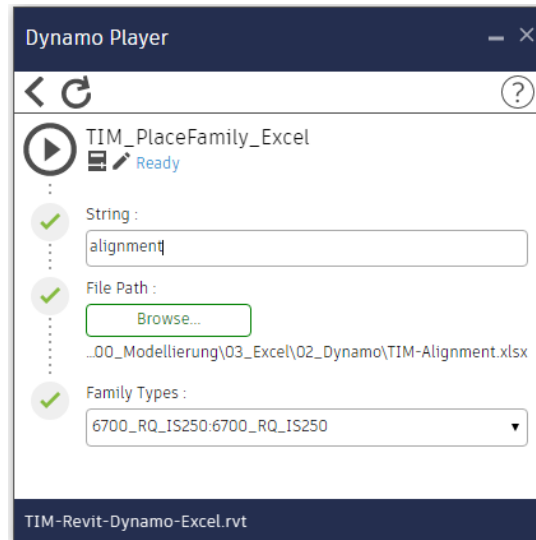


Figure 5-4: Dynamo Player

### 5.1.2.1 Alignment

With the help of Dynamo®, many different approaches can be taken to incorporate an alignment. For this thesis, the alignment was implemented through a list of coordinates based on which a set of points are created that can then be linked by a model curve. The coordinates are specified within an excel file. However, the setup for this Excel file does not have to follow a specific structure, wherefore it can be project and company specific. Obviously, every time the structure of the Excel sheet is changed, the corresponding Dynamo® script needs to be adapted as well. Hence, it is useful to set up a certain template once with the flexibility of extending the template to meet project-specific tasks. The path to creating an operative script may take time, but once it is setup, it will reduce workloads and time immensely for future projects as only minor changes will be required.

For this thesis, a script was designed that will not only integrate the alignment but also place the families created for the cross sections at the same time. The full script, including all nodes and steps, is explained in the appendix. As mentioned, to integrate coordinates, the coordinates need to be transformed in reference to the project base point. For this project the transformation was integrated into the script, but it could be done manually in Excel.

Another very important part of an alignment are chainages or tunnel-meter references. To include chainages or tunnel meters with Dynamo®, an annotation family, a tag, or some other object should be designed. This can be implemented into the project via a script. This chainage family is a one-time development and can be placed during the alignment integration. For this thesis, this step was not implemented into the workflow, but it is noted that it needs to be implemented when dealing with a real-time project.

### 5.1.2.2 Family setup and placement

As explained in Chapter 5.1.1.3 Project Specific Families were modelled as individual families and are already included in the Revit® document. Dynamo® always has a direct link to the project in which the interface was opened and all families included in this project may be selected in Dynamo® via specific nodes. Since the families are setup with two adaptive points, the script is setup to feed a start point and an end point to the family and therefore place the families along the alignment. Once the run is successfully completed, all tunnel blocks should be placed within the project and the project may be saved. The script is explained in detail in Appendix 1.

### 5.1.2.3 Attributes integration

Dynamo® is not limited to modelling. It has a variety of functions to create, implement and manage data. Therefore, it can be used to manage properties within Revit ®. For this master thesis, due to the use of a non-parametric cross section, only the tunnel block length and the rotation of the voids were integrated as parameters. The values of the properties were already set during the modelling process since these parameters are derived from the tunnel block separation as well as the slope of the alignment. Consequently, as a next step only attributes have to be created and integrated. For this, a second script was developed that, based on a pre-specified list of properties, generates and sets the attributes in the already-placed families. The list needs to be setup with the attribute names as well as the attribute types, for example: text, integer, number, material, and so on. Once the script is used and attributes are generated, they may be filled with the next Dynamo® script.

This is one of many ways to create properties. Looking at the entire modelling process, they could be created as early as generating the family. Further, the script that places the families along the alignment could then already include the step to fill all properties right away while placing the families.

### 5.1.2.4 Derivation of two-dimensional drawing

Revit® itself is not capable of creating sloped, bent, or any curved sections. Dynamo® is also not able to do so, however, several sections may be automatically arranged to fit along the alignment, as illustrated in Figure 5-5.

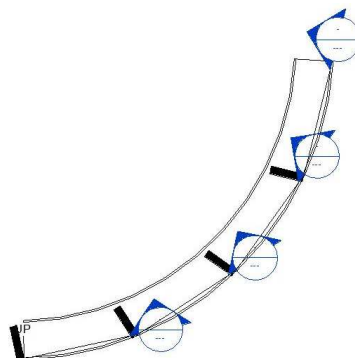


Figure 5-5: Sections along a curve [45]

Moreover, sections and view filters may be generated and managed through Dynamo®. As long as the slope of the tunnel is consistent, a sub-horizontal section can be easily created through a standard section view in Revit®. Otherwise, the same logic of arranging several sections would have to be followed.

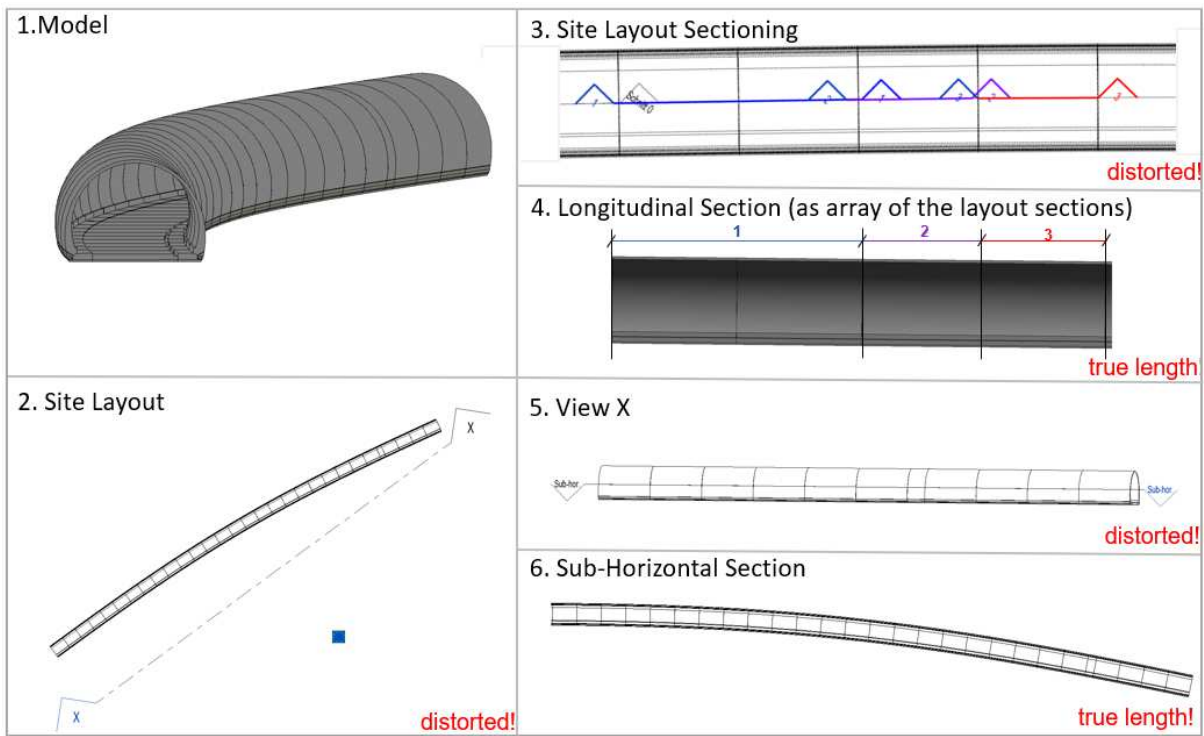


Figure 5-6: Steps to derive two-dimensional drawings

### 5.1.3 FIDES Infrastructure Toolbox “FIT” ®

Right after the download and installation of the FIT ® tool from the FIDES DV-Partner website, a folder with plenty of sample files is generated. These files include a sample project with family templates, Excel file templates and video material to give a short overview and introduction of the capabilities of the FIT ® tool. It provides a good basis for an efficient start into modelling tunnels with FIDES® and Revit ®. Further, a new tab is created named "FIDES" which includes all tools provided (see Figure 5-7). The tools are in general designed for infrastructure projects, with some specific tools for tunnel design.

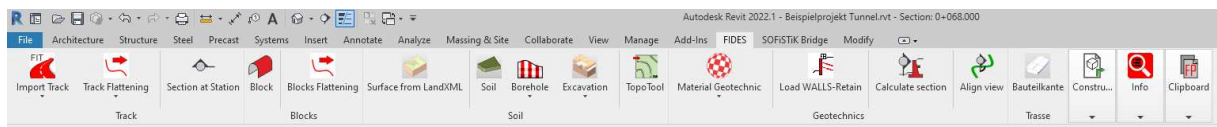


Figure 5-7: Overview of FIDES®

#### 5.1.3.1 General

FIDES® entire setup is based on Excel files, which have to include a very specific structure and naming convention to be recognised by the various modelling tools. The first column needs to include a chainage, the second column the chainage's easting value, the third the northing value and the fourth the height. This is enough information to place an alignment, but the file may be extended to place families as well. To create the excel file, one of the templates may be used and the input changed, as done for this thesis.

#### 5.1.3.2 Alignment

An alignment is created through the import track tool and the therefore setup excel sheet. It needs to be mentioned that at most 300 stations may be implemented as points; otherwise, FIDES® will ignore further chainages and their coordinates (see Figure 5-8). If an alignment consists of tunnel-meter coordinates, the maximum of 300 points may be exceeded quite quickly. Therefore, the data set needs to be simplified or split into several excel sheets if necessary.

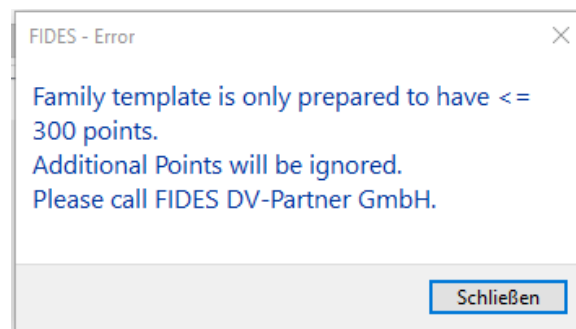


Figure 5-8: Limitation of FIDES FIT ® tool in terms of coordinate number

Even though the number of coordinates that can be implemented is limited, a very useful function is integrated into the alignment tool: the project basepoint relocation (see Figure 5-9).

As stated before, the project base point needs to be close to the model, and the coordinates need to be relative to this point. When including the alignment, the base point may be set manually, the current project base point may be used, or, as seen in Figure 5-9 below, the first chainage may be chosen. The coordinates will then be automatically transformed into relative coordinates, as seen in the second tab of the alignment tool.

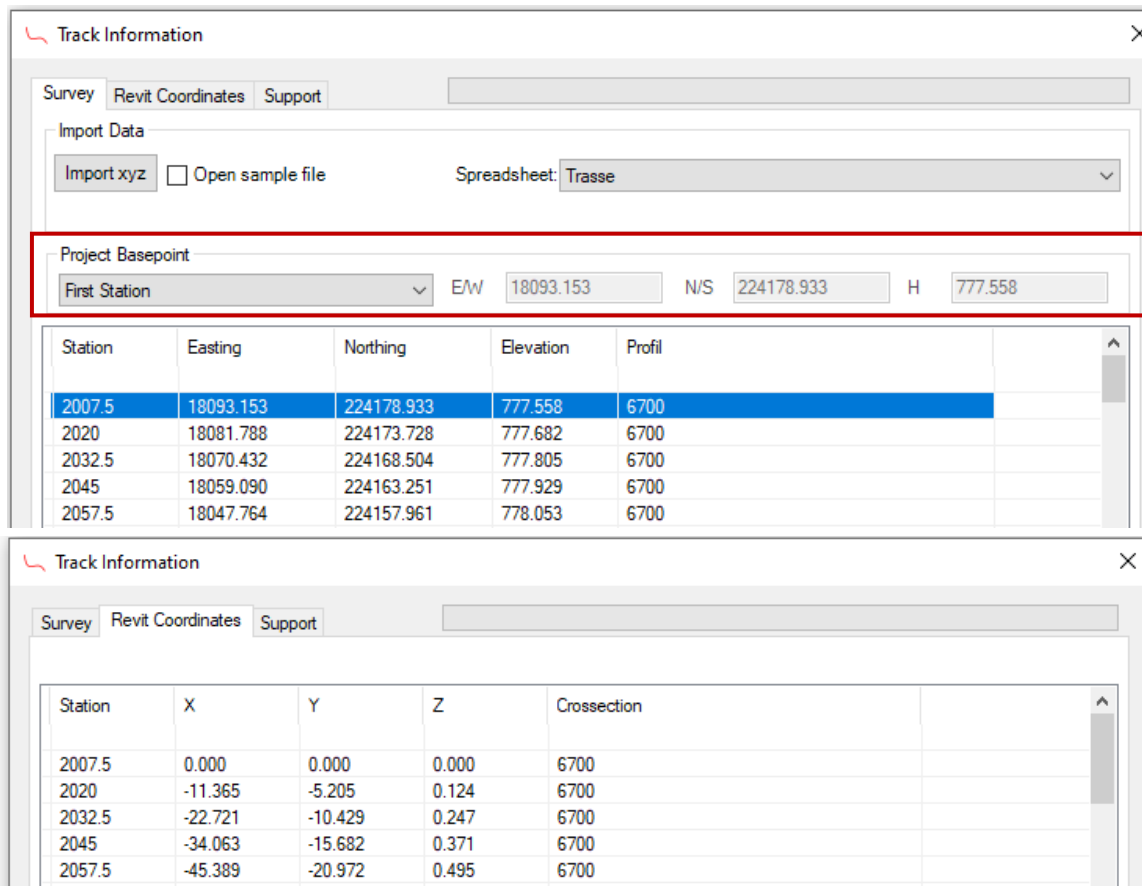


Figure 5-9: Project Base Point relocation and coordinate transformation

Once the alignment is loaded, a generic model family named "FIDES\_Trasse" is placed. It looks like a simple line, but once the family editor is opened, it may be explored that the family consists of one line, including adaptive points at each chainage handed over in the alignment tool. While a chainage name or number was handed over to the programme during the alignment integration, the name or number cannot be found within the family. The adaptive points do include an attribute called "Name," but this attribute is empty. Further, the "Section at Chainage" tool was used to see if they might be integrated in the background somewhere, only to find out that the chainages that may be selected are called "Chainage Nr. 1–X." This may actually be quite confusing if the chainages are not set at a regular spacing. Therefore, just like in Dynamo®, some sort of placement tag needs to be developed and implemented, and the tunnel blocks should include the chainages as well.



### 5.1.3.3 Family setup and placement

Integrated into the files provided by FIDES® during the download of the software are family sample files. Looking at these files, the modelling workflow and options of the FIT tool can be investigated. On one hand, the family setup is very similar to the family used in Dynamo®, in which a block is modelled with two voids at the start and end, as seen in Figure 5-10. On the other hand, the families generated for Dynamo® cannot be used since a handful of specific parameters have to be included and correctly linked to the adaptive points. Therefore, the provided template from FIDES® should be used and adapted.

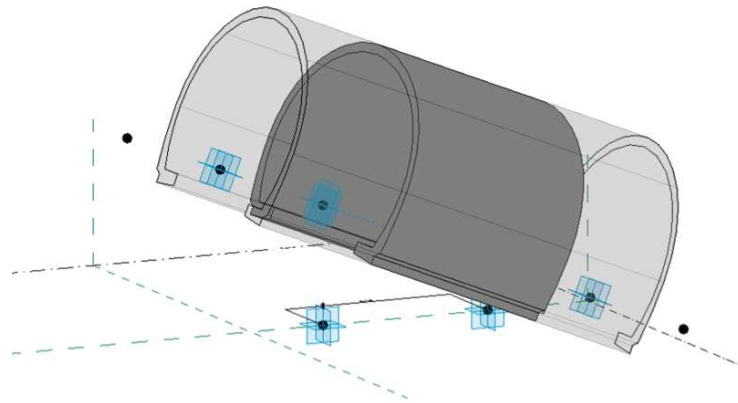


Figure 5-10: FIDES® template family

Once the families are setup, they may be placed in the "Block" function. Therefore, a new excel sheet or worksheet called "Blockteilung" is created; once again, a template is provided, and this time it should definitely be used. The setup is again very specific, and lots of parameters are automatically calculated, but it may be extended to fit specific modelling needs. The exact setup and how it is extended for this project are explained in more detail in the attached Appendix 1 and its FIDES® modelling section. In general, one row exists for a block number, its start and end chainage, and the families that should be placed in this block.

Now the Excel file can be assigned to the "Block" tool and it will start the block arrangement. With this tool, a new "FIDES-Tunnel" family is generated, including the families handed over in the excel file. The block families placed within the "FIDES-Tunnel" family can be separately selected, but not separately moved or edited within the project view. To edit them, the family editor of the "FIDES-Tunnel" family has to be opened every single time anything needs to be adapted or changed. While trying to implement some changes within the "FIDES-Tunnel" family, it was detected that the families may only be moved along the alignment. Further, the properties are static values and not linked to anything. If the family is moved along the alignment, the chainage value does not change. Overall, it can be said that the families, even though they are modelled to be flexibly adapted, end up being very static.

The "FIDES-Tunnel" family may be "separated" using the "Create Parts" function, in which case they appear to be single objects, but they are actually still one family, which is the reason

why the now "Parts" objects do not include or show the properties of the individual tunnel blocks and therefore cannot be extended, updated, or changed. The property sets for each selection differ immensely and may be compared in Figure 5-11.

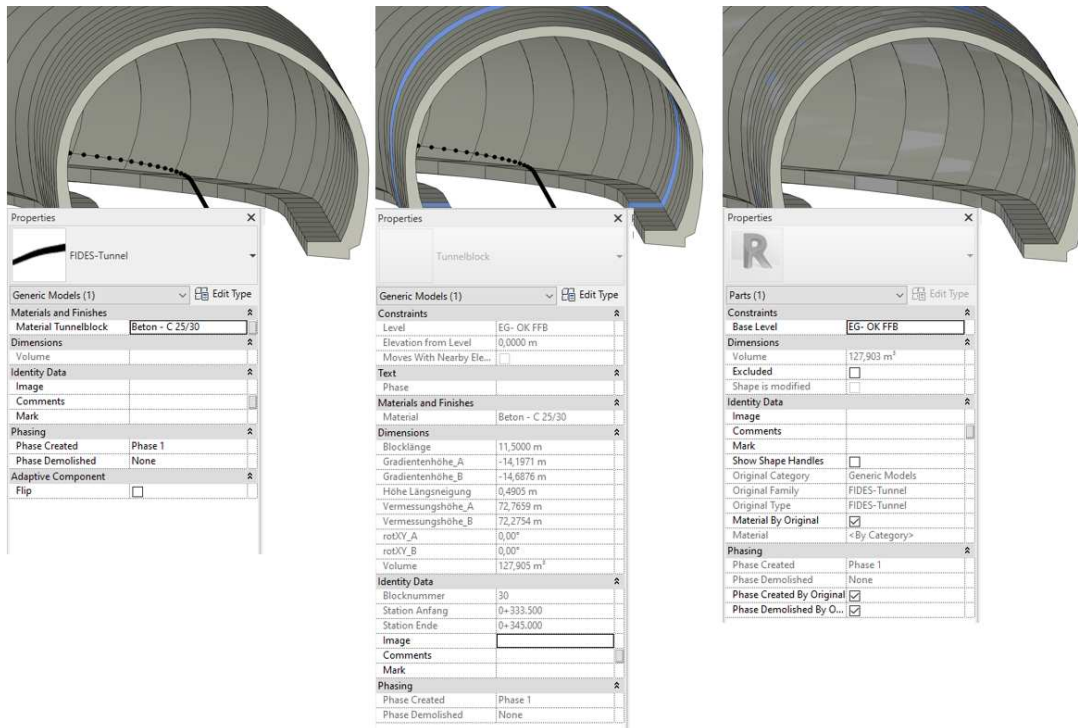


Figure 5-11: Property sets of different selections

The placement of block families with two adaptive points is not the only way of modelling a tunnel with the FIDES® tools. A workflow is included, in which two-dimensional profiles will be placed at each chainage assigned. Then the profiles may be selected at the same time and an extrusion generated through all of them. The two-dimensional profiles give the appearance that each block is modelled separately, when in reality the cross-section components are extruded along the whole alignment. This option is visualised in Figure 5-12, in which the first section shows the isolated profiles, the middle section shows the overall output, and finally the profiles are hidden and the volume is apparent.

