19th Australasian Tunnelling Conference – Acosta-Martínez, Stewart and Hudson-Smith (Eds.)
© 2025 Australian Tunnelling Society, ISBN 978-0-85825-002-4

Automation of tunnel modelling for enhanced project efficiency

P. Bueno Leal, F. Calle Lamelas & F. Ceballos Martinez
TYPSA

ABSTRACT: Cross passage (XP) modelling in tunnel infrastructure projects has unique challenges due to their complex geometry, non-standard alignment, and high volume of repetition. Manual modelling of these structures in BIM environments is time-consuming and facilitates human error. This paper presents the development and implementation of a parametric automation tool designed to model cross passages efficiently using Rhino + Grasshopper. The tool originated from practical challenges in major projects, such as Stockholm Metro or Sydney Metro, where Revit's limitations highlighted the need for a more flexible solution. Developed collaboratively by TYPSA's BIM and Geotechnical teams, the automation enables fast, accurate generation of XP geometries adaptable to various tunnel alignments. By integrating this tool into real project workflows, TYPSA improved modelling speed, reduced errors, and enhanced BIM coordination. This article outlines the conventional challenges, the development process, the tool's structure and testing, and future improvements aimed at generalizing its use.

1 INTRODUCTION

1.1 *BIM Model History*

The graphical representation of civil infrastructure designs has experienced a huge transformation in the last years. From the handmade drawings developed during the XX century, the popularization of Computer-Aided Drawing (CAD) tools during the late 90s and early 2000s revolutionized the typical workflow. Design teams were required to adapt to the technologies, adopting in a short period of time not only the typical development of CAD 2D drawings, but the implementation of 3D models.

Nowadays the design of underground structures cannot be understood without the extensive use of Building Information Modelling tools. However, the implementation of AI-powered tools and automation workflows are still under development, requiring a constant adaptation of the techniques, tools and methodologies.

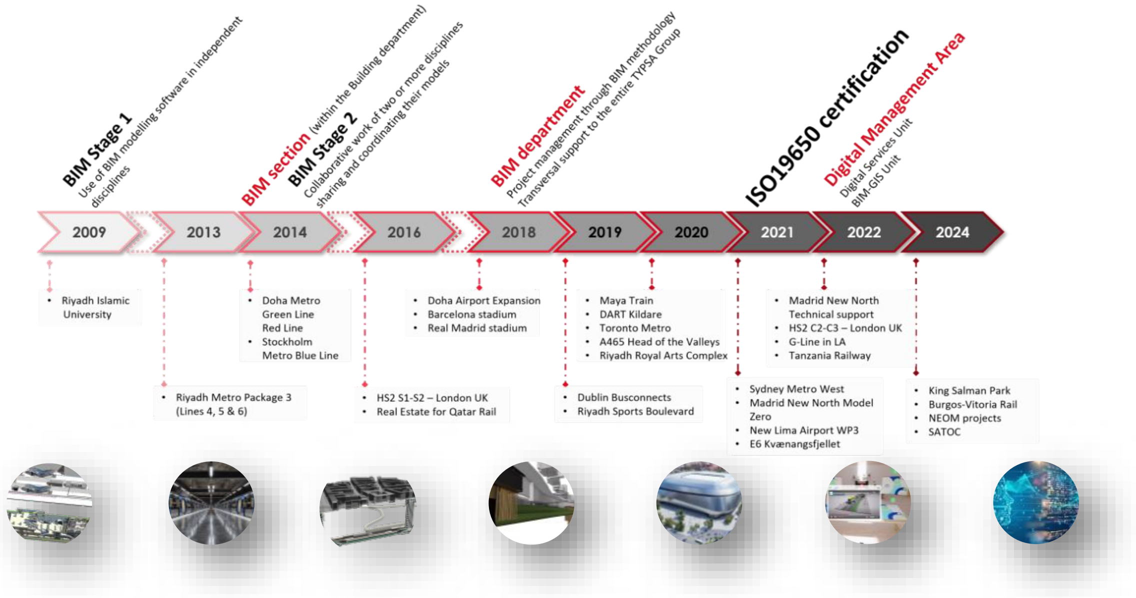

Figure 1. Evolution of BIM methodologies within the company TYPSA

1.2 BIM around the world

Despite BIM being a global methodology, its application differs across geographies. In Spain, BIM is heavily integrated with high modelling standards, and its early adoption gave rise to structured processes, specialist roles and the adoption of BIM methodology by public administrations. In North America, adoption is growing but still faces challenges related to standardization and training across project stakeholders.

