# e-BrIM

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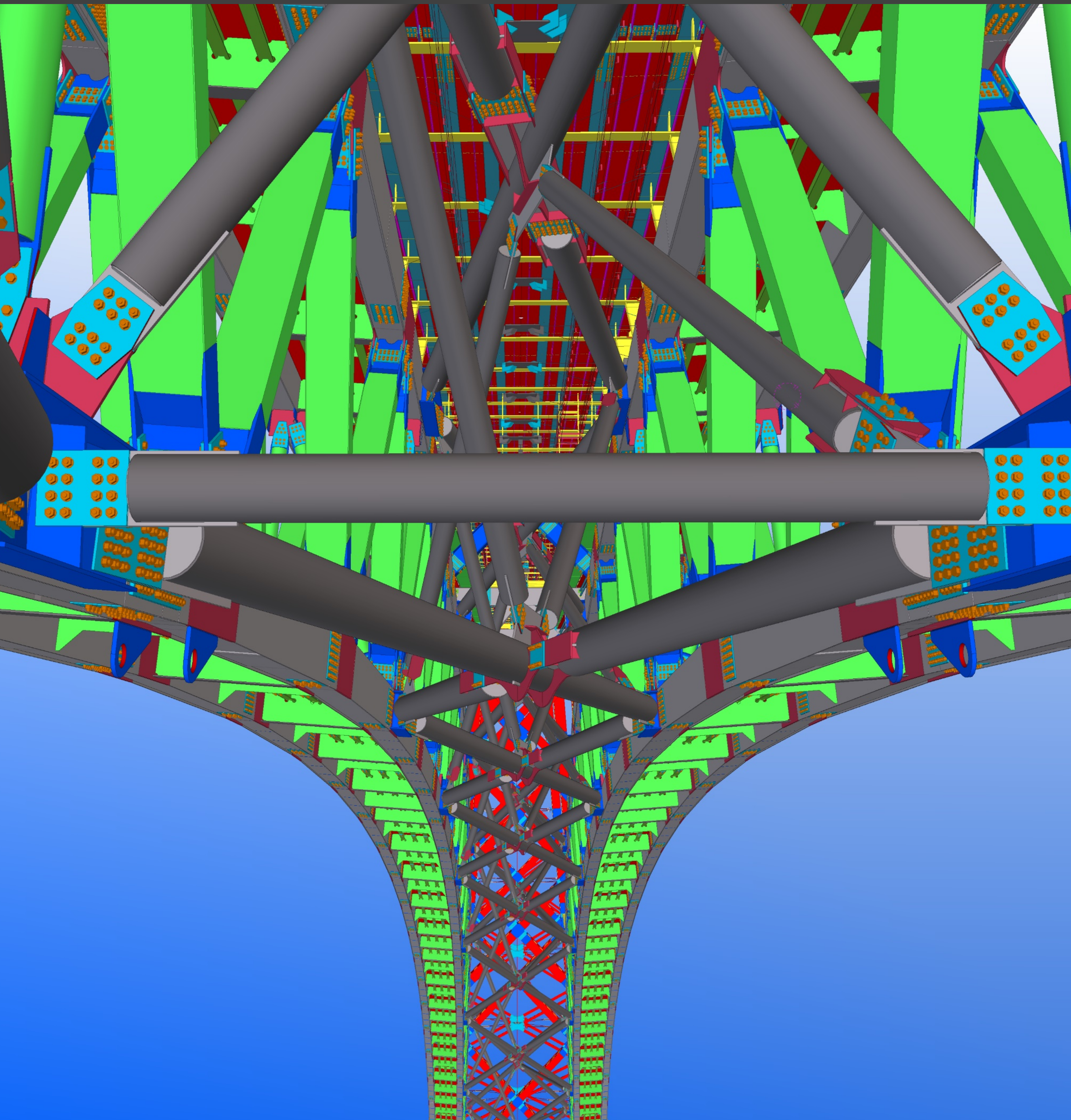

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*Dear Readers*

*The first article of this issue was prepared by* ***Matti-Esko Järvenpää, Director of WSP Finland****, in which he focuses on the* ***Use of BIM in the Design and Construction of the Chenab Bridge*** *in India. Expert knowledge and experience in detailed modelling were one of the main reasons why the engineering of Chenab Bridge was awarded to WSP Finland.*

*If you are interested in the design and construction of the Chenab Bridge, you can also read about it in the special edition of e-mosty magazine. The second special e-mosty edition about the Chenab Bridge will be released on 20th June, again at www.e-mosty.cz.*

*The next article, written by* ***Alejandro Palpan Flores, Bridge Project Coordinator of TSC Innovation, Perú****, explores the benefits of* ***BIM automation in segmental bridge construction*** *using tools such as Rhinoceros, Grasshopper, and Tekla Structures. Case studies of BIM automation in segmental bridge construction in Peru are highlighted, as well as the latest advancements in BIM automation for segmental bridge construction.*

*Our* ***interview with José Matos****, Assistant Professor of the University of Minho, Portugal, is followed by a presentation of the Portuguese current status in the article* ***BMS and BIM: The Portuguese Scenario****. It was originally presented at the IABSE Symposium Prague 2022 and we republish it with IABSE´s kind permission.*

*The usage of* ***BIM at the Porto Metro in Portugal*** *is described in the last article of this issue by* ***Zeljka Devedzic, Allplan****. This project is one of the first major projects where QUADRANTE, a renowned international consulting engineering firm, have used Allplan Bridge as both their design and BIM platform. QUADRANTE is part of the Designer Consortium and is responsible for the design of six main works packages, including the new track, new roads, four viaducts, three underpasses, multiple retaining walls, and the structures of seven new stations and platforms.*

*In the September edition of e-mosty, we will feature the design of the* ***new arch bridge over the River Douro in Porto*** *which will be part of the new Porto Metro. It will be released on 20th September at www.e-mosty.cz.*

*I would like to* ***thank all the people and companies*** *that have been cooperating on this issue and helping me put it together; big thanks to the members of the Editorial Board for reviewing the articles and their cooperation, especially* ***Dr. Vanja Samec****; and also* ***Sandra Komar*** *of WSP USA who kindly assisted with proofreading the article about BIM for the Chenab Bridge.*

*We would also like to* ***thank our partners for their support****.*

*We are already working on the next issue of e-BrIM which will be released on 20th October. We welcome your articles for the October edition, with the first draft deadline of 31st August.*

*Magdaléna Sobotková*

*Chief Editor*

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**The readers** are mainly bridge leaders, project owners, bridge managers and inspectors, bridge engineers and designers, contractors, BIM experts and managers, university lecturers and students, or people who just love bridges.

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ABOUT BRIDGES

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# USE OF BIM IN DESIGN AND CONSTRUCTION OF CHENAB BRIDGE IN INDIA

*Matti-Esko Järvenpää, Director*
*WSP Finland*

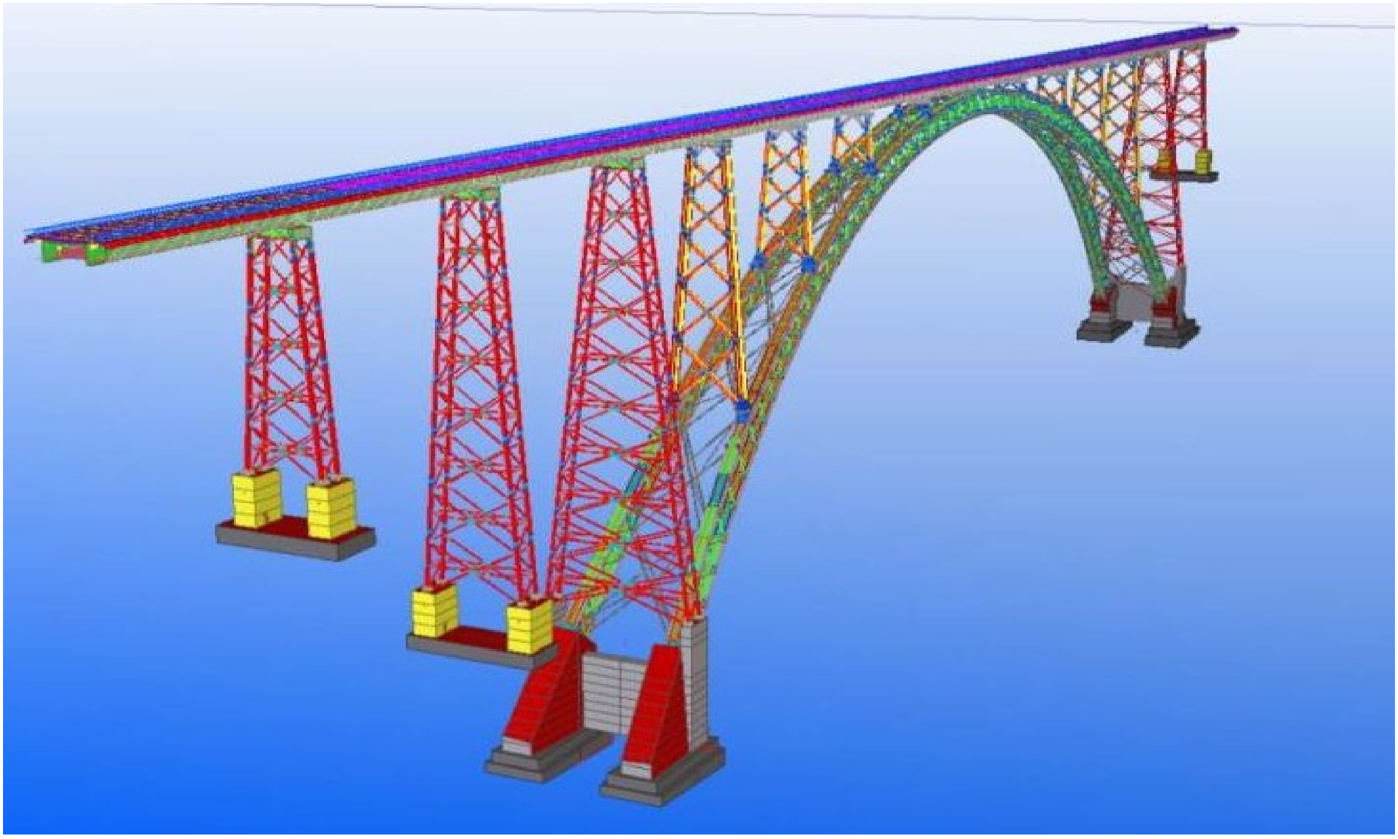


*Figure 1: 3D Model of the Chenab Bridge in Tekla*

## INTRODUCTION

A new railway line between Udhampur and Baramulla has been constructed in the states of Jammu and Kashmir in northern India. The railway has been named a national project, and it is directed by the Northern Railway.

What makes the construction particularly challenging is the large number of tunnels and bridges built in a difficult environment - the rugged and mountainous Himalayan geology. The crossing of the Chenab River between Bakkal and Kauri is one of the most difficult parts of the project.

Constructing one of the world's biggest railway bridges under extremely demanding conditions requires innovative design, an experienced construction organization, and close cooperation between all involved parties.

Our client was Afcons Infrastructure from India and we had a subconsultant Leonhardt, Andrä und Partner from Germany.

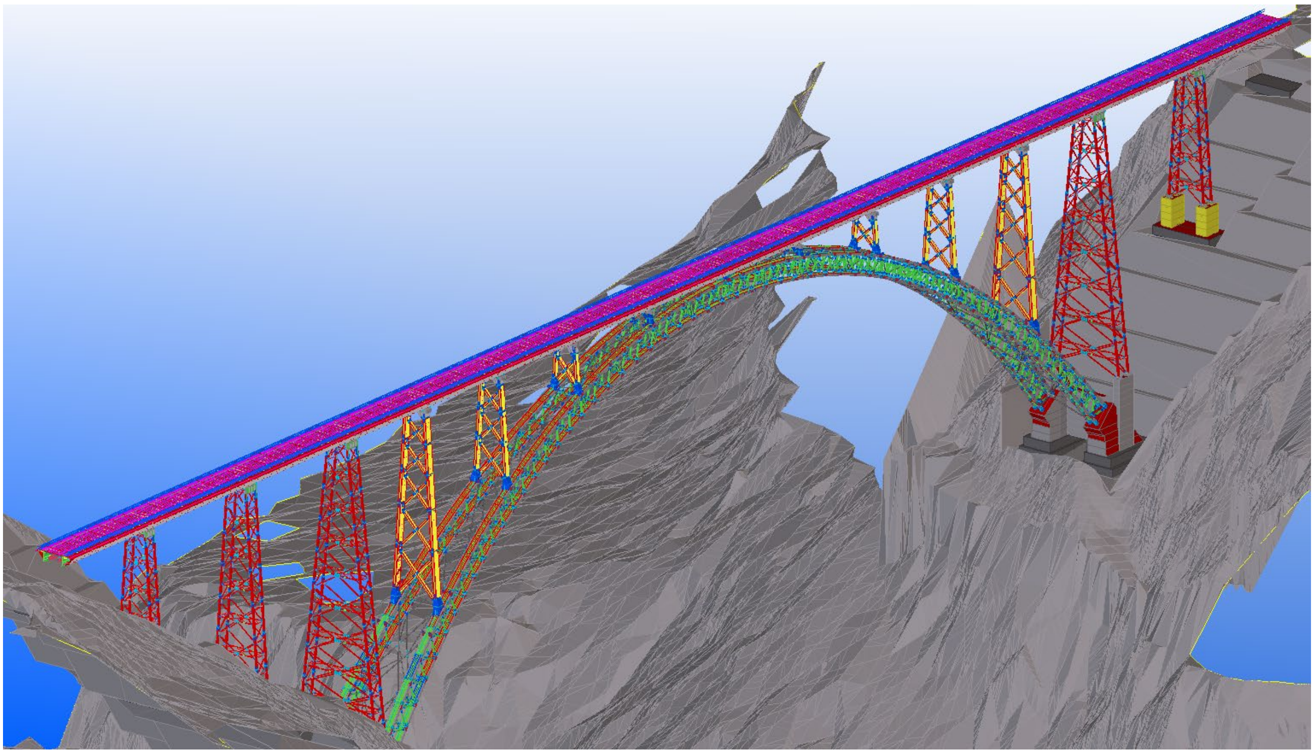


*Figure 2: Combination model of Chenab Bridge*

One of the ways used to ensure effective and real-time collaboration is using Building Information Modelling (BIM) and dedicated software. The model is utilized by staff on site.

When applied to bridge construction, these principles and the consequential process can be referred to as Bridge Information Modelling (BrIM). In this article, BrIM is referred to as BIM.

## PROJECT SCOPE

Using 3D modelling was a prerequisite set by the client Konkan Railways Corporation. The expert knowledge and experience in detailed modelling were one of the main reasons why the engineering of Chenab Bridge was awarded to WSP Finland.

The size of the structure of the bridge is enormous and includes a lot of details. All structures of the Chenab Bridge have been 3D-modelled using Tekla Structures.

The steel structures have been modelled very accurately, and the drawings used to fabricate the steel structure were printed directly from the building information model, such as the temporary cables and related anchoring towers used in the installation of the cantilever.

The high level of development (LOD) and accuracy of the model allowed it to be used for fabrication in the temporary workshops on site. [3]

The modelling team comprised of up to 10 people. The time spent on the model is around 10,000 hours.

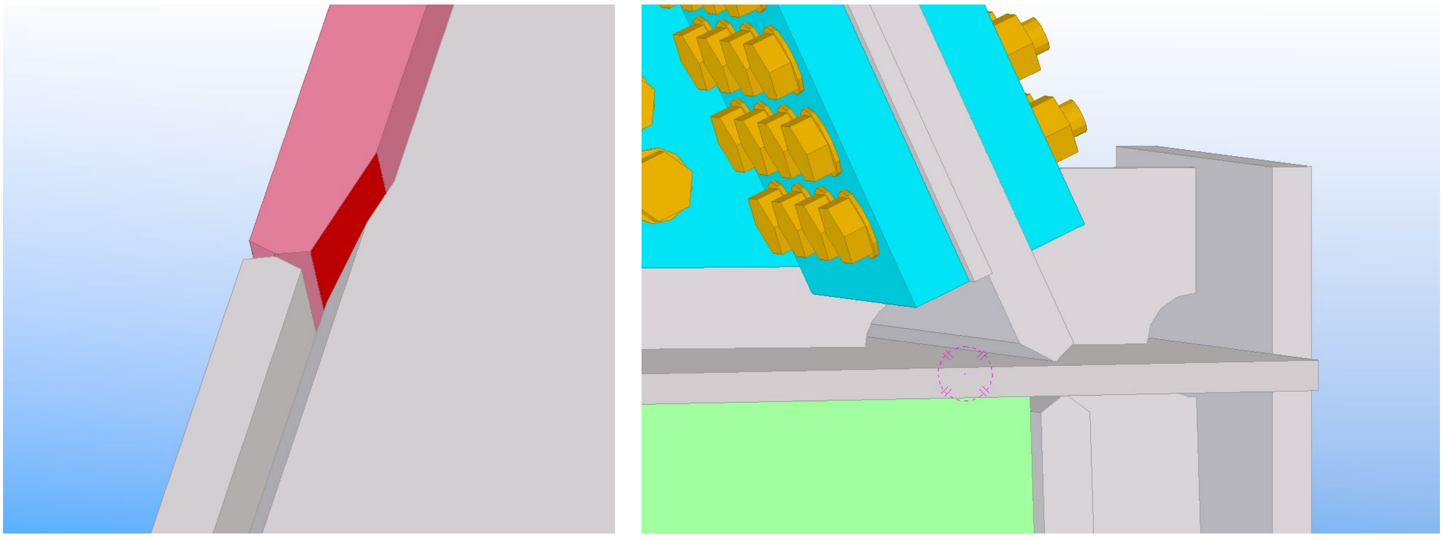
## BIM MODEL OF BRIDGES

The first applications of 3D modelling started in the field of steel structure engineering and detailing. The predecessor of Tekla was called Xsteel, which is a software developed especially for detailing steel structures.

The 3D detailing software provided the compatibility of the parts and especially bolted connections.

The modelling of the Chenab Bridge started at the end of 2004. At that time Tekla Xsteel 9.0 was the latest version of Tekla modelling software available so Xsteel 9.0 was the software used at the start of the project. Later on, the models were updated to a more recent version of Tekla Structures.

The approach viaduct of Chenab Bridge was one of the first bridges in the world where BIM was applied for bridge modelling.



*Figures 3 and 4: Modelled weld preparations in the Tekla Model, web plates of the arch segment*

The first BIM applications were originally meant for building structures. Bridge structures have usually bigger dimensions which leads to bigger thermal movements and bigger deformations than building structures. These issues have to be taken into account when modelling bridges.

When detailing such large structures as the Chenab Bridge, it is often necessary to consider also the minor details in the detailing.

Weld preparations and cope holes were modelled to the required level of detailing, see Figures 3 and 4.

