

ISIM - INFRASTRUCTURES & STRUCTURES INFORMATION MODELING: A NEW CONCEPT OF BIM FOR INFRASTRUCTURES

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ABSTRACT:

The application of Building Information Modeling (BIM) in infrastructure and structural projects, known as Integrated Structural and Infrastructure Modeling (ISIM), has gained attention in recent years due to its potential to revolutionize the construction industry. By providing a digital representation of the built environment, BIM allows for improved collaboration and communication between project stakeholders, leading to enhanced project outcomes. The ISIM approach is centered on the creation of a digital twin, a three-dimensional model of the infrastructure or structure, which serves as a virtual replica of the physical asset. This digital twin provides a platform for analysis, decision-making, and management throughout the project lifecycle, from design and construction to operation and maintenance. One of the key benefits of the ISIM approach is the ability to optimize the construction process, reducing costs, and improving efficiency. The digital twin allows for the identification of potential issues in the design phase, enabling them to be addressed before construction begins. The model can also be used to simulate different scenarios, providing insights into the most effective construction methods, sequencing, and scheduling. Additionally, the use of ISIM can facilitate collaboration and communication among project stakeholders, including architects, engineers, contractors, and owners. The digital twin provides a shared platform for all stakeholders to access and contribute to, allowing for real-time feedback and decision-making. This increased collaboration can lead to reduced errors, improved quality, and enhanced project outcomes. In this paper the authors propose the example of the Meier bridge in Alessandria starting from the 2D drawings to create the 3D model and link it to the external context using Autodesk Infracore software. A virtual reality implementation has been considered as useful tool to improve the maintenance management.

1. INTRODUCTION

The main challenge with BIM design in Infrastructures and Structures (ISIM) is ensuring that practitioners meet a high standard of excellence, given that it is still in the testing phase. In recent years, new or revised approaches have been adopted across all categories related to construction excellence, such as business practices, management, cost control, and procurement methodologies. The use of 3D, 4D, and BIM computer technologies, which offer visualization, coordination, simulation, and optimization capabilities, allows practitioners to better meet customer, design, construction, asset management, facility management, and program requirements. However, it is important to adopt these approaches strategically and incrementally, progressing from 2D to 3D, 4D, and ISIM. Although 3D models are helpful for communication, not all 3D models qualify as ISIM models since the 3D geometric representation is just one aspect of the ISIM concept. In this broader perspective, which includes the entire construction process, the application of the ISIM methodology to Meier Bridge in Alessandria has been proposed.

The Meier bridge in Alessandria, Italy, is an impressive engineering feat, built to span the Tanaro River and provide a vital transportation link for the surrounding area (Figure 1). The bridge was designed with a steel arch truss structure that spans a total length of 303 meters, with a main span of 210 meters and a height of 56 meters above the riverbed (Pleba, 2016).

The construction of the Meier Bridge was carried out in two main phases. The first phase involved the foundation work, including the construction of the abutments and the central pier. The foundations were designed to withstand the anticipated loads and to provide stability against lateral forces (Pleba, 2016).

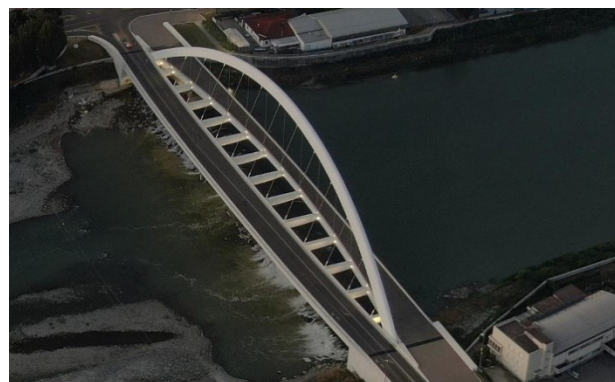


Figure 1. Top aerial view of Meier bridge in Alessandria.

The superstructure elements were erected in the second phase. The pre-cast concrete beams were placed and connected to the and the central pier (Pleba, 2016). Subsequently, the reinforced concrete deck slab was cast on top of the beams, providing a smooth riding surface for vehicles.

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Regular inspections and structural analysis are essential to assess the Meier Bridge's performance and identify any signs of deterioration or structural concerns. Various techniques, including visual assessments, non-destructive testing, and finite element analysis, are employed to evaluate the bridge's load-bearing capacity and structural integrity. For this reason, the implementation of BIM methodology could play a crucial role providing a comprehensive digital representation of the bridge, incorporating all relevant information about its design, construction, and subsequent modifications (Li et al., 2023; Nguyen et al., 2022).