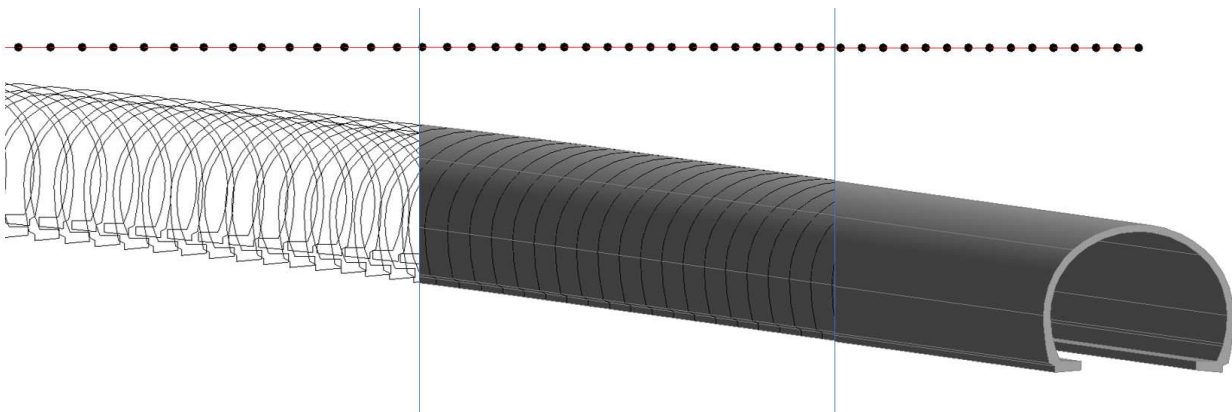
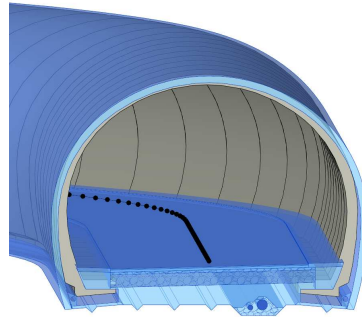


Figure 5-12: FIDES® sample project

Both variants of modelling were combined in the sample project from FIDES®. All components of the cross section except for the inner lining were modelled as a joined extruded profile family, which implies that everything except for the inner lining is one family from start to finish. The inner lining, on the other hand, was generated using the generate block function.



*Figure 5-13: FIDES® extruded profiles family*

For this thesis, independent families for components of the cross sections were selected for the "Block" function. Based on this, different cross sections and all elements using the two adaptive point setup may be arranged along the alignment at the same time. However, one big family, including all subfamilies, is created. A way to separate or "explode" these families was not found. Simply copying and pasting objects from a family environment to a project environment is also not possible within Revit ®.

It is also to be mentioned that the "Block" function cannot be run twice within a project. Therefore, placing one block family along the alignment and then doing the same with the next is not possible. When opening a new project and placing a second block family there, the whole family can be copied from project to project.

#### **5.1.3.4 Attribute integration**

While FIDES® includes some pre-defined properties that will be filled in through the tools and Excel sheets when modelling, it does not include any other tools capable of creating, implementing, or managing attributes or parameters. Therefore, for this, other add-ins or extensions would have to be used since manual integration is not feasible due to the amount of properties created for a tunnel project.

#### **5.1.3.5 Derivation of two-dimensional drawings**

FIDES® includes another tool named "Blocks Flattening." With this tool, the tunnel is selected, and all horizontal turns and bends in the alignment are flattened into a straight line. The output is a completely straightened twin tunnel with true length and height, which has to be placed somewhere within the project layout. This flattened tunnel gives the opportunity to easily derive a longitudinal section. Within this longitudinal section, a downward-facing section may be created next, which will be the sub-horizontal section of the tunnel. This workflow is visualised in Figure 5-14. For this tunnel section, the tunnel was consistently inclined over the entire

section. Therefore, the derivation of the sub-horizontal section was simple. It was not tested if an alignment that changes its slope would be flattened to a consistent alignment as well. A trough or a bend with a high or low point in the alignment would make the creation of a sub-horizontal section more challenging.

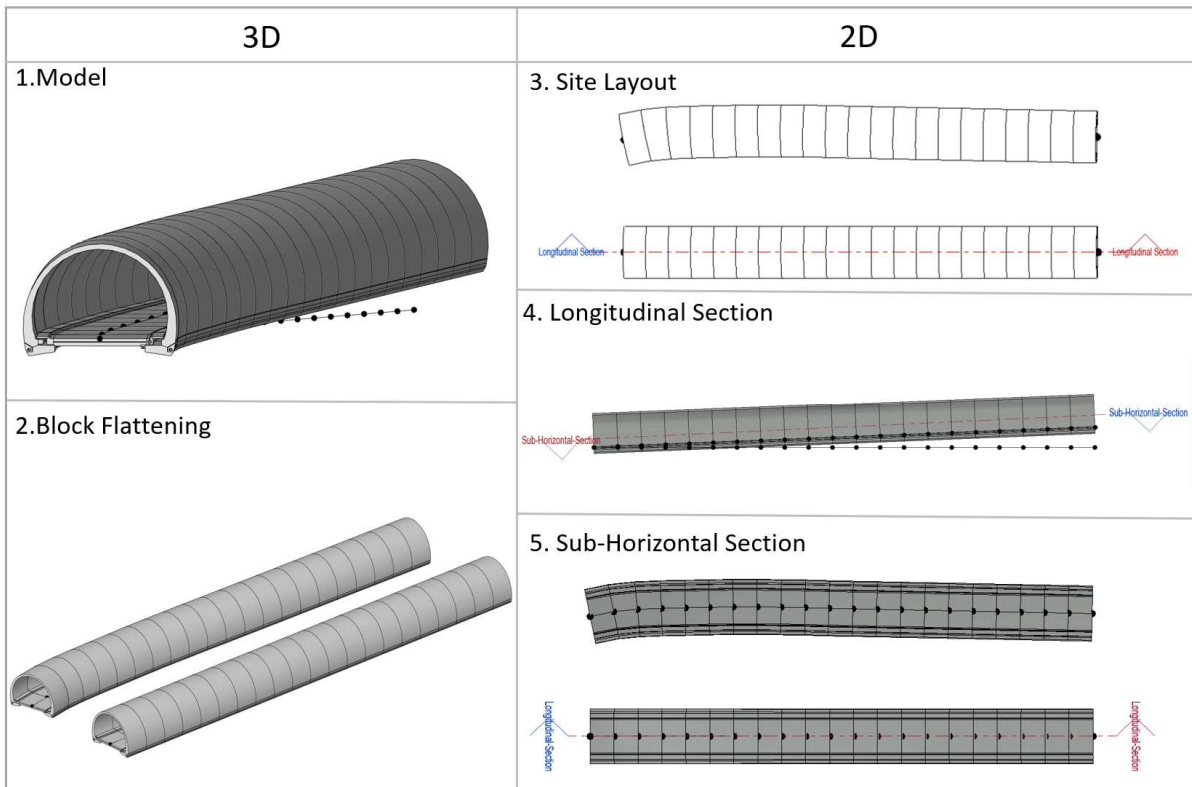


Figure 5-14: Steps to derive two-dimensional drawings with FIDES®

A flaw of this workflow is that the flattened tunnel model and the original tunnel model are not linked. Therefore, every time the tunnel model is changed or updated, the tunnel model would have to be flattened again. Hereby, it does not matter if the geometry is changed or simply a parameter or attribute changes in value. This does not mean that the sections need to be created again, since they will stay in place, and as long as the flattened tunnel is placed at the same location, they should still be active. Two-dimensional annotations not directly linked to three-dimensional objects will also be kept, but dimensions or annotations linked to three-dimensional objects within the sections will be lost in this process.

Obviously, the property handling tool might be used on the real tunnel and flattened tunnel to include the new or changing values. This would still leave a huge source of errors, and a strictly followed workflow would have to be set in place. The value of a single source of truth is hereby lost completely.

### 5.1.4 SOFiSTiK Bridge + Infrastructure Modeller ®

Initially developed for bridge modelling, SOFiSTiK® has extended its use to the entire infrastructure industry and is also being used for tunnel projects. Once installed, a new tab called “SOFiSTiK Bridge” is found in the Revit® interface, see Figure 5-15. None of the integrated tools are solely designed for tunnel modelling, but the bridge modelling tools may be applied to this field as well.

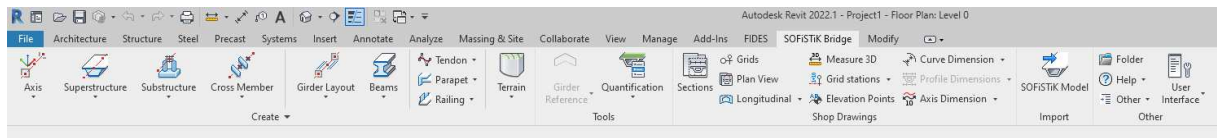


Figure 5-15: Overview of SOFiSTiK Bridge tools

Like FIDES®, SOFiSTiK® provides its users a few templates, including a tunnel block family and a railway project with a tunnel section. On their website they feature webinars including industry use cases and live training. Further, they have an online document explaining all tools, their application as well as release notes and updates.

#### 5.1.4.1 Alignment

As expected from an infrastructure modeller, SOFiSTiK® includes an alignment tool with a wide variety of ways to generate an axis in Revit ®. The alignment is either created from scratch, as seen in Figure 5-16, or imported through a landXML, txt, csv, json or other files.

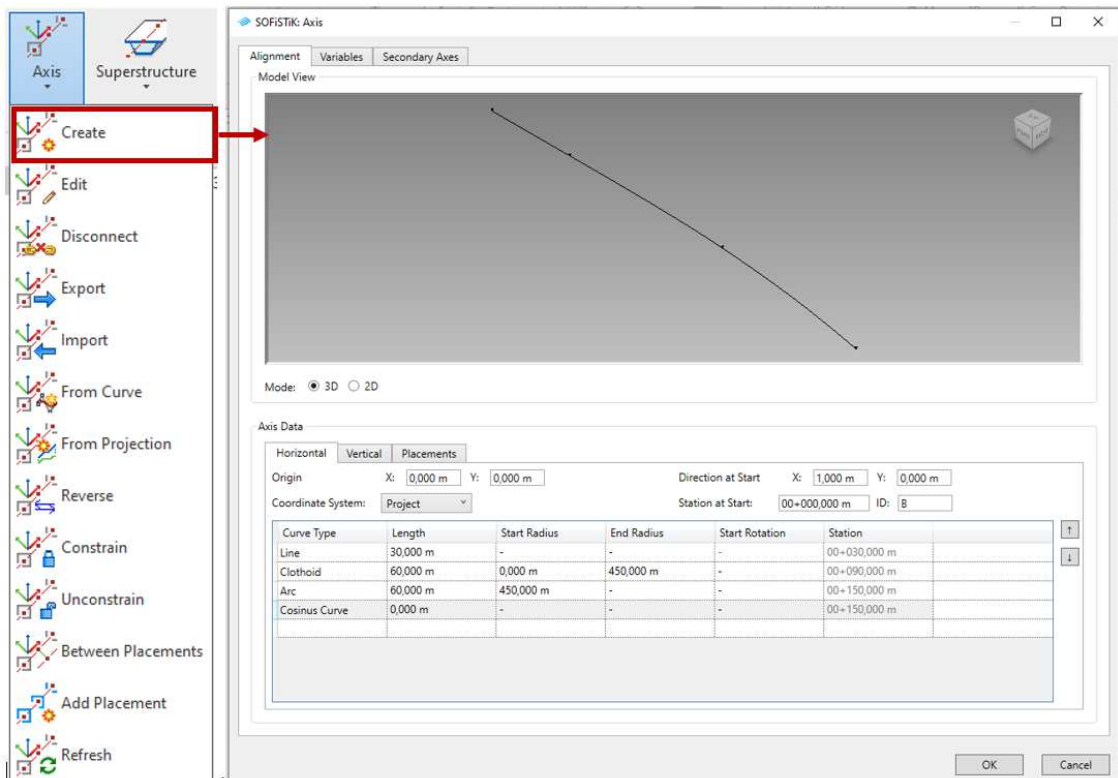


Figure 5-16: Alignment tool of SOFiSTiK®

During the compilation or import of the alignment, chainages may be created using the "Placement" function. Hereby, placement tags are generated at each chainage assigned and may be used later for orientation as well as placing and generating families along the alignment. Adaptive components which are placed in between two tags are linked to these and will move, increase or decrease in number if the tags are changed within the alignment tool. This change will be based on rules initially set while placing the components between the tags.

For example, tunnel blocks are created at chainage tag zero and chainage tag ten. The rule for these blocks during generation is selected as: number of blocks must be four. Therefore, four blocks with the length of 2.5 meters are created between chainage tag zero and chainage tag ten. Now the chainage tag is relocated from 10 to 16 and the tunnel blocks are automatically updated to four blocks with the length of four meters each.

Overall, the placements provide an option to control families, their placement and generation along the alignment, but they may also be integrated at a regular distance simply for orientation reasons. An example of tags can be seen in Figure 5-17.

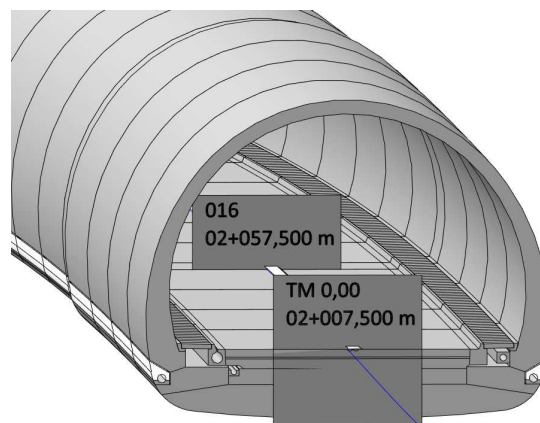


Figure 5-17: Example for placement tags from SOFiSTiK®

#### 5.1.4.2 Family setup and placement

SOFiSTiK® developed three different tools to place or create bridge components along the alignment, the Superstructure, Substructure and Cross Member tool. Each tool includes a slightly different modelling approach and may be used for tunnel modelling as needed. All demand different family input and may even create families while extruding them along the alignment.

The Superstructure tool takes the approach of placing a two-dimensional profile at two chosen chainages and extrudes these profiles along the alignment to create and implement a new three-dimensional family. The two-dimensional profiles can be setup as a parametric family (see Figure 5-18) and the parameters can be set in the Superstructure tool before placing. However, the newly created three-dimensional family does not include the two-dimensional profile family parameters within their property set; therefore, within the Revit® interface, they are basically static components. Using the "Edit Superstructure" tool, the values of the two-dimensional profile parameters may be changed, but the family will be recreated and not just updated.

Consequently, the old family is deleted and a new family is implemented and all changes within the Revit® interface, for example adding project-specific parameters, will be lost.

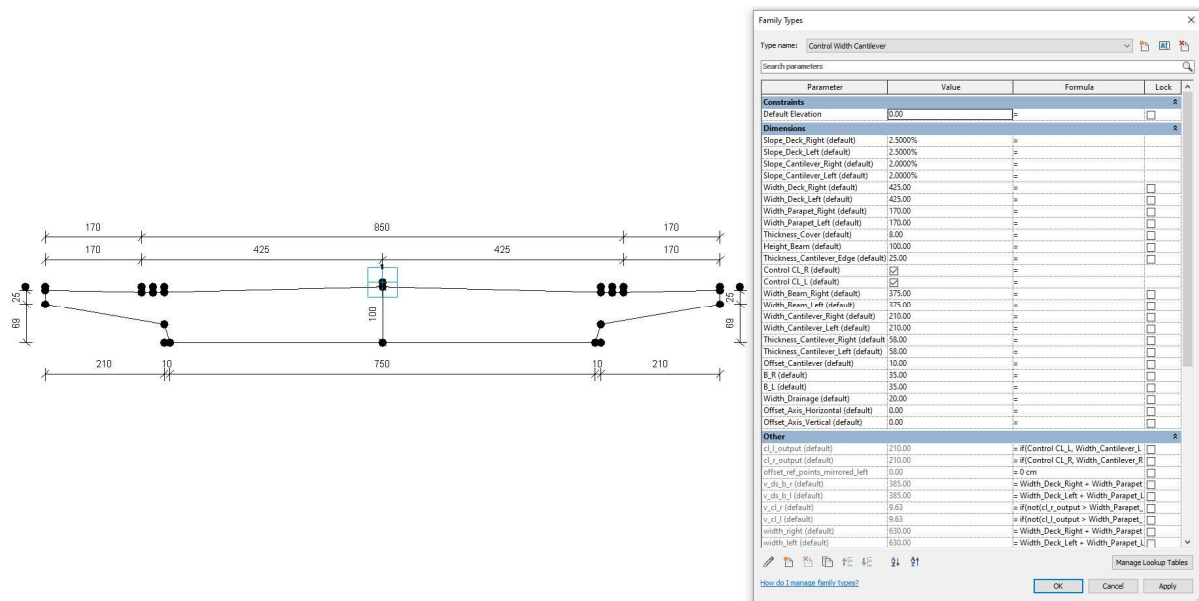


Figure 5-18: Parametric two-dimensional sample profile provided by SOFiSTiK®

This tool includes another function as well, the superstructure repeater. Hereby, while a profile is still extruded within placements, the extrusion along the alignment can be divided using rules to set certain distances. These extrusions will be created as separate families, all of which will have the same name and a sequential numbering at the end. Due to these families being created individually, a single extrusion may be deleted or moved separately from the others. It also means they cannot be selected through the select similar function. If one of these families is updated using the edit superstructure tool, all families initially set will be recreated, and all of them will be updated to reflect the changes. This also means that even if one of these families is moved or deleted, the original state of consistently arranged families will be recreated. Further, this implies that all manual changes will be lost when using the edit function. If project-specific parameters were created and set, these will not be included once the families are updated.

The second tool is the substructure tool. For this tool, parametric, three-dimensional families, including one adaptive placement point, are prepared. These families will then be placed with the substructure tool along the alignment. Hereby, placements need to be selected at which the family should be placed and an offset, rotation, as well as all other parameters set within the family need to be set to the desired output. With this tool, the option of consistently arranging in between points or at a selected distance from a placement is not given. If a family needs to be placed every 10 metres along the alignment for a set distance, either a placement is created at each location and the family may be placed several times in one step, or one placement is created and the families are placed at a selected distance from this placement manually for each family.

Either way, the families placed are all the same family; they may be selected as similar elements together and may be changed as a unit in the family editor. Their parameters may be set within the substructure tool, but they can be changed individually within the Revit® property sets as well. Even though the families were placed together, if a family is selected and the edit substructure command is used to edit or change this family, only this family is changed and the others are not connected anymore. If more families are selected, the edit substructure tool is not available for use.

Lastly, the cross member tool may be used to place tunnel family components. With this tool, three-dimensional families are placed along the alignment on or between placements. Rules may be selected to control the position, quantity and distribution along the alignment. For this, families with one to three adaptive points are supported. Compared to the substructure tool, in which none of the placed objects share any relationships in terms of location along the alignment, the cross member array instead places connected object. While they share a connection based on the generation function, they can still be edited individually and manually. However, if the whole cross member arrangement is updated using the edit cross member tool, all families placed within one run will be regenerated and manual input may be lost.

In terms of tunnel modelling, any of the three provided placement options provide different opportunities and functionalities. The slightly different output they provide can be used as a strength but may also be limiting. Within the SOFiSTiK® project template, the tunnel block family is modelled with two adaptive points (see Figure 5-19), similar to the FIDES® setup. Therefore, the cross member tool was used to arrange these families along the alignment.

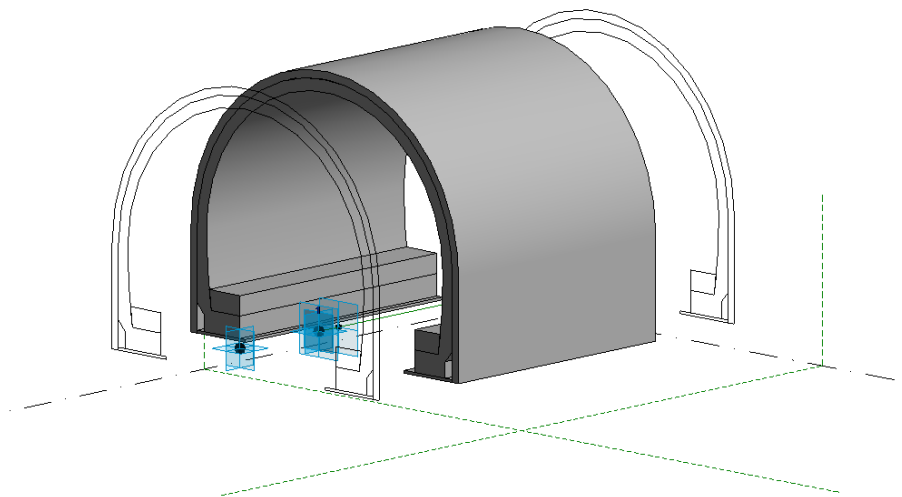


Figure 5-19: SOFiSTiK® tunnel block template

Eventually, the desired use of the model, project-specific requirements and other parameters will be used to decide what modelling approach should be applied. The approach may also differ for the single components of the project. For example, the generation of the pavement as a superstructure, from start to finish as one long extrusion, is a feasible approach, while the tunnel block generation may stick with the cross member array.



### 5.1.4.3 Integration of properties

In general, SOFiSTiK® just like FIDES® does not provide specific tools to create, fill or manage properties. It is possible to control and set parameters integrated through the families within their placement tools and it includes a few dynamic SOFiSTiK® parameters which will report information about location or quantities. However, if project-specific parameters are to be implemented, these must be generated manually or with the use of other add-ons.