One of the principles for modelling large structures is to do the modelling in an organized manner, Figure 5. The model must be divided into different segments. Each structure type gets its own naming and identification. This is utterly important especially when the model is changed and the drawings are revised. [6]

Chenab bridge

First character x means delivery package.
1: Blocks E1-E9 and W1-W9
2: Blocks E10-E17 and W10-W15
3: Blocks E18-E24 and W16-W22
4: Blocks E25-E30 and W23-W28
5: Blocks E31-E37, 36-1, 36-2 and W29-W34

| | | **Main bridge arch** | | | |
|---|---|---|---|---|---|
| Constructions | Structures | Assembly number | Part number | Note | Color |
| UPPER CHORD EAST | | | | | |
| | box walls | xUE1... | xUEW1... | wall | 1 |
| | middle plate | xUE1... | xUEMP1... | plate | 2 |
| | longitudinal stiffener | xUE1... | xUELS1... | longitudinal stiffener | 10 |
| | other plates | xUE1... | xUEPL1... | plate | 4 |
| | sec. beam web | xUE1... | xUESW1... | secondary beam web | 3 |
| | sec. beam flange | xUE1... | xUESF1... | secondary beam flange | 8 |
| | gusset plate | xUE1... | xUEGP1... | gusset plate | 9 |
| LOWER CHORD EAST | | | | | |
| | box walls | xLE1... | xLEW1... | wall | 1 |
| | middle plate | xLE1... | xLEMP1... | plate | 2 |
| | longitudinal stiffener | xLE1... | xLELS1... | longitudinal stiffener | 10 |
| | other plates | xLE1... | xLEPL1... | plate | 4 |
| | sec. beam web | xLE1... | xLESW1... | secondary beam web | 3 |
| | sec. beam flange | xLE1... | xLESF1... | secondary beam flange | 8 |
| | gusset plate | xLE1... | xLEGP1... | gusset plate | 9 |

*Figure 5: Example of organized modelling*

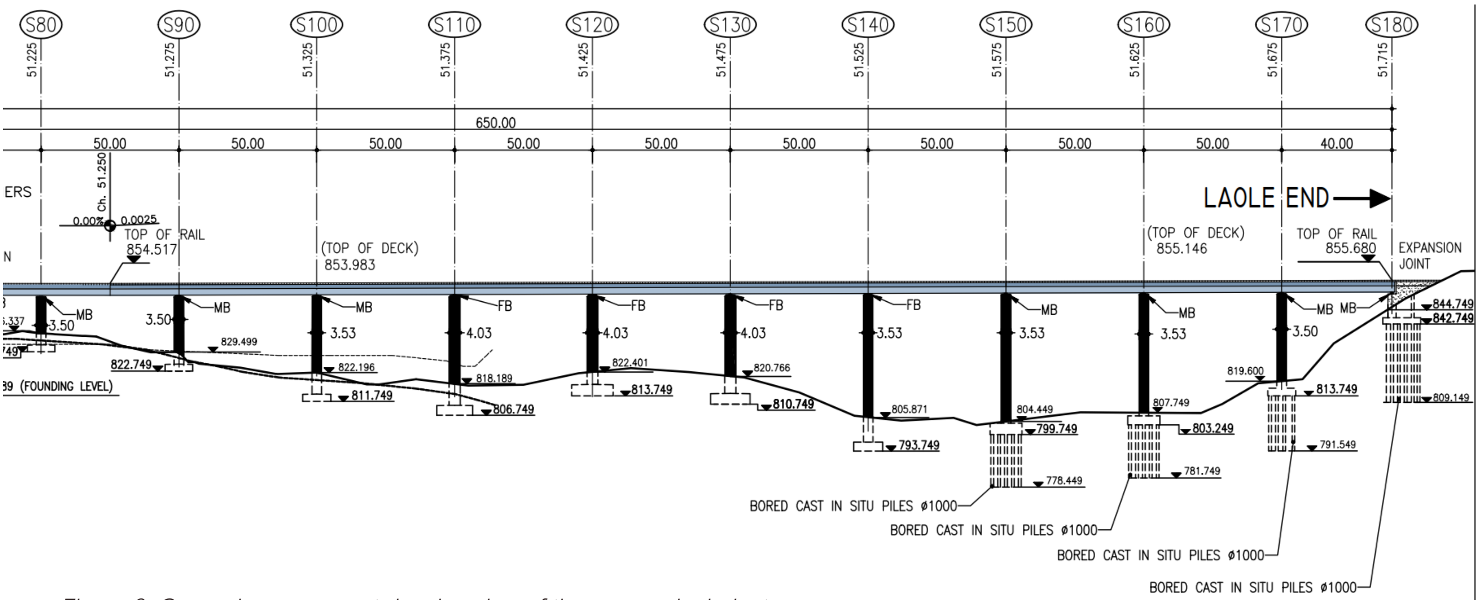



*Figure 6: General arrangement drawing view of the approach viaduct*

## APPROACH VIADUCT

The approach viaduct of the Chenab Bridge consists of a steel bridge deck and concrete piers, Figure 6. The bridge was erected by incremental launching.

The alignment of the bridge is curved. The bridge has been modelled in an unstressed shape including the camber shape. The camber shape includes the deflection caused by the live load and the deflection caused by half of the train load on one track.

The approach viaduct is divided into 66 segments. The segments were fabricated at the fabrication facilities directly by the abutment of the bridge, Figure 7. The length of the segments is approximately 8.5 m and they weigh between 55 and 90 tons.

The bridge segments were fabricated at an upside-down position and rotated to a final position at the stage when the segment was close to being finalized. The rotation was done with the help of a rod which was placed through the webs of the girder at the centre of gravity of the segment.

*Figure 7: Approach Viaduct with the fabrication facilities on the background*

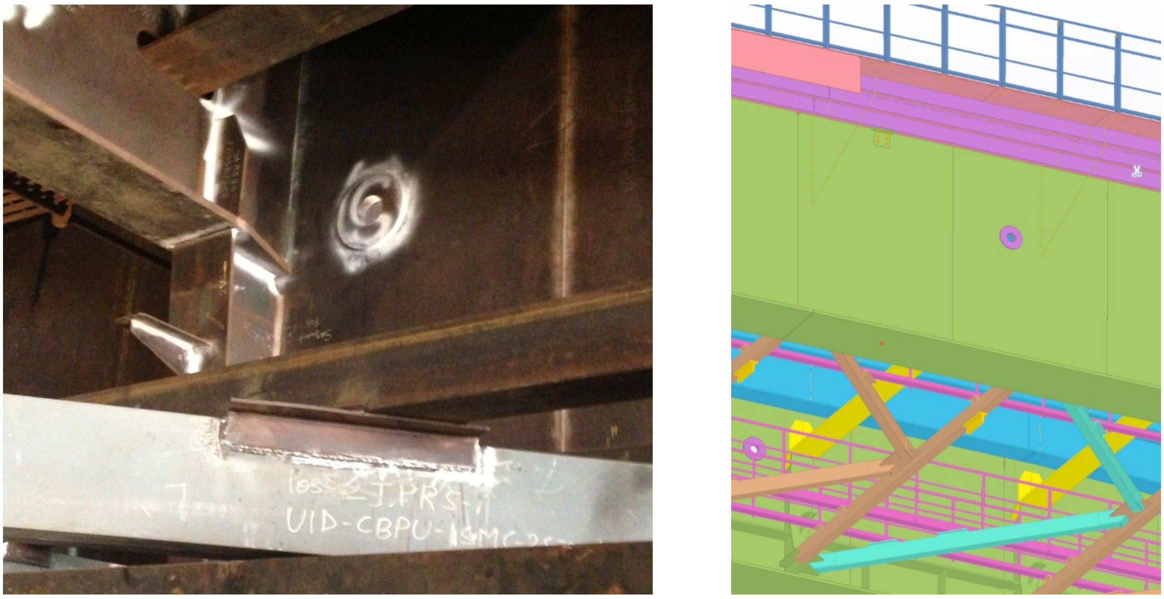
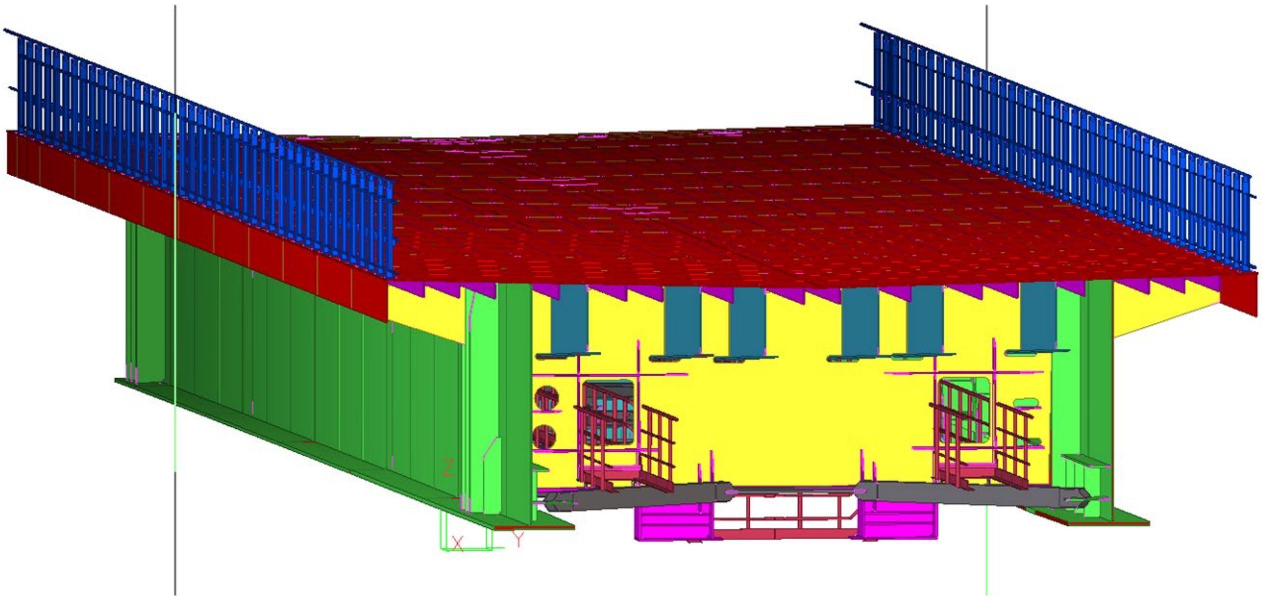


*Figure 8: The reinforced web hole for the turning rod of the segment*



*↑ Figure 9: Approach Viaduct deck, Tekla model view*

*← Figure 10: Approach Viaduct segment, ready for launching on the bed*

## STEEL PIERS

The approach piers of the main bridge are truss-type steel structures, Figure 11. The longest of them is over 130m high. The segments of the piers and the segments of the arch were erected by the cable crane. The maximum capacity of the crane was 36 tons. The erection was completed faster than expected.

All the segments are prefabricated and connected with bolted connections.

All the bolted connections are slip-critical friction grip connections. The box structures of the steel piers are air-tight which was tested after manufacturing.

The structural analysis for the steel piers was done by the Lusas FEM package.

The geometry of the calculation model was transferred to Tekla Structures and then further developed into a detailed BIM model.

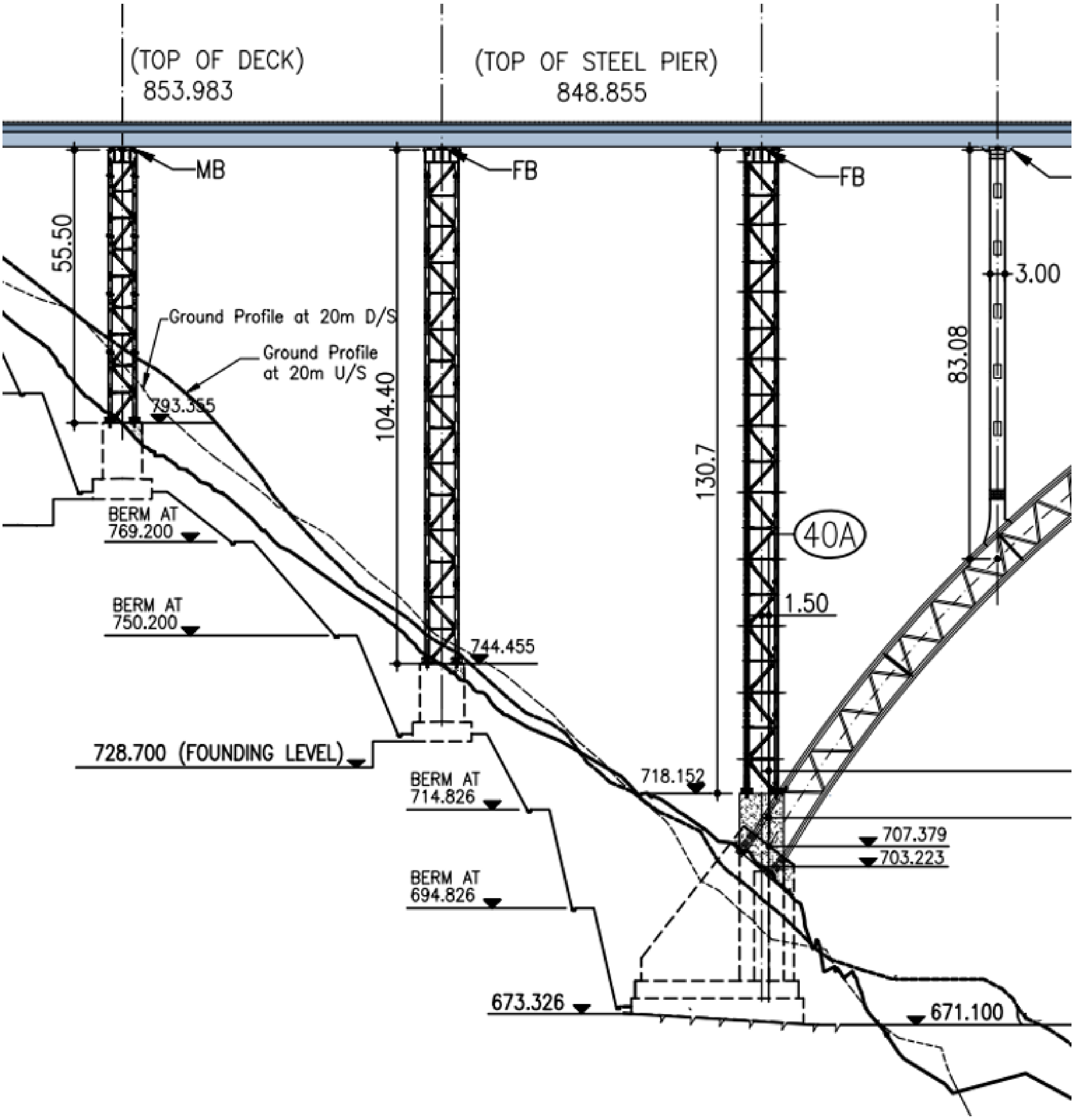



*Figure 11: Approach piers of the main bridge*

*Figure 12. Bracing connection with check valve for airtightness, pier preassembly*

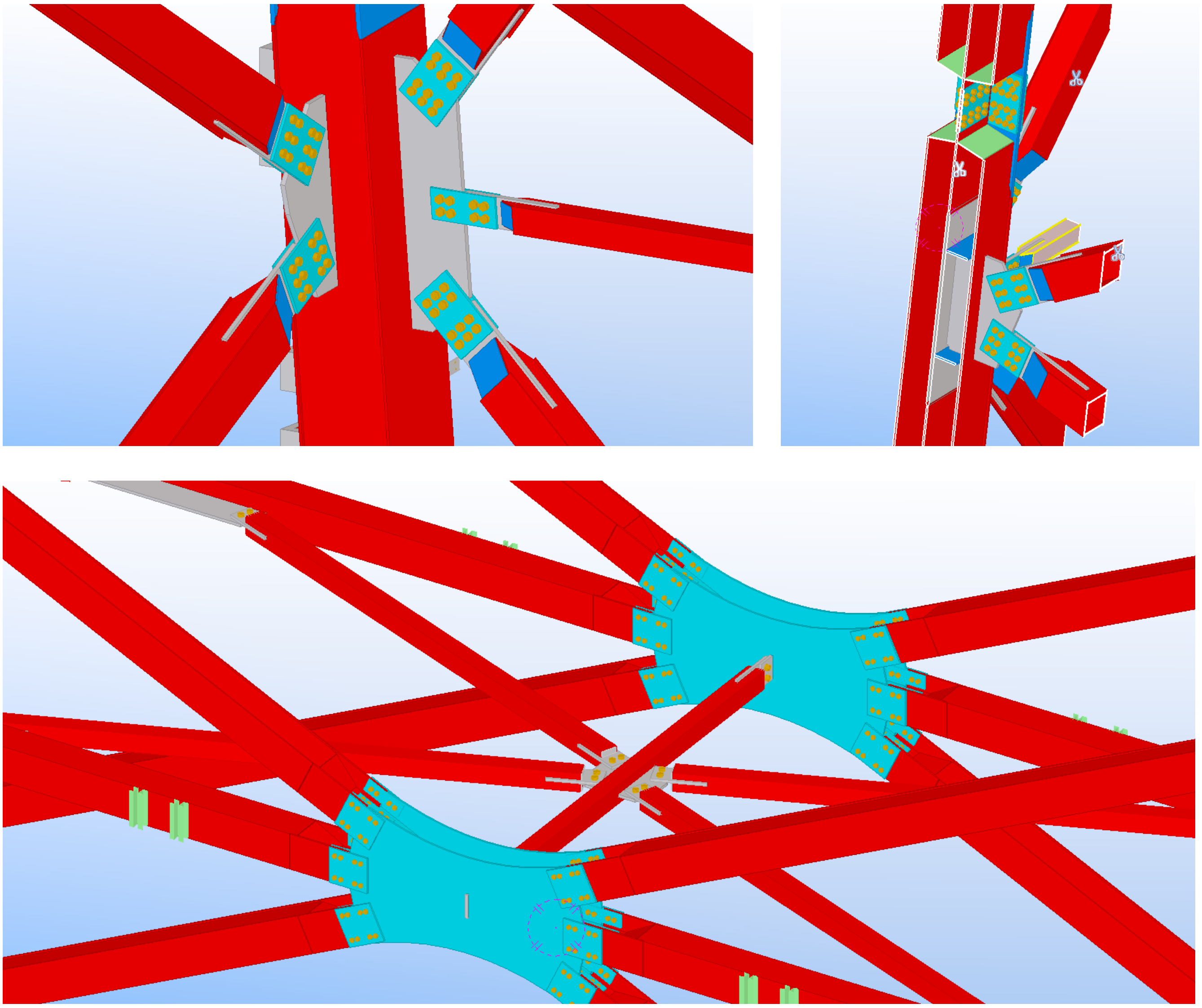


*Figure 13: Connections and details of the approach piers*

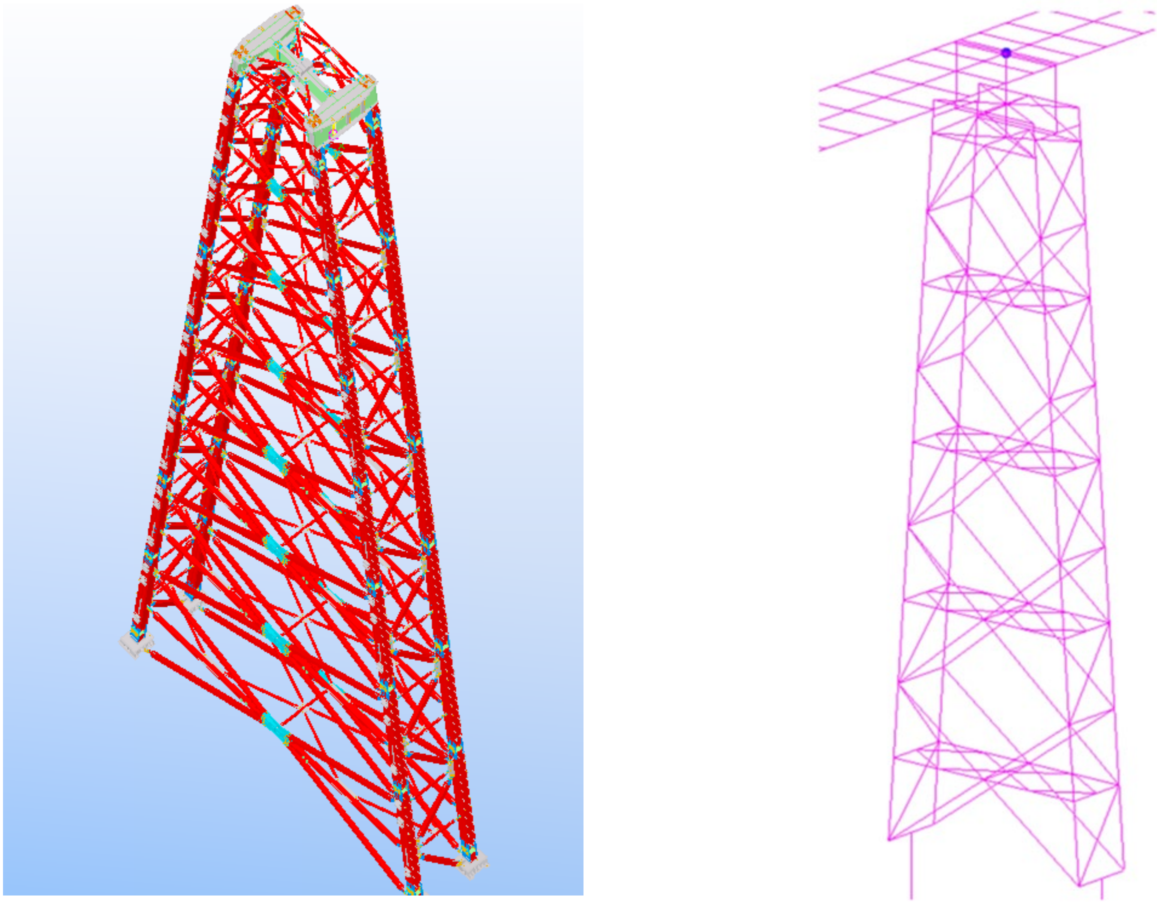


Figure 14: Views from the detailed Tekla model and the analysis model

MAIN BRIDGE ARCH

The main arch members are concrete-filled steel boxes. Diagonals are welded steel tubes and wind bracings are round pipes.

