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Measurements, Simulation, Analysis and Geolocation in a Digital Twin tool for bridge management

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Abstract

This paper presents a digital-twin based tool that can be used for bridge management. The tool offers various capabilities that include embedding BIM geometries, simulations, measurements, GIS location, and performance analysis. These features enable efficient and effective management of bridges by providing detailed information and analysis of the bridge's performance, which can help in identifying potential issues and implementing appropriate solutions. The methodology represents one of the outcomes of Ashvin, an H2020 project aimed to providing assistant solution for design, construction and management of infrastructure systems. The hitherto obtained findings include this digital tool which can be of practical and beneficial use for bridge owners and operators, as it can help them to organize and centralize the bridge data in a way it helps making informed decisions regarding the maintenance, repair, and replacement of bridges. Overall, this paper highlights the importance of embracing technology in the management of critical infrastructure such as bridges, which can significantly improve their performance and extend their lifespan.

Keywords

Digital Twins, Bridge Management, Bridge Maintenance, Load Tests

1 Introduction

A digital twin is a virtual model of a physical system or entity that continuously processes data and generates decisions and actions through measurements, simulations, performance analysis and lifecycle management [1-3]. Digital twins may have different functionalities and as such, a considerable amount of labels and names are nowadays being set for categorization of digital twins in many different fields. Among names and functionalities one can find, for instance: Status twins are used for monitoring physical objects and equipment; Operation twins are used to adjust operating parameters based on linked actions and/or workflows. Simulation twins are used to predict the behaviour of an objective or device under operational conditions in the future [4-5]. On the other hand, several obstacles such as data trust, privacy, cybersecurity, and bottlenecks such as unsynchronized as-built models need to be overcome for the development of a behavioural digital twin in the building and infrastructure sectors [5-8]. This type of digital twin is dynamically updated to imitate the physical system's structure, state, and behaviour and can be used to enhance the asset's performance. On the other hand, a lack consensus in the definition of digital twins stems from the type of connectivity between the physical and the virtual realms. Nowadays, it is understood that there must be an active connection between both realms. Information coming many different sources must flow from the physical to the virtual world at the right time allowing to users to take timely decisions with such information. When the information flows from measurements to the virtual realm with no practical use, the information construct is often referred to as digital shadow. When the information not only flows from the physical to the virtual but provides feedback in the other direction, it is then defined as a digital twin. With the increasing use of the term and of the technologies involved, digital twins are also evolving in this definition.

This paper presents a case study of a digital twin tool that aims to encompass different layers of information from bridge assets, in particular, bridges belonging to railways networks. The paper shows some of the outcomes of an H2020 project called Ashvin whose aim is to establish methodologies and information pipelines to generate digital twin assistants to design, construction and maintenance of infrastructure systems. The tool is fed with information from the site, simulations, performance analysis and geolocation.

2 Digital Twin conundrum

The concept of Digital Twins (DT) has been gaining traction in recent years, and many see it as a game-changing technology. However, a unified definition and a unified scope of a Digital Twin is still a matter of debate. The question that is often heard of in technical debates is: Which is the level of complexity an information construct should have to label it a minimum entity of Digital Twin. Consensus has not yet achieved in this definition but at least, most of the presented definitions suggest that the DT must have an active bidirectional connection between the physical and the virtual realms by at least, one medium. Recognizably, information sources are extremely varied and information pipelines from the physical to the virtual realm may take many forms. Therefore, even if a given DT accomplishes at least one connection, it would be desired that any other information pipeline can also be plugged to the same construct. A key question that arises when it comes to Digital Twins is whether they can effectively integrate all sources of data such as measurements ranging from sensors, images, videos, point clouds, text files, or data streams.

In theory, Digital Twins should be able to integrate all these sources of data to create a comprehensive and accurate model of the system being analysed. However, there are some challenges that need to be addressed to make this a reality.

One challenge is the sheer volume of data that needs to be integrated. Sensors and other measurement devices can generate vast amounts of data, and managing this data can be a challenge. Additionally, the quality and reliability of the data can vary significantly, which can impact the accuracy of the Digital Twin model.

Another challenge is the need for interoperability and standardization. Different types of data are often stored in different formats, which can make it difficult to integrate them into a single model. There is a need for common data models and standards to ensure that different types of data can be easily integrated into Digital Twins. Despite these challenges, there are ongoing efforts to develop solutions to enable Digital Twins to integrate all sources of data effectively. IFC schema as well as distributed IoT platforms based on micro services platforms for developing, shipping, and running applications are becoming useful for these purposes. Distributed informatics services enable to separate different applications from the infrastructure. Consequently, one may have a digital twin that can couple applications from third parties with robustness and ease.