#### 5.1.4.4 Derivation of two-dimensional drawing

Certainly, since bridge modelling thrives through the derivation of longitudinal and cross sections, derivation tools are included in the SOFiSTiK® functions. Plan views, cross sections and a longitudinal section may be created through a click of a button and selection of the alignment (see Figure 5-20). What is missing is a derivation of the sub-horizontal sections. For a consistently inclined tunnel, the section may be created through a normal cut along the longitudinal section, as done previously in FIDES® and Dynamo®. But, just like the others, it also does not include a solution for inconsistently inclined tunnels.

What should be considered is the setup of the longitudinal section. This view does not include the three-dimensional objects modelled and does not provide a direct link to these objects. The tool creates an unfolded section of the objects modelled, consisting of lines and patterns derived from the three-dimensional objects. The only information included in these section details is the material of the element it was derived from, the element ID number, and the family name. Based on this, dynamically changing annotations based on parameters are probably not possible for the longitudinal section.

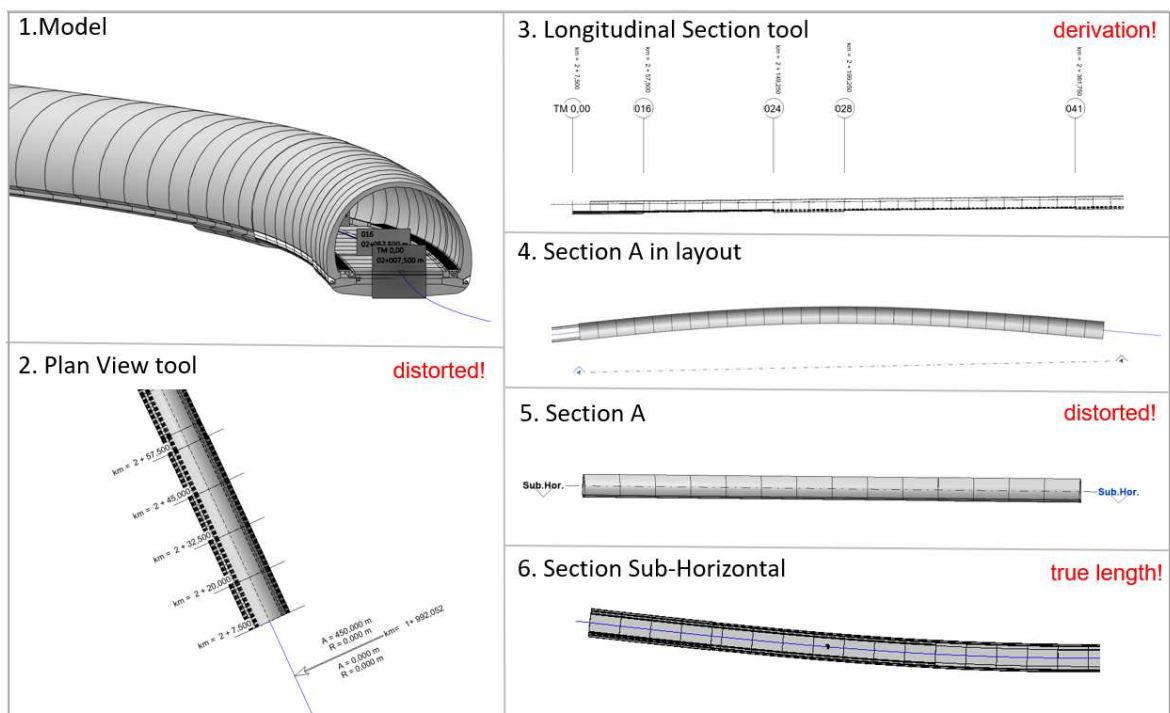


Figure 5-20: Steps to derive two-dimensional drawings with SOFiSTiK®



## 5.2 Bentley OpenTunnel Designer®

### 5.2.1 General

As mentioned before, OpenTunnel Designer® is one of the newest software developments in the Bentley Systems family, with release 1 launching in 2022. Introductions for this software are provided by Bentley Systems themselves online through several channels. At a first glance, (Figure 5-22) OpenTunnel Designer® provides the most obvious tunnel design tools of all the software and extensions used so far.

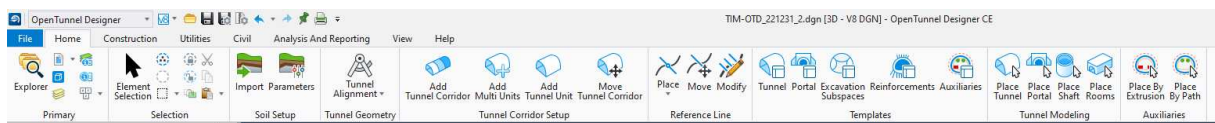


Figure 5-22: Overview of OpenTunnel Designer®

The tools are arranged in the order they are supposed to be used, from left to right. While some functions may be skipped, for example the import of a ground model, some tools cannot be applied if a previous tool was not used beforehand. Reviewing the steps that need to be followed, the setup is very similar to the workflow used in Revit ®. Create an alignment, place chainages, setup a tunnel block template or cross-section components and place these blocks along the alignment.

### 5.2.2 Alignment

Several very specific steps that may not be done in a different order have to be taken to eventually place the templates along the alignment. The alignment is created with OpenTunnel Designer®'s tunnel alignment tool. With this tool, an axis can either be created or imported through one of the supported file formats. Once created or imported, a tunnel corridor needs to be assigned to the alignment; otherwise, the next steps cannot be performed. Now, the tunnel corridor and its alignment are divided into several tunnel units, which all resemble a change in block division or cross-section type. Each unit is defined by two reference lines along the corridor (see Figure 5-23).

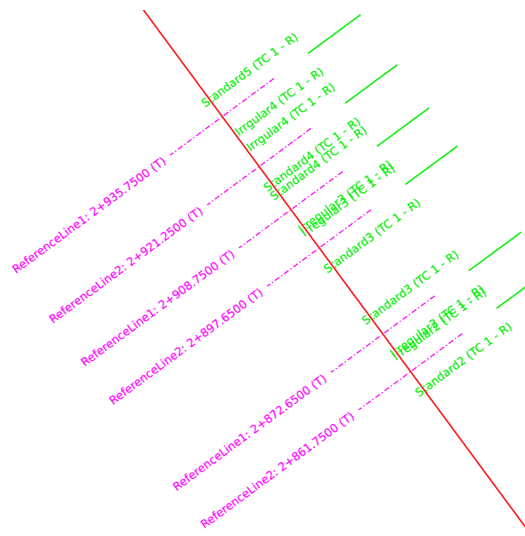


Figure 5-23: Reference lines along alignment

To complete all these steps, many clicks and manual inputs are needed and it was not determined if these steps may be automated. However, if this is the only way to arrange the tunnel blocks along the alignment, it does present itself as quite a lengthy process. Currently, a direct access to the application programming interface by means of visual scripting is not included in the software, but this might be established in future releases.

### 5.2.3 Catalogs and templates

Bentley OpenTunnel Designers'® general modelling approach is to use two-dimensional cross-sections, also known as templates, from a defined catalog and extrudes them along a specified alignment to create volumes for the tunnel model. The catalogs are libraries that contain existing templates for various elements of the tunnel model, which can be customized or reused for new projects. (see Figure 5-24).

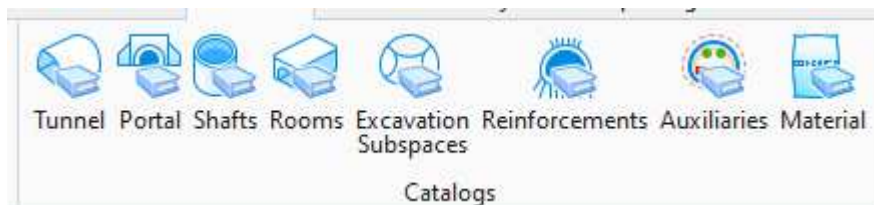


Figure 5-24: Modelling catalogs of OpenTunnel Designer®

A template consists of lines that enclose an area, which can be named and tagged for identification purposes. These tagged areas can then be extruded to create a volume and associated with information such as the material of the element. This approach allows users to define and customize the geometry of the tunnel using these tagged areas, and to assign properties and attributes to them for further analysis and design purposes.

The tunnel catalog includes the theoretical excavation line and the design of the inner lining, which are defined by three continuous lines. While the definition of an inner and outer line for

a tunnel lining of a tunnel boring machine ring is simple, the definition of the inner and outer line for conventional tunnel lining may vary depending on which elements are considered to be a part of the inner lining and what wants to be achieved. Some examples of the template catalogs that are included in the software combine the inner lining, abutments, base slab and, if constructed, an invert in the definition of the inner lining. (Figure 5-25).

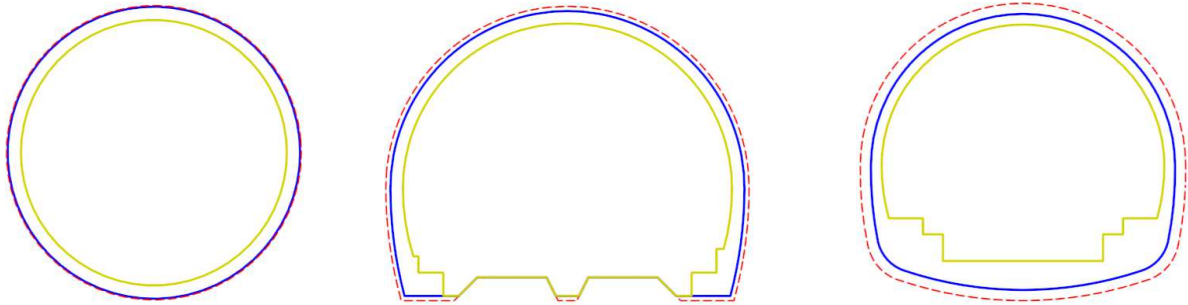


Figure 5-25: Templates for TBM and conventional tunnel cross sections

Once the lines for the inner lining are set, the enclosed area may be further split into several lining parts by simply using more lines to divide the area. It needs to be considered that all lining parts will be placed at the same time and therefore at the same distances for one tunnel unit; therefore, within the tunnel catalog, only components that want to be placed at the same distance should be included. If there are components in the cross section that are supposed to be placed without reference to the placed tunnel blocks, they need to be modelled within the auxiliaries catalog. In the Auxiliaries catalog, two-dimensional areas can either be extruded or three-dimensional elements are placed via a point.

The material catalog includes five pre-defined tabs: concrete, steel, soils, reinforcements and miscellaneous. All have some material-specific, pre-defined additional information, like unit weight, unit price, strength parameters and other details about the material. While the list may be extended and new material may be added, the tabs themselves and their details cannot be extended.

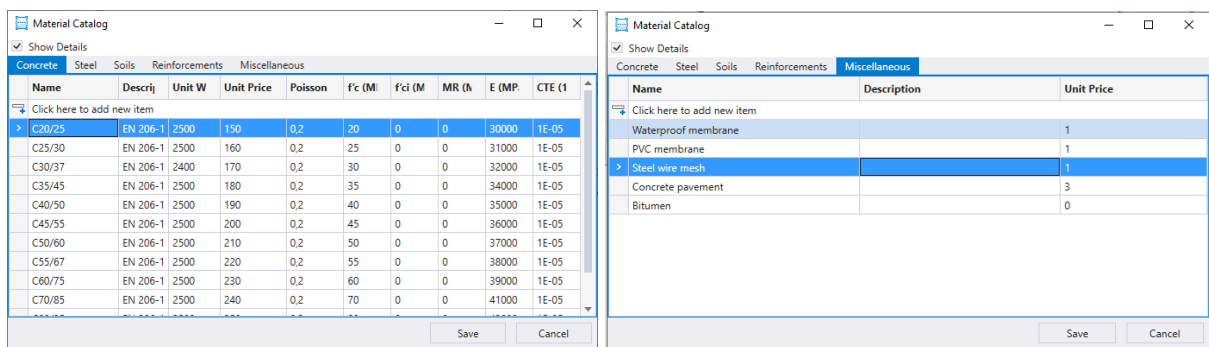


Figure 5-26: Material catalog setup

The other catalogs were not used for the project at hand, but they would provide more specific tools for tunnel modelling. Since the portal, shafts, room and material catalogs are setup as standalone catalogs, they can be reused by transferring them from project to project. In contrast, the excavation subspaces, reinforcements and auxiliaries catalogs are directly linked to one of

the tunnel catalog templates. Therefore, these components can only be reused if the tunnel template to which they refer is used or modified. For example, if a curb stone is modelled as an auxiliary element and needs to be placed along the entire alignment in every cross section at the same location, the curb stone must first be included in every single tunnel template used within the project and then will also have to be placed manually for every single tunnel unit. It cannot be simply extruded along the entire alignment by linking it to two reference lines.

The more templates, units and corridors there are within the project, the more steps and time it takes to place these components.

Once the necessary catalogs are set up and all units are defined along the tunnel corridor, the tunnel templates and auxiliary templates may be placed and therefore extruded along these units accordingly.

### 5.2.4 Placement of tunnel blocks

With the tunnel units and their reference lines defined along the tunnel corridor, the extrusion of the tunnel blocks along the alignment can be done next. For this, a unit needs to be selected to be able to create or modify elements for this unit, a template needs to be selected and the block separation for the unit has to be set. Now the first and last reference lines of the tunnel unit are selected to place the sections. This has to be repeated until all tunnel units are placed. A standard tunnel block in the modelled project is 12,5 meters. During the review of the placed standard tunnel units, something odd was detected. Depending on the selected view, the model seems to include different block separations. Whilst the "Smooth" display style shows a plausible, consistent length, the "Illustration" display style shows a completely different and inconsistent separation, as seen in Figure 5-27.

While testing more view styles, it was determined that most of the display styles actually show an unexplainable separation. However, if a tunnel section is selected in the component list during the "illustration" display style, the selected element does show the correct length.

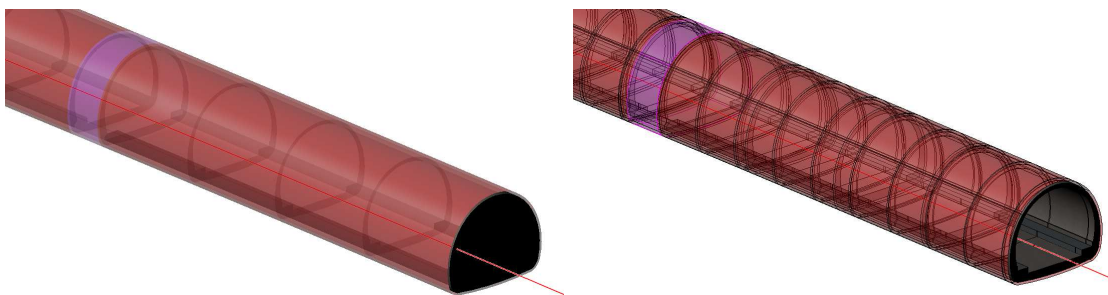


Figure 5-27: Block separation in smooth and illustration display style

The incorrect view could not be solved, even after trying to regenerate the cross section again or placing the same tunnel unit a second time. In addition, to see if this mistake was based on an error within the project-specific tunnel template, a template provided by Bentley was placed, but this error still occurred. As a last test, the model was exported as dxf and obj and imported

in a different software to check what the objects would look like, and they did actually have the right block separation.

### 5.2.5 Attributes

While data for materials and other information (weight, strength parameters, unit costs and other pre-defined attributes) can be integrated in the material catalog, additional data must be added to the areas that have been tagged in the two-dimensional profile editor of each tunnel template. Since the attributes have to be assigned in the cross section, only data that fits all components extruded from this tunnel template may be added. This limits data variability drastically. A possibility to integrate varying data into different objects along the alignment was identified. To do so, the "Attach" ribbon of the "Drawing" workflow (shown in Figure 5-28) is used, in which all sorts of information can be attached to an element.

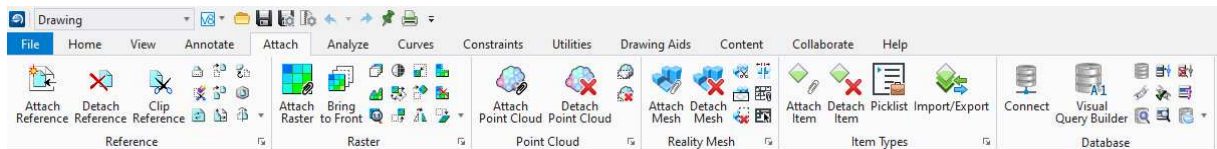


Figure 5-28: Attach properties in OpenTunnel Designer®

However, this input has to be done manually, which takes a long time even for a handful of attributes. OpenTunnel Designer® itself does not include good attribute management yet but may be combined with further software, for example Bentley's in-house solution MicroStation®, to be able to handle property integration.

### 5.2.6 Derivation of two-dimensional drawings

OpenTunnel Designer® includes drawing derivation tools to generate plan views, cross sections and longitudinal sections. Hereby, all sorts of settings, for example, scale, size of drawing, chainages and boundaries, can be chosen to create an envisioned output. For this, all parameters are set within a mask for a tunnel corridor and drawings will be generated automatically for the selected boundaries and a chosen drawing header.

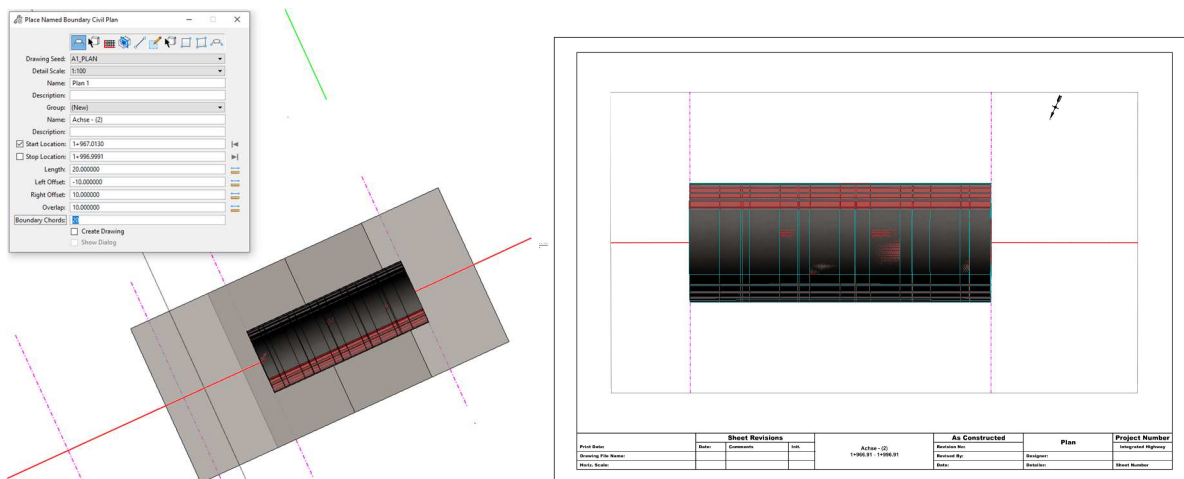


Figure 5-29: Drawing derivation based on defined mask in OpenTunnel

While drawing derivation in OpenTunnel Designer® is easy and uncomplicated, it is limited to the templates and masks provided by the software.

### 5.2.7 Additional information

Since OpenTunnel Designer® is a new software and the current version is its first release, some bugs, which will probably be fixed in future releases, were still found during use. For example, some buttons simply do not prompt any command yet and the room template catalog forced the programme to quit every single time it was selected. Since starting to use the software and the last time it was used while writing this thesis, many commands have been linked to buttons; for example, all the links to online platforms and the online Bentley community now work, whereas they did not a few months ago.

While reading through Bentley's learning path for the OpenTunnel Designer®, the software developer states that there are still some major tunnel modelling features missing. The following limitations are mentioned [47]:

- While the tunnel units themselves may be placed using different cross sections, there is currently no possibility to combine two cross section types with a simple loft.
- The software does not include any tools to implement intersections or cross passages.
- Side-by-side installation is currently envisioned for further releases, due to the schema changes in each release apparently being quite significant.
- Direct IFC export is currently not possible with OpenTunnel Designer®.

Even though features like the creation of cross passages are still missing, they may be implemented using another Bentley software like MicroStation®. For this, the model created in OpenTunnel Designer® is imported into MicroStation® and then modifications that cannot be made in OpenTunnel Designer® yet may be made there. It is not the ultimate solution since Bentley mentions that if changes need to be made back in the original model, the manually adapted elements in MicroStation® will be lost once the tunnel is newly imported.

Further, even though IFC is not yet supported by OpenTunnel Designer® directly, it can be done with OpenBridge®, iTwin® and other Bentley software solutions. Therefore, the model created in OpenTunnel Designer® is imported into one of the IFC export-capable software solutions and exported there.



# 6 Comparison and Discussion

In this section, we will compare the four workflows developed using different software solutions and extensions. We will use the structure of the modelling process to guide the comparison, which was challenging due to the fundamentally different methods used by each solution. The scripting approach is limited by the functionalities offered by the authoring software, leading to many different approaches to the same task, while specific tools are limited by their own functionalities.

The goal of this comparison is to provide a comprehensive evaluation of the software and their workflows, highlighting both strengths and weaknesses. We will summarise the evaluation in a table in Chapter 6.6 Comparison Summary, which presents information on the software features or performance metrics.

## 6.1 General

First, before comparing major modelling steps individually, a few general objectives are compared.

### 6.1.1 User Interface and getting started

The user interface is a highly subjective topic, and different users may evaluate interfaces differently depending on their personal preferences and software experience.