The arch and the piers were preassembled before their final erection.

The most challenging part of modelling the arch was to model the structures in unstressed shapes with the camber. The deck was also modelled in an unstressed shape.

Due to the construction sequence, the precamber value in the deck was lower than in the arch. In the arch, the precamber is approximately 149 mm whereas in the deck 156mm, Figure 15.

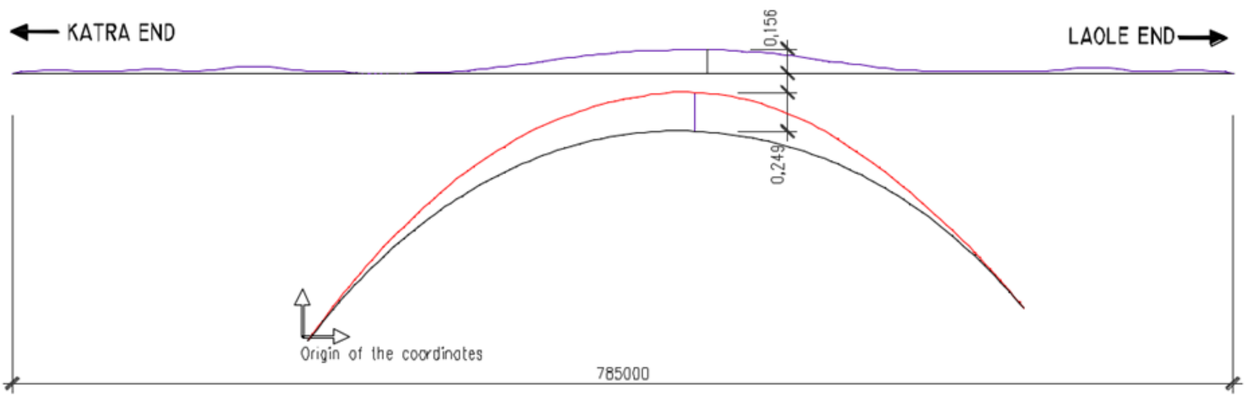



Figure 15: The difference between the camber shape of the deck and the camber shape of the arch

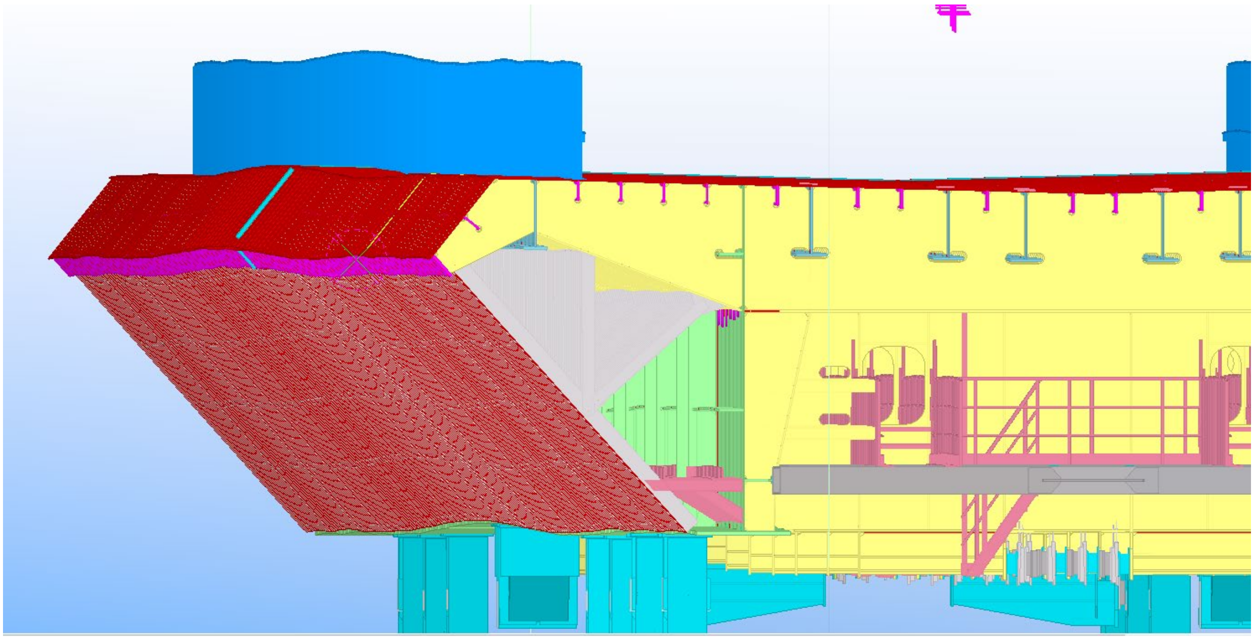


Figure 16: Cambered deck structure of the main bridge

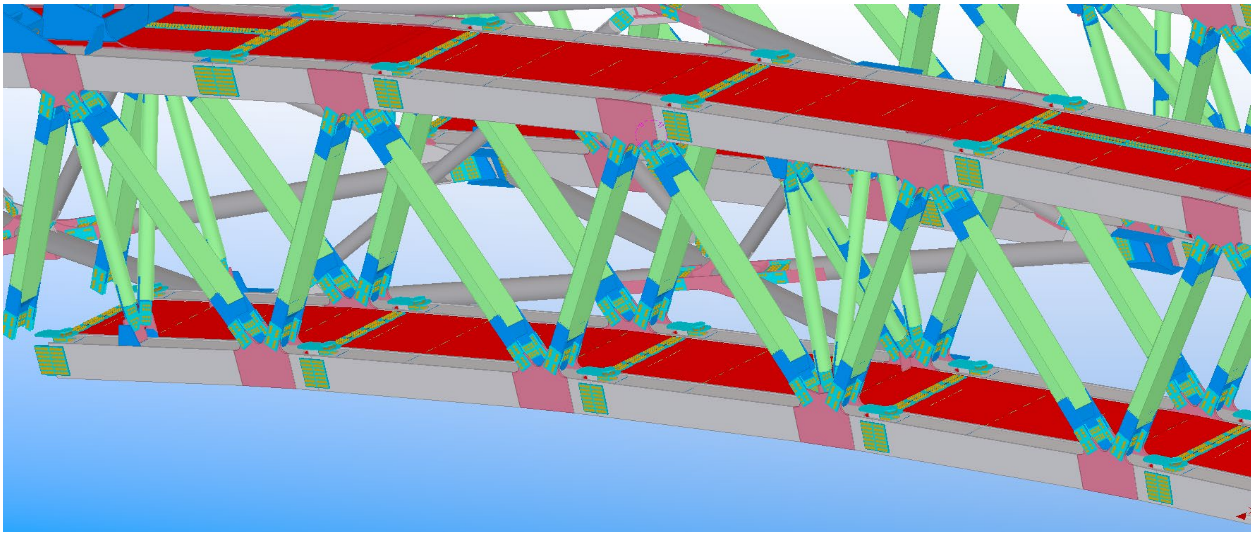
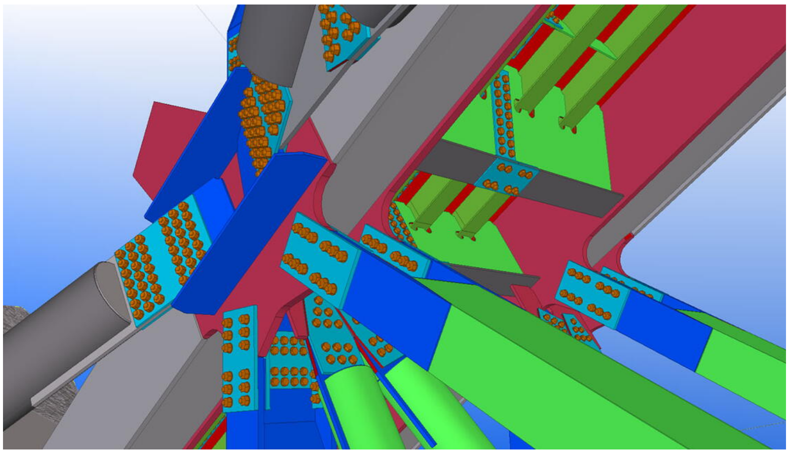


Figure 17: Detailed Tekla Model of the arch structure

The whole structure was detailed with bolted connections, Figure 18. There was no structural site welding in the arch steel structure. Similar to the piers, all connections are slip-critical friction grip connections.

The box girders in the arch structure are filled with concrete. The structure works as a composite structure for the traffic loads.



→ Figure 18: Bolted connection of the arch structure

**Fabrication drawings of all the structures were extracted directly from the model. Whenever the model changed, the drawings changed as well.**

There are two types of fabrication drawings for workshop fabrication: assembly drawings and single-part drawings, Figure 19.

Assembly drawings contain information on the steel element to be erected on site and all the information which is necessary for the manufacturing and the assembly.

The drawings have geometrical information and information on all the parts which belong to the assembly. They also include information on welding, surface treatment and NDA inspection. [7]

The single-part drawings of the structure contain all the information to manufacture single steel parts. [7]

*Figure 20: The cross beam web the approach bridge*

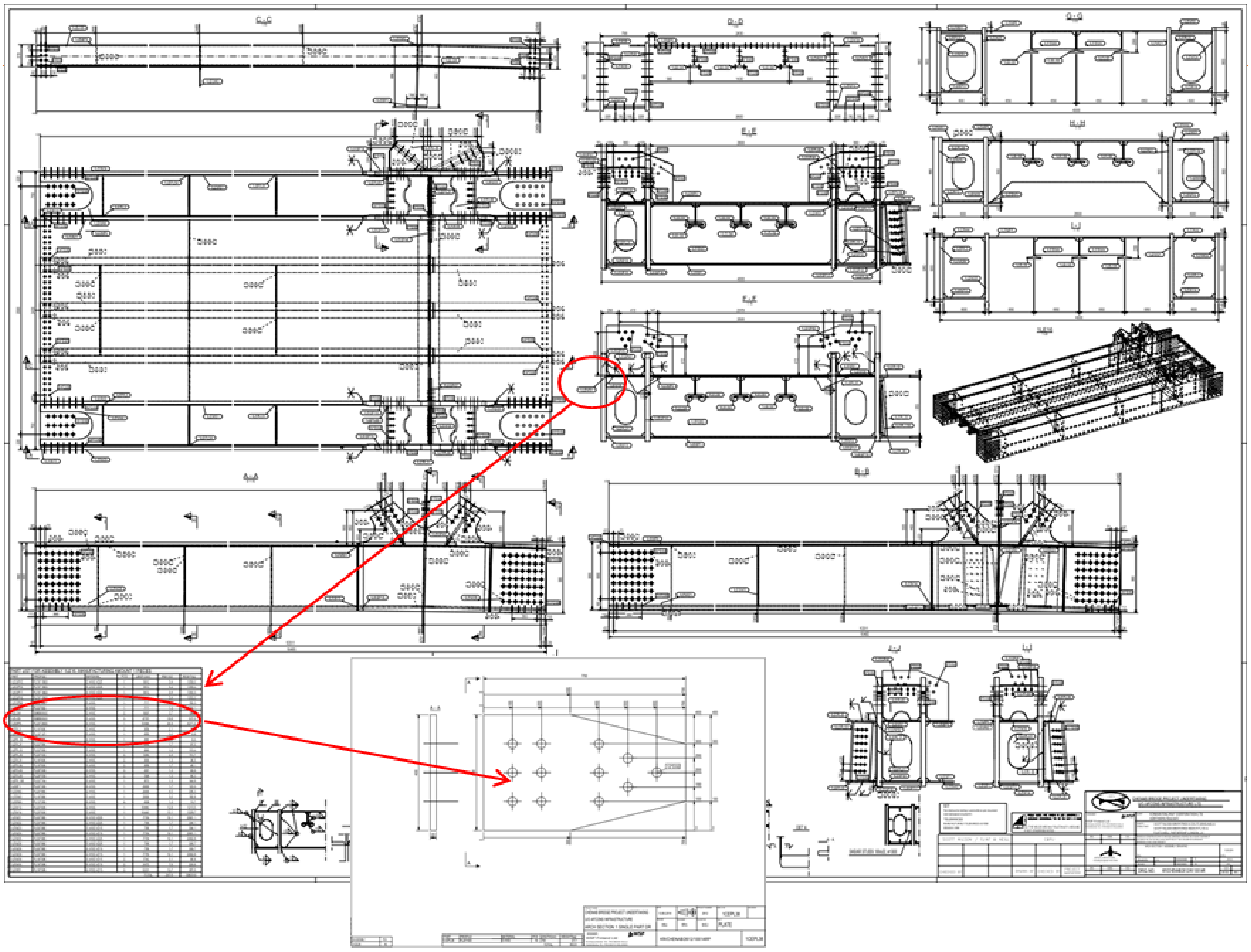


*Figure 19: Automatically created parts of the numbered assembly and single-part drawings*

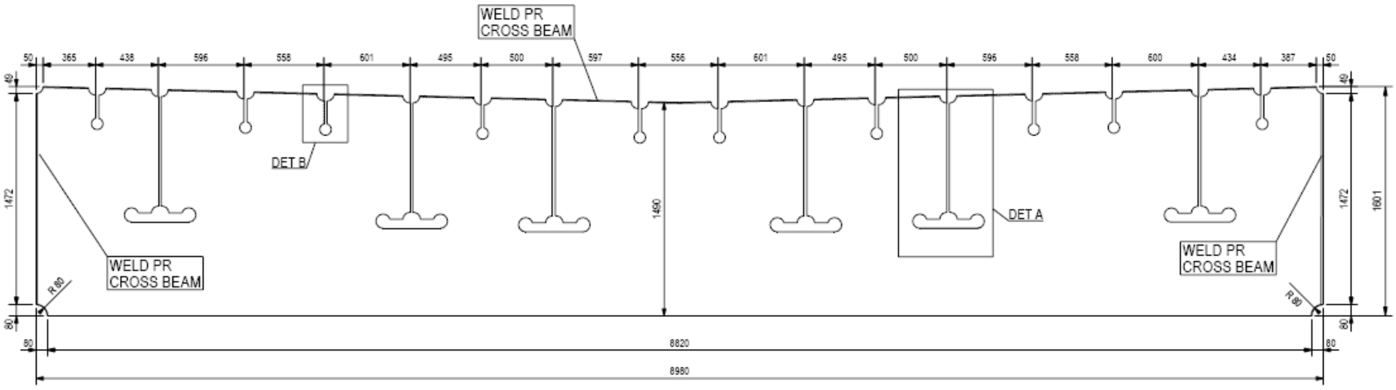



*Figure 21: Single-part drawing view of the web plate*

In addition to the segment assembly, the plate nesting and cutting were done on site. NC data was exported directly from the BIM model to NC machines, see Figure 22.

The segments and other structures of the bridge were fabricated with the help of the fabrication documents extracted from the model.

In addition to the final bridge information, the fabrication documents contain necessary information for fabrication such as lifting lugs and centres of gravity.

## TEMPORARY STRUCTURES

BIM was applied to the temporary structures of the bridge as well. The towers for the temporary stays were modelled similarly to the permanent structures.

The anchor structures for the temporary cables, see Figure 24, were considered similarly to anchors in a cable-stayed bridge. Cable sag was taken into account to achieve an accurate angle for the anchors.

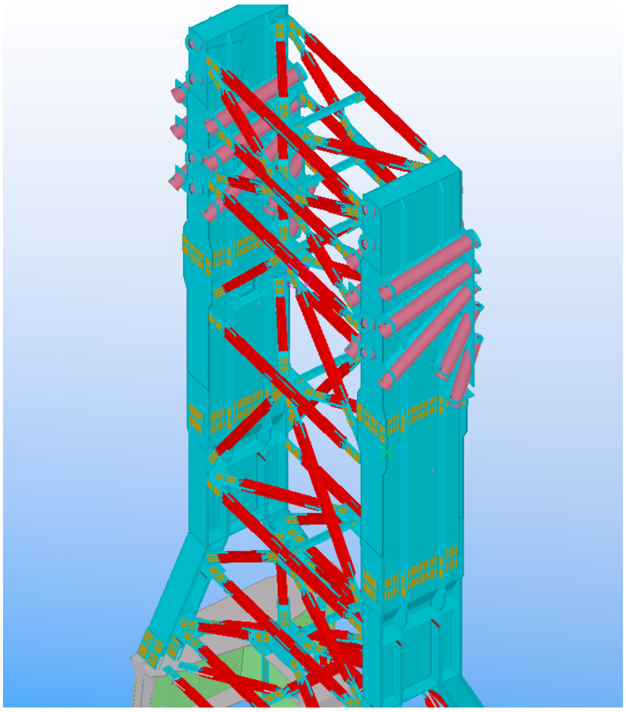


*Figure 23: The temporary pier for the temporary stays*

*Figure 22: Web plate cutting by NC-machine*

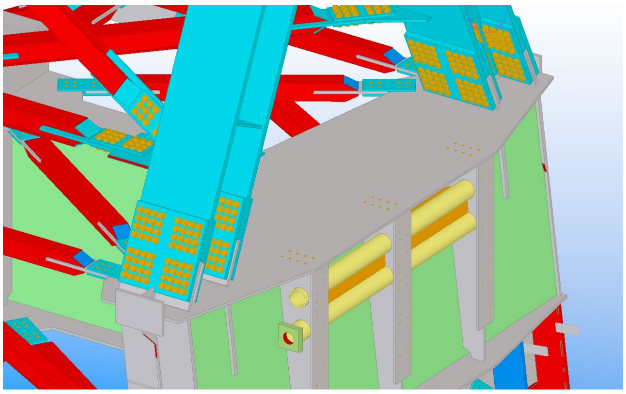


*Figure 24: Connections for the temporary pier at the pier cap, anchor structures for longitudinal stays on the side of the pier cap*

## FOUNDATIONS AND CONCRETE STRUCTURES

The foundations and concrete structures were also engineered by utilizing BIM, Figure 25. The abutments of the bridge are extremely large in size. Because of their size, it was extremely important to plan the concrete casting work and the casting periods. This was done through the BIM model. The casting segments and construction joints were modelled in Tekla.

Once the construction joints and the cast segments were in the model, it was possible to use the model information for time scheduling and planning material orders.

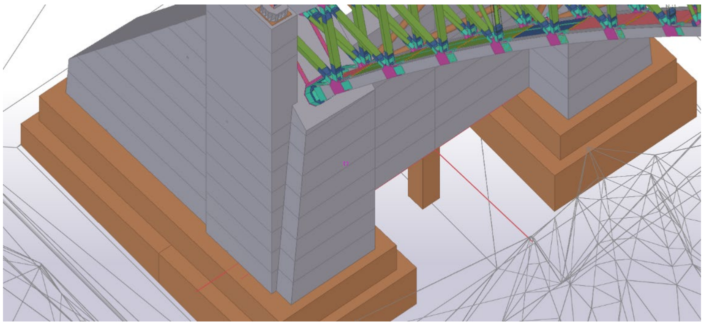


*Figure 25: The abutment of the arch; construction joints are shown in the model view*

## BIM ON SITE

The bridge BIM models were a great advantage on site as well. The site crew was able to get additional manufacturing information from the models.

The arch assembly was done directly with the help of the models. The shape of the arch in the model was the unstressed shape.

During the pre-assembly, Figure 27, it was possible to get all the dimensions and coordinates directly from the model.

The building data can be used by various project participants from contractors to subcontractors, to enter and output measurements and dimensions.

The staff members used the models daily, running the files for production management. The model was also utilized for planning installation and logistics.

The contractor had many BIM users working on the project, and the site management used Tekla BIMsight for reviewing the model on site. [4]

## PEER REVIEW OF THE DESIGN BY UTILIZING THE BIM MODEL

The BIM model of the bridge was an advantage in the peer review of the structure as well. The British third-party inspection company reviewed the model together with other design documents.