3 Related work

In recent years, literature on digital twins in the Construction sector has focused on two areas: (i) Conceptual designs and frameworks, and (ii) Development of semi-automated pipelines of information fully or partially embedded into DT systems. This short review focus on the former [1-10].

Several researchers have explored the application of digital twins in the construction industry. For example, [1] drew on the manufacturing sector to provide an overview of DT in manufacturing that could be adapted to the Architecture, Engineering, Construction, and Operations (AECO) industry. Meanwhile, [9] and [10] summarized the extensive literature review about the DT application in the construction industry from a construction perspective, which can be used as a basis to develop conceptual designs and frameworks. Additionally, [11] developed a DT framework for facility management that could help stakeholders make more informed decisions and generate more efficient outcomes from their assets, while [12] developed a DT framework for structural health monitoring. More recently, researchers have developed DT frameworks to support the overall construction process. [13] proposed a framework to use muti-faceted BIM applications, along with IoT and artificial intelligence, to evolve towards the construction digital twins in evolutionary phases. Meanwhile, [14] developed a step-by-step DT workflow for the built environment to support relevant stakeholders with the best decision-making. [15] established a data-driven DT framework integrating BIM, IoT, and data mining to avoid potential bottlenecks and prevent possible failure for advanced project management, and [16] presented a lightweight DT for transforming bulk material silos into smart silos and supporting the construction supply chain.

4 Ashvin - H2020 Research and Innovation Action Project

This study is conducted as part of the Ashvin project [17], which is a European H2020 project aimed at exploring research and innovation strategies for developing Digital Twins that can serve as assistants for Design, Construction, and Maintenance of infrastructure systems. The project is comprehensive in scope and covers various aspects ranging from DT conceptual frameworks to advanced informatics tools, with the development of multiple information pipelines. The project's test beds comprise demonstrative case studies of various structures, including buildings, bridges, footbridges, airports, ports, and stadiums. Reports providing details about these test beds are already available in [18]. The diversity of these test beds offers a broad perspective for exploring as many opportunities for asset twinning as possible.

The operation phase represents an important target of the developments within the project. Different sites have been opened to the project in the form of demonstrators of different information pipelines. Asset monitoring during the operation phase is crucial for ensuring the optimal performance, longevity, and safety of an asset. It allows for the early detection of potential problems or failures, enabling timely maintenance or repairs, reducing downtime, and preventing costly repairs or replacements. Moreover, monitoring also helps in identifying opportunities for optimization and improving asset efficiency, thus maximizing the return on investment. A set of railways bridges in Southern Spain, an Airport in Croatia, a road bridge in Spain (Barcelona area) and a Stadium in Germany represent the assets covering the operation phase within the project.

5 Case study. Load tests in two railway bridges.

Bridges play a crucial role in connecting different regions and providing social and economic advantages. Therefore, it is imperative to ensure that they are properly designed, constructed, and maintained. With advancements in data collection and management, a Digital Twin (DT) paradigm is now possible for bridges. DT has the potential to accurately monitor the structure of an asset by encompassing the physical behaviour measured using sensors together with a representation of its multi-physics with varied synthetic scenarios. Both realms are coupled during an episode of load testing. Load testing of bridges is an ideal way to simulate and adjust physics behaviours, as it provides a known and controlled load, restricts the serviceability of the asset, and offers a detailed plan of sensors and specific requirements according to local standards.

Although load tests are relatively expensive and require considerable coordination between owners, machinery, designers, monitoring staff, and construction companies, they represent a valuable episode in the construction or operational phase of the bridge that can also generate economic benefits. Therefore, it is important to extract as much information as possible during load testing episodes. Load tests are a significant milestone for twinning bridges in digital platforms, as they involve specific structural models and measurements quantifying the structural response. By matching both results using IoT-based digital twinning, the asset can enter the service phase not only physically but also virtually.

For the development of a comprehensive digital twinning during load testing, two viaducts from the Extremadura high-speed railway network in Spain's have been opened as demonstrators. The viaducts include simply supported beams and continuous beams, both of which are repetitive throughout the railway network, adding to the usefulness of the demo case. One of the viaducts is called the Valdelinares Viaduct, which is an 8-span structure with a total length of 280.4 meters. Figure 1 displays the asset's location, while Figure 2 shows a drone-view of the viaduct.