In the Bentley Community forum, some users have described Bentley System software as more complex than Revit®. Beginners may be overwhelmed by the number of available workflows and the resulting changes in the ribbon setup. To help users get started and understand the software workflows, Bentley provides videos, documents, and an online learning path. However, these materials currently lack a basic introduction to the user interface, including how to run and exit commands or an overview of the general setup. While they do provide a quick start to modelling with the software, basic tasks such as viewing properties or hiding/showing levels and their elements can be challenging to figure out. Ribbons often contain a large number of functions, making it difficult to understand their capabilities.

It is worth noting that the software is still in its early stages, and more content is being created and uploaded every week. Therefore, some of the missing pieces mentioned above may become available shortly.

Revit®'s overall interface appears less overwhelming than Bentley System software; however, when it comes to making decisions like template setups, family categorization, property setup, and viewing templates, it can be just as complex. Nevertheless, the Autodesk community has a

vast range of online webinars, videos, introductions, and extensive help guides on its various platforms and communities.

The setup of the extensions in Revit® is straightforward and simple, but to use them, families must be constructed or provided, which requires in-depth knowledge of family creation and editing. FIDES® provides its users with video material explaining the extension, while SOFiSTiK® has created a detailed online user guide. Although both extensions provide specific information about their use, a comprehensive understanding of Revit® authoring software is required to implement a project.

Compared to the extensions, which were implemented as ribbons within the software, Dynamo® has its own interface that appears once it is launched within Revit®. The start screen immediately displays forums, websites (such as the Dynamo Primer), video tutorials, dictionaries, and more links to provide guidance and help. Several sample files covering basic setups, such as importing and exporting data to and from Excel, are provided and may serve as a basis. Although this is an excellent starting point once the interface is open, a basic understanding of modelling terms and data integration logic is necessary to modify and extend the scripts and create your own functions and tools.

### **6.1.2 User profile and user teams**

While the initial user profile of a typical CAD technician has already been changed by the TIM method, the workflow of a software will further demand specific understanding of processes and data as well as possibly require compatibility in terms of coding. Based on the need for data integration, often more input than just the regular geometry is necessary, which further implies the need for a basic understanding of building materials and their relevant parameters. To prevent clashes within the model, another field (clash detection) was introduced with the TIM method. Therefore, coordinators or modellers need to know how objects are intersected or combined with each other, which is usually defined based on a deeper understanding of the construction processes.

OpenTunnel Designer®, FIDES®, and SOFiSTiK® mainly focus on the modelling aspect of the model generation and are less focused on, or based on, data integration and management. However, Dynamo® is applied as a versatile tool to handle both modelling and data management aspects. For this, a very basic principle of coding forms the basis of using Dynamo® to model and manage data.

Nevertheless, with repetition and automation, modelling itself will eventually play a much smaller role in the overall design and construction process compared to data integration and management. For this, typical TIM project positions like the TIM manager, TIM coordinator, and TIM modeller are adopted from building information modelling to ensure a well-coordinated and collaborative TIM application.

While these additional positions were defined to ensure the implementation of overall collaborative and coordinated TIM projects, even within those new positions, several sub-positions might be useful. For instance, due to the software and their setups being highly

complex, it would make sense to establish different users for the TIM modeller position. This would ensure that these users are experts within their fields and can contribute to the project setup based on a deep understanding of the smaller objectives of a software. It would also contribute to a learning path since users could start with one position and develop more skills once they mastered it. This would be especially helpful in adopting TIM into one's practice, since the all-knowing TIM manager, modeller, and coordinator does not exist, and even TIM users in general are hard to find.

For example, a TIM modeller group for the Dynamo® workflow may consist of a project template and model coordinator, a family modeller, as well as a Dynamo® scripter. Each user should know the overall modelling workflow and have some knowledge about the other users' tasks, but they will be experts in their niche and responsible for smaller parts of the project implementation. Hereby, while the template and model coordinator should be working on a specific project, the other experts could contribute to several projects based on the reusability of their families and scripts for other projects. Obviously, this needs to happen as a collaborative workflow without losing sight of the overall modelling goal.

### 6.1.3 IFC Export

While IFC export capabilities are not defining features of TIM software, many pilot projects are currently using IFC files for data exchange, even though IFC has yet to standardize properties for the tunnelling field (official implementation of ifcTunnel is still outstanding). [48, 49]

Therefore, while IFC may not be the ultimate solution, there is still a need for IFC export capabilities. While some workflows involve designing geometric models in one software, exporting them as geometric data, and attributing them in another software, these workflows often fail to efficiently incorporate geometric changes based on modifying the initial model. Therefore, the authoring software should be capable of integrating IFC properties and exporting IFC models.

OpenTunnel Designer® does not yet support direct IFC export, but the Bentley Community suggests sending the OpenTunnel Designer® project to iTwin® or MicroStation®, other Bentley Systems solutions, to export the IFC file there. Since OpenTunnel Designer® does not yet support efficient property generation and management, there may not be a big need for direct exchange since attribution is limited. However, since it is only the first release of OpenTunnel Designer®, the software will possibly support IFC in the future.

Revit® supports the IFC format, which may be one of the reasons for its frequent use despite its limited infrastructure specialization. While SOFiSTiK® and FIDES® as modelling-oriented extensions do not include any helpful IFC tools, Dynamo® can help read and evaluate IFC files and schema files for property integration. For this, nodes may need to be coded or add-on packages installed.

## 6.2 Alignment

The alignment, provides the foundation for every infrastructure project. The path of the alignment is usually defined in advance of creating the structure model. Thus, importing data is a key aspect of generating an alignment within the modelling software. For this, data types, data size and coordinate implementation play a first role in the generation.

### 6.2.1 Data import

While OpenTunnel Designer® provides its users with a wide variety of data import options, it is specifically designed to import real coordinates. In contrast, Revit® as authoring software provides a first challenge in coordinate handling due to its limited modelling boundary of 32 kilometres and point integration logic. While the size of this boundary is seemingly large and would probably cover most projects' lengths, geometry that is placed far away from the internal origin may be less accurate, and the graphical representation less reliable. Therefore, large projects are usually split into several smaller ones in advance to prevent problems down the road. Based on this boundary, the "size" of the coordinates is limited to 30000, meaning everything over five digits will not be placed. Distances are relative to the project base point, so coordinates need to be transformed. For this transformation, FIDES® and SOFiSTiK® both include functions within their imports that move the project base point to a desired location and transform the coordinates in relation to the placed project base point (see Figure 5-9 and Figure 5-16). Within Dynamo®, a transformation may be done by subtracting the project base point coordinate from the values of the imported coordinates (see detailed script set up in chapter 9.1.1 Dynamo®).

### 6.2.2 Element

Once the alignment is placed as an element within the project, it becomes part of a certain object type, which usually further defines how to modify or edit the element.

In OpenTunnel Designer®, upon importing the alignment, two objects are generated: a complex element as a projection of the alignment on a horizontal plane at zero elevation and a 3D linear element that includes the elevation and real length. The complex element is used to include chainages, annotation, and reference lines into which the tunnel corridor is divided, while the 3D linear element is used to extrude and place the geometries.

In Revit®, all objects are modelled as families, which are assigned to a defined set of categories that provide a standard set of functions and properties for similar components. The extensions each have a certain family type assigned to their alignment tool. With Dynamo®, any type of object that can be created in Revit® may be used as an alignment.

The modifications for these elements depend on their types as well. While for FIDES®, the alignment will be edited through the modification of the Excel file used to generate it, in SOFiSTiK®, all changes are done within the mask of the alignment tool. In Dynamo®, another script will be generated to either adapt or regenerate the element used for the alignment.

The three-dimensional linear element of the axis in OpenTunnel Designer® includes control points that may be selected and dragged with the mouse. However, no function was detected to modify the complex element. Only the complex elements defined by reference lines have obvious modification tools.

### 6.2.3 Orientation

Infrastructure projects often require orientation along a particular alignment, which is typically implemented using chainages and tunnel-specific tunnel meters. The chainage provides a reference to a structure's location along an overall infrastructure corridor, while the tunnel meter offers a reference to a structure's internal coordination point. To facilitate orientation, annotations for both the tunnel-meter and chainage should be visible in all sorts of views, including 3D, top views, sections, etc.

In OpenTunnel Designer®, either the chainage or the tunnel-meter can be linked to the alignment, and as a result, moving the mouse along the axis will display the chainage. Actual annotations are typically placed on the horizontal plane on which the complex element lies, which means that the chainage is visible in top view but not in perspective. Revit® includes annotations via 3D annotation tags or 2D annotations in views, although the lack of an actual alignment means that the annotation needs to be calculated based on a tag integration with Dynamo®.

Including the actual chainage value at the tags requires the chainage to be linked or calculated using software like SOFiSTiK®. However, FIDES® does not include proper chainages and annotations, even though they would be included in the Excel sheet for the tunnel blocks and axes. The values are included as simple numbers and have no relationship to any length, coordinate, or other parameter.

There is significant room for improvement in terms of annotation in every software and its extensions, particularly in terms of chainage-based annotations in perspective views and direct object-to-location links using the integration of attributes or parameters for chainage and coordinates.

## 6.3 3D-Modelling

Integrating the alignment into modelling software is usually straightforward; however, modelling the elements along the alignment is more complex. Two approaches are available: placing static or dynamic 2D profiles that are extruded or swept along the alignment, or static or dynamic 3D objects that are placed at or in-between points along the alignment. The latter method typically provides more editing options, based on value changes of parameters, and the ability to group objects or use them individually. In contrast, profile extrusion or sweeps tend to function as units with restrictive handling based on the loss of their profile parameters after extrusion.

Despite this, standalone components can still be created using sweeps based on manual inputs and repetition. However, this process usually needs to be repeated for every individual component. Moreover, the repetitive nature applies not only to placement along the alignment but also to each component and type of cross-section.

### 6.3.1 Tunnel block

A tunnel block is an excellent example of an extrusion along the alignment in a repetitive manner, varying in length or its type of cross-section. The block's length is defined by the sections in which the concrete will be poured and varies from project to project, based on the size of the formwork carriage and the location of cross passages or bends within the alignment. While this length does not apply to every component of the cross-section, placing each element with its actual length would end up in separate tasks for most modelling workflows or a complicated, lengthy script. Therefore, the need to model components at their actual length or schematically with the tunnel block needs to be evaluated on a case-by-case basis. Although every software and extension create the same visual output, the process and handling of the output vary tremendously for each.

OpenTunnel Designer® has a specific setup that is primarily based on profile sweeps instead of placing individual elements. For this purpose, the tunnel block cross-section elements are defined in the 2D tunnel template. The specific model setup in the corridor, units, and tunnel template provides a certain structure that can be both beneficial and restrictive. Changes to the tunnel template will be applied to all units it was used for, which can be challenging to modify. To make changes to specific elements, the template could be duplicated, and changes applied to the duplicated template, which has to be placed again. The old elements of the specific unit that need modification will either be deleted or reference lines adapted. However, the selection of an individual element and a quick change of geometry through a value change is not possible in OpenTunnel Designer®.

Revit®, with its family-based approach, offers options to create both profiles and volumes for each element. Each approach includes different ways of parameter handling, modifying, editing, and grouping options. Depending on the setup, elements can be geometrically modified through parameter values, both individually and in groups. The families and their parameter definitions, as profiles or volumes, are created in the Revit® family editor and are extension-independent. However, extensions can impact the process of placing the families.

### 6.3.2 Placement

Each software and extension has a different approach for setting up and placing elements.

Again, OpenTunnel Designer® generates elements based on units, which define a consistent section length and cross-section type. Each unit must be placed individually, which means that the more variation there is in the project, the more units, and thus more time it will take to

generate the elements along the alignment. Additionally, not only do the tunnel templates have to be placed separately for each unit, but the tunnel templates for auxiliaries are also placed in a second step, which further adds to the time required for generation. Even though the simplified project on hand only included two types of cross-sections, a total of 17 units had to be defined based on changes in block length along the 2-kilometer alignment. To place each unit, several steps are required, such as activating the unit to be edited, activating the place tunnel tool, selecting the cross-section type, and manually setting the block length. Once all of these steps are completed for every unit, only the tunnel lining remains. The more variation there is in the project, the longer this process will take.

For FIDES®, the placement of families or profiles is controlled by an Excel sheet template. In this template, the points at which the profiles or 3D elements should be placed need to be defined. All elements that are placed on one sheet will be combined into one family. This means that if a tunnel block is placed along the entire alignment, the whole block chain will end up as one family with several sub-elements. This further implies that if changes to single blocks are needed, either the family editor of the block chain family needs to be opened and changes made there, or the Excel file must be adapted and the entire family regenerated. The placement of individual blocks is therefore possible, but it will have to be defined as an individual Excel sheet for every block, which may not be an efficient approach to placing.

SOFiSTiK®, with its various bridge modelling tools, offers multiple ways to generate or place families. Objects can be placed using tags created along the alignment, lists, manual inputs, or rules that can be set. However, while there are many methods available for generating and placing objects, different families cannot be placed simultaneously. Consequently, an automated workflow cannot be created with SOFiSTiK®.

Dynamo® offers a lot of flexibility when it comes to placing families. Using lists of points or lengths, model lines or curves can be evaluated and calculations, algorithms, or logical functions can be created with the scripting method. Furthermore, multiple families can be placed along the alignment simultaneously, and attributes can be instantly integrated or parameters set. However, the more that is generated and placed with one script, the more complex the script will be, and the longer it will take to execute. Additionally, setting up a functional script can take a long time and may require lots of trial-and-error runs, especially for beginners. Once the script is functional, however, it can be applied to future projects or similar tasks with only minor modifications.

## 6.4 Properties

Overall, when comparing the two authoring software, Revit® and OpenTunnel Designer®, it can be seen that each software handles and integrates properties differently.

In OpenTunnel Designer®, information is attached either in the 2D tunnel template manager for a tagged area or in 3D to an extruded element. For the attachment within the 2D template, the information has to be consistent for all elements that will be generated within this area, whereas when it is attached to an element, the information can be individually set for that

element. However, currently, according to the Bentley Community, it is not possible to attach a set or list of attributes in reference to objects or locations without selecting and inputting the data manually.

Revit® has several types of properties, each catering to different levels and groups within the project. Attributes may be defined for the overall project, specific categories of families, or individual families and can be used as standalone or global (values that are applied to several parameters) values. The benefit of the parameter and attribute setup in Revit® is that setups can be saved and transferred from project to project. Therefore, company- and project-specific Revit® templates or shared parameter files can be created, which can be implemented and specifically extended for each project. Additionally, files for IFC-file export can be created to ensure information transfer to other software.

The extensions FIDES® and SOFiSTiK® do not include any attribution or parameter management tools. They are modelling-driven extensions. In contrast, Dynamo®, the flexible self-programming tool, includes numerous different parameter management nodes. Properties can be created, data integrated, imported, and exported via Dynamo®.

Based on the fact that FIDES® and SOFiSTiK® are modelling tools that do not contribute to information management and that OpenTunnel Designer® has yet to improve property management and integration to use it as a standalone BIM software, a more detailed consideration and comparison was not feasible. However, since property management is one of the main topics in TIM and OpenTunnel Designer® promises to integrate better property implementation in future releases, it should be evaluated further down the road.

## 6.5 Drawing Derivation

Infrastructure projects are typically represented in two-dimensional drawings using cross-sectional, longitudinal, and sub-horizontal sections. One of the challenges is to ensure that the sections accurately follow the alignment, which may involve curves, crests, and dips to show the true lengths of elements. Most software tools only include straight linear sections or generate three-dimensional element curves based on a reference plane derived from two-dimensional drawings made of lines and hatches.

However, TIM excels in creating a link between elements and information. Dimensions and annotation tags placed in views can have a direct relationship with the geometry or attributes of the element they are used on. Therefore, if changes occur, these dimensions and annotations will be automatically updated in all views and sections where the element is displayed. On the other hand, with a literal derivation, there is typically no direct link to the object, and even if the derivation can be updated based on its geometrical changes, annotations and dimensions must be manually set or changed.

Ultimately, the goal of two-dimensional views should be to accurately depict sections that include the element itself, rather than just its derivation to lines and hatches.



### 6.5.1 Cross Section

Based on its linear nature, the cross-section is the simplest of the three sections to produce. The only challenge may be controlling the location of the cross-sections.

In OpenTunnel Designer®, sections are generated using the Create Drawing tool. Cross-sections may be produced at regular intervals or at specific locations along the alignment. Several settings may be chosen, such as vertical exaggeration, top, bottom, and side clearance of the displayed cross-section, as well as the scale for the drawing and annotations. Once the command is executed, drawings are generated, including a header, north pointer, and chainages. In Revit® with SOFiSTiK®, the section tool is used to create sections at specified stations or intervals. These sections include the elements themselves, and any changes made within the sections would modify the data or geometry of the element within the project. Therefore, if dimensions and annotations are placed, they would be automatically modified if any minor geometrical or attribute values are changed. Additionally, these sections include standard view templates, view scales, and display modes.

In Revit® with FIDES®, cross sections are generated using the "Section at Station" tool. However, this tool only creates sections at the chainages handed over during the generation of the blocks. Additionally, even if the Excel sheet included actual chainage numbers, the stations that may be selected are numbered "Station No. X," starting with 1 in ascending order. This may be confusing when trying to locate specific chainages along the alignment, since the attributes "station start" and "station end" do include the values handed over with the list.

Dynamo® uses the standard section function in Revit® to generate cross sections. Depending on the method of component placement, different ways of creating the cross sections can be scripted. They can be generated at points from a list, along an alignment, or via the bounding box of an element. In addition to the standard nodes, several add-on packages, including section view generation, can be found in the package library.

### 6.5.2 Longitudinal Section

The longitudinal section may present a challenge in terms of drawing creation. Due to bends and turns, there is no simple straight-line parallel view to depict the true length of the tunnel. Axis-based software typically includes a longitudinal section as a standard drawing creation tool, whereas building software often lacks this option.

OpenTunnel Designer®, as a tunnel-specific software, includes a longitudinal section creation tool. This section is generated similarly to the cross-section workflow. A boundary box is defined, view scale, intervals, and other settings are selected, and based on the input, the sections are created. The most valuable feature within the generation process is the option of vertical exaggeration. To fit the entire alignment on one drawing, the view scale is usually quite large. Therefore, by exaggerating the z-axis, components of the tunnel can still be recognized based on their shape and not solely as a single line.

Revit®, and consequently its add-on Dynamo®, can only create linear sections. However, linear sections can be created as an array to be placed alongside each other to display a combined longitudinal section, as explained in Chapter 5.1.2.4 Derivation of two-dimensional drawing, modelling sub-chapter in Dynamo®. The advantage of this solution is that the components shown in the sections are real 3D objects and will include the information and adapt modifications to the overall project, not solely to the view. The downside is that once placed, the section itself needs to be selected, and editing must be opened to pick elements and obtain their properties.

SOFiSTiK®'s approach includes the literal derivation and the creation of lines and hatches based on a reference plane. Thus, the elements themselves are not included in the section, and their properties are not linked to the section. The only reference to the 3D elements is the object ID, which is used as an attribute within the hatch properties. Dimensions and annotations can be added to the sections, however, if the derivation is ever updated, it must be checked to ensure that the content is still up-to-date and in the correct location.

The FIDES® solution of the "flattened" tunnel is another creative solution. The flattened tunnel includes all properties and their values from the original objects, so annotations can report these values when placed. However, an instant link to the original elements is not established. Therefore, if modifications are made, the tunnel has to be flattened again, and the old flattened tunnel will be deleted once elements regenerate. Attributes can only be managed in the original tunnel model and not in the flattened model, otherwise, data will be lost, especially if the flattened tunnel is regenerated, and the file size increases due to duplicate elements and information data. Moreover, it would have to be ensured that in an export, only the original tunnel elements are exported and not the flattened tunnel model.

### 6.5.3 Sub-horizontal Section

The sub-horizontal section is similar to the longitudinal section in that it follows the same principle. It aligns with the slope of the axis facing downward at a consistent height across the cross section. In OpenTunnel Designer®, all drawings are generated using the 'Place Named Boundary' command. However, this command only offers the option to create a 'Civil Plan' layout view, and it's unclear if a sub-horizontal section can be created using the currently available tools.

Revit® uses levels to create layout or plan views, which can only be generated horizontally within the project. Levels cannot be rotated or sloped, but their height can be adjusted. However, Revit® allows sections to be rotated in all directions, which means that a downward-facing section can be used as a sub-horizontal section. FIDES® and SOFiSTiK® do not provide a dedicated sub-horizontal section tool, so this type of view must be created manually. In contrast, Dynamo® includes nodes that allow views to be created based on bounding boxes and coordinate systems. With the appropriate alignment, points and vector sections can be placed using a script.

While the example project has a consistent slope, other projects may have sections with crests and dips. For a consistent slope, a sub-horizontal section is a straight-line section, but for an alignment with varying elevations, an array of sections identical to the longitudinal section must be generated. The same challenges, limitations, and solutions for further drawing annotation that apply to the longitudinal section also apply to the sub-horizontal section

## **6.6 Comparison Summary**

After conducting a thorough evaluation of the software tools for TIM, the findings and their evaluation have been summarised in a final overview and comparison table, as described in detail in the previous chapters. This table provides an overview of the overall output of the comparison and highlights the strengths and weaknesses of each tool. However, it should be noted that more detailed and background information is often necessary to fully understand the summary.