Maintenance teams could be facilitated to access accurate and up-to-date data regarding the bridge's components, materials, and structural elements by an efficient planning and scheduling of maintenance activities, allowing for better resource allocation and reduced downtime (Byun et al., 2021, 2019; Nguyen et al., 2022). Various scenarios can be assumed, to assess the impact of potential modifications or repairs, and make informed decisions to ensure the optimal performance and longevity of the bridge. The utilization of BIM methodology in bridge maintenance enhances efficiency, reduces costs, and improves overall safety by promoting proactive maintenance practices and enabling effective collaboration among stakeholders (Byun et al., 2021; Li et al., 2023)

2. METHODOLOGY AND CASE STUDY

BIM (ISIM) is a powerful tool that can be used to improve the design, construction, and maintenance of bridges. By means of its implementing project stakeholders can benefit from improved collaboration, accuracy, and efficiency. The successful implementation of ISIM in bridge projects requires a collaborative approach and a commitment to digital technologies, leading to improved project outcomes and a more sustainable built environment. Concerning planning and design, the first step is to define scope and requirements: GIS is the well-known tool to assess the site for topography, geotechnical conditions, utilities, and other relevant information. GIS is a technology that captures, manages, analyses, and presents geospatial data (Aitken and Michel, 1995). It provides a framework for storing, querying, and visualizing geographical information related to bridges and infrastructure, such as terrain, land use, and transportation networks.

The integration of 4D BIM and GIS technologies has emerged as a powerful approach to enhance asset management processes and optimize decision-making in the field of bridges and infrastructure. Stakeholders can visualize the planned bridge or infrastructure project in its geospatial context. This allows for better alignment with the surrounding environment, analysis of environmental impacts, and optimized design decisions. GIS provides a platform for storing and managing asset-related data, such as maintenance records, inspection reports, and facility management information. 4D BIM enables the visualization and analysis of asset performance, aiding in preventive maintenance planning and decision-making (D'Amico et al., 2020; Jang et al., 2021; TUDublin and Kennedy, 2020).

BIM, as previously discussed, is a methodology that holds significant potential for smart and sustainable infrastructures development. BIM has revolutionized the construction industry over the past two decades, but there remains a research gap in its application for large scale management. The limitations of BIM in terms of horizontal expansion have led to its integration with GIS to overcome these constraints and harness the advantages of

BIM in infrastructure development processes (Joshi et al., 2016; Marzouk and Othman, 2020).

Infrastructure assets often span large areas and require mapping scales that are better suited for GIS. By integrating GIS, which excels in geographical data, with BIM, which offers engineering detail, a more comprehensive and effective solution for infrastructure asset management can be achieved. In particular, Asset Management (AM) roles a crucial role, especially considering control, monitoring and optimization through the whole asset life cycle; this enables proactive decision-making regarding repair, rehabilitation, or replacement strategies (Garramone et al., 2020).

Combining BIM with Virtual Reality allows stakeholders to visualize bridge designs in an immersive and realistic manner. Designers can create virtual models of the bridge and explore them in a digital twin environment. This immersive experience provides a better understanding of the scale, proportions, and aesthetics of the structure, enabling stakeholders to make informed decisions and identify potential design issues early in the process (Inzerillo, 2013; Inzerillo et al., 2022; Tarek and Marzouk, 2022).

Bridge projects often involve multiple stakeholders, including clients, local communities, and regulatory agencies. VR can be leveraged to create virtual walkthroughs of the bridge design, allowing stakeholders to experience and provide feedback on the proposed structure. This interactive engagement enhances communication and fosters collaboration between the project team and stakeholders, ensuring that their concerns are addressed early on (Bień and Salamak, 2022; Shahzad et al., 2022; Tarek and Marzouk, 2022).

2.1 Revit 3D model creation

The Meier bridge BIM model can be used then to create accurate 3D models of the bridge, including piers, abutments, beams, and deck (Figures 2-3).

Reconstruction of the BIM model occurred starting from the import of Figure 2-3 images on the Autodesk Revit software. The properly scaled images allowed to set grids and reference levels for the construction of the model and generate a full-scale BIM model of the bridge.