Australia, on the other hand, has rapidly embraced digital processes, with demanding requirements from clients that have driven innovation and automation. The market's maturity has facilitated the adoption of advanced workflows, including data-rich models, automated validation processes, and integration with construction planning and digital twin strategies.

2 CONVENTIONAL MODELLING

2.1 *Repetitive tasks*

Modelling repetitive elements manually, especially the multiple cross passages (XP) that can exist in any linear infrastructure, involves highly repetitive workflows: copying geometries, adjusting slopes, and aligning with tunnel axes. Each cross passage is similar in function but unique in its geometry, requiring extensive manual adjustment. The workload escalates quickly, making the manual process time-consuming, inefficient and prone to fatigue-driven mistakes.

Moreover, manual modelling slows down coordination between disciplines, especially when late-stage design changes occur. Updating models one by one introduces a risk of inconsistencies, misalignments, or coordination errors with adjacent systems.

2.2 *Complex geometries*

The detail design of cross passages rarely follows a standard layout. They involve non-orthogonal geometries, varying slopes, and custom profiles. Additionally, non-standard geometries (such as elliptical surfaces) are typically used in some underground design traditions. Accurately modelling these using conventional tools like Revit is complex, as the software is designed for horizontal/vertical structures rather than linear infrastructure.

Tunnel projects often require the alignment of two or more tunnel axes at differing elevations and angles. Modelling the transition geometry between these requires spatial precision and adaptable logic—capabilities which standard BIM tools lack out-of-the-box. This leads to time-consuming workarounds that limit design agility.

2.3 *Human Errors*

Repetitive manual modelling, combined with complex geometries and coordination with multiple disciplines, often leads to human errors—misaligned components, missing elements, or naming inconsistencies. These errors introduce rework and increase review cycles.

Errors may not always be immediately visible in the model, but can propagate into documentation or clash detection, leading to on-site construction issues. Additionally, maintaining design intent across dozens of manual models becomes increasingly difficult without a controlled, automated system.

3 IMPLEMENTATION OF AUTOMATION

3.1 *Genesis*

The need for automation comes from difficulties faced during multiple projects, especially in those where Revit was preferred. Revit, being tailored to buildings, struggled to accommodate non-parallel tunnels with varying Z-coordinates. Civil 3D, with subassembly composer was considered and worked well for linear elements but not for unique features like cross passages. Bentley Suite (OpenRoads/Aecosim) proved effective for detailed geometry modelling; however, case-by-case adjustments and poor cross-discipline integration limit its practicality.

Inspired by product design workflows, the team turned to Rhino + Grasshopper. These tools allow parametric control of geometry using minimal inputs: tunnel alignments, XP types, and section templates. This provided both precision and speed. Early trials with Revit and Dynamo proved insufficient; the final setup used Rhino + Grasshopper, optionally integrated with Revit (via Rhino.Inside).

By using these tools, a cross passage could be generated automatically by simply defining connection points and a few parameters, drastically reducing modelling time and increasing flexibility. The switch from manual modelling to parametric logic marked a pivotal shift in how the team approached tunnel infrastructure.

Figure 2. Software researched

3.2 *Research and development*

Once the potential benefits of the automation tool were identified, a collaborative team was assembled, combining expertise from TYPSA's BIM and Geotechnical departments, with support from a Grasshopper specialist. Although the development was overseen by TYPSA's R&D Committee, it was primarily driven by practical project demands rather than a formal research framework. This allowed for a fast-paced and iterative process, where an agile working environment enabled rapid prototyping and continuous feedback.