In the overview table, tasks that are deemed possible or feasible are marked with a check mark, while categories marked with an "x" are considered to be insufficiently integrated or not possible at all. This helps to quickly identify which tools are most suitable for specific tasks and applications.

It is important to recognise that modelling 3D objects provides a necessary foundation for TIM, but it is not the sole component. The evaluation has only superficially touched upon some additional tasks outside the modelling aspect, such as property generation and export options. More in-depth analyses may be necessary for a comprehensive evaluation of the software tools in these areas.

Additionally, it should be noted that the assessments presented in the evaluation are limited to the findings of the self-study and the capabilities of the current software release. As technology advances and new software versions are released, the capabilities and limitations of these tools may change, affecting their suitability for different projects and applications.

Despite these limitations, the evaluation provides valuable insights into the performance and suitability of the software tools for TIM. The final overview and comparison table, together with the detailed analysis presented in the previous chapters, offers a comprehensive picture of the strengths and weaknesses of each tool and can serve as a useful guide for practitioners and researchers in the field.

CRITERIA		REVIT			BENTLEY	
		Dynamo	FIDES	SOFISTIK	OPENTUNNEL DESIGNER	
General	User Interface		Interface based on disciplines (architecture, civil, annotate, analyse, ...) Programming, scripting -> knowledge of names of nodes	Simple set up manageable number of tools can all be seen at once	Lots of different interfaces (workflows) including same functions	
	User Profile		Coding + modelling	Modelling		
	Scripting Capabilities		✓	Other add on or apply Dynamo (free software)		
	IFC Export		✓			Indirect
Alignment	Data import	Import file types	Any Revit possible import *.xlsx, *.csv, *.json, *.txt,	*.xlsx	*.xml, *.cdb, *.txt, *.csv, *.xyz, *.tra, *.gra, *.json	*.xml, *.ifc, *.12dXML, *.fil, *.inp, *.txt, *.alg, *.gpk
		Data types	Coordinates, objects	Coordinates	Objects or coordinates	Objects or coordinates
		Coordinates	coordinate transformation			World coordinates
	Element	Object	Model line, any family type, multi-segment grid	Model line	Generic model family	Axis (complex element and line)
		Modify or edit	Move elements with script	Modify points in excel	Alignment tool	Manually editable
	Orientation	Chainage as reference	Script example: control chainages via axis and length	x	✓	✓
		Annotation in perspective	✓ (3D annotation family, place with script)	x	✓ (3D annotation family = placement)	x
		Annotation in 2D view	✓	x	✓	✓
	3D Modelling	Tunnel block	Object	Family		
Concrete structure			2D profile extrusion or 3D adaptive component			2D profile extrusion
Parametric after placing			Separate values for each element			Tunnel template
Changes			✓ Script example: change parameters	✓ Family parameters		✓ Family template, not single volumes
Flexibility		High	Restricted	High	Restricted	
Placement		Length control	Points or lengths from excel, direct input, calculations, ...	Points from excel	Placements (chainages) and lengths	Tunnel unit reference lines and lengths
		Different cross section types	Together (as individual components)	Together (as <u>one</u> family)	Separately	Separately for tunnel templates (auxiliaries together)
	Automate placing	✓	✓ (as one family)	x	x	
Attributes	Management Tool		Code	x	x	Vision for further releases
	Setup		Flexible for each element within the project (individual, as type, shared, ...)			Manually for areas or elements
	Create		Script: create shared parameters	Within individual families or as shared parameters for family categories		Assigned to areas in 2D tunnel template or 3D elements
	Fill and Manage		Script: from Excel SetParameteValueByName	Manually or other add-on		Manual
Derivation Drawing	Cross section	Create	✓	At points from excel	Flexible definition via placements, intervals	Boundaries, chainage and interval
	Longitudinal Section	Create	Script: place sections along alignment	Tool - flatten tunnel	Tool - derivation to lines and hatches	Tool
		Chainage annotation	Script: gridlines at chainages, annotation families	x	✓	✓
		3D objects editable in sections	✓	x	x	x
	Sub-horizontal Section	Create	Simple section			Layout view with drawing generation set, sub-horizontal section to be determined
		Chainage annotation	Code	x	x	
		3D objects editable in sections	Script: gridlines at chainages, annotation families	✓	✓	
Limitation		Solutions for consistantly inclined sections				

## 7 Conclusion

The objective of this thesis was to evaluate and compare various software solutions and their extensions for generating a tunnel structure model for TIM, with a particular emphasis on parametric modelling. To test and compare the chosen software solutions, an exemplary structure model was implemented, and a step-by-step guide was created for the applied modelling solutions. Based on a literature review and the constructed workflows, the different capabilities of TIM to create a structure model were evaluated and compared. According to the experiences and findings, it can be concluded that all applied methods have benefits as well as challenges for modelling. While tunnel-specific tools provide immense potential for first-time software users, they may limit the implementation of project- or company-specific requirements. In contrast, while visual scripting comes with a high degree of flexibility, the method presents challenges for scripting beginners due to their limited knowledge of nodes and code sets.

OpenTunnel Designer® seems to have great future potential as a TIM software, but to get there, the software has to improve its modelling capabilities in terms of flexibility (for example, the integration of cross passages), attribute management and export in order to become a competitive standalone software solution. Currently, only when combined with other, more property-capable software developments like iTwin® or MicroStation® does it present itself as a powerful TIM tool. In contrast, Revit® limitations involve integrating world coordinates and the defined modelling boundary, while it excels at property management and data export.

Overall, TIM is a complex process that requires the consideration of various factors. The selection of software will depend on the overall capabilities and limitations of the software, specific project goals, overall client requirements, and especially user abilities. Based on their current capabilities and release status in 2022, the evaluated software and extensions do not yet fully meet TIM's defined or anticipated needs as standalone software solutions. However, software development is a rapidly evolving field, and new add-ons, further extensions, and software releases are constantly introduced. Ultimately, the choice of which software works best and will be used must be made based on present market developments and the available options and solutions at the time of implementation.

## 7.1 Future research

While this thesis provides insight and a comparison of currently used software products and modelling solutions for generating TIM structure models, TIM is an incredibly vast field, encompassing many different topics and opportunities with ample research possibilities to explore. Therefore, keeping up with current industry developments is necessary due to rapid advancements and further software solutions should be tested and compared to gain a more detailed overview of the solutions available on the market. The exemplary project and the structure of the comparison may provide an organised foundation to compare additional software solutions and extensions. It can also be used to keep track of software developments and future releases. Additionally, it provides an overview of the tools required to create TIM structure models and the capabilities to look for when comparing other software solutions. Furthermore, the created modelling workflows may be used by modellers who want to embark on their TIM journey or by companies that want to introduce TIM to their repertoire. The guidelines can be further expanded and adapted to project-specific solutions or company requirements.

In the end, this thesis provides a solid foundation for future research. The topics only superficially touched upon, such as property generation and management, IFC export, and drawing annotations containing changes create an opportunity for further studies and developments. Finally, the workflows and the resulting models provide a good basis for exploring previously unexplored topics, such as quantity take-off, process simulations, the integration of sensor data, data exchange, and further TIM studies.

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## **9 Appendix**

## 9.1 Modelling workflow Revit®

### General setup

#### Step 1: Create New Project

To guarantee that even users without any prior software experience can follow along with the workflow guideline, a standard project template is used, as seen in Figure 9-1.

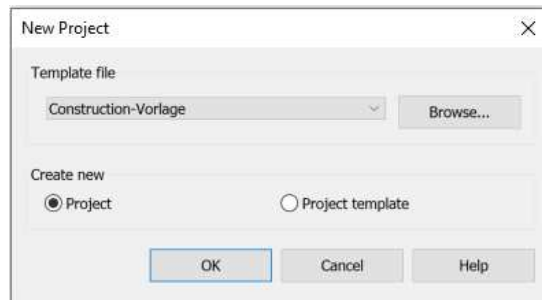


Figure 9-1: Start view of new project

#### Step 2: Change Units

Once the template opens, it is crucial to make a few basic pre-existing set-up changes. For this tunnel project, it was decided to only have one reference level at sea level; therefore, every other level was deleted from the project. Next up, the units should be checked and changed, as seen in Figure 9-2, as they are often initially set in the imperial system.

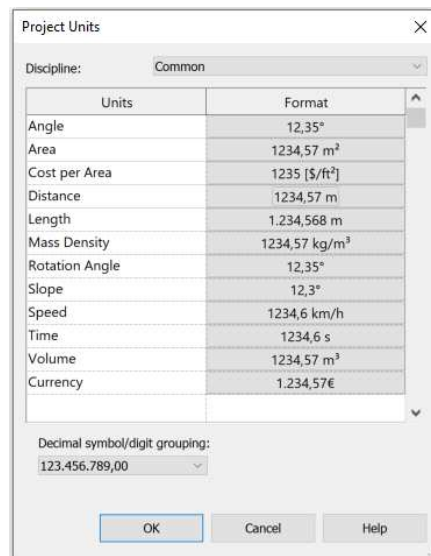


Figure 9-2: Project units within Revit ®

### Location

#### Step 3: Set Project and Survey Base Points

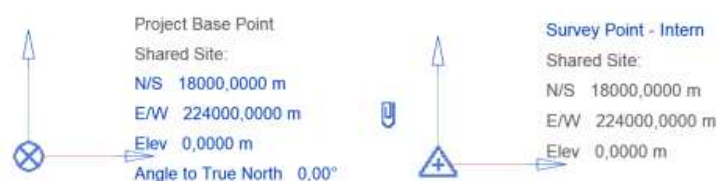
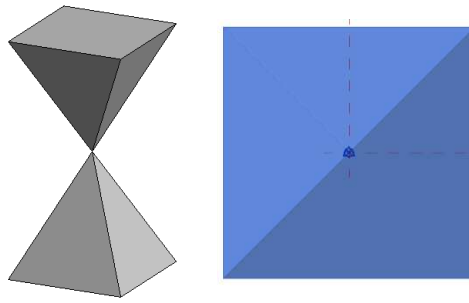
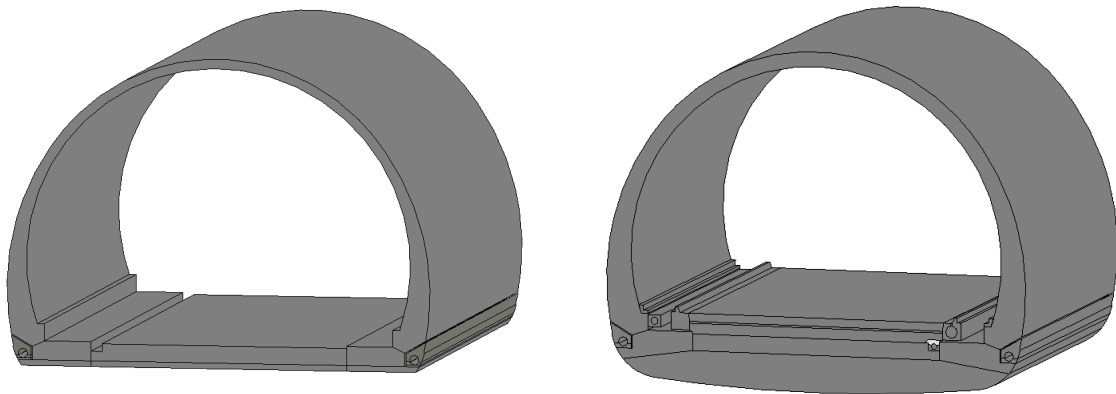


Figure 9-3: Project and Survey Base Point location

*Step 4: Place Project Coordination Marker**Figure 9-4: Project Coordination Marker**Step 5: Pin Project Coordination Marker*

This will make sure the object is not accidentally moved.

**Families***Step 6: Create or import project specific families*

*Figure 9-5: Standard Cross Section - 6700 SCS-IL25*    *Figure 9-6: Standard Cross Section – 6702 SCS-IL40*

*Step 7: Load families into project**Step 8: Save project as template*

If the project is saved after the above-mentioned steps, the setup can be used for all future coordination sub-models in the same segments. It not only saves some time since the steps don't have to be repeated, but it also eliminates possible project and survey point location errors that can occur when set manually.

**9.1.1 Dynamo®****Import Alignment and Place Families***Step 9-1: Set up excel files*

For Dynamo®, the TIM-Alignment excel file was split up into three sheets. The alignment sheet includes stations with their coordinates and the corresponding profile as seen in Table 9-2. Then

sheets for each profile type were generated, including stations, block name, block length, as well as the tunnel metre station shown in Table 9-2.

Stations	X (E/W)	Y (N/S)	Z (Elevation)	Profil
02+007,50	18093,15	224178,93	777,56	6700
02+020,00	18081,79	224173,73	777,68	6700
02+032,50	18070,43	224168,50	777,81	6700
02+045,00	18059,09	224163,25	777,93	6700
02+057,50	18047,76	224157,96	778,05	6700

Table 9-1: Setup of alignment sheet

Station	Block Name	Block Length [m]	Tunnelmeter [m]
03+035,75	096	12,50	1028,25
03+048,25	097	12,50	1040,75
03+060,75	098	12,50	1053,25
03+073,25	099	12,50	1065,75
03+085,75	100	12,50	1078,25

Table 9-2: Setup of 6700 and 6702 sheet

As the second Excel file TIM-Attributes-Parameters, include all attributes and parameters which are to be integrated into objects of the model, as shown in Table 9-3.

Date	Time	Tunnelmeter from East	Round of Length	Geo Docu No.	No. of round	Docu in %	Docu from	Saved Server [A]	Saved [ÖBA]	Section	Advance class	Station	Section I	Rock Type I	I %	Section II	Rock Type II	II %	Sum	Rock behaviour
27.05.2016	NA	9,40	0,00	1	1	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	9,40	A	GA-F01	90	B	GA-L06	10	100	3
27.05.2016	NA	10,70	1,30	2	2	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	10,70	A	GA-F01	80	B	GA-L06	20	100	3
28.05.2016	NA	12,00	1,30	3	3	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	12,00	A	GA-F01	50	B	GA-L06	50	100	3/11
28.05.2016	NA	13,30	1,30	4	4	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	13,30	A	GA-F01	40	B	GA-L06	60	100	3/11
28.05.2016	NA	14,60	1,30	5	5	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	14,60	A	GA-F01	40	B	GA-L06	60	100	3/11
29.05.2016	NA	15,90	1,30	6	6	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	15,90	A	GA-L06	75	B	GA-F01	25	100	3/11
29.05.2016	NA	17,20	1,30	7	7	100	IM	ja	ja	Kalotte	KF-6; (bis 1, 30)	17,20	A	GA-L06	60	B	GA-F01	40	100	3/11
30.05.2016	NA	18,50	1,30	8	8	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	18,50	A	GA-L06	40	B	GA-F01	60	100	3/11
30.05.2016	NA	19,80	1,30	9	9	100	IL	ja	ja	Kalotte	KF-6; (bis 1, 30)	19,80	A	GA-F01	60	B	GA-L06	40	100	3 (bzw. 3/11)

Table 9-3: Setup of TIM-Attributes-Parameters excel file

Step 10- 1: Generate (or adapt if existing) Dynamo® scripts

“TIM\_PlaceFamily\_Points-Blockdistance-from-Excel.dyn”

The first script will create a line according to the alignment sheet coordinate points, and then use the second script to generate tunnel blocks according to their block length in the given profile. The steps of the script are described in more detail on the following pages.

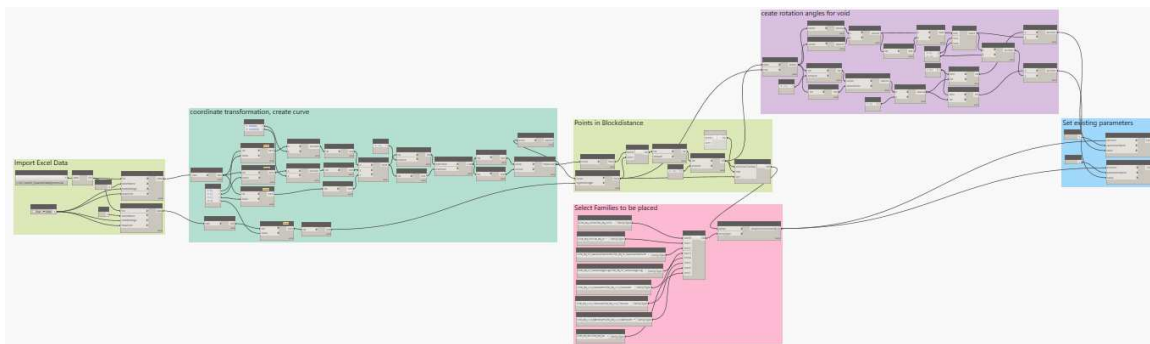


Figure 9-7: Overview of Dynamo® script



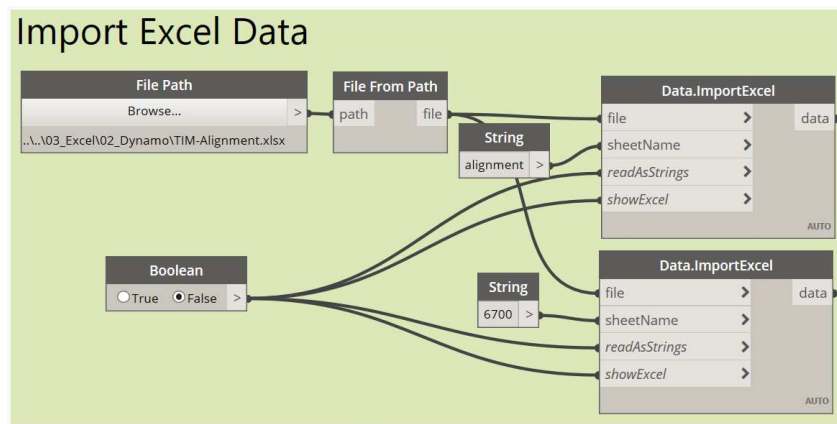


Figure 9-8: Data from excel, group 1

The excel file is imported into Dynamo® and the alignment sheet is used, Figure 9-8.

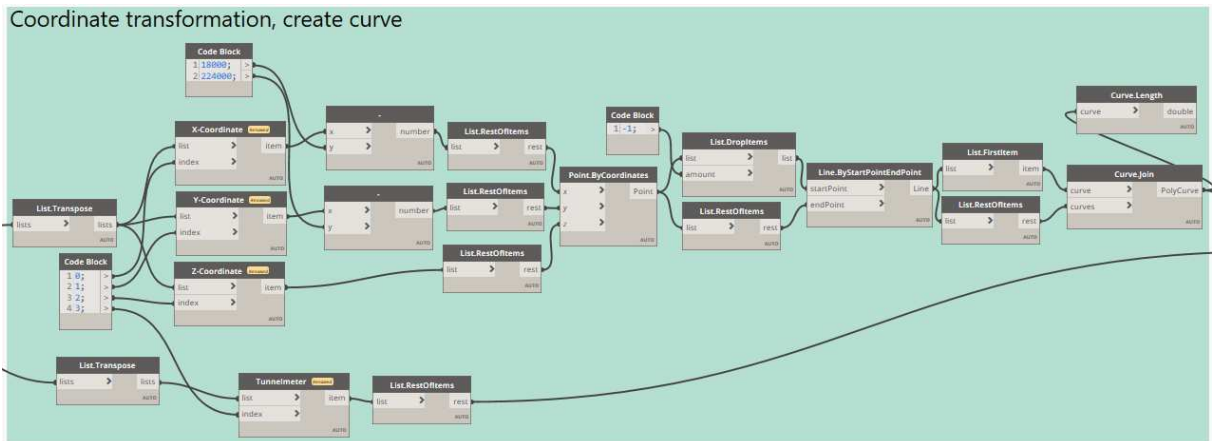


Figure 9-9: Create a model curve using coordinates, group 2

X, Y and Z coordinates are transformed to fit the modelling boundary of Revit® and points are created. These points are used to create a curve to show the alignment within Revit®, Figure 9-9.

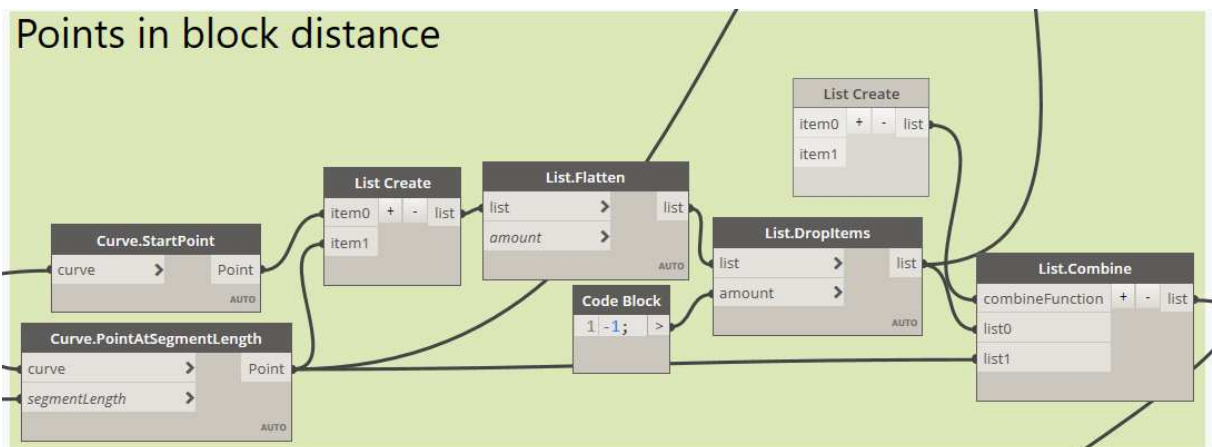


Figure 9-10: Points in block distance, group 3

This step can be skipped if the coordinates of the alignment already represent the block distance points. If not, this group of nodes uses the alignment and creates points along the curve at a distance fed by the excel sheet in terms of tunnel meters, Figure 9-10.