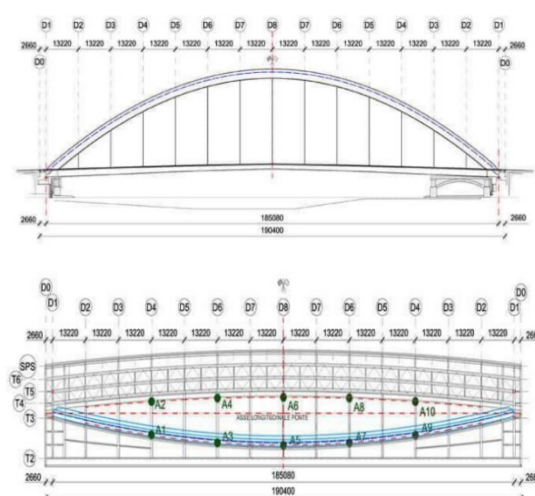


Figure 2. Side and top view of the bridge. (Source: Strade & Autostrade).

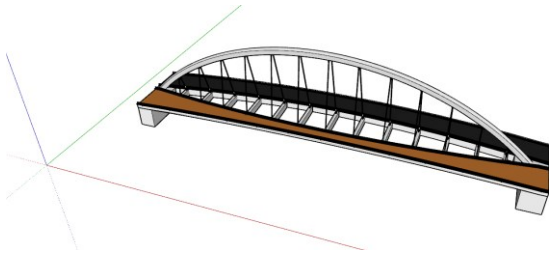


Figure 3. BIM Meier bridge 3D model

Reconstruction of the BIM model occurred starting from the import of Figure 2 image on the Autodesk Revit software. The properly scaled images allowed to set grids and reference levels for the construction of the model and generate a full-scale BIM model of the bridge.

The BIM model construction was developed at Level Of Development - LOD B (generic object), according to the Italian UNI – 11337 standard, which correspond to LOD 100 (symbolic representation) of the AIA G202-2013 Building Information Modelling protocol and LOD 2 (concept) of the BIM protocol of the Construction Industry Council (CIC) for UK and US standards respectively (Figure 4).

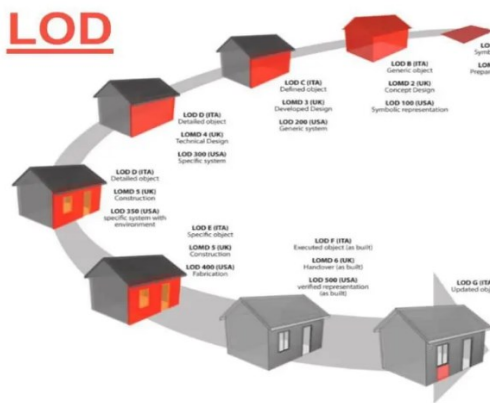


Figure 4. LOD in the US, United Kingdom, and Italy (Carnevali et al., 2019).

Concerning the BIM model generation, three masses were created for pedestrian deck, driveway, and bridge arch respectively. These masses were necessary to obtain support points for the insertion of the 3D elements families (Figure 5).

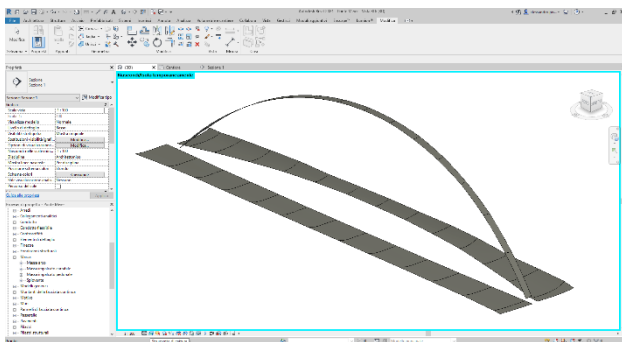


Figure 5. Generating forms and anchorages through mass creation.

Several adaptive families were created for the model construction. Two types of cable family were modeled, for the pedestrian and for the driveway respectively, starting from the generic model family metric adaptive. A 2-point adaptive cable family was generated, by setting the radius parameters and the material (Figure 6). The same approach was used for extreme anchorages of cables (Figures 7-8).