Lessons from early testing cycles were quickly incorporated, creating an effective feedback loop that significantly strengthened the tool's robustness within a short timeframe. The initial draft of the Grasshopper workflow was developed in approximately two weeks. The final version was completed two weeks later, and the solution can now be integrated into new projects in just one week.

3.3 *Multidisciplinary approach*

The collaboration between tunnel engineers and digital specialists was smooth and effective. Geotechnical engineers defined the required outputs in terms of geometry, constraints and requirements, while the digital team translated these into parametric rules that allow, by means of simple tasks and logic and geometrical relationships, the definition of the solution.

Although weekly meetings and test iterations allowed the team to develop a solution naturally, the close collaboration and the continuous communication between the team members was key for the success of the initiative.

This type of integrated approach exemplifies how BIM can bridge domain expertise. Rather than separating roles, the project benefited from shared ownership, with both teams working closely to ensure the generated models met geometric, constructability, and information requirements.

4 AUTOMATION TESTING

4.1 *First tests and limitations*

Initial tests were promising. Geometry aligned correctly, and elements fit into place. However, when new alignments or sections were introduced, unexpected errors emerged—mostly due to Grasshopper's internal logic. For example, tangency or coinciding curves would cause the software to misinterpret intersections. Debugging became essential. Despite this, the tool showed the potential, being fast and improving consistency.

4.1.1 *Slope and Tunnel Geometry*

One major limitation in Revit was its inability to handle non-parallel tunnels in different Z-levels (sloped XP). Grasshopper, however, handled this seamlessly, allowing accurate interpolation between tunnel axes.

Additionally, the use of 3D curve logic enabled the tool to automatically adapt the XP orientation to the local slope and rotation of each tunnel pair, ensuring consistency with the project's geometric constraints

4.1.2 *Curve Logic and Debugging*

Many failures were due to geometric edge cases. Grasshopper treats curves with overlapping endpoints as not intersecting, which caused certain operations to fail. These were solved through careful input conditioning and script logic updates.

4.1.3 *Grasshopper Limitations*

Grasshopper still has some limitations; it is necessary to script the model in a cautious way previewing all the steps in order to make sure everything is correct.

- Grasshopper works with geometric objects but not metadata. Attributes need to be added post-modelling.
- Input order (curve direction, point index) is critical and must be controlled.
- The tool must be adapted to each project's XP types.
- Assigning BIM data requires extra steps—either via IFC scripting (e.g., Python) or through Revit integration using Rhino.Inside.

Despite these limitations, the benefits of the automation far outweigh the manual alternative. The current approach balances technical flexibility with real-world constraints, making it scalable for a wide range of projects.

4.2 *Modelling Workflow*

This workflow describes the step-by-step process followed to develop the automated system for generating 3D models of cross passages using Rhino and Grasshopper. The goal was to streamline the modelling process, ensure design compliance, and allow for rapid updates based on input changes.

4.2.1 *Input Data*

The input data are the variables that define the Cross Passage and locate it in the correct location. If any of these variables change, the Cross Passage updates automatically.

- Tunnel alignment data (main tunnel centerline) from CAD or GIS formats.
- Tunnel radius
- Cross Passages Cross-Sections, including collar (if required) and central.
- Cross Passages Chainages: The chainages of each Cross Passage
- Other geometrical data defined in the next sections.

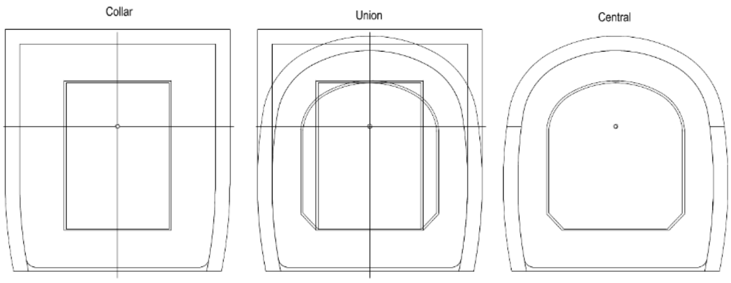

Figure 3. Collar body workflow

4.2.2 *Collar Methodology Script*

The first step in the scripting process focuses on generating the collars at both ends of the cross passage. The process begins by placing the cross-section profile at the specified chainage along the tunnel alignment. This section is then oriented vertically, ensuring correct alignment for further geometry generation.