The review was done through an open IFC -format exported from the Tekla model. The IFC model accompanied with the drawings was a solid basis for the third-party review.

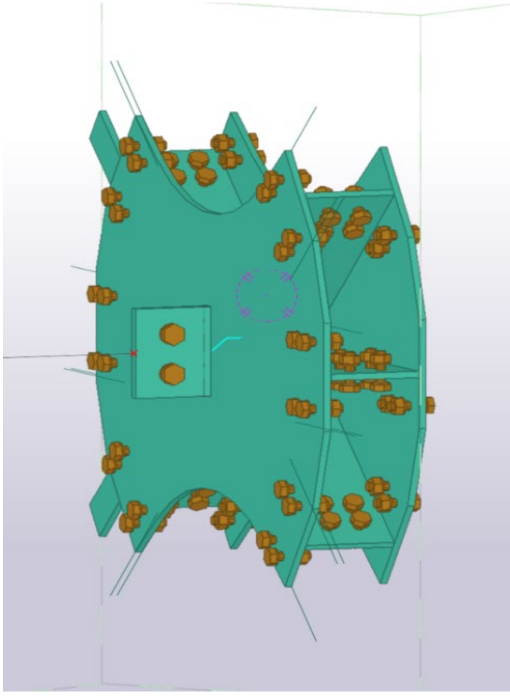


*Figure 26: The centre connection piece of the pier*

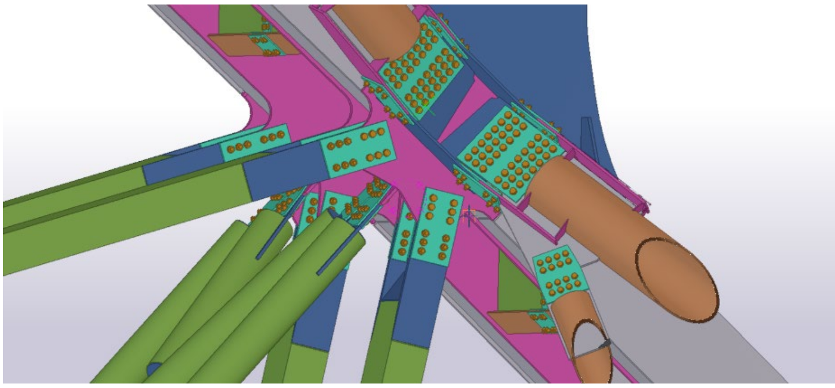


*Figure 27: The arch structure in the Tekla model and positioned for pre-assembly on the assembly field*

The model provided numerous benefits such as:

- Improved collaboration: BIM models facilitate effective collaboration between bridge engineering contractors and other stakeholders. This helps to ensure that the design is efficient, cost-effective, and constructible.
- Enhanced Visualization: BIM models enable all the parties to visualize the structural design in 3D, making it easier to identify potential issues and make informed decisions.
- Error Reduction: BIM models allow for the identification of errors and clashes before construction, reducing the risk of costly errors and rework.

## CONCLUSION

Digitalization has made the BIM model a superior tool for communication between different parties (engineer, designer, contractor, check and the client) in the project.

Successful fabrication and erection of such a large-scale steel structure as the Chenab Bridge would not have been possible without a fully detailed BIM model.

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e-BrIM

# BIM AUTOMATION IN SEGMENTAL BRIDGES USING PARAMETRIC MODELLING APPLICATION CASES IN PERÚ

*Alejandro Palpan Flores, Bridge Project Coordinator*

*TSC Innovation, Perú*

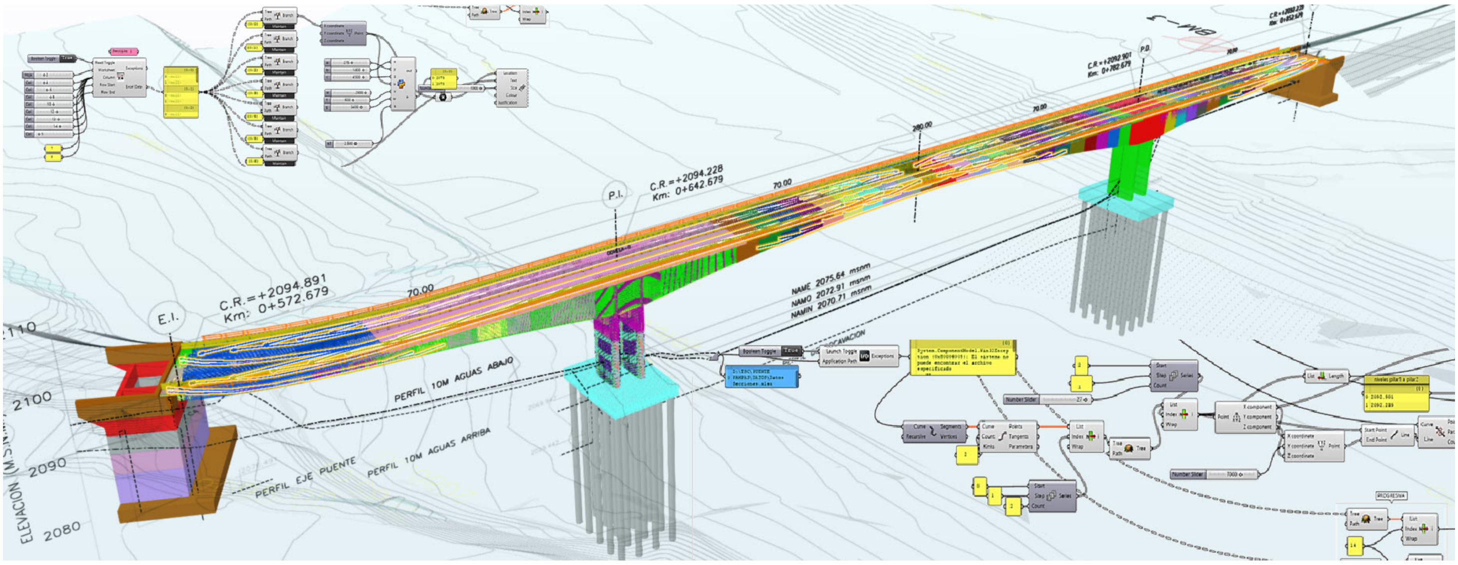



*Figure 1: BIM Model, Pampas Bridge, Perú*

## INTRODUCTION

BIM or BrIM is a digital representation of bridge characteristics widely used in the engineering and construction industry.

It is often used with parametric modelling in segmental bridge construction.

This article explores the benefits of BIM automation in segmental bridge construction using tools such as Rhinoceros, Grasshopper, and Tekla Structures.

By using a VDC approach, significant improvements have been made in creating digital models for structural coordination and digital fabrication of reinforcement steel.

Case studies of BIM automation in segmental bridge construction in Peru are highlighted, as well as the latest advancements in BIM automation for segmental bridge construction.

## BIM IN SEGMENTAL BRIDGES AT TSC INNOVATION

In recent years, segmental bridges have gained significant relevance in the construction of long-span bridges in Peru.

These bridges are characterized by their construction method, known as the balanced cantilever method, which is cast in situ.

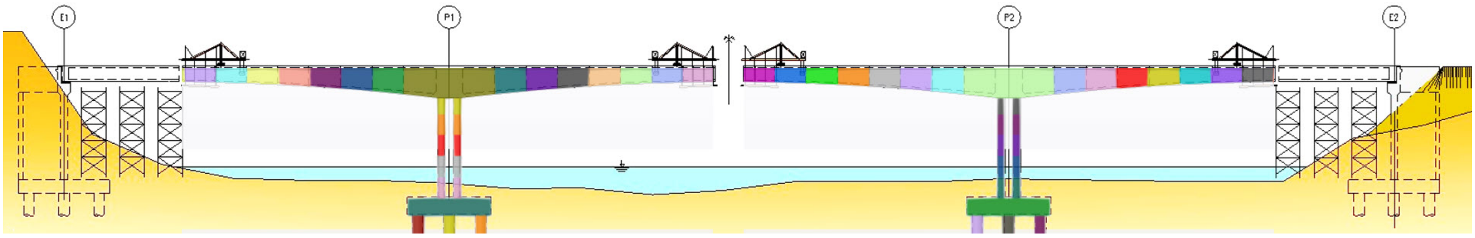



*Figure 2: General View of Segmental Bridge*

The superstructure is built in stages, with the previously constructed segments providing support for the additional segments.

These segments are created by pouring concrete on site as the work progresses, using a specialized form traveller system.

One of the key advantages of these bridges resides in their exceptional structural behaviour.

The framed configuration and the deck section, commonly designed as a box girder, enable efficient distribution of loads throughout the entire bridge span.

Furthermore, these bridges are widely recognized for their remarkable seismic resistance, making them an ideal solution for covering long spans without compromising stability and structural resistance.

At TSC Innovation, we specialize in detailed engineering and the supply of dimensioned reinforcing bars for this type of segmental bridge constructed using the method of successive segments.

We have had the opportunity to participate in prominent projects in Peru, such as the Allcomachay Bridge (2016-2017), Kutuctay Bridge Design (2020-2021), Ollachea Bypass Bridge 2 (2020-2021), Pampas Bridge (2021), Salvador Bridge (2022-2023) and Kutuctay Bridge Construction (2023).

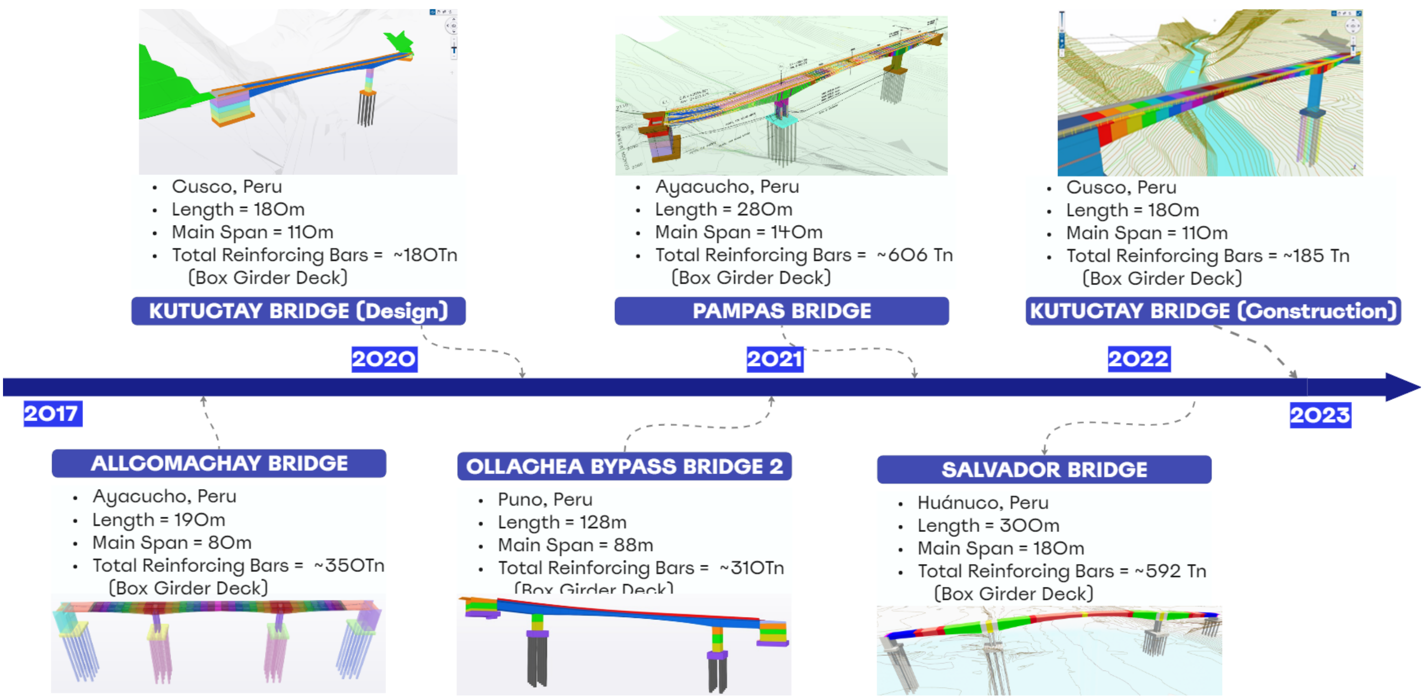



*Figure 3: BIM models of segmental bridges developed at TSC innovation*

In the case of the Salvador Bridge, we have successfully implemented BIM automation, utilizing advanced parametric modelling tools such as Rhinoceros, Grasshopper, Python, and Tekla Structures, among others.

This has allowed us to optimize the detailed engineering process, enhancing efficiency and precision throughout the bridge construction phase.

## AUTOMATION USING PARAMETRIC MODELLING

Automation is a fundamental pillar in modern construction as it aims to reduce repetitive tasks and optimize processes.

Applying automation in the generation of BIM models for structures offers several key advantages in the detailed engineering process. One of these advantages is the reduction of BIM modelling time by automating tasks and enabling efficient adaptation to changes, thereby minimizing rework.

Furthermore, automation allows for the precise and efficient modelling of complex structures, facilitating the dynamic management of BIM models.

There is a significant opportunity to automate the generation of BIM models in diverse project types, such as bridges, roads, tunnels, and linear structures.

The most efficient approach to achieve this automation is through parametric modelling. Parametric modelling involves utilizing algorithms and visual programming to create 3D models.

By controlling parameters, which define the size and shape of the model, it becomes possible to manage attributes and connect data to the model.

Any changes made to the parameters are automatically reflected in the model, enabling the automation of repetitive design tasks.

To fully comprehend the potential of parametric modelling and the opportunities for enhancing engineering processes, it is essential to examine Figure 4 in detail.

This graphical representation illustrates the analogy between the "Real construction" process and the "virtual construction" process.

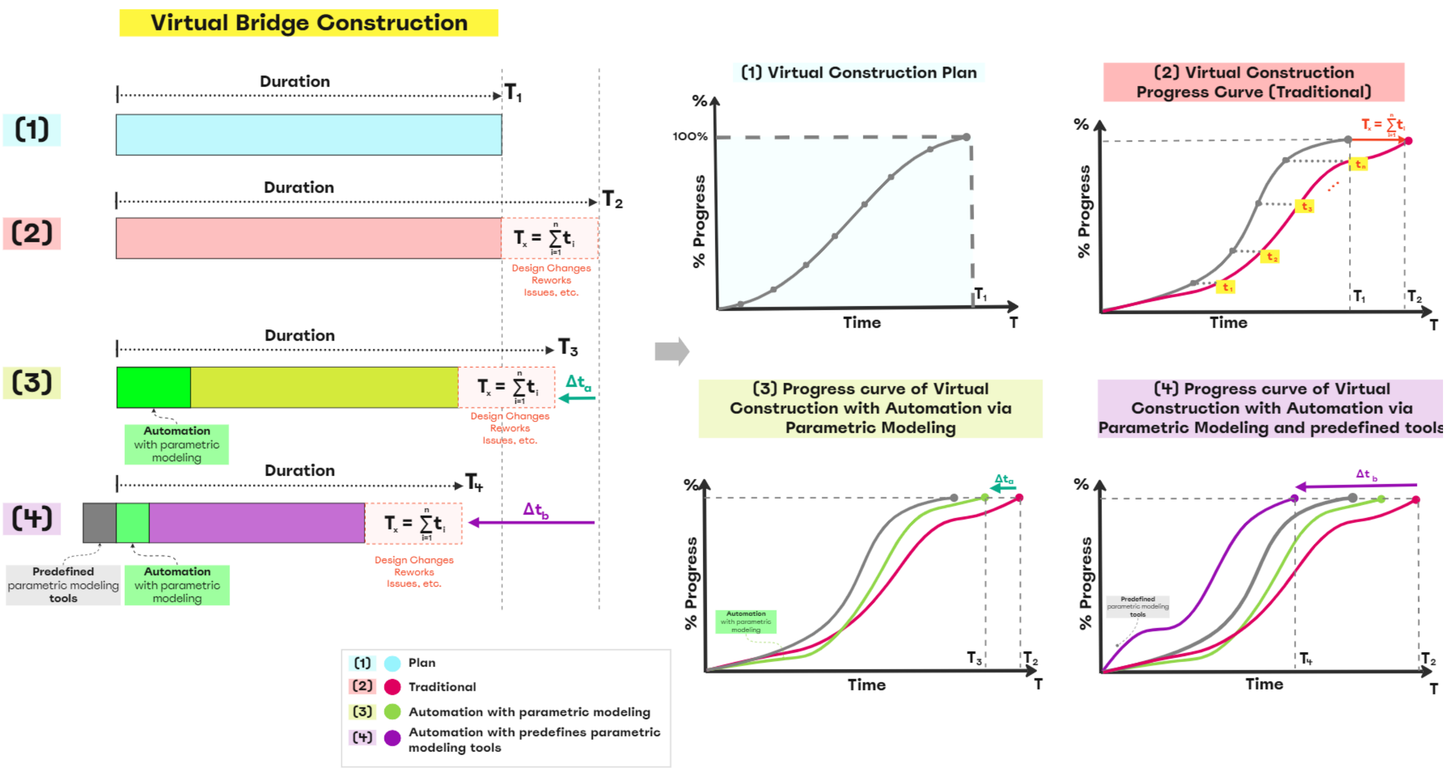



*Figure 4: Impact of Parametric modelling on the virtual bridge construction*

Initially, a plan for virtual construction is established **(Point 1)** with an estimated completion time (T1).

However, in the actual context, it is inevitable to encounter the inherent variability in engineering, characterized by design changes, unforeseen issues, and other factors that result in constant delays **(Point 2)**, extending the timeframe to T2.

Although variability in engineering will always exist, it can be reduced, or its impact minimized. The implementation of parametric modelling emerges as a viable solution for achieving agile virtual construction and addressing these delays.

At **point 3**, the parametric model is employed, involving the development of tools that expedite model generation and can adapt flexibly to changes. This approach enables a significant reduction in the execution timeframe, transitioning from T2 to T3.

However, it is important to note that the initial implementation of these tools may introduce some complexity in the project's initial phase, due to the need for programming and configuration.

It is in this context that the use of pre-defined tools, specifically designed for segmented box section bridge projects **(Point 4)**, provides a substantial advantage.

These pre-established tools facilitate agile adaptation of the code to the new project, allowing for flexibility and dynamism during the virtual construction process.

Consequently, the duration of the initially planned timeline (represented by T4) is effectively optimized, taking into consideration the reduced resources required for modelling tasks.

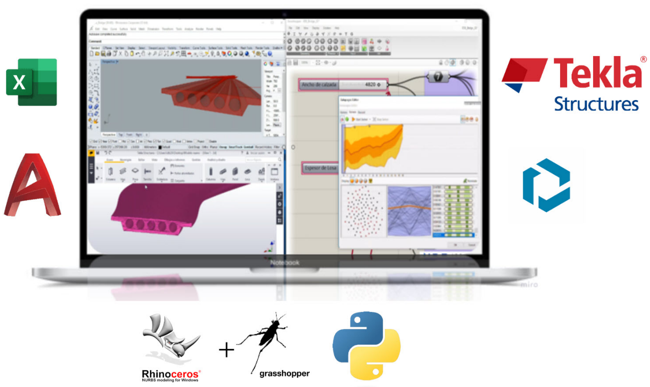



*Figure 5: Tools for parametric modelling of bridges*

## Parametric modelling tools

Among the most notable software tools for parametric modelling are Rhinoceros, Grasshopper, and Tekla Structures.

These tools, with their visual and script-based approach, facilitate the generation of precise and flexible parametric models.

In the case of segmental bridges, where the deck consists of a variable cross-section box, the integration of Rhinoceros, Grasshopper, and Tekla Structures proves highly effective due to the complexity of their forms.

Grasshopper, in combination with Rhinoceros, allows for the creation of sophisticated parametric models, while Tekla Structures, which specialized in structural detailing for manufacturing, facilitates the comprehensive development of BIM models for the bridge, Figure 5.