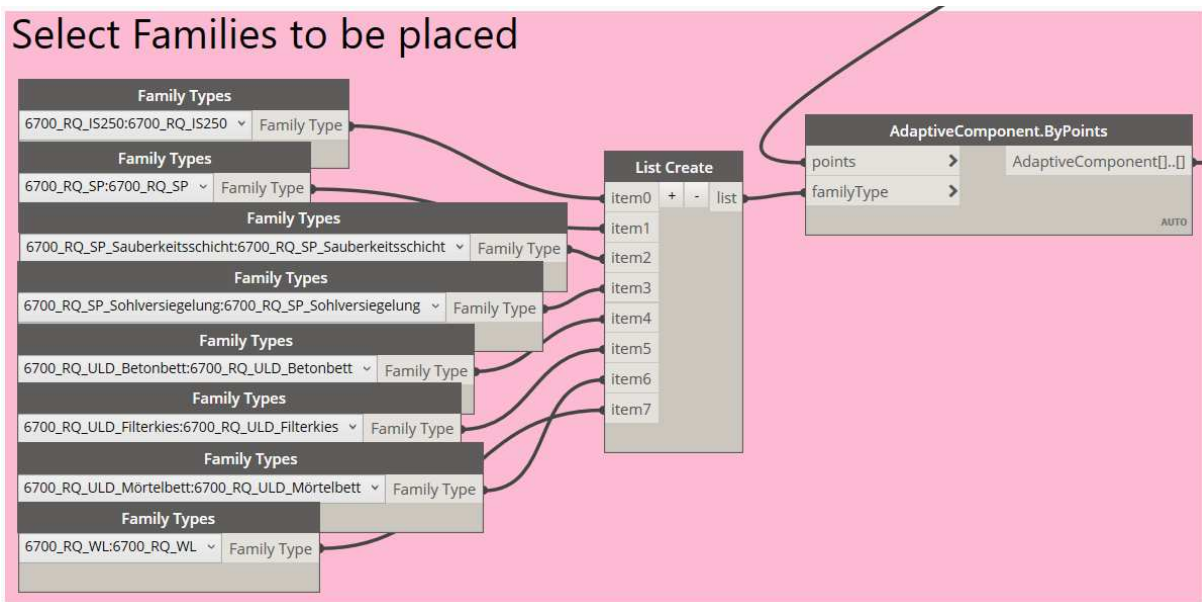


Figure 9-11: Select families to be placed, group 4

In Figure 9-11 all families that will resemble the cross section will be selected and fed to the place where adaptive component points are located. All families include two adaptive points, which will be handed over as the points list is created in group 3, Figure 9-10.

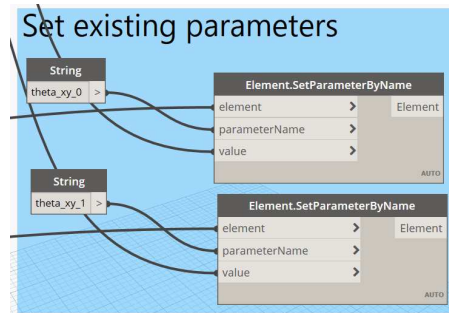
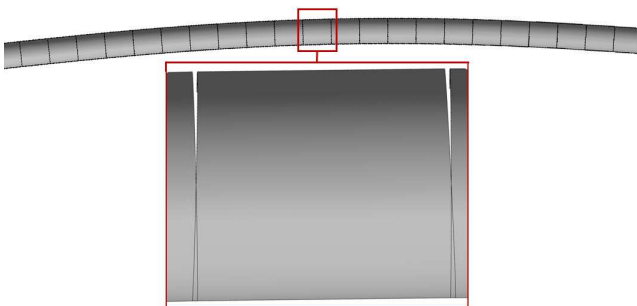


Figure 9-12: Gaps in curves along the alignment without rotation of void

Figure 9-13: Set rotation parameter, group 5

Once the family is placed, any included parameter may be instantly set if possible. In Figure 9-13 the adaptive component point is set as an element, the properties that are to be filled need to be set as names and the values will be added in the end. Here, the rotation angles of the void sitting on the xy plane are set to be able to create bends and curves along the alignment to eliminate the gaps between segments, as seen in Figure 9-12. The needed angle is hereby calculated through vectors within the Dynamo® script see Figure 9-14, they could be calculated in Excel as well and fed directly to the parameter as well.

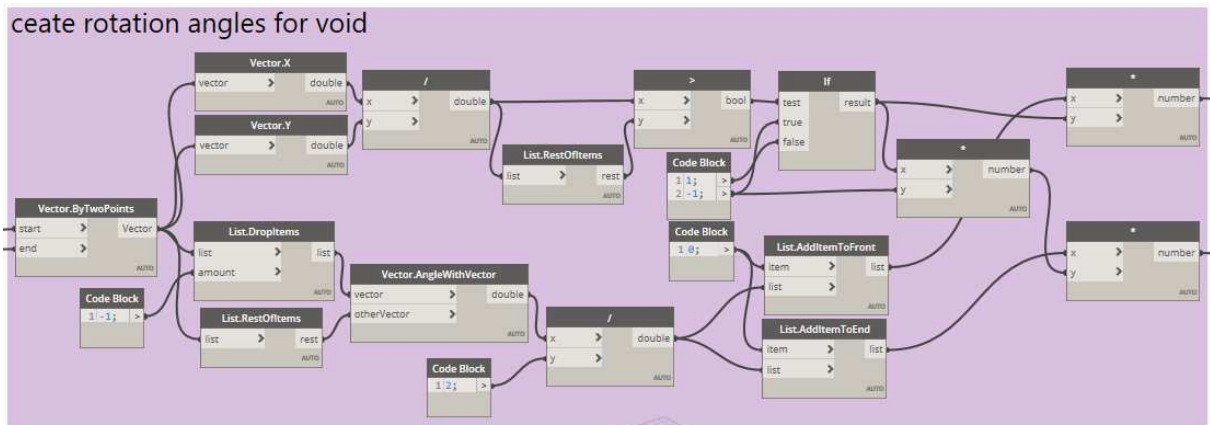


Figure 9-14: Calculating rotation angles with vector, group 6

Step 11-1: Run scripts

### Check output

Step 12-1: Check output in terms of logic and correct implementation of attributes on a sample basis

Once all elements are placed, the output needs to be checked and verified, Figure 9-15. Especially if the script run ends with warnings or errors, even if the script runs successfully, there may be a wrong outcome in terms of parameter or attribute integration, which makes the need for a random object check a necessity.

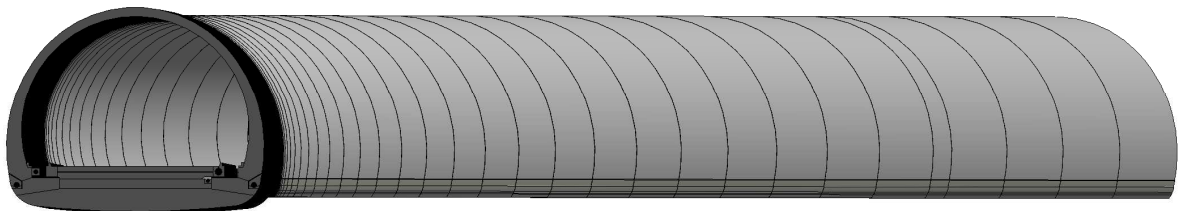


Figure 9-15: Generated model with Dynamo® script

## Attributes and Parameters

### Create Attributes

For this project, property sets for attributes were created using another Dynamo® script. This script may be used once the objects are placed and will create property sets from the Excel list “TIM-Attributes-Parameters”, Figure 9-15. This is one of many ways to create parameters and attributes. Another option is to include them right away once the families are generated; another is to use other extensions that help with parameter integration.

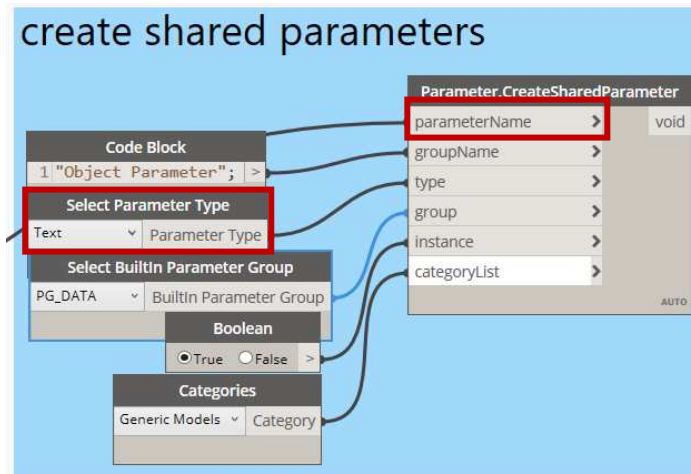


Figure 9-16: Create shared parameters for generic model category

The property sets may be generated using an Excel list. For this, the lists need to be set up with parameter names as well as the referring parameter types. Once the script is used and the parameters are generated, they may be filled with the next Dynamo® script.

*Step 13-1: Run script*

### Fill Attributes

The last step is to fill the property sets, either by editing the values manually in Revit® using another Dynamo® script. For this, object need to include some sort of reference to be filtered and to add information to the right location.

To achieve the correct correspondence the Object ID may be exported into an excel sheet including these parameters, to directly have an ID linked to information. This is one of many property management options. Better solutions should be attained.

### 9.1.2 FIDES® Infrastructure Toolbox “FIT”

Use template from *step 8* and continue below.

Once the FIT toolbox is loaded, Revit® has a new group named “FIDES®”. Here we will be using the functions “Import Track” as well as “Block” as seen in Figure 9-17.

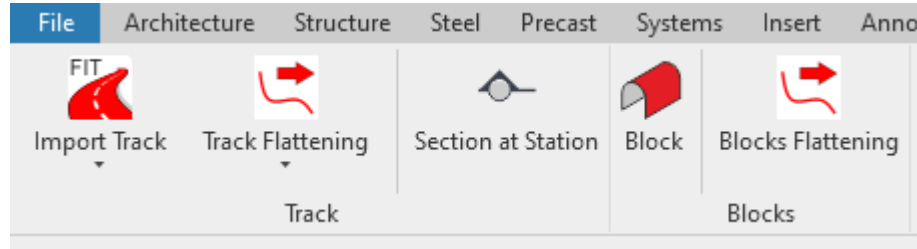


Figure 9-17: Extension functions in FIT toolbox

### Alignment with FIDES®

*Step 9-2: Set up excel file according to FIDES® template*

The first excel file is split into two sheets “Trasse,” Table 9-4, which includes stations, coordinates and the profile that has to be placed and “Tunnel”, Table 9-5, which further details the cross sections. To actually use the tunnel sheet, the families need to be specifically set up in a way to be able to use the parameters included.

Station	Easting	Northing	Elevation	#Profil
02+007,50	18093,15	224178,93	777,56	6700
02+020,00	18081,79	224173,73	777,68	6700
02+032,50	18070,43	224168,50	777,81	6700
02+045,00	18059,09	224163,25	777,93	6700
02+057,50	18047,76	224157,96	778,05	6700

Table 9-4: Excerpt of the Excel sheet “Trasse”

Station	Easting	Northing	Elevation	#Profil	#Profil	#Profil	#Profil	Querneigung
0+000.000	3361525,418	5664388,365	86,963	02_Ausbruch	02_AS_ring	02_Innenschale	02_Unterbau	2
0+004.000	3361524,888	5664384,400	86,805	02_Ausbruch	02_AS_ring	02_Innenschale	02_Unterbau	2,05
0+008.000	3361524,359	5664380,435	86,634	02_Ausbruch	02_AS_ring	02_Innenschale	02_Unterbau	2,1
0+012.000	3361523,830	5664376,470	86,464	02_Ausbruch	02_AS_ring	02_Innenschale	02_Unterbau	2,15
0+016.000	3361523,300	5664372,506	86,293	02_Ausbruch	02_AS_ring	02_Innenschale	02_Unterbau	2,2

Table 9-5: Excerpt of the Excel sheet “Tunnel”

Another Excel is set up to place the tunnel blocks. The first sheet, “Trasse,” is similar, as seen in Table 9-4, with the exception that the profile row is needed. The second sheet, “Blockeinteilung,” is set up as seen in Table 9-6. The orange fields need to be manually added, whereas the rest will be calculated. It is further necessary to have the referenced family within the same file path as the Excel file.

nr	von	bis	#FamilyName	Start Station	End	Blocklänge
1	2+007.500	2+020.000	Tunnelblock	2007,50	2020,00	12,5
2	2+020.000	2+032.500	Tunnelblock	2020,00	2032,50	12,5
3	2+032.500	2+045.000	Tunnelblock	2032,50	2045,00	12,5
4	2+045.000	2+057.500	Tunnelblock	2045,00	2057,50	12,5
5	2+057.500	2+061.750	Tunnelblock	2057,50	2061,75	4,25
6	2+061.750	2+074.250	Tunnelblock	2061,75	2074,25	12,5

Table 9-6: Excerpt of the Excel sheet "Blockeinteilung"

## FIDES® Families

Step 10-2: Create project specific families based on FIDES® template

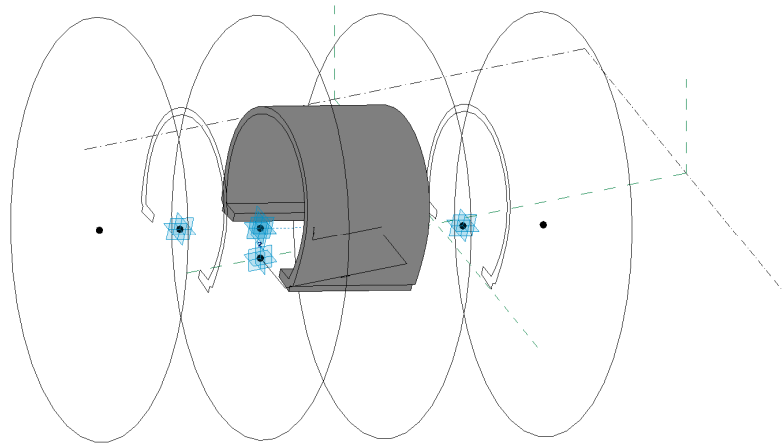


Figure 9-18: Sample family provided by FIDES®

## Project Specific Families

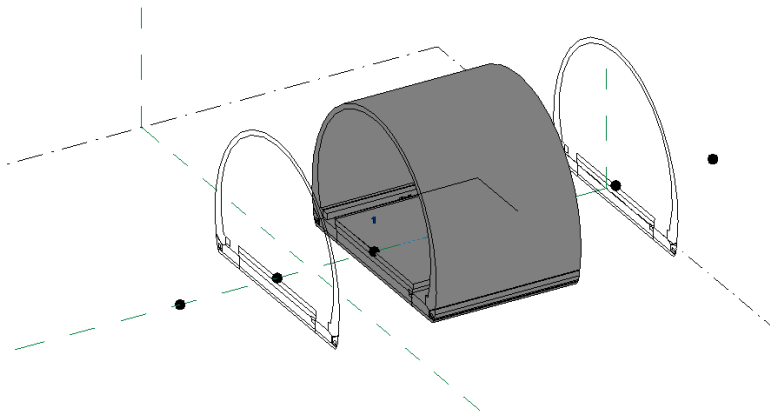


Figure 9-19: Project specific family set up (based on FIDES® template)

For each cross section, a separate family is created. Here the previous families used in Dynamo® 6700 and 6702 are used due to the already fitting setup.