To define the plane of the cross-section, a perpendicular vector to the tunnel alignment at the specified chainage is calculated. This vector lies in the horizontal plane (i.e., it has no Z-component), ensuring that the cross section remains upright regardless of tunnel slope.

Once the cross-section has been positioned and oriented, the next step is to generate the collar volume. This is done by:

Extruding the cross-section along the orientation vector (defined earlier) for a distance equal to the Collar Length plus the External Radius of the Tunnel. This ensures that the collar fully intersects the tunnel lining.

If the tunnel rings are not provided as input geometry, they are generated parametrically based on the tunnel alignment and known section dimensions. The extruded collar solid is then trimmed by subtracting the tunnel rings from it, using Boolean operations. This process creates a collar that precisely fits the tunnel interface, avoiding overlaps or clashes with the existing structure.

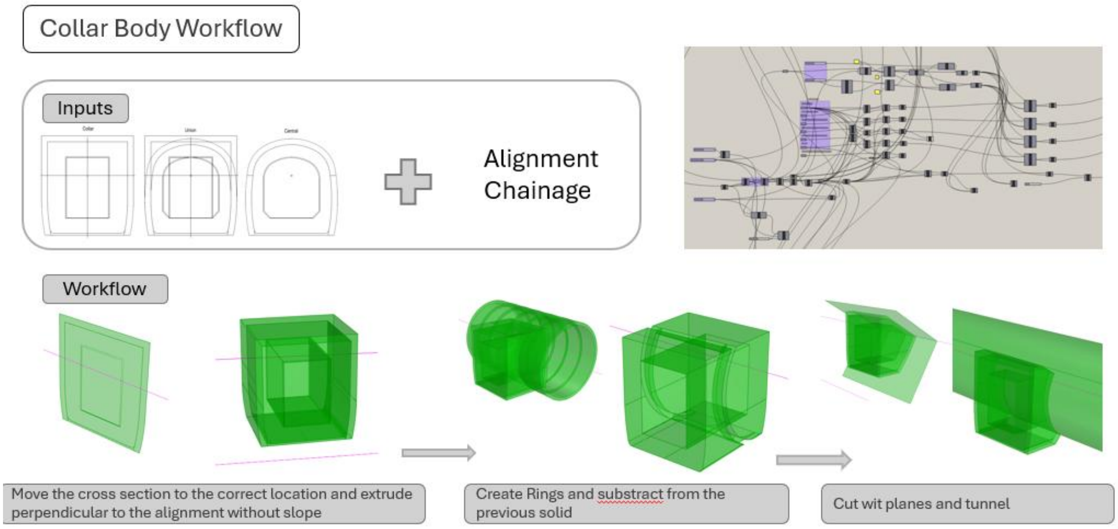

Figure 4. Collar body workflow

This collar serves as the starting point for further modelling steps, such as generating the transition geometry between both tunnel ends.

To finalize the collar geometry and ensure it integrates seamlessly with the tunnel, Cutting Planes are created at the collar's inner and outer limits, aligned with the tunnel geometry and cross passage axis. These planes define the start and end of the collar within the tunnel body.

The tunnel body (whether imported or generated) is used as a reference to trim the collar solid, ensuring it aligns correctly with the tunnel lining and does not extend beyond intended boundaries. Boolean operations are applied to perform a precise subtraction, resulting in a clean, clash-free collar that fits perfectly within the federated tunnel model.

4.2.3 *Center Body Generation Script*

With the collar geometry completed, the next step is to script the central body of the cross passage that connects both collars. This requires establishing a set of reference planes to guide the geometry generation.

Two planes are taken directly from the end faces of each collar, preserving their orientation and alignment with the main tunnel axes. A third plane is constructed perpendicular to the segment connecting the centre points of the two collar ends. These three planes serve as the control sections for interpolating the cross passage geometry, ensuring a smooth and coherent transition between both ends. They also provide a consistent framework for lofting or blending operations in the next modelling step.