It is worth noting that while Valdelinares features a cross-section comprising of a concrete slab and two prestressed concrete girders (as depicted in Figures 3 and 4) whereas La Plata has an in situ cast pre-stressed concrete deck (as shown in Figures 4 and 5).

Figure 1 Viaduct La Plata. Extremadura. Spain. Source: Authors

Figure 2 Viaducto Valdelinares. Extremadura. Spain. Source: Authors

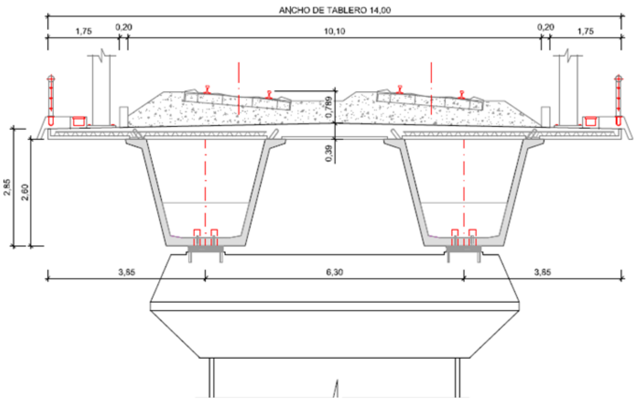

Figure 3 Cross-section of Valdelinares.

Figure 4 Cross-section of Valdelinares. View from underneath. Source: Authors

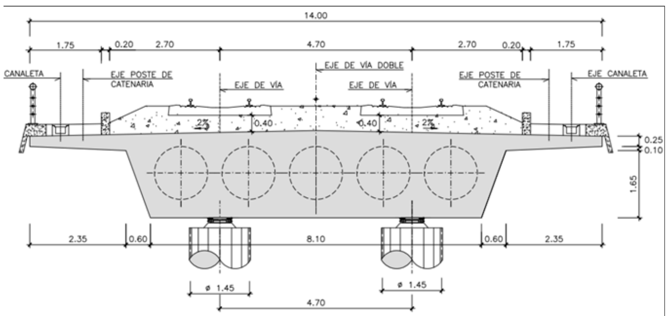

Figure 5 Cross-section of la Plata.

Figure 6 Cross-section of la Plata. View from underneath. Source: Authors

6 Information layers

A common data environment (CDE) is a shared platform where all project stakeholders can access and manage project information. Adding multiple layers of information to a CDE is crucial for effective collaboration and decision-making. Each layer adds a different perspective to the data, allowing stakeholders to gain deeper insights into the project. For example, a layer with data from a site can help stakeholders better understand the project's status. A layer of costs can help to visualize the budget and expenses, while a layer with construction drawings can help them visualize the project's physical structure. Adding layers for project schedules, risk assessments, and communication logs can also provide valuable information to stakeholders. By adding multiple layers to a CDE, project teams can enhance their ability to collaborate, reduce errors, and improve project outcomes. It's important to ensure that each layer is properly managed and maintained to ensure accuracy and relevance. Four layers of information are encompassed in the first version of the digital tool. Namely, measurements, simulations, performance and geo-location.

6.1 Measurements

The construction industry has always required a deep understanding of the natural and built environments. Today, advancements in sensor technology, computer vision, and remote sensing offer unprecedented opportunities to gather data. However, extracting value from this wealth of information remains a significant challenge for the Architecture, Engineering, and Construction (AEC) sector. Measuring techniques have become more ubiquitous, accessible, and interconnected. As infrastructure systems incorporate more sensors, centralized platforms and information hubs will play a critical role in managing data. Digital twins, which aggregate multiple layers of information, can provide a comprehensive understanding of infrastructure systems. Therefore, it's crucial to collect and embed sensor, image, and remote sensor-based data meaningfully within digital twin platforms [19]

In this demo site, both static and dynamic data were collected. The static load test collected two types of measurements: the vertical deflections of the beams and supports. Linear Variable Differential Transducers (LVDTs) were used to measure the deflections, with a range of +/-25mm and a precision of 0.01mm for the beams and a range of +/-5mm and a precision of 0.01mm for the supports. For illustration, Figures 7 and 8 describe the locations where the vertical displacement measurements were taken in La Plata Viaduct. LVDTs were placed on the bottom part of the deck (Fig. 7) in a series of points along the four spans (Fig. 8). The measured deflections reflect the active deflection caused by the applied load. Locomotives and loaded wagons were provided by the owners during load testing. Two LVDTs were placed for each track of the railway at the centre of the spans (yellow points), while one LVDT was placed at each support (black point). In addition, to measure the strains at the bottom of the prestressed concrete slab of the bridge or the concrete girders, PL-60 strain gauges with active length, thermally self-compensated and directly complemented by a data acquisition system, were installed at the center of the spans for each track. Figure 9 shows blue points located on the drawings, which represent the installed uniaxial strain gauges.