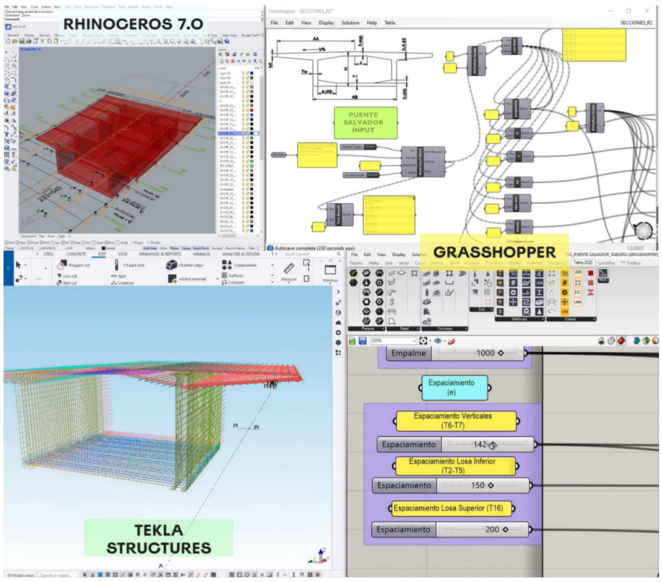



*Figure 6: Parametric segmental Bridge modelling*

## Parametric modelling process

The generation of a parametric model involves a structured process.

Firstly, a thorough analysis of the input data is conducted to identify key parameters and establish their variable or constant nature.

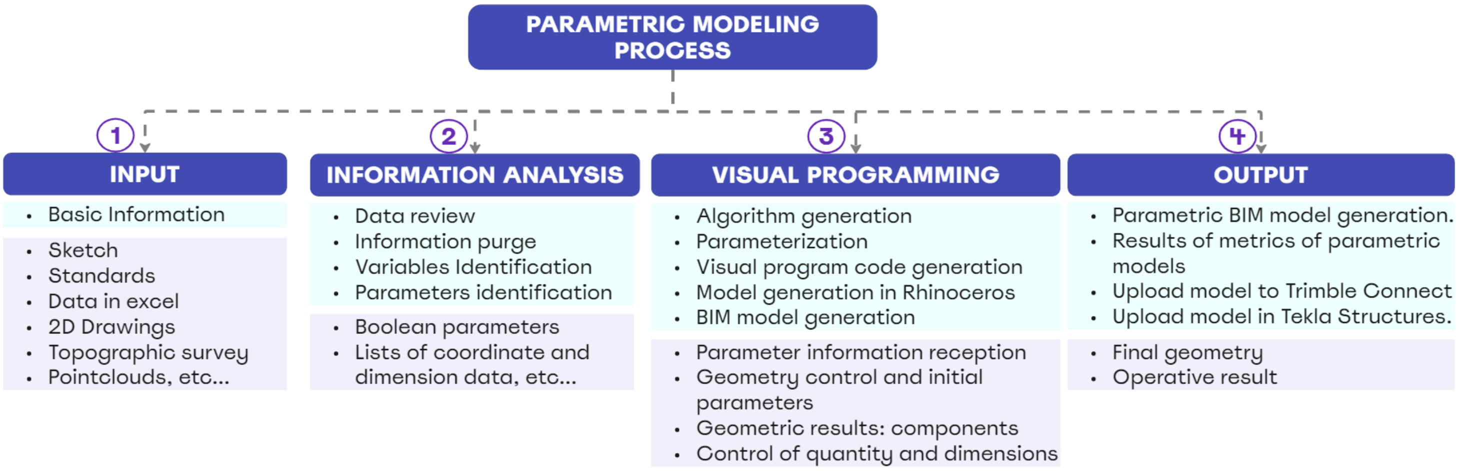



*Figure 7: Overview of the Parametric modelling process*

This careful selection ensures the adaptability of the model to different scenarios, design requirements, and information modelling.

In the next stage, visual programming is employed to develop custom algorithms based on the collected data. These algorithms are translated into specific visual codes for each type of structure.

Rigorous testing is performed during this phase to validate the functionality and effectiveness of the algorithm, ensuring its proper performance in various situations.

Once the preceding stages are completed, the BIM model is generated, integrating all parametric features.

Additionally, parametric models can be linked to external data sources, enabling dynamic updates of the model based on changes in the input data.

This adaptability ensures that the design remains synchronized with the most up-to-date information.

## APPLICATION CASES IN PERU

TSC Innovation specializes in detailed engineering for the structural component, following the Virtual Design and Construction (VDC) methodology.

Our approach focuses on the early integration of designers and/or constructors to establish clear objectives and metrics that quantify the benefits of transitioning from traditional processes to optimized production systems.

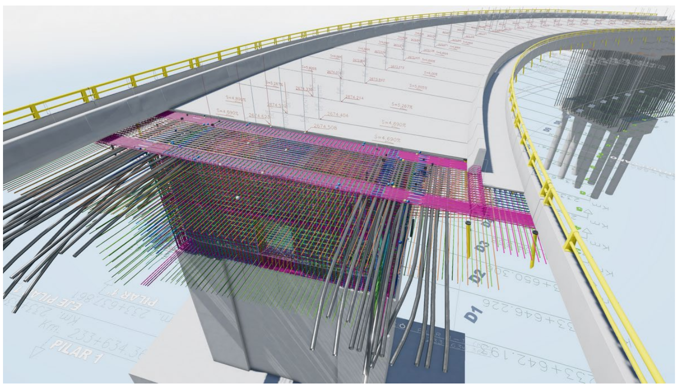


*Figure 8: BIM Model. Ollachea Bridge 2, Puno, Perú*

*Figure 9: Construction of Ollachea Bridge 2, Perú*

We employ innovative technologies based on digitization and automation to optimize costs, time cycles, capacities, and work in process (WIP).

In collaboration with Aceros Arequipa, we have developed this methodology for numerous bridge projects in Peru, with a special emphasis on the industrialization of reinforcements.

Below is a case study on the construction of the Salvador Bridge, focusing primarily on the VDC management framework employed during the project, resulting in a 100% compliance rate for delivering compatible detailed engineering plans and dimensioned reinforcement bars on the established deadlines.

Our objective was to reduce the "cycle time" for generating BIM models and bar bending schedule (BBS) for fabrication for each segment by 20%.

Through the application of parametric modelling, we successfully automated 65% of the BIM model development.

As a result, we successfully reduced both time and resource costs without compromising the quality of engineering and manufactured materials. Additionally, it provided excellent change management capabilities during construction.

Figure 10 on the following page showcases the VDC management framework for virtual construction and the agile development of the automated tool. It encompasses a range of metrics related to technology, collaboration, and process improvement.

By identifying and focusing on controllable factors that have a significant impact on production objectives, we were able to ensure efficient progress and adherence to deadlines without incurring additional resource expenses.

Figure 11 provides a visual representation of the interconnectedness between metrics and objectives, facilitating a comprehensive understanding of their relationships.

To reduce the time required for generating the voussoirs, the decision was made to prioritize automation.

This approach involved identifying the structural specialties that needed to be parameterized, as shown in Figure 11.

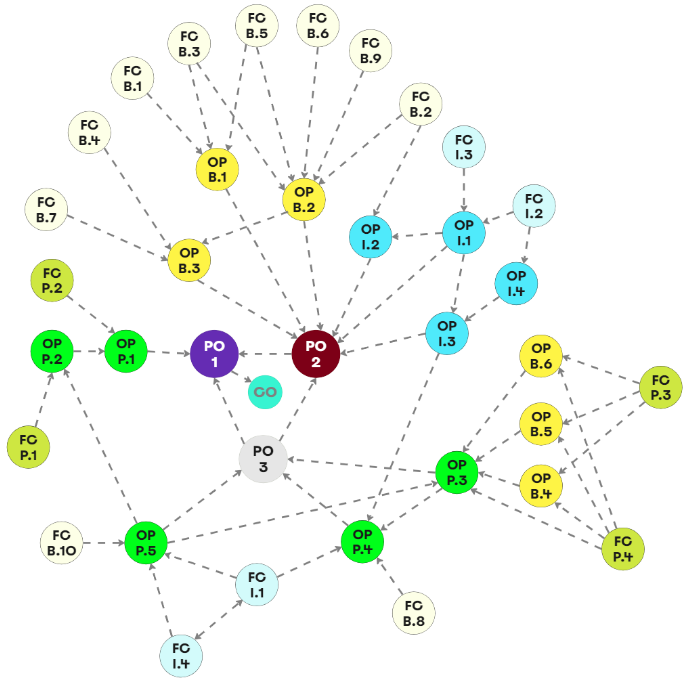



*Figure 11: Map of metric interrelationships*

A 3-week timeframe was set for the development and coding of the parametric tool, requiring a dedicated development team focused on automation.

By parametrizing the geometric properties (G) of each type of segment using a collection of data tables, a direct connection was established with the Grasshopper code.

For post-tensioning (P), the code was divided into two parts: the first part extracted information from the cable design in CAD format and generated 3D models of each cable in its final georeferenced position.

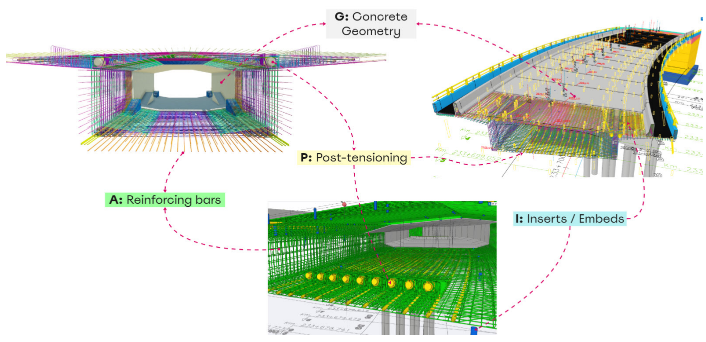
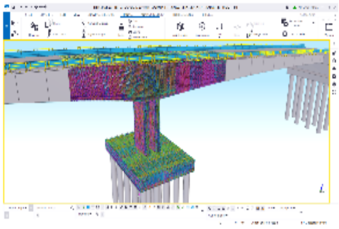



*Figure 12: Specialties (G), (P), (A), (I)*

**PROJECT OBJECTIVE 1:**
Achieve **90% compliance** with the delivery plan and validation of compatible detailed engineering compatible (Models, drawings and bending list for the manufacture of dimensioned reinforcing bars) for the construction of the superstructure of the Salvador Bridge.

**PROJECT OBJECTIVE 2:**
Obtain a **100% validation** of the compatible structural item, through the development of a high level of detail BIM model that includes concrete, reinforcing bars, post-tensioning and inserts, within the established milestones.

VDC Application

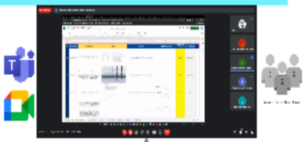


**PROJECT OBJECTIVE 3:**
Reduce by **20%** the time cycle in the generation of BIM models for the production of segments, through an automation of **60%** through the application of parametric modeling.

**INTEGRATED CONCURRENT ENGINEERING (ICE)**

Establish a development **team for BIM Automation**. Generate agreements and commitments for collaboration and **promote constant feedback** among the members of the work team.

Promote **active participation** among project stakeholders to foster the exploration of **effective solutions for issues**, design changes, and other related matters. This collaborative approach aims to **achieve compatibility and ensure structural constructability**

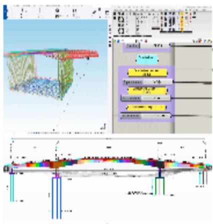


Collaboration
Commitment

**BRIDGE INFORMATION MODELING (BIM)**

Develop the **virtual modeling process** by employing parameterization algorithms through **programming in Visual Code** using tools such as Rhinoceros, Grasshopper, and Python Script.

Achieve a compatible structural BIM model that incorporates a **high level of detailed engineering for reinforcement fabrication** and ensures complete traceability of project information. This information will be stored in a **cloud-based platform**, facilitating seamless collaboration among project stakeholders.

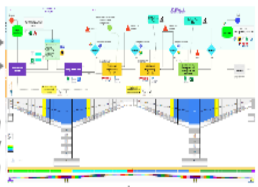


Automation
Optimization

Technology
Digitalization
Information

Production System
Strategy
Lean

**PROJECT PRODUCTION MANAGEMENT (PPM)**



Establishing a collaborative work process to enable **optimal communication flow**, along with a robust monitoring system of the process

Mapping and **optimizing the BIM model production system**, effectively managing resource utilization to develop automation and **reduce the cycle time** in modeling and agile model updates, ensuring compliance with established deadlines and deliverable quality.

**Metrics:**

| CODE | DESCRIPTION | METRIC | TARGET |
|---|---|---|---|
| OP.B.1 | Raise model observations | # Raised observations / # Total of observations | 100% |
| OP.B.2 | N° of elements with BIM attributes | % elements with BIM attributes / Total | 100% |
| OP.B.3 | Digital fabrication from the BIM model | % bars manufactured from the BIM model | > 98% |
| OP.B.4 | Increase the level of automation in geometry modeling | % of automation based on volume | >=95% |
| OP.B.5 | Increase the level of automation in the post-tensioning modeling | % of automation based on length | >=80% |
| OP.B.6 | Increase the level of automation in the modeling of reinforcing bars | % automation based on bars | >=60% |
| FC.B.1 | Interference report with Clash Check | Frequency | Alternate day or at the end of the model of each segment |
| FC.B.2 | Update the model in Common Data Environment (Trimble Connect) | Frequency | Dayly |
| FC.B.3 | Ensure graphic and non-graphic representation through the BIM development level of Concrete Geometry (G) and post-tensioning (P) | LOD (Level of Development) | 350 |
| FC.B.4 | Ensure graphic and non-graphic representation, as well as specifications and details for the digital fabrication of Reinforcing bars | LOD (Level of Development) | 400 |
| FC.B.5 | Ensure the graphic and non-graphic representation through the level of BIM development of other structural elements necessary for accounting such as Inserts / Embeds, Support Devices, joints, railings, etc. | LOD (Level of Development) | 350 |
| FC.B.6 | Definition of matrix of attributes for BIM Model | Specialty | Each specialty |
| FC.B.7 | Constructive simulation of reinforcing bars placement | N° simulations | >= 1 per sector |
| FC.B.8 | Control of modeling times and updating due to changes | Timekeeping record/modeler | Dayly |
| FC.B.9 | Update the model in Tekla Structures | Frequency | Daily or at the end of the model of each segment |
| FC.B.10 | Identification of parameters by type of structure and specialty for coding in Grasshoper and Python | Specialty Structure type | 100% |

**Metrics:**

| CODE | DESCRIPTION | METRIC | TARGET |
|---|---|---|---|
| OP.I.1 | ICE sessions with the contractor | Frequency | >= 1 by week |
| OP.I.2 | % queries raised in ICE sessions | #Raised queries/#Total | >= 80% |
| OP.I.3 | Reduction of query latency | Frequency | <=1 Week |
| FC.I.1 | Scrum Dayly Meeting with the Development Team | Frequency | Dayly (11:30am) |
| FC.I.2 | Set the agenda in advance | Frequency | <= 1 day |
| FC.I.3 | Compliance with commitments in ICE agenda | %Commitments Fulfilled/Agenda commitments | 100% |
| FC.I.4 | Define the list of key project participants for ICE session | #Key participants by specialty | >=1 |
| FC.I.5 | Measure the time of the daily meeting | Meeting time | <=1 hora |

**Metrics:**

| CODE | DESCRIPTION | METRIC | TARGET |
|---|---|---|---|
| OP.P.1 | Achieve the BIM engineering delivery plan for the Superstructure | # deliverables on time/# total | 95% |
| OP.P.2 | Compliance with the BIM Weekly Progress Plan | PPC | >=80% |
| OP.P.3 | Automation in the generation of BIM model with parametrization code | % Automation | 60% |
| OP.P.4 | Reduce time in the engineering modeling of segments | Optimized time/Initial time | >=60% |
| OP.P.5 | Get the code for parametric modeling (G+P+A) | Duration | 3 Weeks |
| FC.P.1 | Preparation of the BIM Weekly Progress Plan | Frequency | Weekly (Every monday) |
| FC.P.2 | Review the deliverable validation plan | Frequency | Weekly |
| FC.P.3 | Optimized process flow design and review | Flow proposed and validated by internal work session | >=1 |
| FC.P.4 | Standardization of automation processes by discipline | Code validated by discipline | >=1 (G) (P) (A) (I) |

*Figure 10: Strategic VDC management framework with metrics*

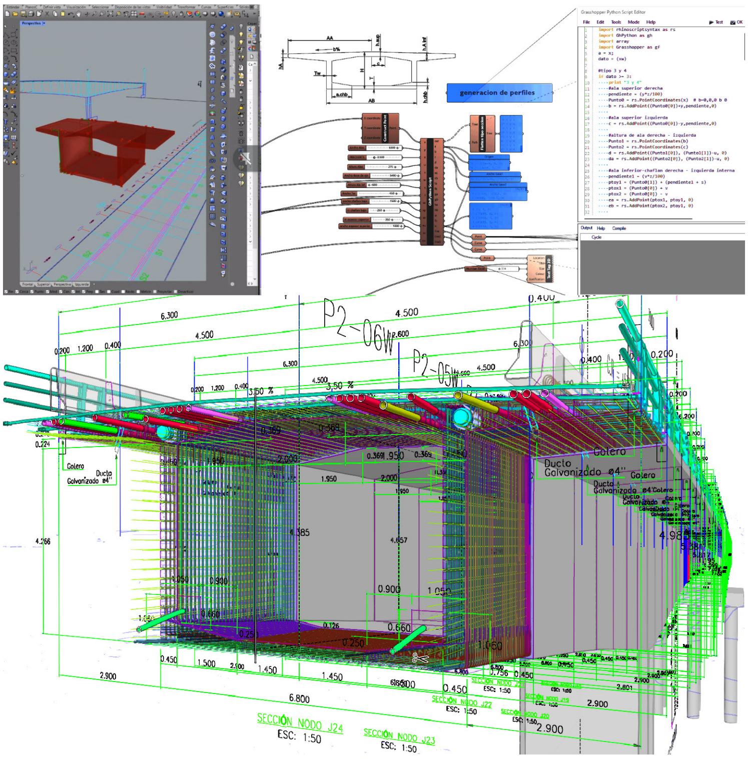



*Figure 13: Parametric Modelling, Salvador Bridge*

The second part relied on a coordinate table to generate the cables, awaiting calculations provided by the supplier to determine the definitive cable arrangement, taking into account the manufacturer's considerations.

This process resulted in various variations based on the initial design.

As for the reinforcing bars (A), it was parameterized according to the geometry of each segment, considering aspects such as hooks, coverings, and other factors stored in a database containing the minimum requirements for digital fabrication.

We achieved 65% automatic reinforcement modelling. While it is true that not all reinforcements could be parameterized, the remaining percentage had to be manually created directly in Tekla, as well as adjustments made for interferences detected with post-tensioning or inserts.

It was crucial to closely track the process, both for code development and detailed engineering delivery.

By using various communication tools, we aimed to achieve an optimal workflow in engineering.

The most challenging activity was the BIM generation and coordination of the reinforcement bars.

We set a target of 6 to 8 segments per week, as it was essential for engineering to stay ahead of fabrication and require multiple approvals from project stakeholders before moving to the fabrication stage.

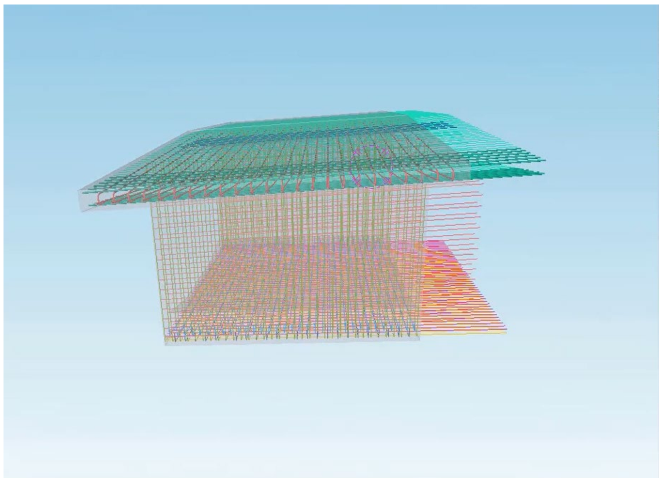
Based on our previous experience, we used to require approximately 8 hours/segment.

However, to improve efficiency, we managed to reduce that time to around 4 hours/segment, resulting in a 50% reduction in the reinforcement bars detailing.

We were able to ensure proper compatibility and maintain stringent quality control throughout the process.

The construction of segmental bridges demands a meticulous workflow that tolerates no errors.