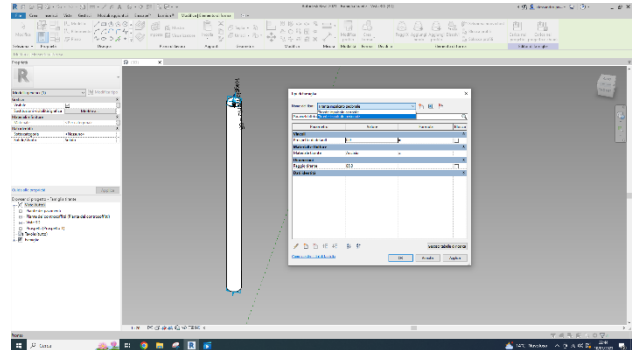


Figure 6. 2-point adaptive cable family creation.

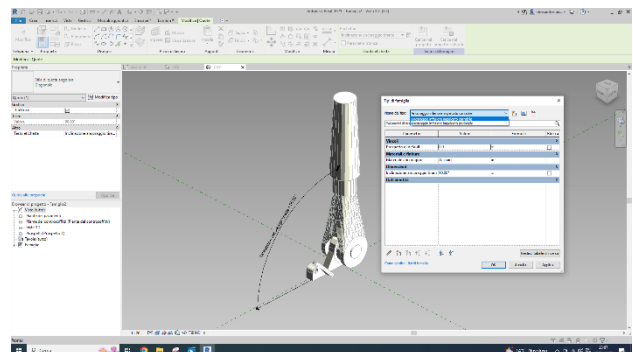


Figure 7. Lower parametric cable anchorage family.

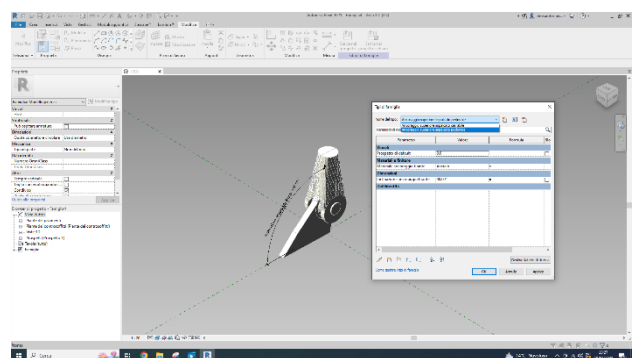


Figure 8. Upper parametric cable anchorage family.

By constraining the model representation to LOD B (LOD 200) the bridge arch was created as a single piece as a parametric adaptive 15 points beam starting from the generic model family of adaptive metrics. In this case, the arch section and the material selection were parameterized (Figure 9).

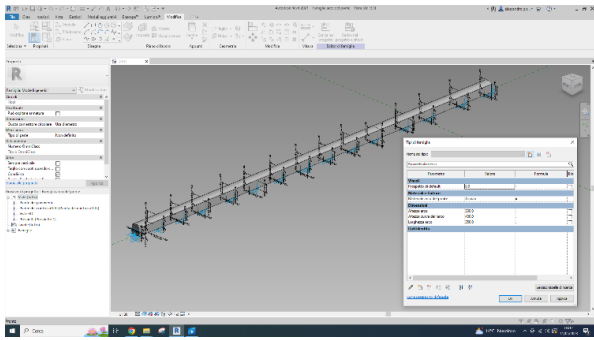


Figure 9. Parametric adaptive 15 points beam.

The assembly of the different parts, created at LOD B, has allowed to generate the BIM model of the bridge. An additional plan part for the engagement of the same infrastructure with the aero-photogrammetric model of the area was considered. The 3D model has also completed with some materials assignment for a better identification of the object after its integration into the territorial framework. Several views are shown below to describe the completion of bridge modelling and parametrization on Revit (Figures 10-11-12-13-14).

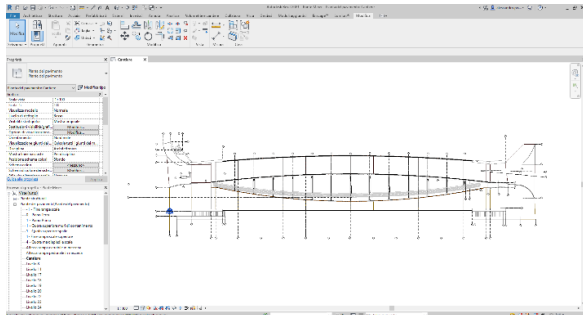


Figure 10. Top view.

