Study on comparing current software for parametric modelling in Tunnel Information Modelling

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ABSTRACT: The Tunnel Information Modelling (TIM) method has presented the tunnelling industry with certain modelling challenges. Tunnel structures are characterised by the arrangement of recurring components along an alignment and the therefore resulting lengthy and repetitive modelling task requires automation through parametric design. This paper presents an evaluation of currently used software solutions for TIM, which are able to implement parametric modelling via extensions or scripting. The comparison includes aspects of geometrical modelling, integration of alphanumerical information into model components and drawing derivation. The resulting table gives a consolidated overview of the findings and caters to anybody who is currently looking at the implementation of a viable software options for the application of TIM.

Keywords: BIM, TIM, parametric modelling, digitalisation, tunnelling.

1 INTRODUCTION

Building Information Modelling (BIM) is a process that integrates alphanumerical information into digital three-dimensional models, enabling efficient design, construction, and operation. While there is no longer any doubt that the application of the BIM method has revolutionized and transformed project implementation, its use within projects related to infrastructure, especially underground construction is still residual. Even though, research efforts in the application of BIM in the infrastructure field has increased in recent years, publications in the field of tunnelling, also referred to as Tunnel Information Modelling (TIM), are still scarce (Costin et al. 2018, Zaid et al. 2021 and Inzerillo et al. 2023).

The endowed chair "Tunnel Information Modeling (TIM)" at the University of Innsbruck conducted interviews and a comprehensive literature review, examining the shortcomings of BIM in infrastructure construction. The research findings, as highlighted by Exenberger et al. in 2022, revealed that existing modelling software products have not adequately addressed the specific needs of tunnel and infrastructure construction. Based on this research an objective was defined to compare a range of software solutions and their extensions in terms of their capabilities for infrastructure design. A scientific thesis was developed, conducting an exemplary project using specific modelling solutions to directly compare their performance in achieving a common output, see Figure 1 (Salzgeber, 2023). The emphasis of the output was specifically on the efficient creation of the tunnel structure model, which serves as one distinct partial model of the envisioned digital TIM twin, as defined by the University of Innsbruck (Flora et al. 2021).

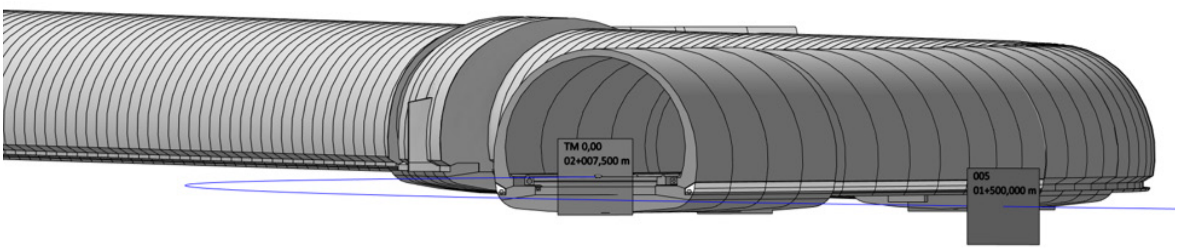

Figure 1. Example of output of the tunnel structure model (Salzgeber, 2023).

Tunnels and their typical long linear structure require a unique modelling approach using adaptable and customizable models to accommodate repetitive elements and variations between predicted and actual conditions. Therefore, parametric modelling has become an indispensable tool for design, construction, and management of projects in TIM. Hereby, parametric modelling is a method to create and manipulate 3D geometries and models using predefined parameters, instead of manually adjusting geometric elements. The objective is to utilize object associations, functions, and rules to not only modify a single element but also alter all elements that are connected to the modified object. Parametric design can be integrated into a software in many ways. While some develop tools (custom tools), which incorporate dynamic parameters, others base their concept of parametric modelling on virtual scripting (dedicated tools), a method of programming in which lines of code are represented by visual blocks (Bushra, 2022). Through connecting these blocks, different functions and operations are initiated and controlled, which can further help create and automate modelling processes (Fu 2018). Therefore, it is also used to implement repetitive design work, especially for tasks like placing objects and assigning or linking information like properties to the placed objects.