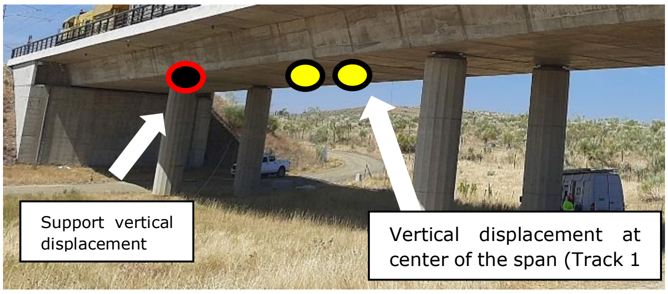

Figure 7 Example of sensor location. La Plata. Source: Authors

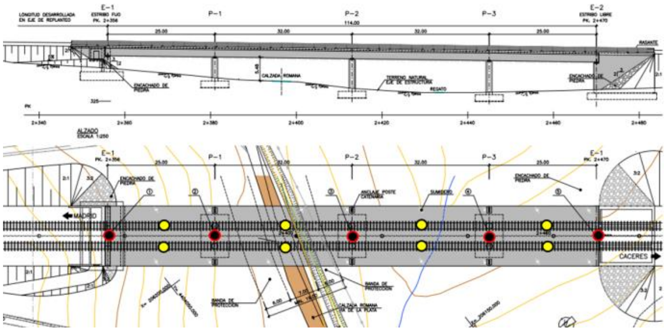

Figure 8 LVDTs location. La Plata. Top view.

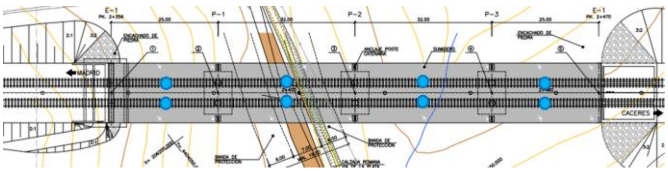

Figure 9 Strain gauges' location. La Plata. Top view.

On the other hand, to obtain physical parameters such as impact coefficient, damping, and vibration frequency, the bridge structure underwent dynamic testing. This involved the load train passing over one of the tracks through the entire structure. The dynamic test was conducted through several actions, including a load train passing over the track at a pseudo-static speed of 5 km/h, half of the maximum speed at 40 km/h, and the maximum speed possible within safety conditions at 80 km/h. Additionally, a breaking test was performed on the structure while the train was passing over the track at maximum speed. Two accelerometers were installed at the centre of the inner spans, as shown in Figure 10.

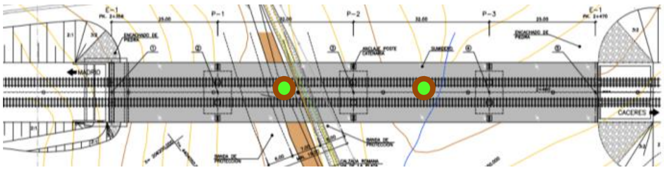

Figure 10 Accelerometers location. La Plata. Top view.

Proper collection, transmission, and storage of information from sites is essential. The open-source IoT platform Mainflux [20] facilitates the orderly transmission, storage, and retrieval of information. Mainflux IoT platform is highly efficient, scalable, and has a small memory footprint. It can operate in the cloud and on edge devices, and supports widely used sensor data protocols such as MQTT, HTTP, CoAP, and LoRA. It follows a microservices paradigm and can be easily extended with additional protocol support. Data can be sent in SenML, JSON, or CBOR formats. Mainflux is based on user-defined entities, namely "things" and "channels," which are used as building blocks to create a meaningful data-collecting environment. "Things" typically represent devices (or applications) that publish or consume data, while "channels" organize, structure, and share data between devices. Data published to the platform is available as a stream via MQTT or Web-Socket, or retrieved from the structured time-series database via a REST API. To set up the platform, users create a "thing" and a "channel" and connect them. Each user requires authentication, and devices must be set with credentials and topics to which they should send messages (usually measurements from sensors).