It is crucial to conduct early engineering validation and ensure high precision, as the rebar must be manufactured with precise cuts and bends, without any margin for error.



*Video 1: Salvador Bridge Automation*

*Click on the image to play the video*

*You can also play it on [youtube]*

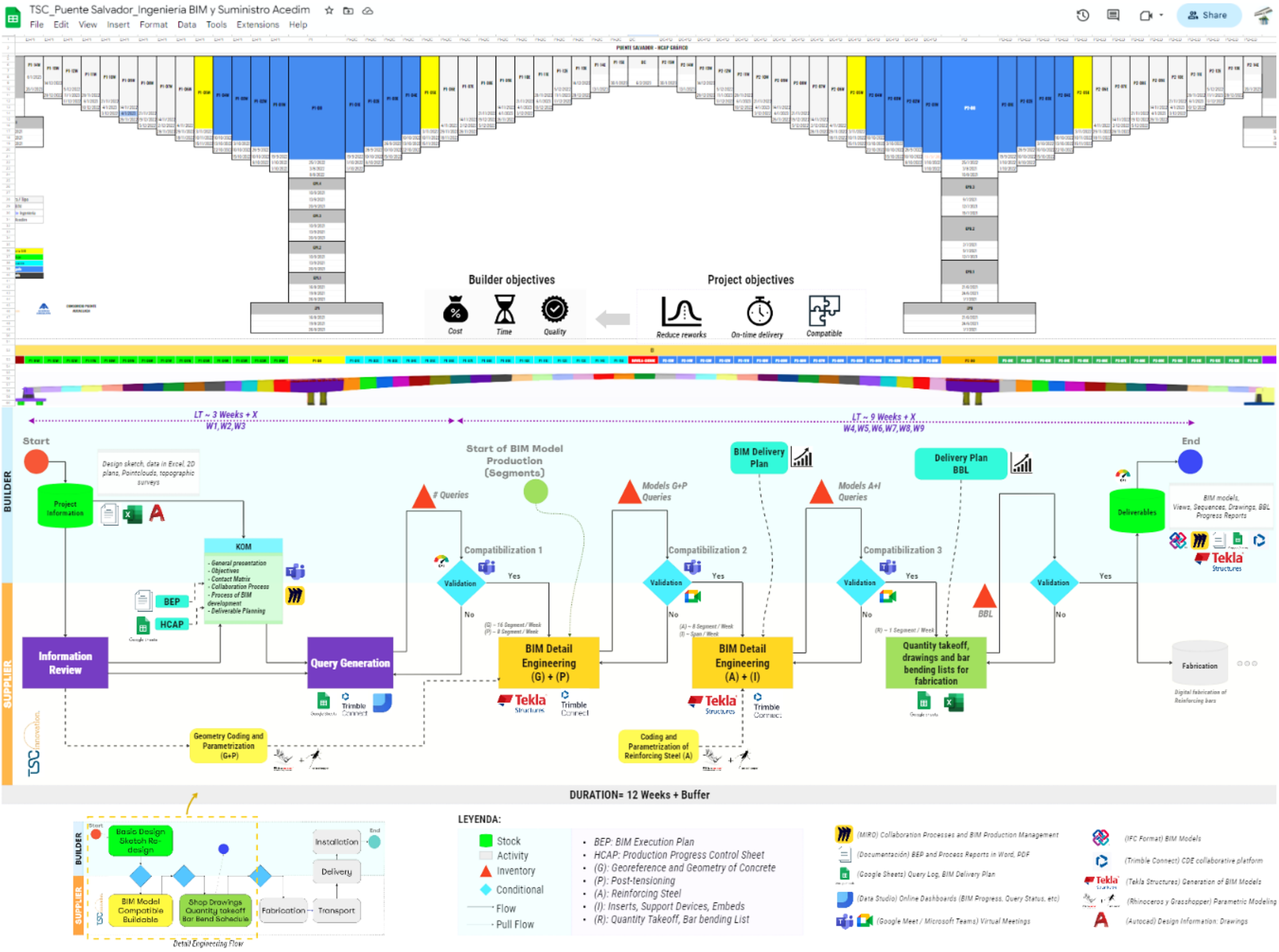



*Figure 14: Mapping, tracking, optimization, and control of the BIM engineering production system*

## CONCLUSIONS AND RECOMMENDATIONS

- The integration of parametric modelling tools such as Rhinoceros, Grasshopper, and Tekla Structures in virtual bridge construction is crucial.

  It empowers engineers in the design and construction stages to create precise and flexible BIM models, leveraging computational power to streamline repetitive tasks in BIM model generation.

- It is essential to recognize the level of parametric feasibility to avoid overly complex algorithms that can lead to errors.

  Segmental bridges, with their high potential for parameterization, are ideal candidates for applying these tools.

- In the case of the Salvador Bridge, a parametric approach was successfully implemented, achieving automation by 95% for geometry, 80% for post-tensioning, and over 65% for reinforcing bars.

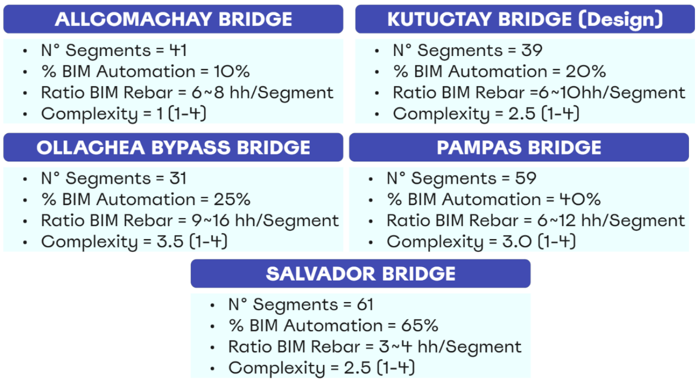



*Figure 15: Summary of results in % of automated modelling and resulting man-hour measurement per segment*

- Parametric modelling significantly minimizes the impact of design changes, especially when combined with predefined tools or algorithms from similar projects. There are different levels of automation observed when compared with other modeled bridges, Figure 15.
- Not all structures can be effectively parameterized. Therefore, a thorough analysis of information and identification of key characteristics such as typology, shape, and scope are necessary to determine the potential for parameterization. As seen in the Salvador Bridge project, an average of 60% of components could be successfully modelled.
- Continuous review and validation are crucial in parameter-based design to prevent deformations. Regular controllable factors should be conducted to ensure that the algorithm is consistently producing the desired results.
- However, the increased complexity of parametric modelling requires specific training to master the chosen software. In some cases, Python scripting can be employed to reduce visual code complexity and improve comprehension.
- It is vital for design and construction professionals to acquire knowledge in process automation. They should strive to transcend the role of passive users, employing engineering-based solutions to address challenges in civil engineering development.

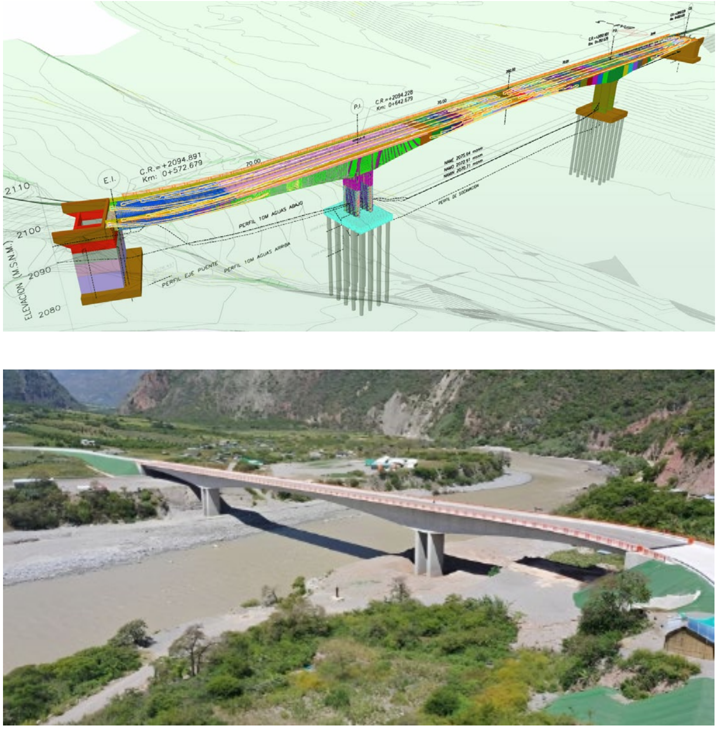


*Figure 16: Pampas Bridge, Ayacucho, Perú*

## <u>FUTURE OF PARAMETRIC DESIGN IN SEGMENTAL BRIDGES</u>

The advancements in BIM automation are taking us to a new level of excellence in the design and construction of segmental bridges.

We can now generate parametric models during the structural design phase and seamlessly connect them with calculation software.

These tools offer extensive optimization possibilities through the use of heuristic algorithms and AI, enabling us to explore different design options and find the best solution based on identified key parameters.

The outcome is an optimal structural design that, being parametric, allows us to develop comprehensive detailed engineering within a BIM environment.

This breakthrough revolutionizes efficiency and precision at every stage of the project, opening up new possibilities in segmental bridge construction.

# INTERVIEW WITH JOSÉ MATOS

## ASSISTANT PROFESSOR
## UNIVERSITY OF MINHO, PORTUGAL

*Magdaléna Sobotková, Vanja Samec*

First of all, thank you for your time for this interview.

As both our magazines, e-mosty and e-BrIM, revolve around bridges, let us ask you about your relationship to bridges and what inspired you to become an engineer.

Who has most influenced you, your career, mission and way of thinking?

*This is a very difficult question since I was born into a family of engineers, civil engineers, and bridge engineers.*

*Thus, I would say that from a very early stage, my career was influenced somehow by my grandfather, Armando Campos e Matos, and then by my father, Antonio Campos e Matos, both Professors at the University of Porto.*

*Later, during my ongoing studies, my mission and way of thinking were somehow influenced by my supervisors/mentors, such as Professor Joaquim Figueiras, Porto University, Professor Joan Ramon Casas, Catalonia Polytechnic University (UPC), Professor Paulo Cruz and Professor Isabel Valente, both from Minho University.*

*I would also like to mention here Professor Paulo Lourenço, from Minho University, who did also have a strong impact on all these three vectors.*

*I would also like to use this opportunity to acknowledge all of them that directly or indirectly have an impact on my life.*

Can you remember the number of bridges you have been involved in? What was your role?

*This is a very difficult question as well since my main focus, currently, is on the management of bridge networks, and I do have a strong group of researchers collaborating with me on this. Therefore, the number of bridges with which I had interaction at different levels was so large that I do not have an answer for you.*

*About my role - I was involved in their conceptual design, comparing solutions, accompanying their construction, SHM design and implementation, LCCA, risk-based analysis, forensics, and their management.*

Forth Road Bridge, Edinburgh, Scotland

*I would say that I have already been involved with most of the roles that concern a bridge life cycle, from different types, and this is good as it gives me a wide perspective on how should we approach each bridge or a network of bridges.*

**Are there any projects special for you? What are your favourite ones? Have you worked on any of them?**

*There is not a specific project special for me, concerning bridges we have quite interesting engineering projects that are a challenge in the design stage, others during construction, and others during operation and maintenance.*

*Due to my liaison with Portugal, I always mention the bridges in Porto and Lisbon, which are an example where engineering was used at the utmost level during design and construction.*

*On the operation maintenance level, there are many bridges that are being monitored and maintained under very hard conditions, with some of which I did have some liaison with, and these are also very good and strong examples where engineering is used in the extremes.*

**What is the most personally satisfying project you have worked on? Why?**

*As mentioned before, all projects in which engineering is taken to its extremes are more satisfying for me. Fortunately, I had an opportunity through my research group to work and apply engineering on practical examples and within a multidisciplinary team.*

*And, from all the projects, I would say that those related to the maintenance and operation of existing bridges are the ones more challenging for me since you need to put into practice all your knowledge as well as you are directly working with society.*

*Therefore, I cannot indicate one specific bridge on which I have collaborated as the most satisfying project but can mention that those multidisciplinary projects dealing with bridge network management (e.g. SustIMS, SafeWay, SIRMA, among many others), and where innovation meets industry, are those most satisfying for me since we are solving problematics raised by the whole ecosystem.*

**Can you comment on the changes in bridge technology over your career? What do you see has been the most significant technical advance?**

*I would identify three main changes over my career as there is a focus on the whole life management of bridges, namely, on the way sustainability is addressed from design to demolishment stage; on the use of innovative tools to achieve such aim; and also on the novel construction processes.*

Footbridge in Quindio Botanical Garden, Armenia, Colombia


*Interview for Portuguese TV about management of bridges*

*Accordingly, we can identify, among others, technological advances in using digital tools (e.g. Digital Twins, IoT, Big Data, AI, among many others), in the implementation of a multi-criteria decision-making approach, addressing sustainability goals (e.g. environmental, economic and social impact), as well as using new and more sustainable materials (e.g. eco-efficient concretes and clinker efficient binders).*

**Can you suggest how academic research organizations could assist the bridge industry to deliver safe and quality-assured solutions, especially taking care of existing bridge structures?**

*Firstly, it is important to bridge the gap between academic research organizations and the bridge industry.*

*On one side, the former are mostly focusing on their research lines, and their courses are based on traditional subjects, being very difficult to go far beyond their comfort zone, and on the other side, the latter are duly focused on solving their problems and therefore the availability to discuss important issues with the former ones is very low.*

*We all know that changing current BSc and MSc courses towards industry needs is a quite difficult and slow process.*

*Therefore, the development of short courses, which can be made through programs such as COST Action (e.g. COST Action TU1406), CSA projects (e.g. IM-SAFE project) or NGOs (e.g. IABSE, EuroStruct), the integration of doctoral thesis on industry environment (e.g. Marie Curie Industrial Doctoral Networks), and the development of one-year Erasmus Mundus Joint Program (e.g. NORISK Master Program), could be a way to introduce in an easier way such needed skills identified by the industry for HRs.*

*This way, a new generation of professionals with additional skills in the operation and management of bridges, reducing their risk, could be created.*

**You are very active at IABSE organization, co-chairing Commission 5 (Existing structures) and leading Task Group 5.2. Can you please point out the focus of your Task group and the connection to BrIM?**

*On IABSE Task Group 5.2, we are establishing the definition of the Key Performance Indicators (KPIs) that should be addressed within a quality control plan to support a decision-making process for the operation and maintenance of existing structures and infrastructures, such as bridges.*

*BrIM is a process supported by various tools, technologies and contracts, involving the generation and management of digital*

*Palace Bridge, St Petersburg, Russia*

*representations of bridges. Accordingly, the KPIs approach established on this Task Group could be implemented within a BrIM.*

### How do you see the development of BIM utilisation worldwide for existing bridges?

*The development of BIM has increased substantially in recent years. One of the main advantages of BIM is the way information is managed between all different stakeholders which do have an intervention in the bridge's whole life, including society.*

*BIM started to be used in the design and construction of bridges, but, recently, it was extended to the maintenance and operation of existing bridges.*

*During this period, there is a large number of stakeholders involved, as well as much information that is collected and managed (e.g. visual inspections, NDT, SHM, among others), resulting in the need of applying BIM on existing bridges.*

*However, it is the duty of society to guarantee that such data should be open, and, fortunately, there are some movements in this direction (e.g. BuildingSMART).*

*It is important to raise that the bridge operation and management process should not focus on having the data, but instead on how such data is effectively used.*

### In what ways has the introduction of BIM changed your work?

*In our group, we started to use BIM in an integrated way within the operation and management of existing bridges. This was developed under some projects (e.g. GOA BI, among others) and was a request from the industry.*

*Currently, I may say that integrating BIM with BMS results in a much more efficient way to manage information and therefore the stock of bridges.*

*Therefore, it is nowadays possible to establish the assessment, management and operation of existing bridges in an integrated way and within a BIM process. Additionally, and from an academic perspective, BIM is continuously given within the courses I am involved in.*

### Can you give any examples of the current usage of BrIM for existing bridges in Portugal?

*The project GOA.BI, led by company BETAR, and with Minho University and CCG as co-partners, is the most recent development and implementation of BrIM on the operation and management of existing bridges in Portugal.*

*Within GOA.BI there will be a set of road bridges for which BrIM will be fully integrated in GOA BMS. The main objective is to extend this to all bridges. However, there are other issues to be solved, such as the computation costs, but that is now overcome.*


*Course on risk of bridges, Santo Domingo, Dominican Republic*

### What future do you think BrIM will have? What development and utilisation can we expect?

*First of all, it is extremely important that BrIM should be based on open data formats. BrIM could play a relevant role in the operation and management of existing bridges since the way information is modelled and used will be much more efficient and liable. Therefore, it is expected that some developments will be made, namely on interoperability of software, on integrating BrIM with BMS and GIS, as well as with other tools, and, extremely importantly, on semantics.*

### What are the tasks and challenges for the future?

*In the future, the main tasks, apart from those raised before, would be to integrate other information, such as environmental and social data, into BrIM, and establish a multi-criteria decision-making procedure.*

*In the future, the challenges will be the development of standards that will fix the use of open data formats, and also the change of paradigm of the ecosystem towards the use of an integrative BrIM.*

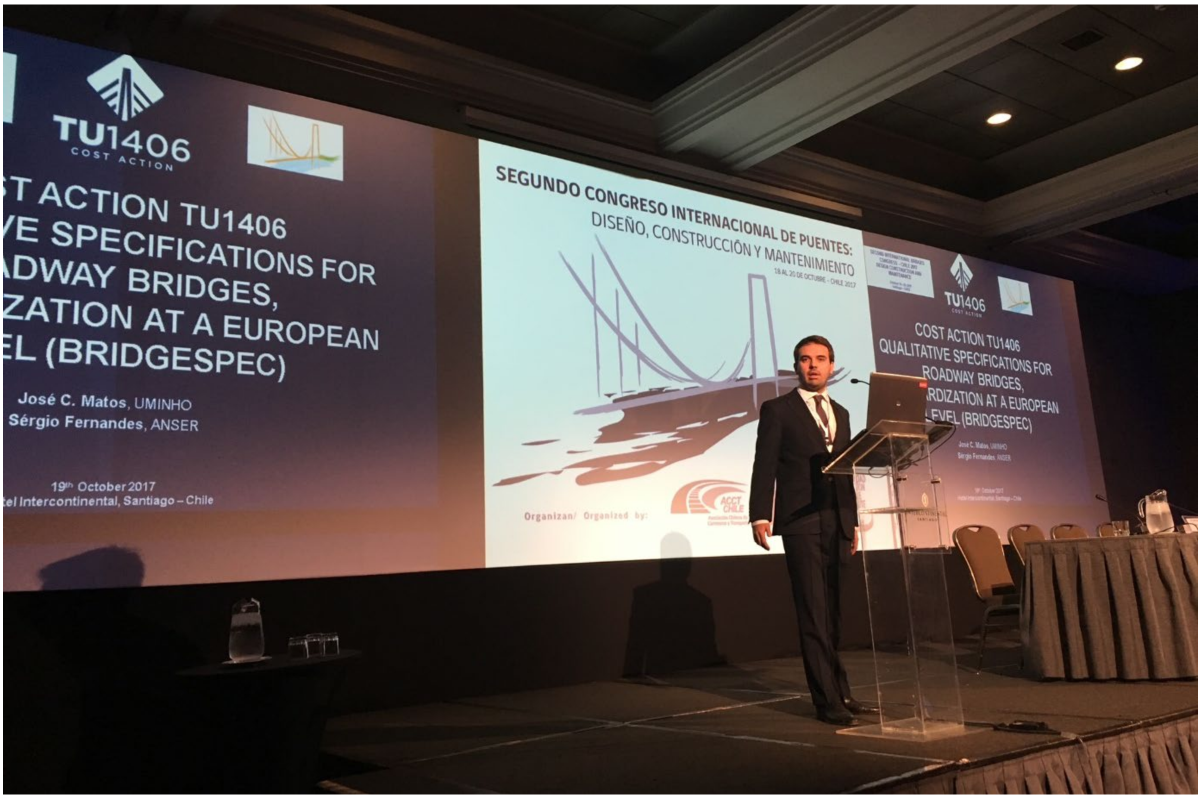
### What advice would you give to young engineers starting their careers?