2 SOFTWARE

The selection of software to create tunnel structure models was primarily based on the current usage of software in pilot projects, parametric design capabilities, and market developments as of 2022. The software evaluated includes Rhinoceros 7 3D®, Revit® 2022 including two extensions FIDES® Infrastructure Toolbox (FIT) and SOFiSTiK® Bridge + Infrastructure Modeller and the tunnel-specific software OpenTunnel Designer® 2022. All initially developed for specific tasks or niches, most software gradually expand into multiple fields, depending on the functionalities and flexibility of their tools. To broaden a software repertoire, developers often introduce specific tools through new releases or extensions. Another approach is to empower users by providing them with the ability to create their own tools and workflows through programming, such as virtual scripting interfaces.

Rhinoceros 3D® (Rhino) was initially developed to replace drafting tables and found its footing in all sort of fields. The release Rhino® 7 in combination with Grasshopper®, its virtual scripting interface, is known to be one of the most flexible parametric and freeform modelling software in the 3D modelling industry. However, it does not yet include the capability of flexible alphanumeric integration and is therefore not treated as a fully comprehensive BIM or TIM software without further add-ons (Hussain, Zheng, Chi, Hsu, & Chen, 2023). Autodesk Revit® 2022 initial niche is building design. The software is currently thought to be one of the most widely-used BIM software in the world (Gächter et al. 2021 and Hegemann et al. 2020 and Yin et al. 2020). While Revit® 2022 does not include any tunnel-specific tools, various software developers have created Revit® add-ons to meet the needs of infrastructure modelling. This evaluation includes two Revit® 2022 extensions, FIDES® Infrastructure Toolbox (FIT) and SOFiSTiK® Bridge + Infrastructure Modeller, as well as Autodesk's visual programming interface, Dynamo®. Further, Bentley Systems' newly-introduced software, OpenTunnel Designer® 2022 Release 1, was also included in the comparison. As stated by Bentley, OpenTunnel Designer® is the first and only purpose-built software for tunnel modelling and design, featuring automated modelling tools that do not require coding or scripting (Bentley Systems 2023).

3 METHOD

A self-study conducted by Salzgeber (2023) compared OpenTunnel Designer®, Revit®, and its extensions in the generation of a tunnel structure model. The study utilized a simplified drill and blast tunnel project as a basis, but the evaluation of the software and workflows can be extended to mechanized tunnel projects as well. In this context, the same project was implemented in Rhino®, and the findings were incorporated into the existing comparison and conclusions from this research.

The exemplary project and its modelling process (Figure 2) were split into packages which can be evaluated independently of the overall workflow, see . For this, three main fields were defined:

- Alignment (Base Data and Alignment)
- 3D Modelling (Tunnel-Block and Placement)
- Further TIM Needs (Properties and Drawing Derivation)

The criteria were defined from a modeller's perspective and are subject to project specific goals, needs and solutions. However, the evaluation does not only include the ability to accurately model the specific as-built structure in 3D, but to further evaluate the tools and functions in terms of replicability of the workflow for other projects as well as the flexibility to adapt to different tunnel information modelling requirements. Figure 2 shows the schematic modelling process in its partial steps, which was implemented in each software.

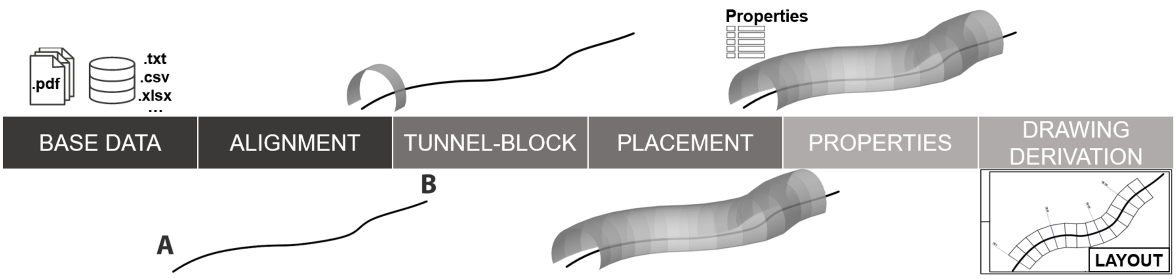

Figure 2. Modelling process which was implemented in each software.