6.2 Simulations

Numerical simulations aimed at accurately reproducing these load tests were performed. The static load test model was firstly created using preliminary FE-models constructed with frame elements representing the cross sections of the bridge deck. For boundary conditions, displacements were restrained, and rotations were set up as free for all supports, as shown in Figure 11. It is important to note that these preliminary models were not fully connected to the under development tool at the beginning of the study. Fig. 11 shows bending moment diagrams on a model of a continuous beam loaded with live loads applied in two spans.

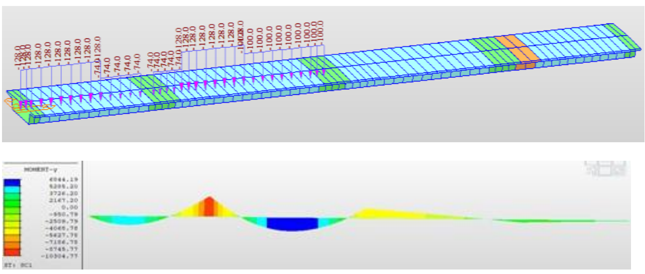

Figure 11 Preliminary simulations. La Plata. Two spans loaded.

The load distribution was designed to be in line with several hypotheses planned for these load tests. The loads were applied to the central axis of the frame elements, taking into account the effect of the surcharge in both tracks. The elastic young model was defined as 32.22GPa, considering the elapsed time since the construction of the viaduct. Initially, these numerical models were created using proprietary Licence Software (MIDAS Civil), followed by updating the model to the data flow using codes from MatchFEM, the connector included in the CDE that is described in section 7. For La Plata, pre-stressed concrete decks were represented by frame elements supported as a continuous beam. However, for Valdelinares, beams with two pre-stressed concrete girders were idealized using simply supported frame elements. In the preliminary models, beams were connected with rigid links to shell elements, representing the concrete slab. Simulations for static load tests were performed by applying uniform loads on the FE models, which accounted for the actual live loads produced by locomotives and wagons, considering all loads hypothesis. Vibration modes were determined for dynamic load tests.

During dynamic analysis, acceleration data obtained during the dynamic tests were pre-treated and processed to obtain the main vibration frequencies of the structure, modal shapes, and associated dynamic damping. This was achieved using the Multiple Operational Modal Analysis Platform (MOMAP), a Python software for signal analysis. Data pre-treatment involved processing the signals to reduce noise and eliminate frequency content outside the range of interest, thereby increasing the accuracy of the structural values obtained. Data analysis included obtaining the dynamic parameters of the structure using various OMA techniques, which do not require control or knowledge of the applied load during the test. These algorithms only require the response of the structure to dynamic disturbances, in this case, accelerations. MOMAP includes connection with Mainflux and SQL databases, from where measurement data series are obtained, representing an exemplary application of third-party integration within the data environment. Various methods for analysis are available, such as the Enhanced version of the Frequency Domain Decomposition and Covariance-driven Stochastic sub-Space Identification [21].

6.3 Performance analysis

Performance goals are the primary driver for decision-making procedures and activities in infrastructure management. The management process is evaluated based on the attainment of predefined goals. For example, determining whether users receive the desired services at the quality level they are willing to pay for and comparing alternative service providers to identify the most effective way of providing infrastructure services. A framework that connects goals to key performance indicators (KPIs) and performance indicators (PIs) is necessary to ensure consistency in the databases and the information provided. The indicators are regularly updated to maintain relevance since information needs, types of agencies using PIs, and their relationships to one another vary over time and throughout the life cycle of assets, from design and construction to operation and maintenance. The measurement of performance with KPIs is primarily based on the following key areas:

- Economic performance, which compares the economic outcomes such as the number of passengers, vehicles, or freight to technical outputs such as train-kilometres, number of lanes or flights. However, if supply exceeds demand, high productive output may lead to low economic efficiency. The main focus is on occupancy rates as they determine whether economic outputs can be compared to technical inputs such as labour and capital.
- Productivity, which assesses the output-to-input ratio of an activity based on conventional economic evaluations. For example, train-kilometers or seat-kilometers are two possible outputs. The analysis can be based on the quantity of capital or labor, measured to varying levels of complexity. It also calculates basic or complex indicators such as production boundaries.
- Operational efficiency, which encompasses various aspects related to the use of infrastructure at the structural or network level, which impact users and society. Availability, punctuality, accuracy, and traffic safety are some of the indicators used to define and analyze operational efficiency.

The main objective of maintenance management planning is to specify service standards and performance benchmarks that must be met before analysing maintenance options to determine the optimal one based on KPIs. A maintenance plan is then derived, which details the timing, operational requirements, and specific work procedures suggested to provide the necessary levels of service.