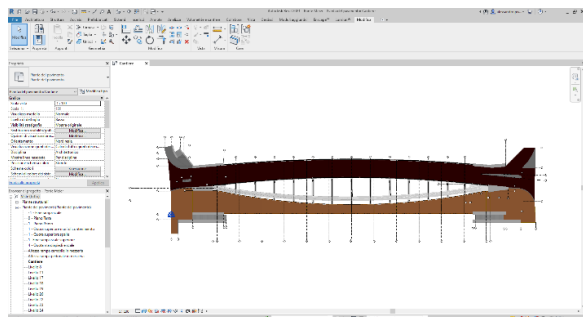


Figure 11. Top view with material characteristics.

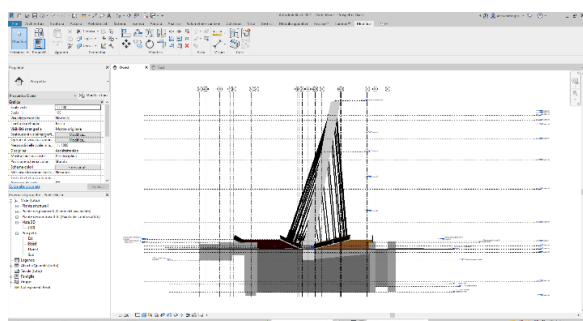


Figure 12. West elevation view.

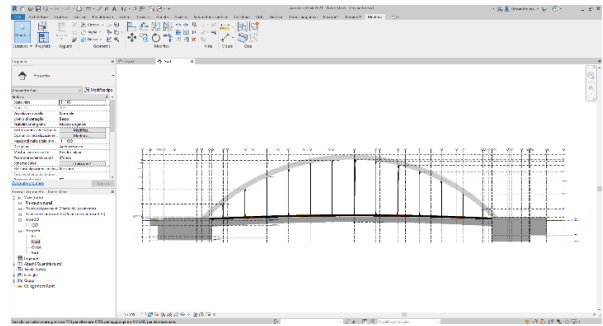


Figure 13. South elevation view.

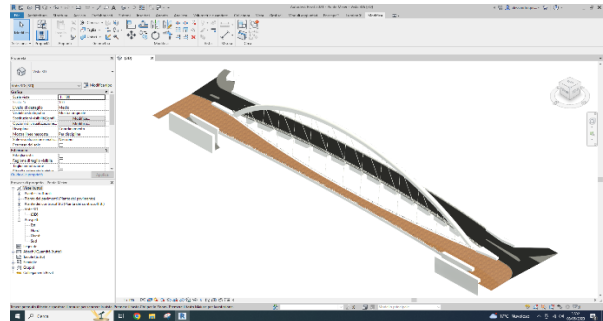


Figure 14. Aerial view of the 3D model.

2.2 BIM-GIS integration

Concerning GIS integration within ISIM-BIM approach, Autodesk Infracore software was used in which the land 3D model in Wavfront OBJ format was imported. More specifically, the land model has been input from the OpenStreetMaps database. This kind of map service provides simplified representations of the natural and built context near a construction site. Although it often lacks information about the height of the buildings, it accurately depicts their outlines in relation to streets, infrastructure networks and other structures (Hilfert et al., 2016).

The area model was configured according to LL84 coordinate system, setting the coordinates of the chosen reference point (lat 44.918714, lon 8.609251).

In order to improve the accuracy of the land model, starting from images extracted from the OpenStreetMaps library, the aero-photogrammetric 3D model of the area was generated through Agisoft Metashape software (Figure 15). In particular, Super-Resolution process has been employed to enhance the extracted images resolution and level of detail. It leverages advanced algorithms to combine information from multiple low-resolution images to generate a high-resolution output (Baldion et al., 2021; Inzerillo et al., 2022).

Autodesk Infracore software allowed to import the 3D model of the bridge as a BIM file (IFC format) of Revit within the 3D context model that was created in the previous step (Figure 16-17).

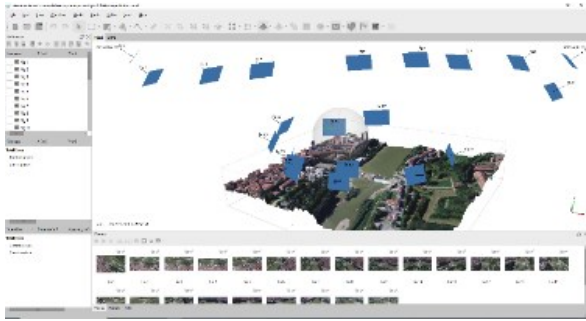


Figure 15. Agisoft Metashape 3D model of the site starting from Super resolution images process.