4 COMPARISON

Each software, achieved a similar and comparable geometrical output. However, the modelling processes and alphanumerical property integration differed immensely. The fields defined in the modelling process were used as guideline for the comparison to derive more specific fields or tasks to achieve an in-depth comparison (Salzgeber 2023).

The findings of significant differences are summarized in table 1 as overview. The checkmark signifies that the software can generally accomplish a task, often described in brief terms. An "x" indicates that the task is not feasible or inadequately achievable. For instance, the "x" for property integration in Rhino® does not imply that information cannot be incorporated entirely. Considering the current extent and diversity of data to be integrated, Rhino® lacks the necessary flexibility and automation capabilities to effectively handle alphanumeric integration.

As overall result it can be stated that the scripting approach is limited by the range of functionalities offered by the authoring software, resulting in a wide variety of solutions to a single task, while specifically developed tools are limited by their own functionality.

Table 1. Summary of key findings from software comparison for exemplary project (Salzgeber, 2023).

			Bentley®	Revit®			Rhino®
			OpenTunnel Designer®	**Dynamo®**	**FIDES®**	**SOFiSTiK®**	**Grasshopper®**
Alignment	**Data Import**	**Import File Types**	*.xml, *.ifc, *.12dxml, *.fil, *.inp, *.txt, …	*.xlsx, *.csv, *.json, *.txt, …	*.xlsx	*.xml, *.cdb, *.txt, *.csv, *.xyz, …	*.xlsx, *.csv, *.txt, …
		Data Types	objects or coordinates	objects or coordinates	coordinates	objects or coordinates	coordinates
		Coordinates	World coord.	Coordinate transformation based on boundary			World coord.
				-	300 points max,	-	
	Axis	**Object**	axis (complex element)	any Revit® component	Model line	generic model family	line or polyline
		Modify or Edit	manually editable	move elements with script	points in excel	in alignment tool	new points with script
		2D and 3D Chainage	✓	script - create tags with text	x	✓	script - create tags with text
3D Modelling	**Tunnel-Block**	**Component type**	element / 3D volume	family			Brep
		Component creation	2D profile extrusion	2D profile extrusion or 3D adaptive component			2D profile extrusion
		Parametric after placing	via tunnel template in 2D	extrusion – less flexible adaptive component – parameters			static once "baked"
		Changes	tunnel template, not objects	change parameters with script	change family parameters		in script before "baked"
		Flexibility	restricted	high	high	restricted	until changes high
	Placement	**Length control**	tunnel unit reference lines and lengths	points or lengths from excel, calculations, ...	points from excel	placements (Stations) and lengths	points or lengths from excel, calculations
		Several Components	separately	together (as individual)	together (as one family)	separately	together (as individual)
Further TIM Needs		**Property integration**	manual input limitations	flexible for each element within the project (individual, as type, shared, …)			x
		Drawing Derivation	✓	Revit® sections	flattened tunnel	derivation to lines and hatch	derivation to lines and hatch
		Scripting	x	✓			✓
		IFC export	indirect	✓			indirect
		User profile	model	code + model	model	model	code + model

The following sub-chapters aim to provide additional context and deeper insights into the summarized findings. For a more comprehensive analysis, readers are encouraged to refer to the detailed comparison conducted by Salzgeber (2023).

4.1 The alignment

The alignment is a fundamental part of TIM as it provides the foundation to every infrastructure project. For the tunnel structure model, an alignment is usually provided in form of point data. Thus, importing data is a key aspect in generating an axis. This first task of implementing world coordinates already provides a challenge in Revit® due to its limited modelling boundary of 32 kilometres.