To ensure that the cross passage complies with space-proofing and clearance requirements, the Minimum Clearance Outline (MCO) is modelled from the central reference plane defined earlier. This approach guarantees that the cross passage maintains the required section profile throughout the Cross Passage alignment.

The MCO is positioned at the midpoint between the two collars, using the central plane previously established and then extruded symmetrically in both directions along the axis connecting the collars. This method ensures that the section remains consistent and that the geometry is fully compliant with clearance and accessibility criteria. Once the MCO extrusion is created, it can be used to trim or guide the final solid generation of the cross passage body.

The final step involves generating the solid geometry of the cross passage body. This is achieved by lofting between cross sections, including the inner faces of both collars and any additional control sections required for curvature or clearance control.

This loft operation creates a smooth transition between both ends. The resulting solid is then validated for space-proofing using the MCO and prepared for integration into the overall 3D tunnel model.

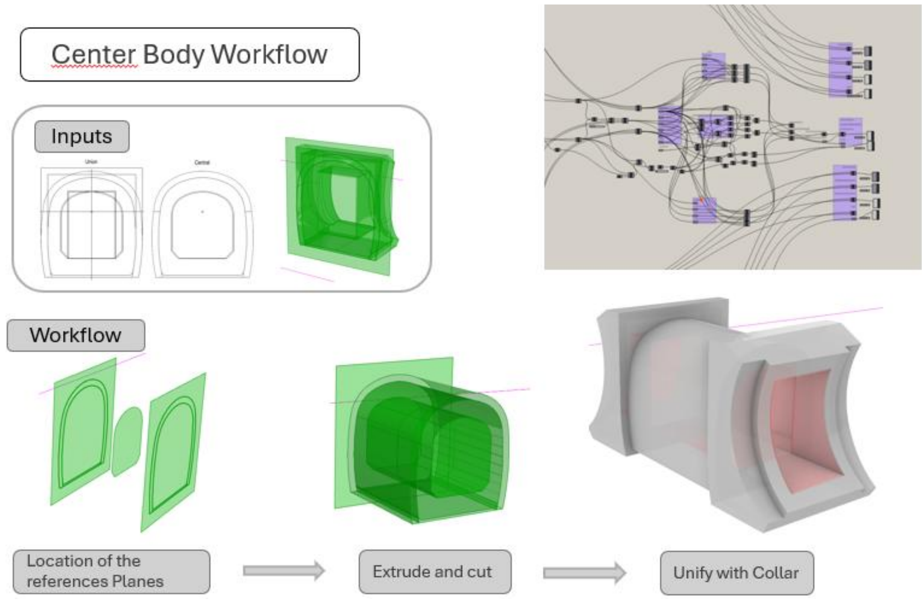

Figure 5. Center body workflow

The complete Grasshopper script developed for the cross-passage automation is shown in the following image. The script is designed to be modular and adaptable, requiring only minor adjustments to be implemented in new projects. Input parameters such as tunnel alignment, chainage, section profiles, and collar dimensions can be updated to reflect project-specific conditions, enabling rapid deployment across different design contexts.

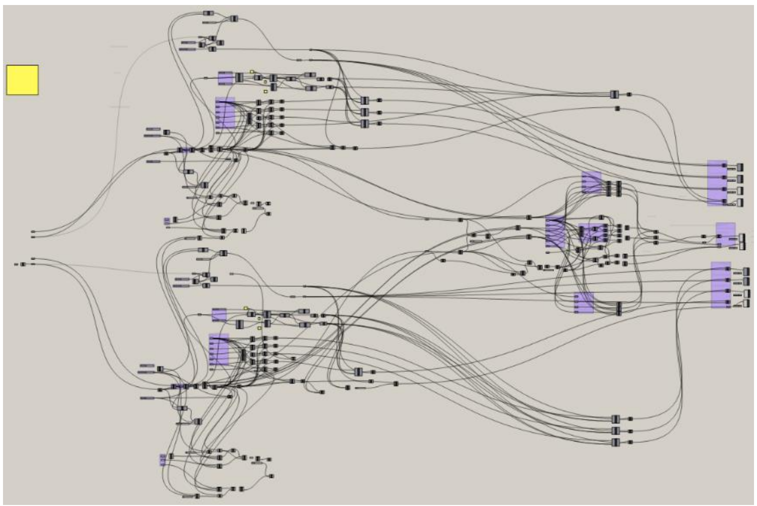
Figure 6. Caption of Grasshopper script.