*My advice first reflects the fact that civil engineering is nowadays a very important profession. Indeed, the need for engineers for the assessment, maintenance and operation of bridges is a reality, and therefore many engineers are needed for this aim.*

*However, the basis for civil engineering is extremely important, and therefore all students should have such a basis given by current BSc and MSc programs. Afterwards, they should increase their skills by integrating one short course, one of the one-year's Master programs, or even one doctoral program (preferably, integrated in one industry).*

*The integration in current Task Groups of NGOs, such as those from IABSE, is quite relevant as young engineers could extend their network. The same happens with the integration of Erasmus+ and Marie Curie programs. Thus, in the resume, there is a huge need for civil engineers, especially in the maintenance and operation of existing bridges, their basis is very important, but additional skills are extremely relevant.*

Thank you very much for your time.




*Keynote lecture on Quality Control of Bridges, Santiago, Chile*

# BMS AND BIM: THE PORTUGUESE SCENARIO

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## ABSTRACT

Considering the preparation of Europe´s near future, two major concepts are mandatory: digitalization and climate change adaptation. In the particular context of bridge management, any future development should also take these two concepts into account.

Hence, the existing Bridge Management Systems (BMS) should be upgraded to allow considering the effects of ongoing climate changes, on one hand, and the digital transition expected for the next years, on the other hand. The latter aspect is discussed in the present paper.

The first step to prepare BMS digital transition consists of a screening of its current status and definition of requirements.

Regarding the digitalization methodology, Building Information Modelling (BIM) is the way to go. Several efforts are undergoing worldwide to foster the process of BMS digitalization.

The present paper aims at contributing to the BMS and BIM integration by presenting the Portuguese current status. Existing trends, but also gaps, are highlighted. In addition, ideas for a faster and yet sustainable transition are provided.

**Keywords:** Digital transition, Bridge Management System (BMS), Building Information Modelling (BIM), Portugal

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## 1. INTRODUCTION

Large civil infrastructure systems (bridges, dams hospitals, schools, and roads, among others) are recurrent topics of political and technical discussions. The political issue is raised due to the massive investments that such infrastructures require throughout their entire lifecycle. This leads to constant efforts by government and public companies to adjust their budget, as well as establish new taxes, to face infrastructure´s needs.

On the other hand, technical aspects are derived from engineering and should lead the implementation of technology and innovation to assure infrastructures perform as expected to fulfil the functionality they are expected to.

In both situations, political and engineer decision-makers should join efforts and be aware of environmental and social aspects which are, along with the economy, the three pillars of sustainability.

This work inserts in the Portuguese context and is focused on the current challenge related to the management of the existing bridge stock that requires engineering breakthroughs. To face this challenge, several bridge management systems (BMS) have been developed since the late 20$^{th}$ Century [1].

According to the authors' best knowledge, currently, there can be identified two major BMS in use in Portugal: *GOA* [2] and *SustIMS* [3]. These two systems are used in the management of other transportation assets besides bridges, but for the sake of the present work, they can be considered as BMS.

Nowadays, it is considered that existing, well-established and consolidated BMS need to be upgraded to meet the new requirements associated with digitalization and climate change adaptation.

This upgrade should include joint efforts from all stakeholders, including bridge owners, bridge managers, research and academic institutions, among others.

Any reference to digitalisation in the construction sector immediately leads to the introduction of Building Information Modelling (BIM). BIM is one of the major topics in the construction industry and is believed to be the most adequate option to support the digital transition in this sector.

Hence, the present work focuses on the integration of existing BMS with BIM methodology.

This integration is the logical way to go since both are concerned with information management and such a combination can result in an innovative-technology-based tool and method to support the lifecycle management of bridges.

To this end, a systematic literature review on the topics of BMS and BIM was conducted. Since the main focus was taken on the Portuguese context, the literature review mainly addressed the proceedings of two of the most relevant Portuguese conferences in this field, namely, *PTBIM* (a major Portuguese conference on the BIM topic) and *Betão Estrutural* (major Portuguese conference on structural concrete and bridge engineering).

In the end, gaps, challenges, and future directions are given on how to integrate BMS tools and BIM methodology.

## 2. BRIDGE MANAGEMENT SYSTEMS

During the 90s and at the beginning of the 21st Century, Portugal made high investments to develop transportation infrastructures to drive its economic growth as expected by the Organisation for Economic Co-operation and Development (OECD) and the European Union (EU).

In 1994, Brisa (Portuguese Transport Agency) experienced significant growth in their asset stock, which directed them to be pioneers in the development and implementation of bridge management systems in Portugal.

Later, in 1997, Betar (a Portuguese Private Company) started the first version of *GOA®* (*Gestão de Obras de Arte*) BMS [2].

By that time, little attention had been given to bridge management. Unfortunately, the collapse of the Hintze Ribeiro Bridge in 2001 [4] highlighted this low awareness and many doubts were raised about the safety of the remaining bridges countrywide.

After that, bridge management activity entered a new stage with a lot of opportunities, new specializations like bridge inspection, and partnerships between academic institutions and important agents of the sector, among others.

The impacts of this tragedy also affected public companies functioning and *Refer* (National railways company) established that main inspections should be performed only by engineers. Also, both *Refer* and EP (National roadways company) implemented *GOA* [2].

Today, there is a single Portuguese public company to manage transportation infrastructure assets (*Infraestruturas de Portugal*) which resulted from the fusion between REFER and EP, taking advantage of EP procedures, *Infraestruturas de Portugal* uses *GOA* as its BMS.

The current Portuguese BMS framework, presented in Figure 1, is very similar to that of the majority of BMS available worldwide.


*Figure 1. BMS main modules*

The database module is the oldest, i.e. when BMS were created, this was the only existing module. Normally, this module is divided as follows:

i. ***Inventory*** where general information is introduced for each asset (ID, location, bridge type, structural typology, construction year, number of spans, spans lengths, total length, deck width, deck area, list of components, components type, components materials, geometric properties of the main components, among others);

ii. *Inspections* where the information obtained from the routine, principal, and underwater inspections and surveys are introduced. This information is later used to assign a condition state index to all bridge components and the overall bridge system;

iii. *Interventions* where the type of maintenance and repair interventions available per component are stored. This includes details about the activities to be conducted, the resources to be allocated, as well as the costs of maintenance interventions.

This database module is essential to support bridges' management throughout the design, construction, operation and maintenance phases, as all data required to do so is expected to be in it.

However, it is important to highlight that in Portugal, when BMS started to be implemented, most of the bridges were already in service.

Consequently, relevant information was missing for existing bridges, which is being solved as new inspections are being conducted on all these bridges.

The module of prediction is composed of the deterioration/performance models and cost models. Deterioration models allow the prediction of condition states of any component in a certain period.

Typically, these are based on Markov models which take advantage of the historical condition states stored in the database. Cost models are based on the lifecycle cost analysis allowing the determination of different costs, namely intervention, inspection, and user costs.

Successful use of this module depends on the quality of data available on the database given that it influences the prediction as well as the decision-making process.

The optimization module runs on the outputs of the previous module and should be supported with a quality control plan in which threshold requirements are defined. In this module, there is the possibility for the user to predefine the maintenance intervention plans or an algorithm can be used to automatically generate different scenarios [5].

## 3. BUILDING INFORMATION MODELLING

It is recognized that the implementation of Building Information Modelling (BIM) in Portugal is still very limited when compared with other countries. Nevertheless, in the last years, many relevant developments have been carried out to minimize this difference.

Particularly in 2015, the Technical Commission 197 was created in Portugal. This TC197 aims to develop standardization within the scope of classification systems, information modelling and processes throughout the lifecycle of construction projects and follow up with the developments of CEN/TC 442, the European Committee for Standardization regarding BIM standardisation.

In 2016, the first edition of PTBIM, the major BIM-related Portuguese conference, was launched. This conference is held every two years; in 2022, the 4th Conference took place.

The following sections present the results of the literature review towards understanding the current

| Conference | Year | Total number of papers | BIM in facility operation, maintenance and inspection | BIM in infrastructure management | BIM in bridges "BrIM" | Bridge management systems |
|---|---|---|---|---|---|---|
| *Betão Estrutural* | 2016 | 105 | 1 | 0 | 0 | 1 |
| *Betão Estrutural* | 2018 | 178 | 0 | 0 | 0 | 0 |
| *Betão Estrutural* | 2021 | 158 | 1 | 1 | 1 | 1 |
| *ptbim* | 2016 | 52 | 9 | 4 | 1 | 0 |
| *ptbim* | 2018 | 67 | 10 | 4 | 1 | 1 |
| *ptbim* | 2020 | 89 | 13 | 4 | 1 | 0 |

*Table 1. Results from literature review*

status of BMS and BIM integration in Portugal. Table 1 provides an overview of the existing work, which is further discussed.

The first three columns in this table identify each conference reviewed, the year it took place and the number of papers presented.

The remaining columns present the number of papers of interest that were filtered and are further discussed.

It starts by looking at the broader fields of BIM usage in facility operation, maintenance and inspection in the context of buildings (fourth column); and BIM applied to infrastructures management (fifth column).

Then the few papers addressing BIM in bridges are presented in column six. Finally, an even smaller number of papers discussing explicitly BMS (one of them together with BIM, which is the main goal of the present review) appears in the last column.

Analysing the numbers in Table 1 it can be seen that the interest in the reviewed topics is low compared with others addressed by the other papers published in the same conferences.

The topic of BIM in facility operation, maintenance and inspection is concerned with the maintenance of buildings and equipment.

In the works that fall in this criteria, buildings are referred to as being complex infrastructures due to the high flow of people (e.g. hospitals, shopping centres, universities, and airports, among others), and the implementation of BIM methodology is shown to be essential to manage facilities required for the functioning of buildings (e.g. power supply, use of renewable energies, heating and cooling, water distribution and wastewater drainage, and ventilation).

A closer look into the works identified in this topic shows five papers devoted to generic and/or conceptual discussions about BIM on asset management [6–8], one of them addressing specifically buildings [9] and another that mentions very briefly the particular case of bridges [10].

However, the main group of works included in this topic refer to practical applications on buildings including University Campus [11–14], research laboratory [15], business buildings [16–18], shopping centre [19] and its parking [20], hospital [21], hotel [22] and several on different heritage buildings [23–28].

The topic of BIM in infrastructure management is similar to the previous one in terms of approach, i.e. asset management aspects are covered and case studies are presented. The major difference is that now, instead of presenting buildings, the authors show practical examples of other types of infrastructures.

There is one study on telecommunication towers [29]. Four works address water infrastructures including a water lift station [30], sewage treatment station [31], water supply network [32] and even an Olympic swimming pool [33]. The last five papers on this topic, refer to transport infrastructures.

The particular scenarios of railways [34,35] or roadway pavements [36,37] are addressed, while in the work developed by Silva et al. [38] a set of applications of BIM methodology to demonstrate its potential in different types of transportation infrastructures (roadway, railway and airport sectors).

All these applications can be compared with the so-called digital twins since information collected by in-situ sensors was being used to feed the digital model.

The last two columns, representing a convergence to the topic of interest in the present work, have a smaller number of papers, highlighting the current status of BMS and BIM in Portugal.

The first two works to mention were presented at the Betão Estrutural conference and do not include BIM, but only BMS.

The first one refers to the use of the GOA Bridge Management System to manage bridges on the Portuguese island of Madeira [39].

The second presents a case study discussing the development of a performance classification method to be used in the municipality of Leiria [40]. The classification method is applied to five different bridges existing in that municipality.

Two other papers to be mentioned refer to the BIM on bridges but do not refer to BMS as they mainly deal with the design stage.

One discusses the use of BIM together with visual programming tools to fasten the design process of bridge trusses [41] by the definition of a set of parameters that are then processed. The other one describes some details about one of the first fully drawing-free bridge projects recently developed with the collaboration of a Portuguese design company [42].

The last paper to be mentioned is the only one found in the reviewed Portuguese conferences that explicitly connects BMS and BIM [43]. It shows a proposal to use BIM methodology for the management of information collected during a bridge's visual inspection, followed by the implementation in a case study (reinforced concrete bridge). The proposal includes principles and rules for bridge modelling, levels of development (LOD), and methodologies to represent damage/anomalies in the BIM model.

Information collected during inspections is modelled through new "entities" which aim to represent observed damage, and information about samples collected, among others.

However, as the real geometric representation of damage is difficult to incorporate, due to the existence of a large set of patterns (e.g., crack development), the proposal of the authors is based on the assumption that, during the inspection process, the representation of the real geometry is not relevant.

Thus, this assumption allowed us to characterize damage homogenously in the models, as well as to simplify data introduction from the inspection team. Anomalies and damage are represented by symbolic rectangles as shown in Figure 2(a).

Different colours are associated with different damage as exhibited in Figure 2(b), in which red is corrosion and green is bio-colonization of concrete. The damage evolution is observed from images linked to the component and the information should be manually updated by the inspection team.

The BIM model was built based on the points cloud obtained from laser scanning. In addition, 360º panoramic pictures were added to the BIM model through fictitious spheric elements as displayed in Figure 2(c).

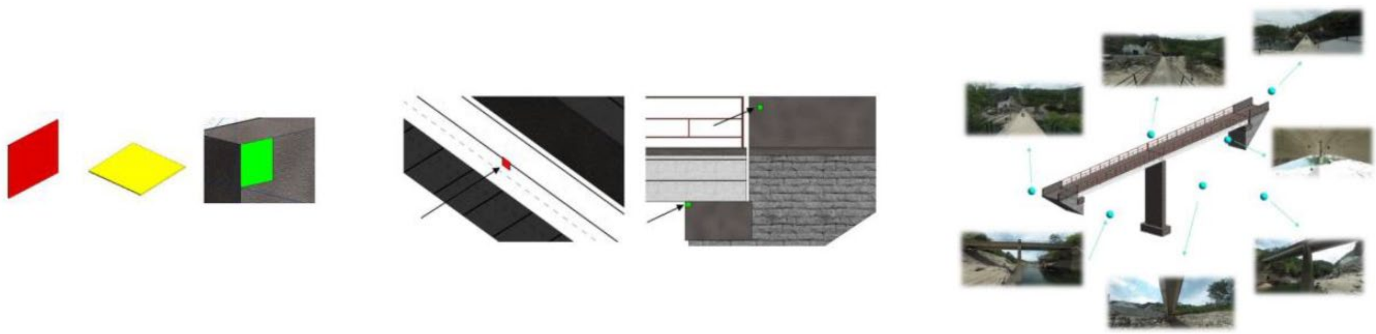
These elements incorporate the attribute "URL", which should be the link to access the repository in the cloud. Later, after finalizing the BIM model, a free BIM viewer was used to access all information.

## 4. BMS AND BIM INTEGRATION: CHALLENGES AND FUTURE DIRECTIONS

As mentioned in the Introduction, the main BMS used in Portugal is GOA. Hence, an upgrade on this BMS towards BIM integration should make the current Portuguese status move forward.

In this context, a consortium led by Betar (GOA's owner) and including the University of Minho, launched a research project entitled "GOA.BI – GOA Bridge Management System – Bridge Intelligence" aiming at, among other things, integrating GOA BMS with BIM methodology.

This project revisits the entire bridge management process, identifying the information exchanges with the GOA system, the moments when they occur and the stakeholders involved in those processes.



(a) (b) (c)

*Figure 2. Techniques described in the proposal: (a) BIM objects (patch); (b) Damage representation in the BIM model; (c) Illustrative spheres to storage inspection images* [44]

This allows the development of new digital-based working methodologies so that the entire bridge management process is supported and targeted at the bridge digital model.

GOA is fed with BIM models, which certainly occurs particularly on new bridge projects. It is expected to take advantage of the GOA's large database to feed BIM models for the existing bridges as they are intervened in the future.

## 5. CONCLUSIONS

From the literature review carried out and presented in this document, there are a set of findings and challenges that can be identified in Portugal:

- BIM methodology is being used to support the lifecycle management of different civil infrastructures including bridges;
- There are BMS with the same features and modules included in the most important BMS worldwide, but the integration of BMS and BIM is still in the early stage;
- There was only one work, amongst the many that were reviewed, connecting BMS and BIM;
- BIM will be at the core of the next generation of BMS and a research project in this regard is already ongoing;
- The integration of BIM and BMS will be essential for implementing long-expected digital twins integrating different types of data collected in real-time from installed sensors.

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# BIM AT THE PORTO METRO PROJECT, PORTUGAL

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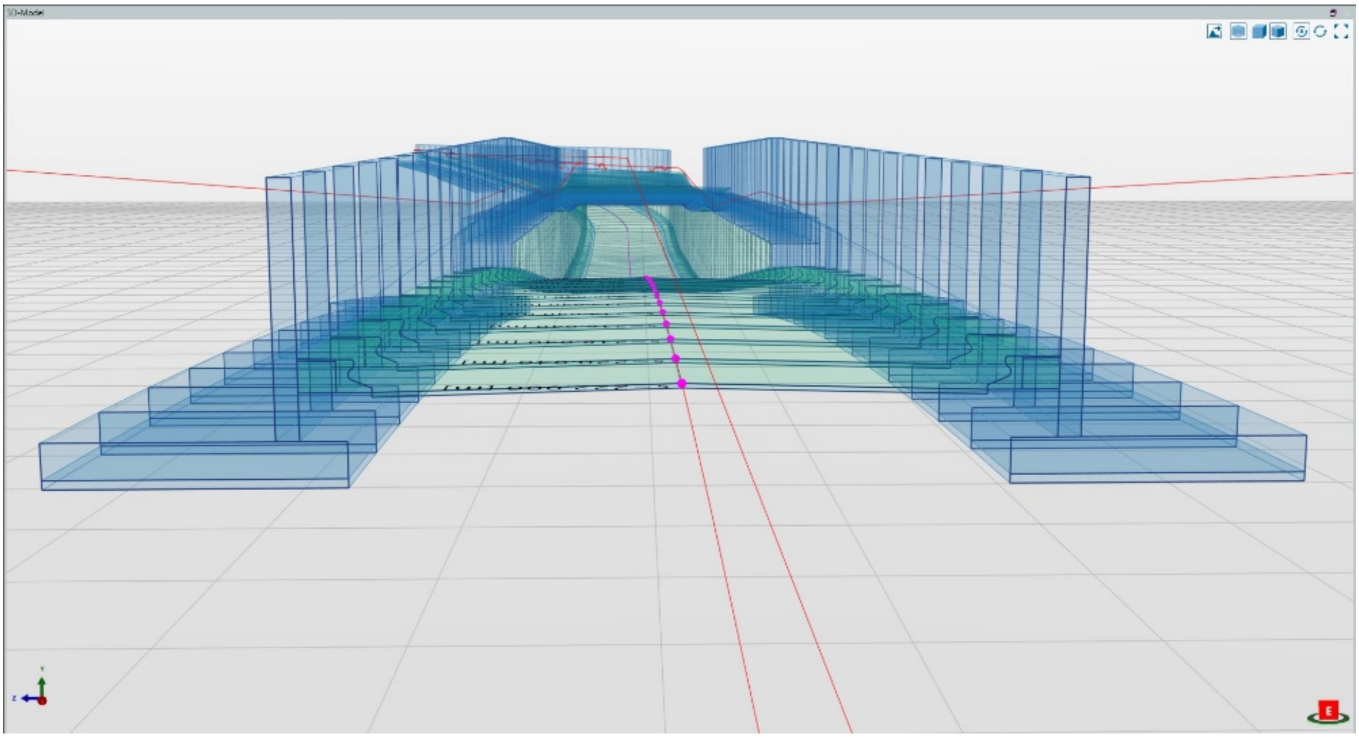


*Ruby Line Porto Metro Project – 3D models in Allplan Bridge and Allplan. Copyright: QUADRANTE*

## INTRODUCTION

The two cities of Porto and Vila Nova de Gaia in Portugal are separated by the Douro River yet they are inextricably linked.

As part of the Porto Metropolitan Area which makes up the second-largest urban area in Portugal, residents often travel between the two cities.

With such a large population, the existing five operational bridges – one railway, three roadway and another one with a roadway deck plus a metro line deck – no longer offer sufficient capacity for the travel demand.

To address this, Metro do Porto commissioned a new, 6.5km metro line to connect the two areas, which includes a new bridge over the Douro River supporting a metro line, cycle lanes, and large pedestrian path.

The new line will not only provide extra capacity, but also encourage more sustainable travel while supporting the area's recovery from COVID-19.

QUADRANTE, a renowned international consulting engineering firm, is part of the Designer Consortium and responsible for the design of six main works packages, including the new track, new roads, four viaducts, three underpasses, multiple retaining walls, and the structures of seven new stations and platforms.