Moreover, the further the elements are placed from the internal origin, the less reliable are geometries and distances which are generated. Therefore, world coordinates need to be transformed in Revit®, while in OpenTunnel Designer® and Rhino® world coordinates may be included. While almost all applications have a wide variety of import options, FIDES® is the only application with a limited file type and additionally a limited data size, under Data Import in table 1.

The created alignment varies in object type (polyline, generic model, array of curves, …) based on the software and extension. This type further defines the different possibilities to use, change or adapt the alignment, see point Axis. For orientation in large infrastructure projects the implementation of a visible and dynamic annotation of the chainage in both two- and three-dimensional views is important, under Axis in table 1.

4.2 3D Modelling

While the alignment is a very simple component, a tunnel block is more complex. The geometry of a tunnel block is defined within cross sections as well as its extrusion or sweep along the alignment in form of a block chain. Hereby, length, angle, other dimensions and their constraints can be integrated as parameter for every cross-section component as well as the extrusion length. There are two approaches to modelling these components: creating a static or parametric 2D profile and to sweep or extrude this along an alignment, or to create a static or parametric 3D object and place these. The latter approach usually provides more dynamic editing options compared to the former, which often loses its parametric functions once extruded. Additionally, placed 3D components are often standalone objects which can be grouped, while extrusions may be based on units and not as individuals. Standalone profile extrusions often involve manual repetitive tasks, therefore, the focus was set on placing these elements as automated as possible, while keeping their dynamic functions for possible later changes.

The repetitive nature does not only lie in the placement of one object in different lengths along the alignment, but also in the placement of several component (see table 1) and types of the cross section. The scripting approach is able to solve these tasks based on the flexibility and complexity of the self-coded script. In contrast, the tools provide more limited solutions depending on their flexibility. Overall, depending on project specific goals, any of the provided modelling approaches may fit best.

4.3 Further TIM needs

Geometric modelling provides one of the necessary foundations for TIM, but is nowhere near the sole component. Alphanumerical integration in form of properties, drawing derivation, data export capabilities and many other tasks are needed to provide the full range of benefits of the TIM method.

Drawings for construction sites are currently derived from models. TIM offers the advantage of semi-automatically populating annotation text for objects by linking it to their properties. However, it is important to note that for this functionality to work, a direct reference to the three-dimensional object is required, as the link is typically lost when the object is converted into lines and hatches.

For the scripting approach a user benefits of having a basic understanding of coding as well as modelling to timely create tools based on code.

5 CONCLUSION

While each software modelling approach comes with benefits, all include challenges as well. Specifically, designed tools provide great opportunities for inexperienced modelers and first-time software users however, they can be limiting in terms of specific requirements and tasks. In contrast, visual scripting implementation comes with greater flexibility, but provides challenges for software and scripting beginners due to the overwhelming amount of solutions to one single task.

Bentley's OpenTunnel Designer® has potential as a software for the tunnelling industry, but needs to expand its capabilities in terms of modelling flexibility, property management, and data export in order to be a competitive standalone solution. Revit® has limitations in terms of survey data integration and modelling boundaries, it excels in property management and data export compared to other software tested. Rhino®, when paired with Grasshopper®, offers high levels of modelling flexibility, but cannot be considered a standalone BIM/TIM software. However, it can be combined with other property-capable software developments, to become a competitive alternative.

A self-study comparison has benefits but also limitations, such as differing levels of expertise and potential bias. Nonetheless, it provides valuable insights into software capabilities, expertise requirements, and encountered challenges. It offers an overview of software shortcomings and benefits.

None of the evaluated software, based on their current capabilities and releases, fully meet the automation needs of TIM as standalone solutions. However, by combining software or implementing additional manual work, desired outputs can still be achieved. It's important to note that these findings are limited to the capabilities of the software versions used during the study. For instance, Rhino® might introduce a more technically mature object-based parameter and property management, or Bentley may integrate a virtual scripting interface for OpenTunnel Designer® in the future.

In the end, the selection of software is a complex process which has to consider far more factors outside the software capabilities and limitations like project goals, used cases, client requirements, and team member abilities.

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