5 CURRENT SITUATION

5.1 *Workflow implementation*

The tool has been successfully used in the Sydney Metro West – Central Tunnelling Package and is being used in other roads and railways tunnel projects around the world. Its flexibility in adapting to varying geometries makes it broadly applicable. The workflow includes modelling in Grasshopper, exporting to IFC or Revit, and then assigning attributes via additional automation.

Thanks to the open-ended logic of Grasshopper, the tool supports a range of configurations, including different tunnel diameters, offsets, and orientations. This makes it easy to implement in early design stages, where changes are frequent, and standardization is still evolving.

5.2 *Integration with BIM software*

A successful integration of the Rhino-generated 3D models into other design platforms such as Revit and AECOsim has been implemented. The connection with Revit is achieved using the Rhino.Inside.Revit plugin, which enables the Rhino model to behave as if it were native to Revit, supporting parameter-driven elements and full BIM integration. For AECOsim, the models are exported in a format compatible with the platform's native environment. Additionally, the resulting models have been incorporated into the federated model using Navisworks, allowing for interdisciplinary clash detection and coordination.

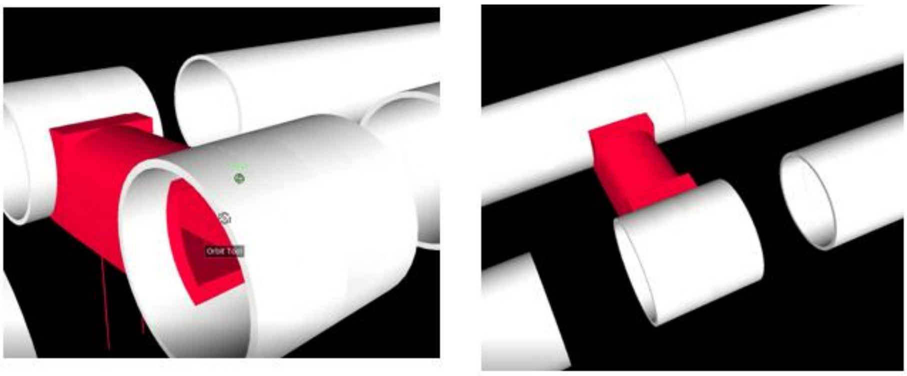

Figure 7. Integration with the Federated Model in Navisworks

5.3 *Further Developments*

The success of the R&D project and the implementation in the design methodologies of the developed tool marked an important milestone in the modelling automation. However, further enhancements of the tool are under development, including:

- Modularizing scripts for easier reuse
- Developing a user-friendly interface
- Automating property attribution to support full BIM workflows
- Creating a reusable XP section library
- Exploring AI to optimize initial configurations

These next developments aim to improve usability, reduce reliance on digital experts, and streamline integration into broader BIM workflows. Ultimately, the goal is to enable designers and engineers to generate and adapt tunnel components without needing to write or modify scripts.

With further refinement, the automation can serve as a template for similar linear infrastructure use cases beyond tunnel cross passages, opening a new frontier in digital civil engineering workflows.

6 CONCLUSIONS

The automation represents a leap forward in tunnelling and XP modelling—turning a repetitive, error-prone process into a streamlined, adaptive workflow. With parametric control, changes can be applied in minutes, and design iterations become agile and low-risk.

The ability to replicate geometries with high precision, ensure alignment, and easily incorporate design changes provides both strategic and practical advantages. It also facilitates better coordination with other disciplines by maintaining geometric consistency throughout the project.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of the BIM and Geotechnical teams at TYPSA. Without their contribution and the feedback of those who tested and implemented the tool in real projects, especially in Sydney Metro West, the implementation of this tool could have not been possible.