One of the viaducts includes a substantial partial demolition of an existing viaduct, with two new viaducts to be built beside the remaining section.

Meanwhile, another viaduct will be built over an existing major roundabout. In addition to three conventional subway stations, there are two surface stations and one station that is both above and below ground are to be designed.

The track is approximately half underground, half overground, with the tunnel design and construction being undertaken by the other member of the Designer Consortium.

Additional works on the project – such as the bridge over the river – are also the responsibility of other parties.

QUADRANTE commenced detailed design in September 2021, with its completion in 2022.

Construction is expected to take two and a half years, opening to the public by the end of 2025.

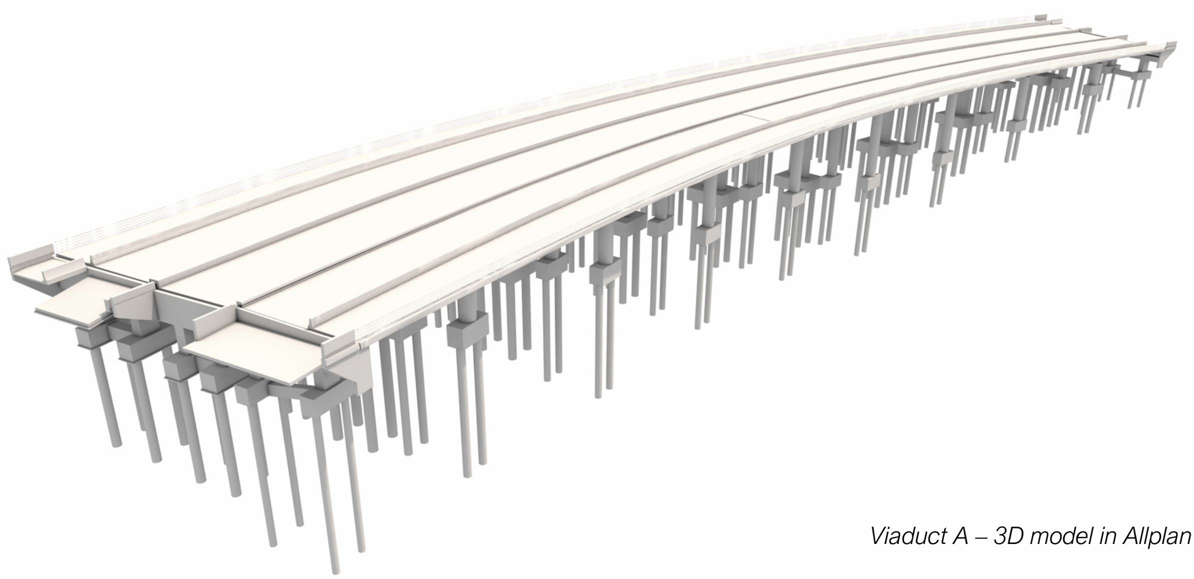
BIM has been a part of QUADRANTE's workflow for over 7 years on all their architectural building projects, yet their approach is unique.

Rather than adding BIM to projects as an extra requirement to meet, they instead have a mindset they call 'Projects in BIM, not BIM of projects' – or, in other words, they work in BIM from the very first sketch.

Having recently now introduced BIM on their transportation projects in 2021, the Porto Metro project is one of the first major projects where they have used Allplan Bridge as both their design and BIM platform – with great success.

*"The move to doing projects in BIM has required a mindset shift for QUADRANTE's infrastructure team, not just in terms of the process, but also being open to change and flexibly adapting to a new way of working.*

*However, with Allplan Bridge, we have made a significant leap forward in this area"*, says José Rolo Duarte, Operations Director – Transports, QUADRANTE.



*Viaduct A – 3D model in Allplan*

## COMMON BIM APPROACH AND DATA FORMAT

With such a complex project and several partners working on different sections, ensuring that each package of works is smoothly coordinated between the different parties is critical.

Therefore, agreeing on a common approach and data format for sharing information is also of the utmost importance for delivering the project successfully. Additionally, ensuring that all the sub-models for the various sections are aligned between the different disciplines and partners is another crucial consideration.

In terms of QUADRANTE's work, one of the biggest challenges is the number of variations that would need to be modelled.

Because the section of track traversed through tunnels, viaducts, retaining wall sections, and both above and below-ground stations, there are a good number of different cross-sections needing to be taken into consideration.

Similarly, the underground tunnels also have variable cross-sections. Designing the models for these elements and creating the documentation for them would be a time-consuming activity.

In addition, building the project in BIM meant that all models would need to be kept updated so that everyone could access the current status of information as and when required.

The urban location is another issue, as many of the proposed designs are located in built-up areas with space constraints.

For example, one of the viaducts that QUADRANTE is responsible for is located next to a stormwater attenuation area, adjoining a 120-meter-long tunnel that needs to be constructed using box jacking.

The space constraints meant a solution needed to be developed to support the hydraulic jacks during the construction phase without affecting the stormwater attenuation scheme.

The viaduct to be partially rebuilt also posed some difficult challenges, not only in aligning the new viaduct sections to the remaining section but also as this section of carriageway must remain open during the works.

Similarly, the viaduct by the major roundabout would also need careful modelling and consideration of how it would be built while minimizing disruption to traffic.

## PARAMETRIC DESIGN WITH ALLPLAN

The team encountered some initial challenges with structuring IFC files and organizing BIM levels. However, this was overcome when a collective agreement was made between all the partners involved on the project. After that, sharing files and models is accomplished more easily.

Allplan and Allplan Bridge were chosen as the QUADRANTE design solution not only for Open BIM functionality, but principally for the powerful parametric design options offered. QUADRANTE implemented a new, parametric workflow in order to develop their viaduct designs.

In fact, they further improved Allplan Bridge's capabilities by creating a tool that manipulates the TCL file so the user can create tables of the viaduct girders in Excel, which significantly accelerated their workflow. They were then also able to use the Excel file for further analysis.

For example, the team used the tool to create dynamic cross-sections of the area that would need to be reserved for the trains on the track.

The size of this area depends on the gradient of the track – the elevation difference between the left and right rails. A static table that would define the width of the reserved area was created and imported into Allplan Bridge.

However, when a table was required where was the inverse ratio of the radius of the curves on the static table, that was created using the tool QUADRANTE developed and then quickly imported into Allplan Bridge.

For the track model, the team imported the near 7-kilometer-long railway alignment axis into Allplan Bridge. As it was provided in LandXML format from the rail engineers, QUADRANTE used Bimplus to import the file.

To create the model, they developed a series of cross-sections, including the track rails, drainage, cable channels, emergency evacuation areas, and the reserved area for the trains themselves, as already mentioned above.

The team created a combined cross-section for the different track sections by adding the cross-sections for the individual elements, including overground, underground, viaduct, retaining wall, and station sections.

Allplan Bridge is extremely useful here, as preparing the model as well as all the documentation and tables for the different variations along the route would have been extremely time-consuming otherwise.

In addition, keeping the model updated and available in real-time without a BIM approach would have been a difficult task.

Where the depth is not suitable for the NATM tunneling method, these shallower sections of tunnels were designed for top-down construction.

Here the team imported the LandXML axis using Bimplus again and designed cross-sections. They used PythonParts to model the piles along the walls of these tunnel sections as that would speed up the modelling process rather than having to individually model each pile.

Once the tunnel model was complete, the adjacent section of the NATM-constructed tunnel model was imported using Bimplus to check that the two tunnels would line up exactly.

Precision was also necessary for designing the substantially re-built viaduct. For this section of the works, three viaducts would need to be designed and located in such a way as to be adjacent yet without each individual structure touching.

Being able to visualize the interaction between the three structures without a 3D model would have been incredibly challenging.

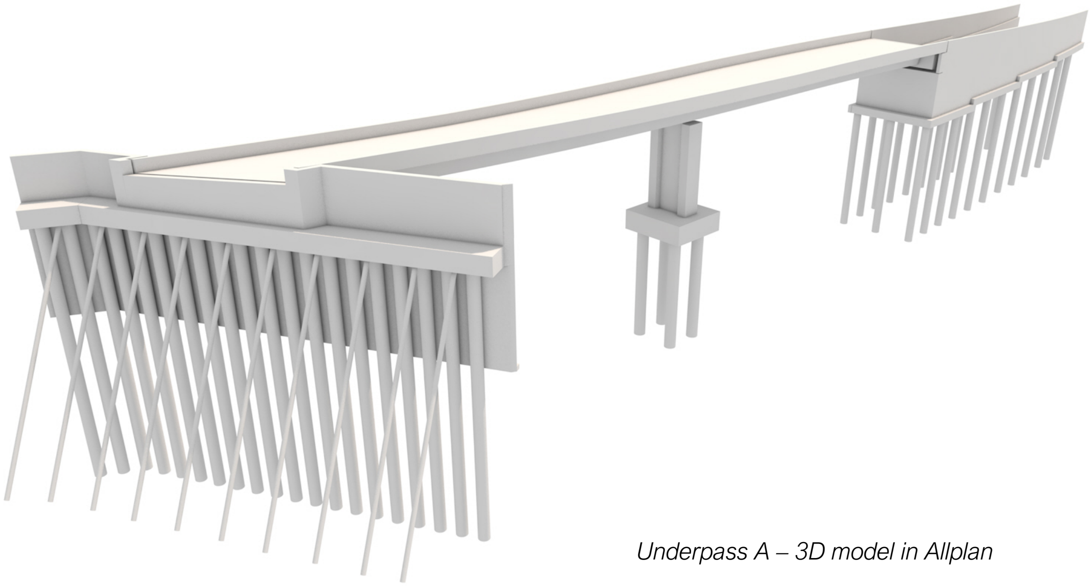
With Allplan Bridge, however, the structures were designed and precisely aligned with the existing viaduct portion without any clashes.

Similarly, when planning the box jacking section of a tunnel, the visualization that Allplan enabled in 3D allowed the team to develop a solution within the limited space available by importing a terrain model of the area.

The final proposal used a platform to support the hydraulic jacks during construction without affecting the stormwater attenuation area.

Being able to rule out clashes between existing tracks and stations, different disciplines, and external sub-models is another benefit.

The station structures were developed and exported using the tools in Allplan and then coordinated with other team members such as the architect, MEP designer, and other structural engineers.



*Underpass A – 3D model in Allplan*

Then, in Bimplus, the team at QUADRANTE could check the federated model and resolve conflicts, visualize the works, and implement any required changes directly from within Allplan.

This made the process much more seamless as well as making it easier to manage changes. With a complex project such as this with many different interactions between different components – both new and existing – being able to effectively manage changes helped mitigate their impact and keep the project design process on track.

## STRAIGHTFORWARD DESIGN PROCESS

When choosing a BIM solution for use in their special structures division, QUADRANTE evaluated many different options.

Through its use on the Porto Metro project, Allplan – and Allplan Bridge in particular – have become essential to their daily work.

The powerful tools made the design of this complex project much more straightforward, especially with regard to variant analysis.

The structure of the program enabled options from the concept stage to being considered more easily and with significant levels of detail, even at such an early stage of the process.

In addition, it is especially useful to have a detailed model to discuss options with the client during the initial design.

The drawing production is another area that was accelerated thanks to Allplan. Around 100 drawings per station design are required, which would have had to have been drawn individually using 2D methods.

With Allplan, sections, elevations, and details could be quickly and easily produced from the model, with the added benefit of automatic updates should the model change.

This made producing the construction documentation a more straightforward process that saved a considerable amount of time.

Effective change management is key to keeping the project on track. When designing bridges, tunnels, railways, and roads, there are often many changes to the geometry – and the Porto Metro project is no exception.

The functionality that Allplan offers significantly reduced the impact of changes on the schedule, particularly during the concept phase when many different variants are being explored.

However, producing more detailed models (LOD 300) earlier in the design phase also helped reduce changes further along in the process.

Having the model geometry already prepared at the concept stage provided time savings from the very start of the project, as it was easier to adapt should any changes be needed.

Subsequent design activities were more efficient, and it was easier for the team to finalize their detailed designs.

The move to doing Projects in BIM has required a mindset shift for QUADRANTE's infrastructure team, not just in terms of the process, but also in being open to change and flexibly adapting to a new way of working.

However, with Allplan Bridge, QUADRANTE has made a significant leap forward in this area, particularly with regards to implementing the parametric design.

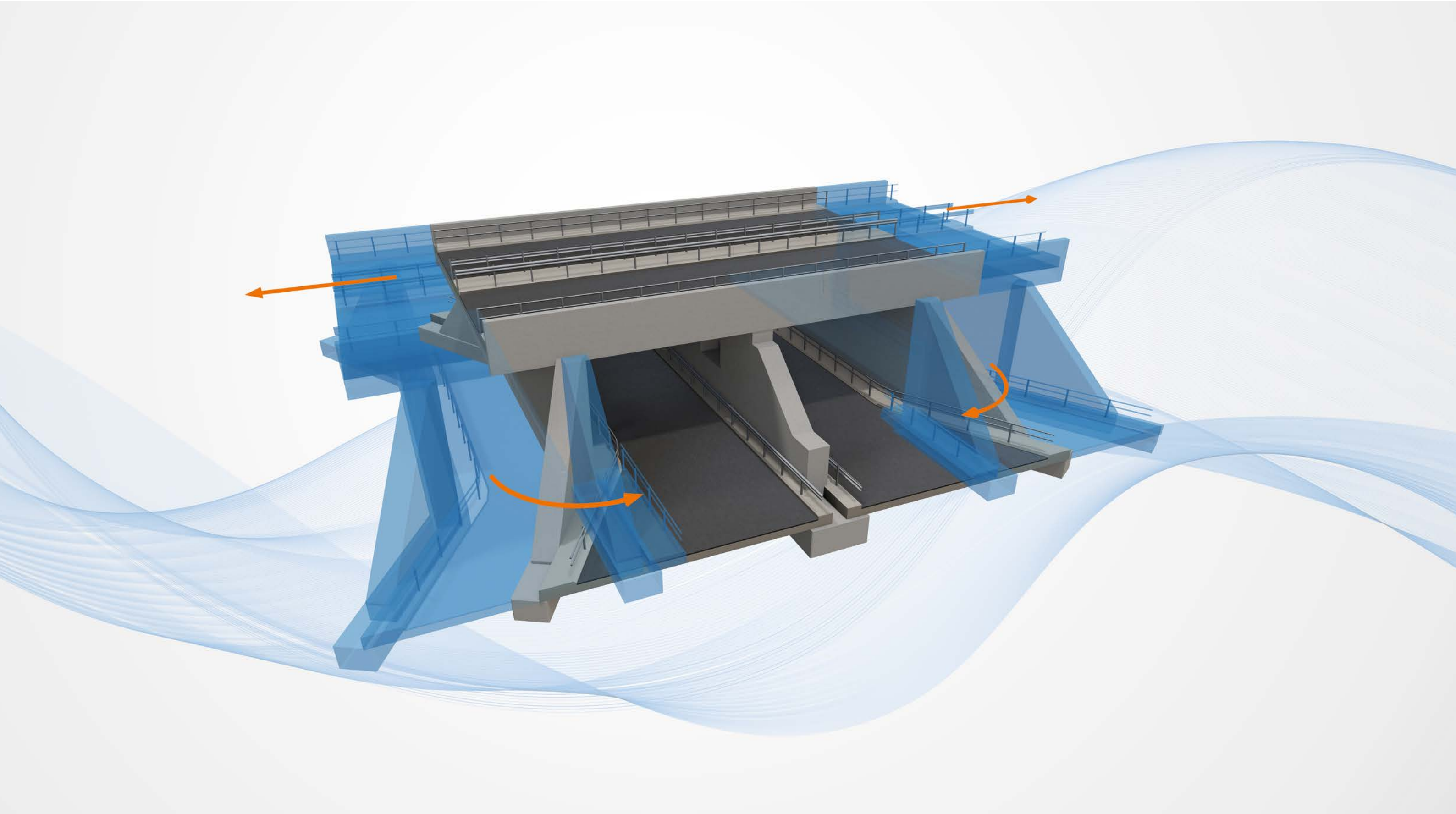
Their innovative spirit and pioneering problem-solving led to not just the successful execution of this project, but new tools that they can implement in future works.

Even the traditional way of working may not be kept for those clients who do not value BIM.

This is because projects in BIM have become embedded in QUADRANTE's approach after experiencing the benefits of it on their various international projects, including this complex, multi-faceted new metro line.

## CONCLUSION

Being open to change and flexibly adapting to a new way of working has helped successfully deliver this complex new metro line in Porto.

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Helgeland Bridge, Norway

Photo : Jules van den Doel

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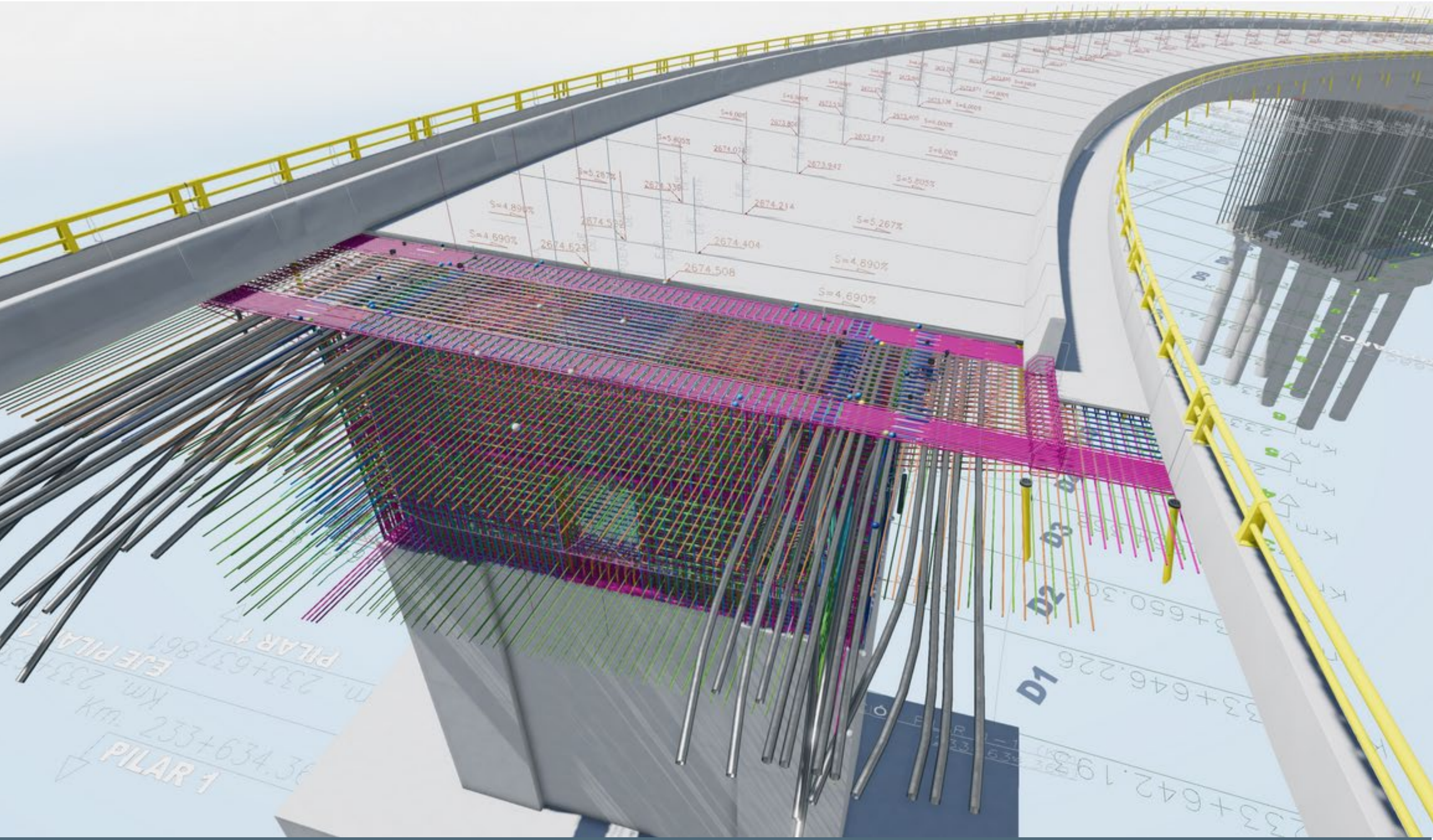


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