6.4 Geo-Location

Georeferencing of assets enables the simultaneous overview (or analysis) of multiple assets in a specific geographic area, as well the analysis of how certain assets are affected by local weather, e.g. temperature, precipitation, wind. The GIS integrator and DT model enable the overview of an asset in a global or a local view. In the case of requirement for maintenance of multiple assets at the same time, for example bridges on the same road or railway network, a traffic organization can be optimized to minimize the impact on availability and to minimize the closure time.

7 Connectors

Digital twins are required to offer a comprehensive framework for exchanging information among stakeholders. When they are designed as virtual assistants, they need to provide context-specific data regarding a particular asset whose status changes dynamically to facilitate informed decision-making for their users. To accomplish this, digital twins should integrate asset information models from various domains within the built environment as well as different data types generated by various stakeholders and stored in separate systems. The information constructs that constitute digital twins must be accessible to a group of computational agents that can extract, transform, and load new abstracted data back into the digital twin system. Furthermore, this system must be able to adapt to the changing needs of the industry and be flexible enough to handle its dynamics, incorporating new information and services as they are added or modified.

In order to create connectors, it is necessary to incorporate multi-physics models, sensor data, external simulation engines, and simulated data into digital twins. The integration of these entities will facilitate the provision of services that improve maintenance planning, validate models using real-world data, establish alert systems based on continuous monitoring of physical parameters, or support the design of assets using simulated information. To achieve this goal, we explore the use of knowledge graphs as the fundamental information foundation of digital twin systems, which enables the aggregation of simulation capabilities.

A graph is a data model represented by a collection of nodes, or vertices, that are connected by relationships, or edges (Fig. 12). Nodes normally represent entities in a specific domain while relationships explicitly define how entities interrelate. Graphs can be directed or undirected. Directed graphs have a one-way relation between node A to node B, while in undirected graphs the relation is two-way. This structure provides a simple yet powerful general-purpose data modelling tool to represent complex relations between entities and how they relate to the world.

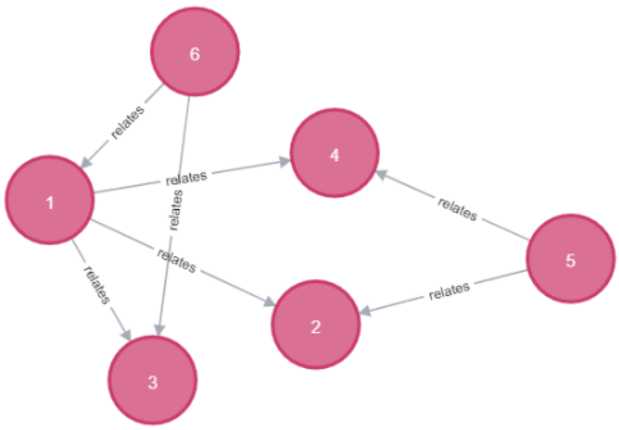

Figure 12 Knowledge graphs for connection of data sources.

As a result, the system can leverage a variety of technologies and software to maximize its benefits. To facilitate this, it is suggested to integrate the ASHVIN Digital Twin platform with a Grasshopper plug-in. This integration creates a dynamic environment where BIM, sensors, data, and structural analysis coexist. The plugin is called MatchFEM and by incorporating it into this environment, structural engineers can use it as end-users, saving time on coding and minimizing the need for specialized software development. The Grasshopper plug-ins components are coded in C#.

MatchFEM within Grasshopper is intended for two types of projects: i) Projects in a scenario of accessible and high LoD BIM and structural analysis models and ii) Projects where information on the virtual asset is not available. The components of the MatchFEM plug-in include the creation and edition of BIM and FEM models using the standard open-source IFC schema.Fig. 13 shows a set of connectors developed within the plugin.

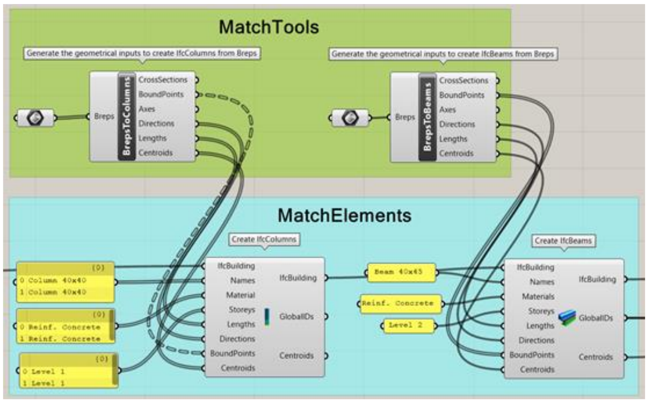

Figure 13 MatchFEM Grasshopper plugin for defining geometries, simulations and sensors.