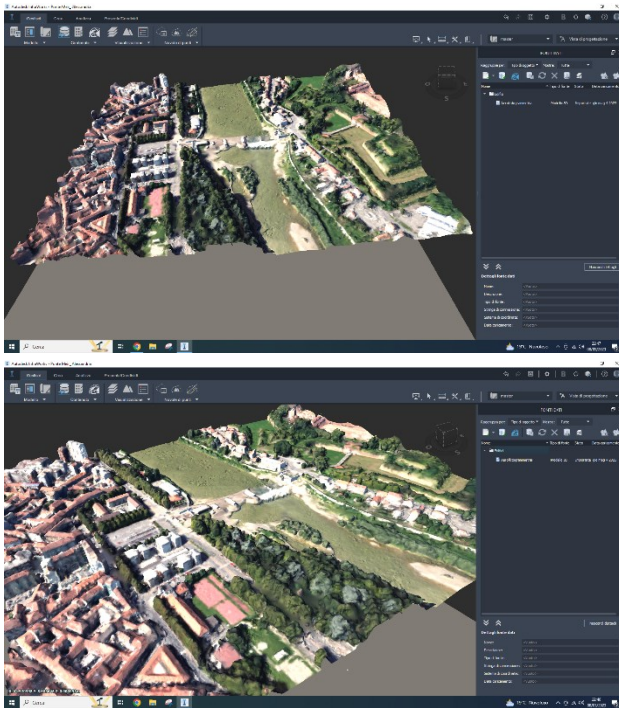


Figure 16. Aero-photogrammetric 3D model import on Autodesk Infraworks.

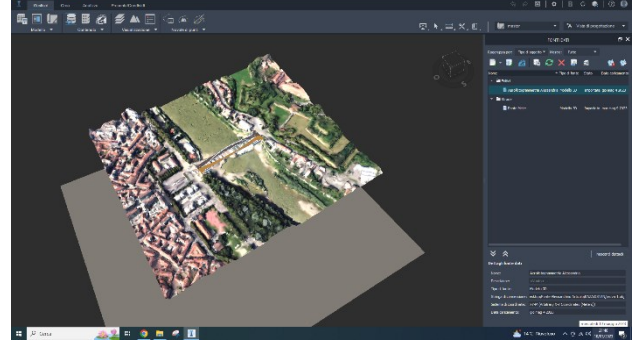
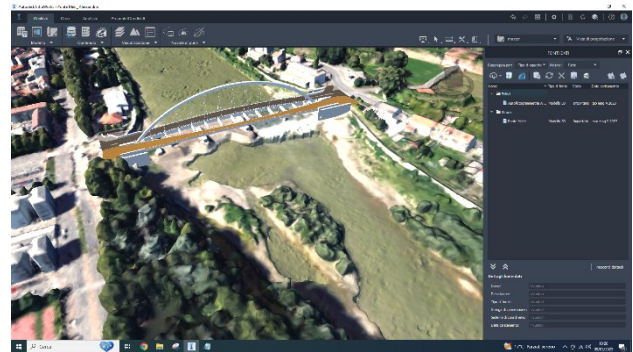
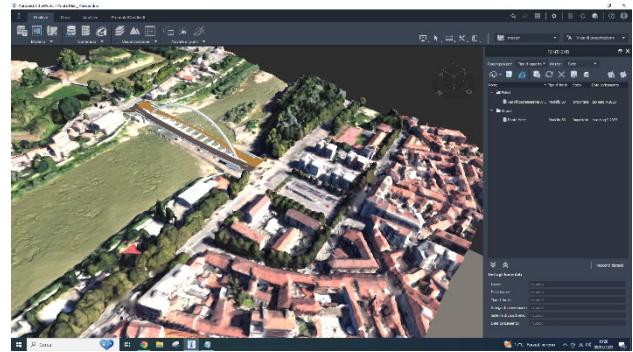
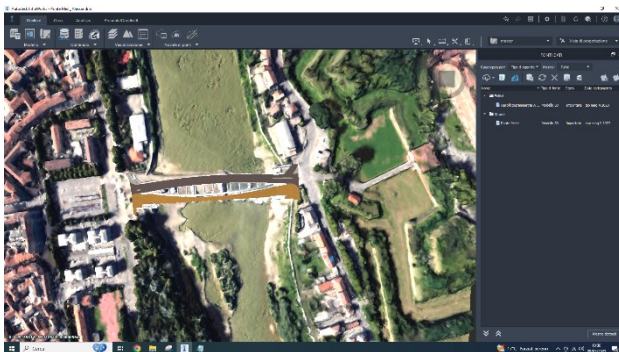


Figure 17. Import of 3D model of the bridge as a BIM file into Infraworks.