### Place Families

Step 11-2: Load excel in “Import Track” with FIT tool

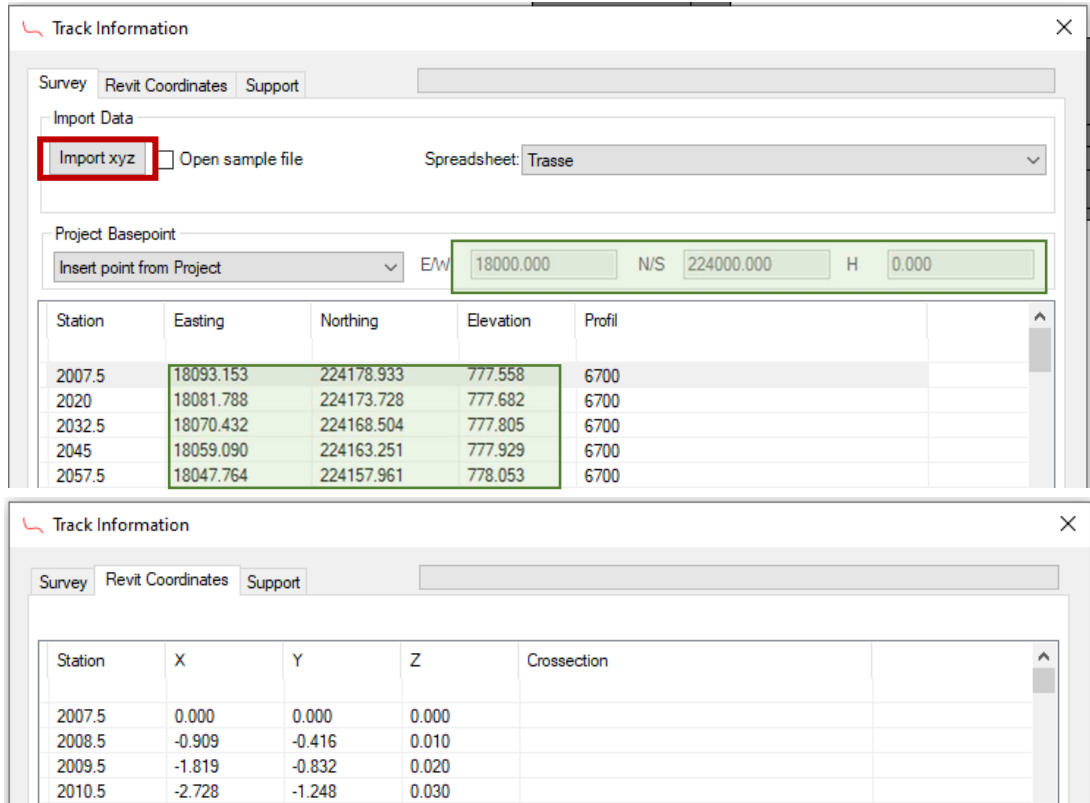


Figure 9-20: FIDES® coordinate transformation during importing

### Step 12-2: Load excel in “Block” with FIT tool

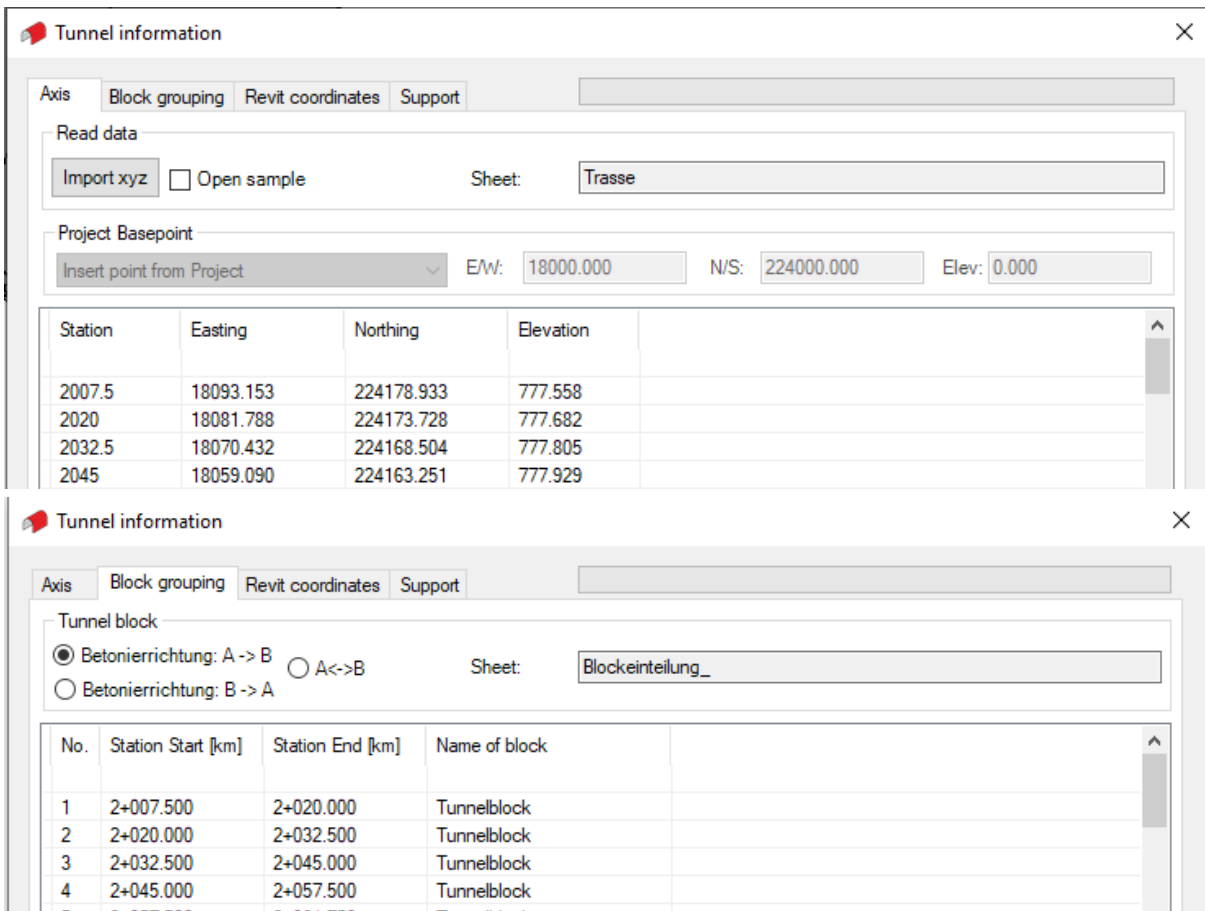


Figure 9-21: Create “Block” function based on “Blockeinteilungs” excel file

## Output

### Step 13-2: Check output

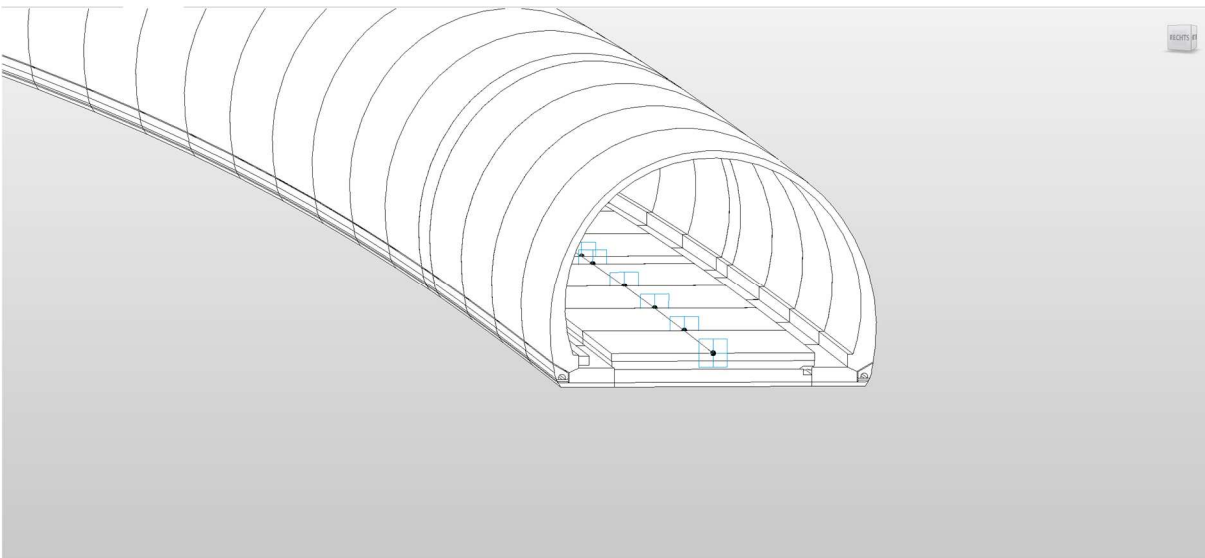


Figure 9-22: Output with FIDES® FIT toolbox



### 9.1.3 SOFiSTiK® Bridge + Infrastructure Modeller

Use template from step 8 and continue below.

Once the SOFiSTiK® Bridge and Infrastructure Modeller is loaded, Revit® has a new group named “SOFiSTiK® Bridge”. Here we will be using the functions “Axis,” see number one, creation of “Structures,” see number two and the drawing derivation tools see number three as seen in Figure 9-23.

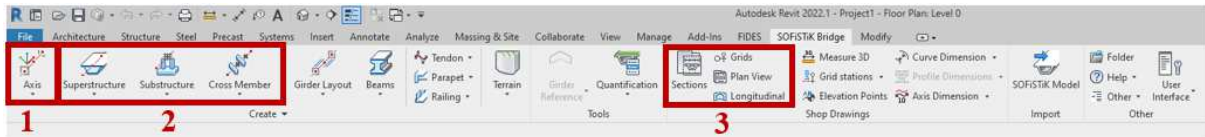


Figure 9-23: Overview of SOFiSTiK® Bridge tools

### Alignment

Step 9-3: Create Alignment (see 1, Figure 9-23)

Create or import an alignment using the axis tool, Figure 9-24. Define placements at stations with block distance or cross-section changes.

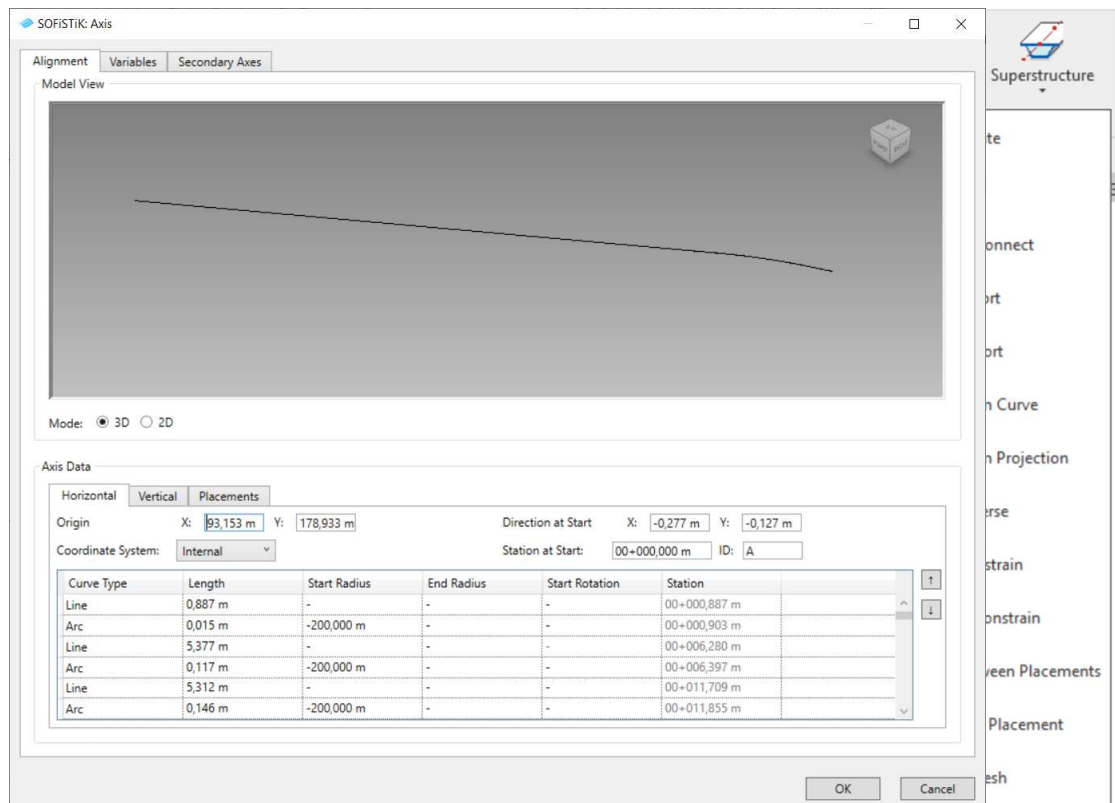


Figure 9-24: Axis manager

Step 10-3: Create Placements

Placements are tags along the alignment that indicate changes or an important station, e.g., for the beginning and end of a niche or a cross passage. In this project, beside the start and end placements, the location of the cross-section change was defined. Furthermore, the placements

include both the project kilometre station as well as the tunnel metre reference, as seen in Figure 9-25.

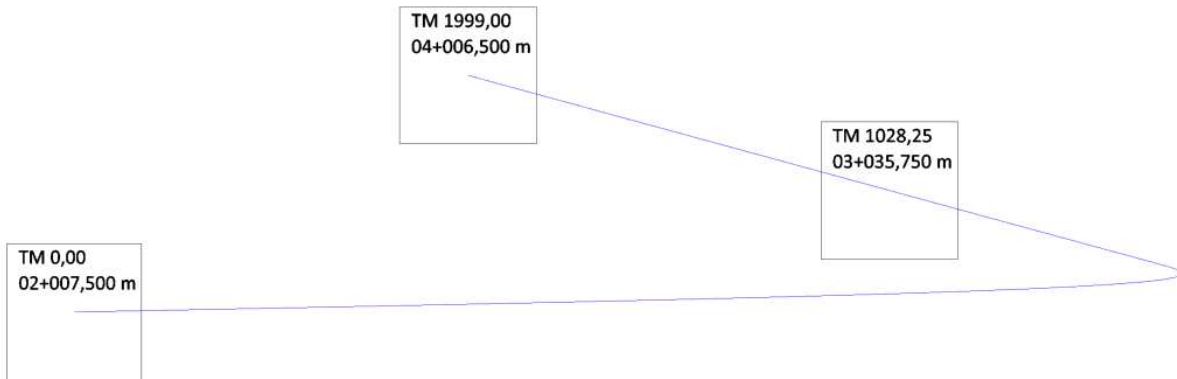


Figure 9-25: Alignment and placements generated with SOFiSTiK®

### Place Adaptive Components

#### Step 11-3: Import or reference families

Under the cross-member tool is a little drop-down menu to access the SOFiSTiK® settings. In the settings, folders are referenced, in which the project families will be taken from and stored. Here the same families that have already been used in Dynamo® were placed, as seen in Figure 9-26

#### Step 12-3: Place first family

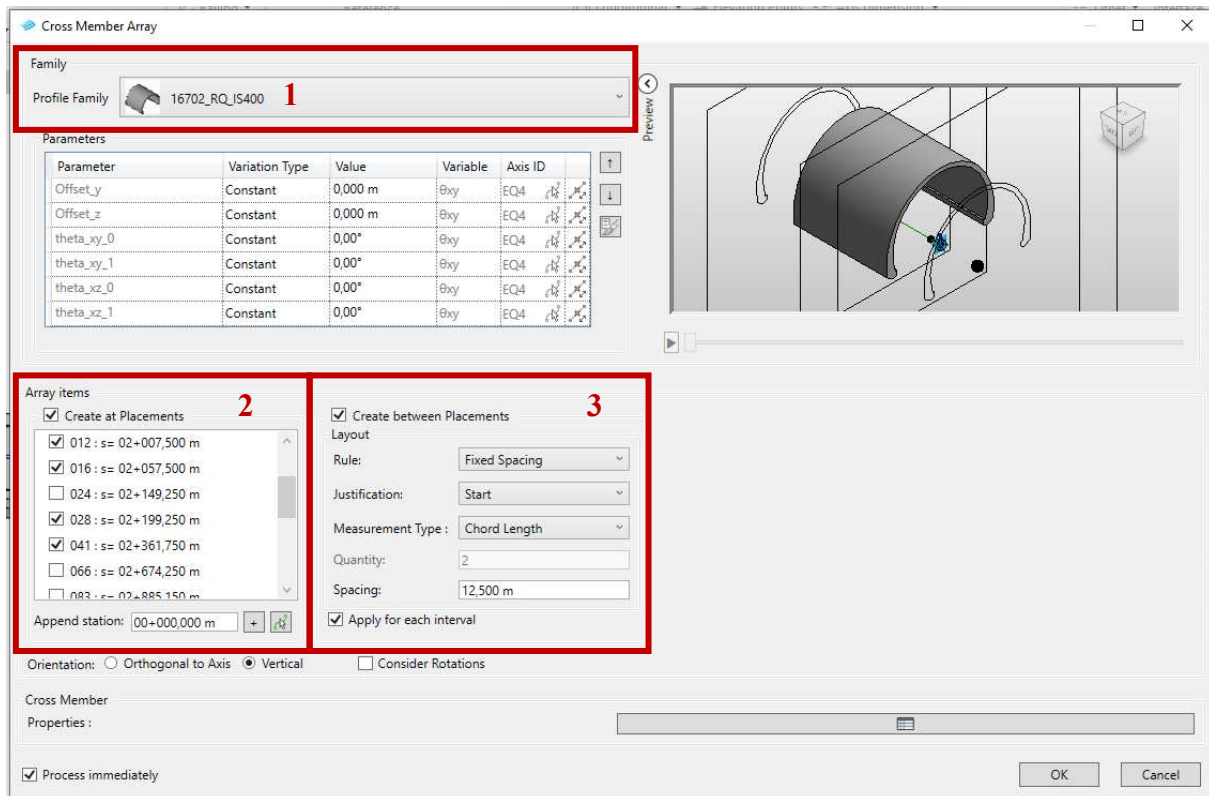


Figure 9-26: Adaptive Component placement with SOFiSTiK®

1. Choose family to be placed
2. Select placements in between families that should be placed
3. Define block division in between placements

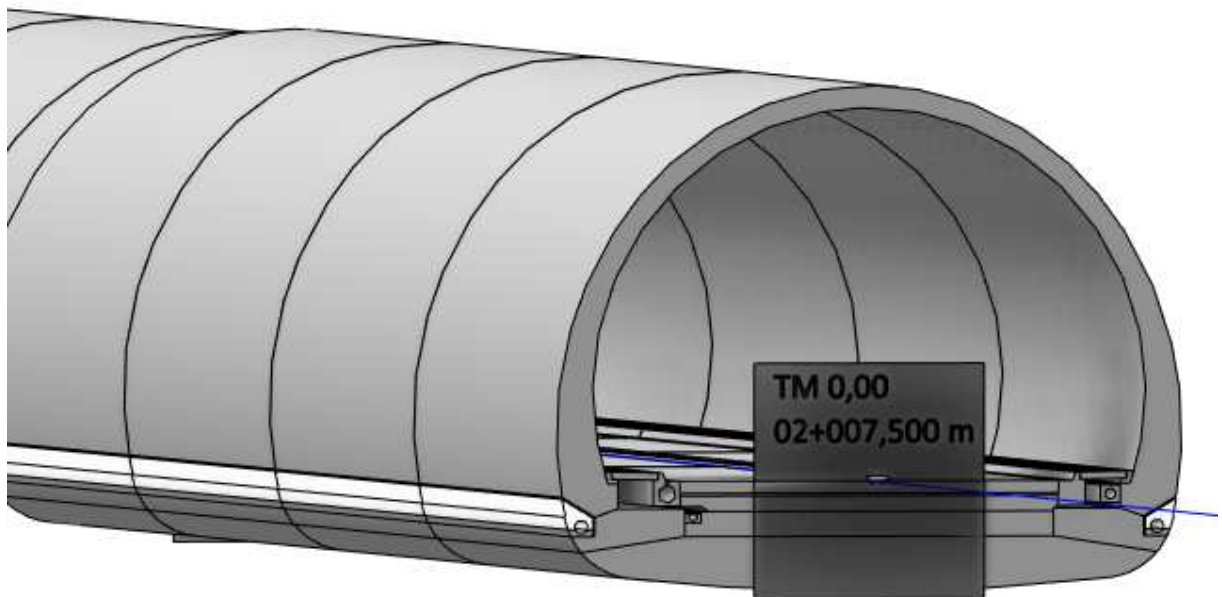
For this project, the usual block length is 12.5 meters, but this is not consistent over the whole alignment due to cross passages, lay-bys, ... The array starts the generation of a 12,5-metre block at each placement; if there is a placement before finishing the 12,5 meters, the block will be shorter and a new block will be generated again. Therefore, if placements are set correctly, all of them may be chosen at the same time with the spacing set to 12,5, and SOFiSTiK® will still consider the shorter blocks and create them accordingly.

*Step 13-3: Place rest*

This step has to be repeated with every family that is to be placed.

## Output

*Step 13-3: Check output*



*Figure 9-27: Finished tunnel*

## 9.2 Modelling workflow OpenTunnel Designer®

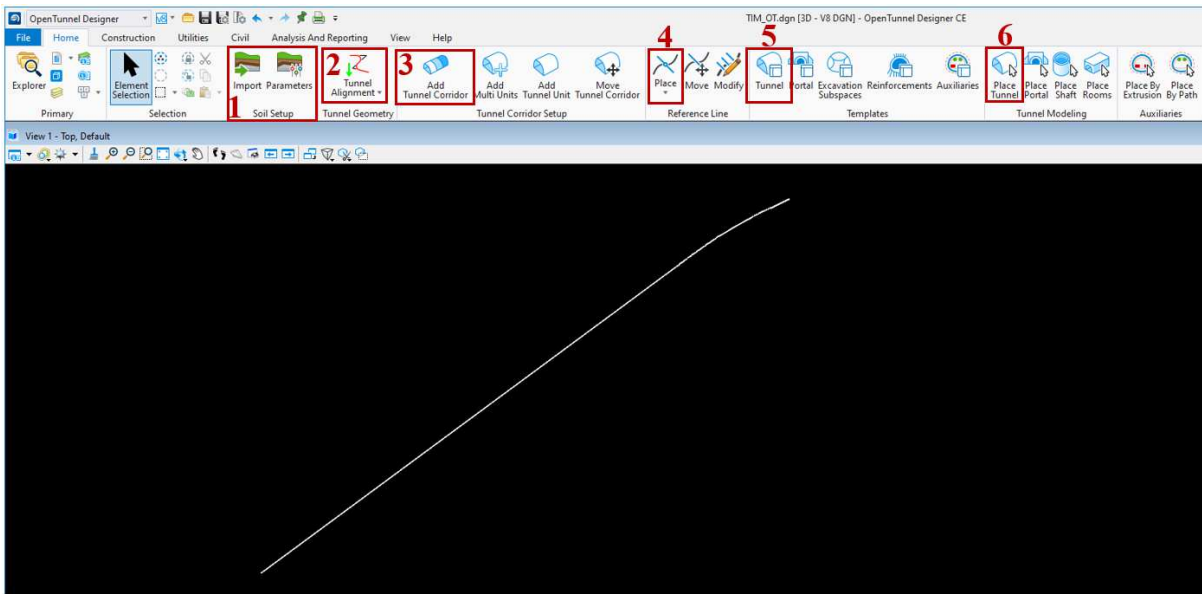


Figure 9-28: Overview of tools in OpenTunnel Designer®

In OpenTunnel Designer® a ground model may be imported for example from leapfrog (see 1, Figure 9-31). This step is not essential and was skipped in this project.

*Step 1: Import landXML alignment (see 2, Figure 9-31)* The alignment was imported using the "Tunnel Alignment" tool. It is important that the alignment have a height reference, for example, due to the longitudinal section of the alignment in Civil3D.

*Step 2: Tunnel Corridor (see 3, Figure 9-31)*

The tunnel corridor is defined by simply selecting the alignment and giving the corridor a name. A corridor can be either different sections of one tunnel or one tube of a twin tunnel. For this project, one corridor was implemented into the project. In this step, the first tunnel unit is already implemented.

*Step 3: Add Tunnel Units (see 4, Figure 9-31)*

A tunnel unit is a section in which the same cross section is set at the same block distance. The units are defined by two reference lines placed at the first and last stations of the tunnel unit. For this a list needs to be created with the unit lengths (see Figure 3) The units were named after the blocks they included. For example:

B12-15	from station KM 2+007,500 – KM 2+057,500 block distance of 12,5 m
B16	a single block with length 4,25 m from 2+057,500 – 2+061,75
B17-80	from station KM 2+061,75 – KM 2+861,75 block distance of 12,5 m
...	

For this the "Add Multi Units" command was used.

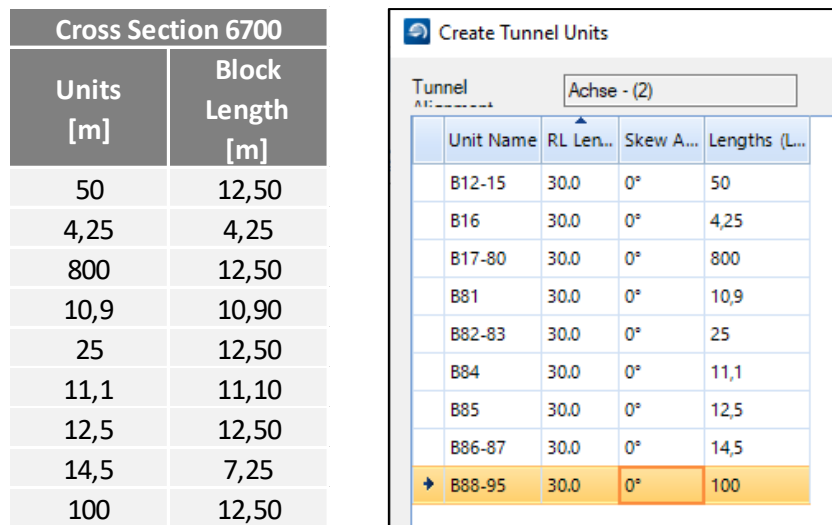


Figure 9-29: Create Tunnel Units

Once created, a reference line for each tunnel unit will be placed, see Figure 9-33.