8 The platform. Ongoing developments

The load tests shown have enabled the creation of effective measures for virtualizing assets, which are designed to be useful during operations. The resulting centralized information can be accessed by maintenance planners to review load test results and monitor potential changes in the assets. Additional information can also be added during subsequent inspection episodes. This section outlines the actions developed thus far, with further developments expected to be included by the end of the Ashvin Research and Innovation (R&I) Action project. The dashboard of the Ashvin platform user interface is powered by a game engine created in Unity [21], featuring various built-in tools that aim to enhance the design, construction, and maintenance of infrastructure systems. The assets are replicated with interoperable geometric entities, and these tools are built upon the geometry to provide access to information, analysis, and decision-making capabilities. Users can extract relevant information from the real asset, simulations, or historical data, enabling them to obtain a comprehensive view of the asset during its respective stage of development. Furthermore, an IoT platform [20] enables communication between the dashboard and the collected data. This IoT platform is scalable, secure, open-source, and patent-free, serving as a vital link to all tools and potential future tools. It supports connections through various network protocols, such as HTTP, MQTT, WebSocket, and CoAP, and consists of multiple microservices (MS) with distinct and well-defined responsibilities. Some examples of MS include managing user and authentication issues, managing things and channels, or custom storage infrastructure. These MS can be executed in different ways, depending on the specific use case requirements. They can be deployed locally or in the cloud, on-premise or off-premise, as a Docker container composition, or as standalone applications on a local host computer.

A geometrical depiction of the La Plata Viaduct, one of the twinned bridges on the platform, is shown in Figure 14. The IFC standard formats and their corresponding metadata can be transferred to the platform. Additionally, all tools displayed provide specific functions throughout all stages, including design, construction, and maintenance.

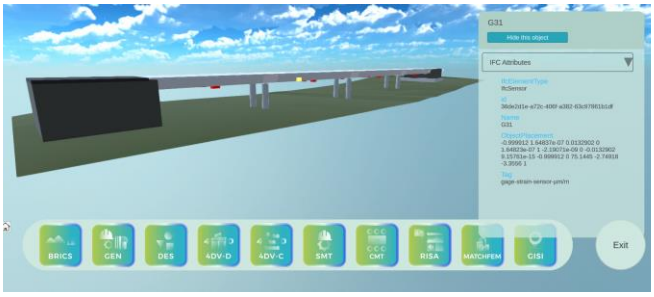

Figure 14 La Plata Viaduct featured in the developed platform.

Creating a Digital Twin of a bridge for load testing requires bridging the physical and virtual worlds by gathering extensive data at project sites. The objective is to seamlessly integrate sensors, measurements, and the virtual asset, thereby avoiding information silos and minimizing the risk of data loss. Figure 15 shows the data flow of an end user while creating a DT from scratch.

Once prepared and connected, users on the Digital Twin platform can retrieve sensor data by clicking it, given that they share the same ID with the thing that holds the data in the IoT platform (Fig. 16).

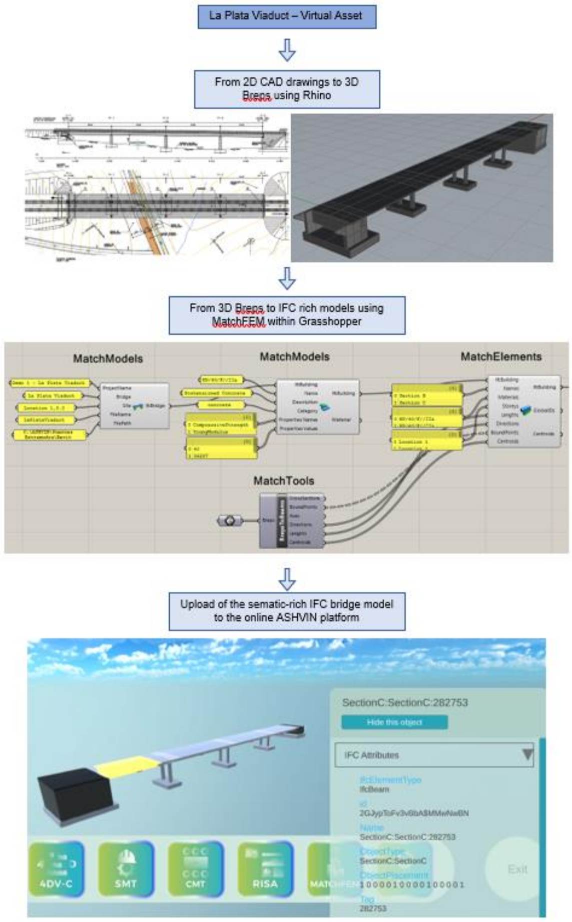

Figure 15 Pipeline for La Plata Viaduct virtual asset generation.