2.3 Virtual Reality implementation

A further enhancement of the implication regarding the maintenance phase is the use of virtual reality technology for maintenance training (Inzerillo, 2013; Shim et al., 2017). BIM model has been implied to create virtual reality simulations of maintenance activities, allowing personnel to practice maintenance tasks in a safe and controlled environment.

To set up a virtual reality approach, it was fundamental to refine the textures choice for the materials to be assigned to the parametric elements of both the infrastructure and the portion of the land model adjacent to the bridge itself. This step allowed to process the high-definition rendering of the model by means of the Lumion 12.5 software. In addition to inserting the materials, outdoor furniture, vegetation, people, buildings and vehicles selected by the software libraries were implemented, adding them in different layers for a proper control management (Figure 18).



Figure 18. 3D element libraries on Lumion.

The command "landscape-height-lowers" to make the riverbed realistic was also used, and subsequently with the activation of the option "ocean-sea", the effect of water was also generated (Figure 19).

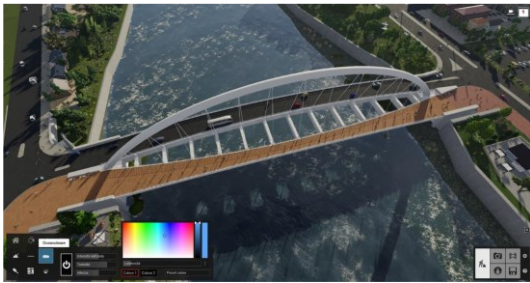


Figure 19. Lumion 11 software interface, "ocean sea" command.

3. RESULTS

Once the definition step relating the 3D model was completed, the rendering by choosing meaningful views of the model and applying the "real sky" effect available in Lumion was carried out. Below, the renders of some exported views, postprocessed in Adobe Photoshop, are shown (Figures 20 to 27).

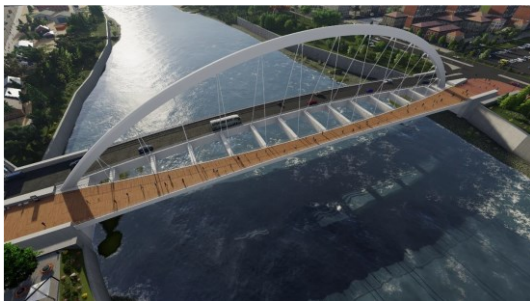


Figure 20. Meier bridge render, with post-production in Photoshop, view 1.



Figure 21. Meier bridge render, with post-production in Photoshop, view 2.



Figure 22. Meier bridge render, with post-production in Photoshop, view 3.



Figure 23. Meier bridge render, with post-production in Photoshop, view 4.



Figure 24. Meier bridge render, with post-production in Photoshop, view 5.



Figure 25. Meier bridge render, with post-production in Photoshop, view 6.



Figure 26. Meier bridge render, with post-production in Photoshop, view 7.



Figure 25. Meier bridge render, with post-production in Photoshop, view 6.

4. CONCLUSIONS

In conclusion, the application of BIM to infrastructure and structures – ISIM, GIS and Virtual Reality technology can greatly benefit all the life cycle of the Meier Bridge in Alessandria. The use of BIM technology allows for the creation and maintenance of a digital model of the bridge, providing a platform for real-time monitoring of its condition and the development of maintenance plans. The integration of GIS technology further enhances the BIM model by allowing for the inclusion of external contextual information, which can inform maintenance decisions and improve overall efficiency. The use of virtual reality technology provides a safe and controlled environment for maintenance training, reducing risks and improving personnel proficiency. By combining the strengths of these technologies, engineers and maintenance personnel can gain a comprehensive and detailed understanding of the bridge, and effectively plan and execute maintenance activities in a timely, safe, and cost-effective manner.

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