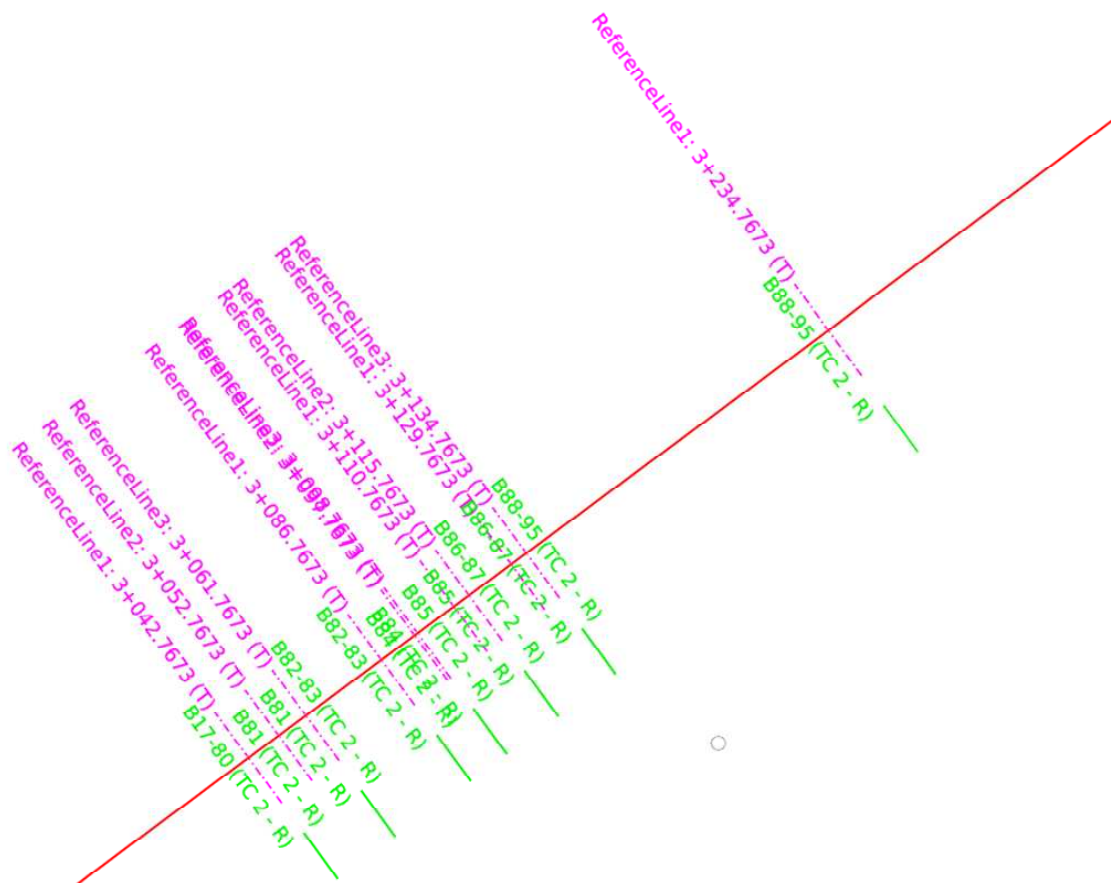


Figure 9-30: Generated reference lines

Step 4: Create or import cross section as tunnel template (see Figure 9-31), tunnel catalog)

In the tunnel catalog a tunnel has to be created or imported to be able to eventually place the elements in the project. For this, the two cross-sections were generated and the inner lining and invert were defined as tagged area in the cross section (see Figure 9-34).

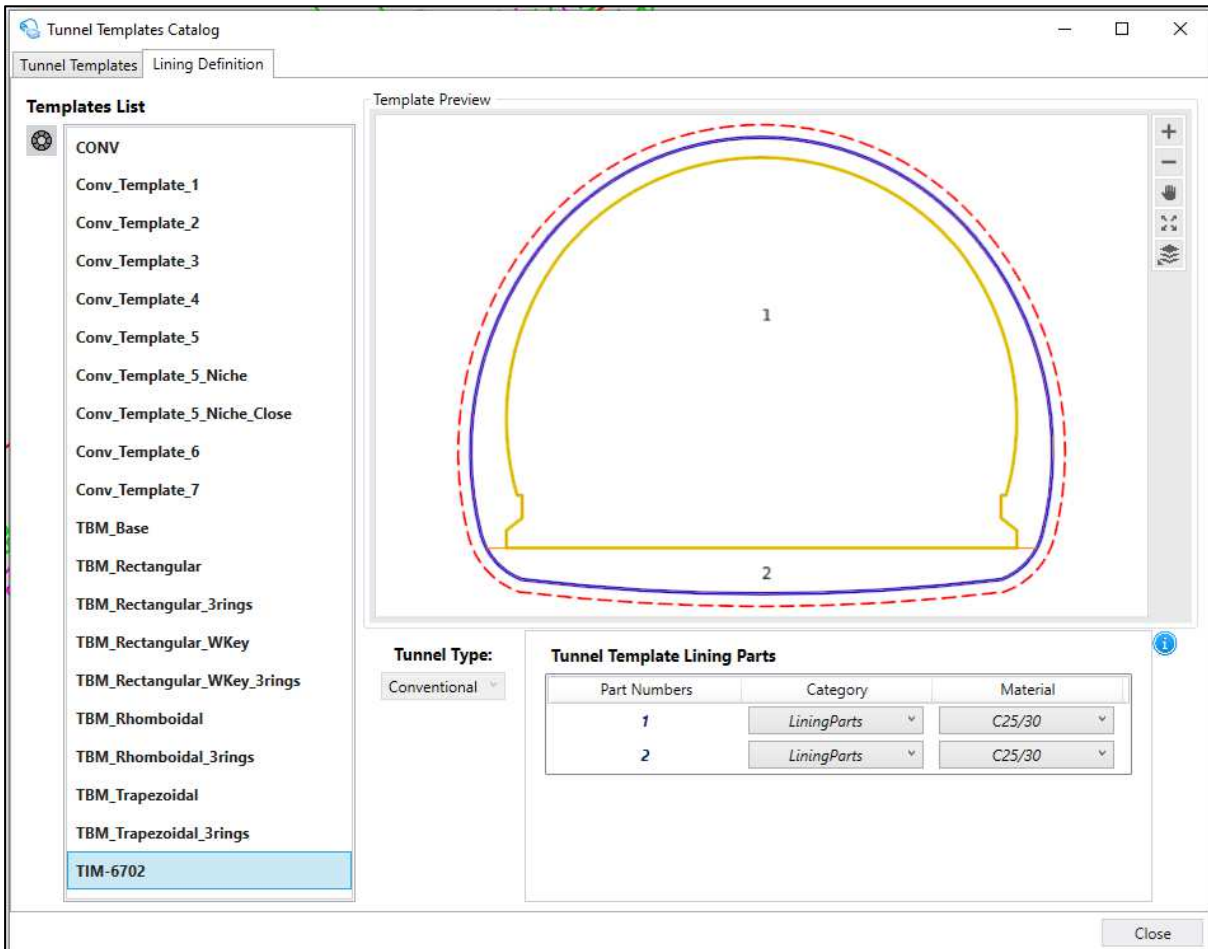


Figure 9-31: Importing or editing tunnel template

*Step 5: Add tunnel template from the catalog to the current project tunnel template (see 5, Figure 9-31)*

*Step 6: Use place tunnel command (see 6, Figure 9-31)*

Before using the tunnel command, the unit in which the tunnel blocks want to be generated needs to be set as “active”. Therefore, in the explorer the unit is selected and with a right click on the mouse the command “Set Active Tunnel” is selected. Now two asterisks are shown beside the active tunnel unit (see Figure 9-35 on the top right).

In the place tunnel command a new window pops up. In this the tunnel template which wants to be placed needs to be chosen and the section length at which the tunnel blocks should be constructed need to be set, as seen in Figure 9-35 on the left side.

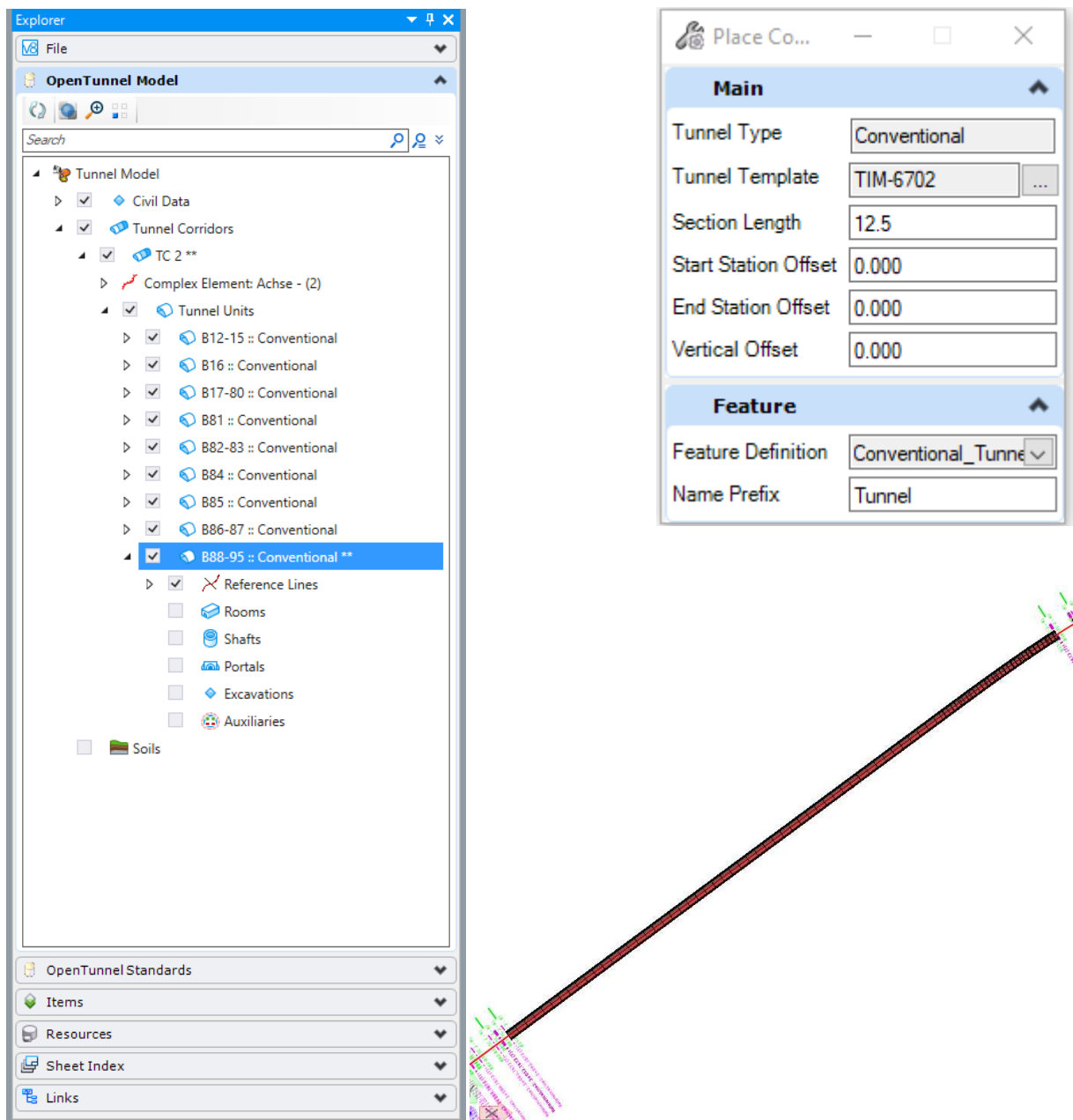


Figure 9-32: Set active tunnel and place tunnel command

Once the values are set, the reference lines of the active tunnel unit need to be selected. Then with a click anywhere else, the tunnel blocks are placed.

This step has to be repeated for every tunnel unit in the project.

*Step 7: Create or import auxiliaries for each implemented tunnel template*

Auxiliaries will be defined in the template as an enclosed area which will be tagged and given a name. After the material needs to be selected and once this is implemented these can be placed in the according tunnel units (see Figure 9-36).

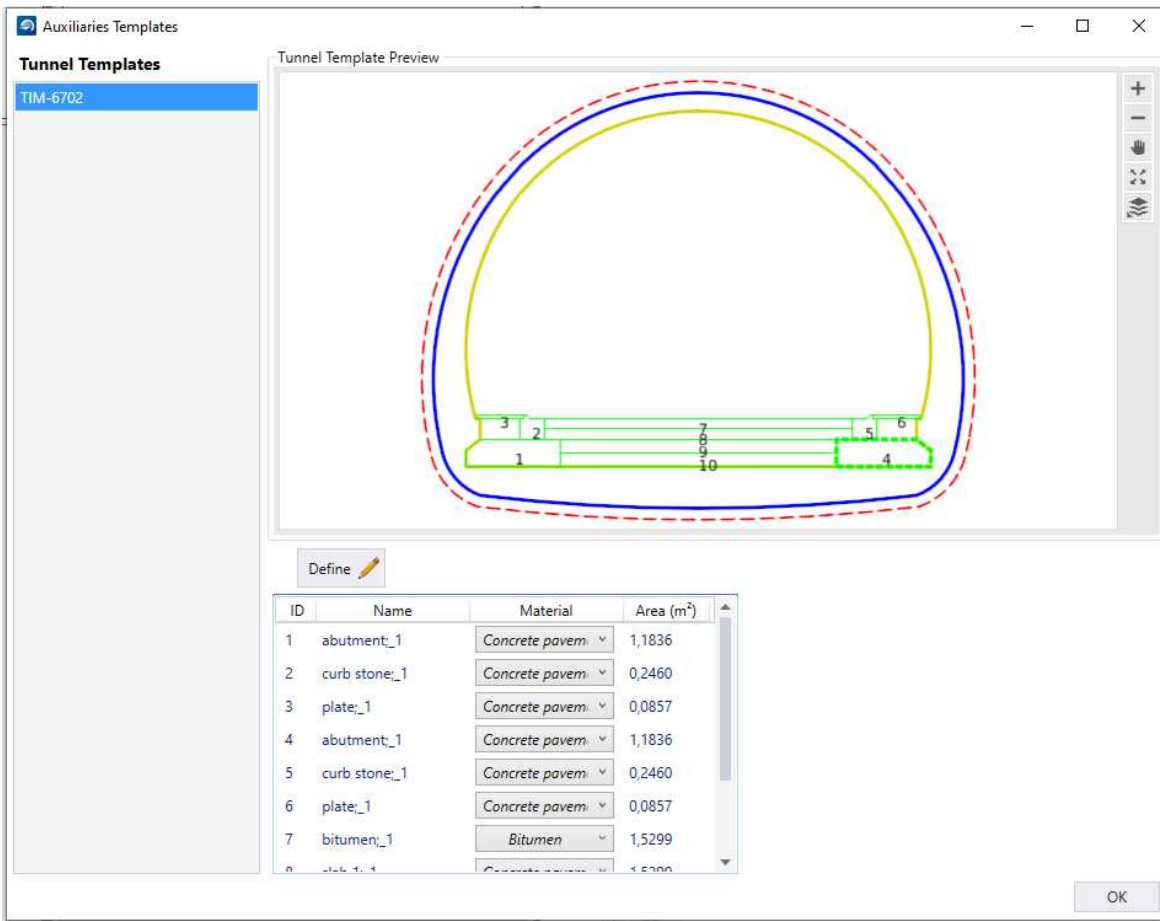


Figure 9-33: Auxiliaries defined for one tunnel template

Step 8: Place Auxiliaries by extrusion (see Figure 9-31 and Figure 9-37)

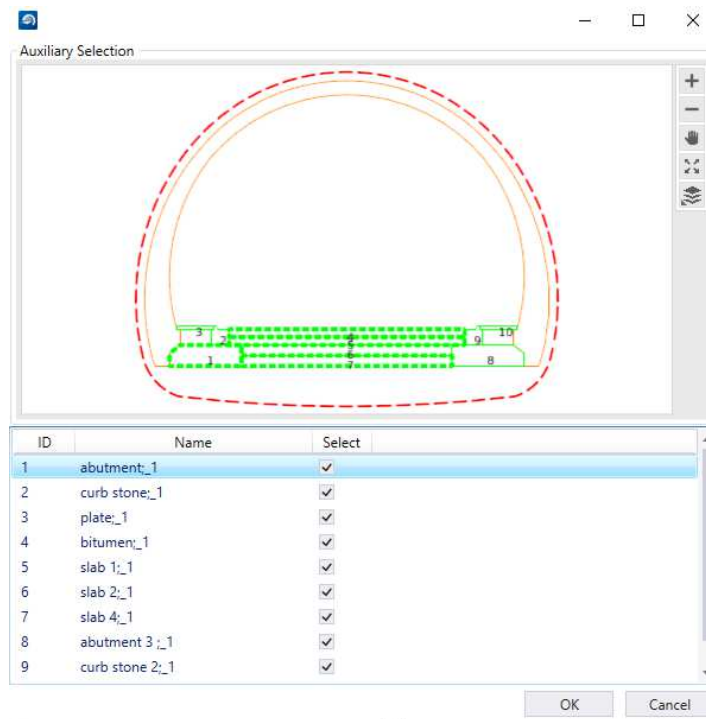
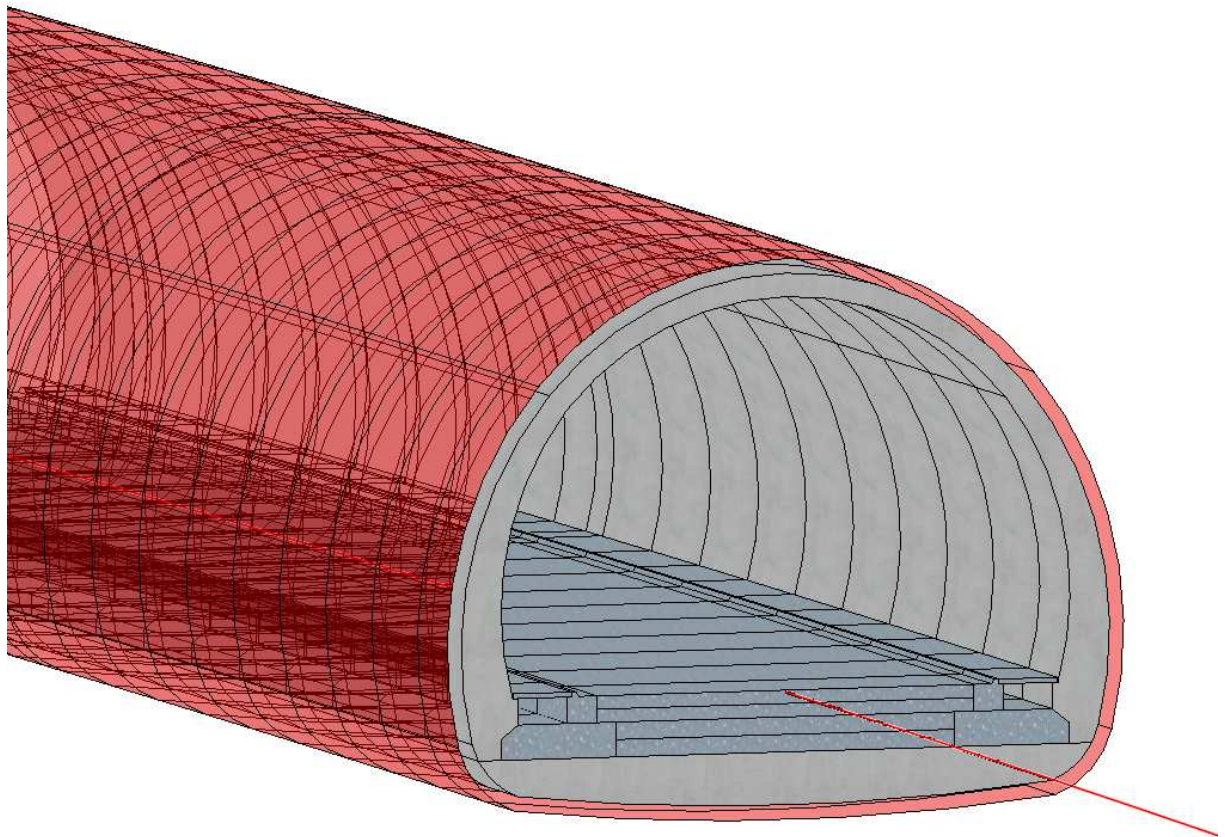


Figure 9-34: Place Auxiliaries by extrusion command place all



With this command the selected auxiliaries will be placed for the active tunnel unit. Therefore, the active tunnel unit must be corresponding with the used auxiliary template. The elements may be generated along the whole unit as single element, or with the tunnel blocks.

Once the active tunnel unit is selected, all checked auxiliaries will be placed. This needs to be repeated until the whole tunnel is constructed. The finished output is seen in Figure 9-38.



*Figure 9-35: Final tunnel structure model*



# Verpflichtungs- und Einverständniserklärung

Ich erkläre, dass ich meine Masterarbeit selbständig verfasst und alle in ihr verwendeten Unterlagen, Hilfsmittel und die zugrunde gelegte Literatur genannt habe.

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Hannah Salzgeber, BSc