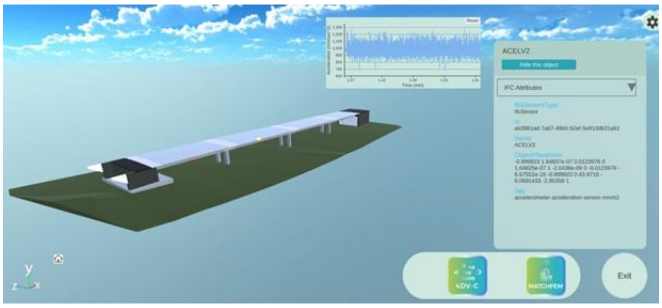

Figure 16 Sensor data retrieved in the Digital Twin platform.

Structural analysis is performed using in-house developed or alternatively, properly connected results obtained with other existing Software. A functionality called Match-Friends included in the Grasshopper plug-in allows connecting with several (and increasing) structural and physics models. In this particular case, the previously developed code CONS [22] is embedded in the simulation. This code alloys developing fiber-based, beam geometries with time-dependent, nonlinear capabilities. The loading scenarios are simulated on the bridge structure. The resulting model is then converted to the IFC schema and transferred in JSON format through the FromCONS component. The next step involves uploading the model and results to the Digital Twin platform using the Ashvin component from the MatchFriends subcategory. This enables stakeholders to access the data through a user-friendly interface. Figure 17 shows a sample of this integration.

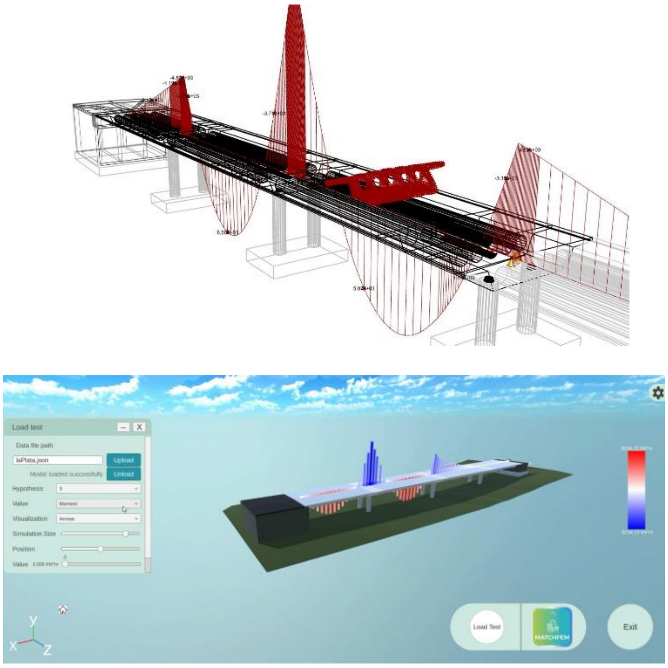

Figure 17 Simulation data retrieved in the Digital Twin platform.

Presently, developments are undertaken at the level of the integration of performance indicators into the platform. Maintenance plans encompass decisions related to when to conduct condition assessments, what conditions necessitate maintenance action, and which maintenance techniques should be employed. These decisions are influenced by various factors such as the inspection policy parameters, the level of deterioration that requires maintenance intervention, and the cost and outcomes of maintenance procedures. The optimization of the maintenance strategy is done sequentially with the aim of minimizing lifetime maintenance expenses while ensuring user and structural safety and minimizing any negative impacts on the environment. To create a risk-based maintenance strategy, four Key Performance Indicators (KPIs) proposed in the ASHVIN project. Productivity, resource efficiency, health and safety, and cost, will be utilized. Finally, the integration of geo-located assets within the platform allows selecting various infrastructure models within a network. This demo site represents a clear example of the need of geo-integration since it represents one asset within a high-speed railway network as a whole, as presented in Figure 18.

Figure 18 Geo-located asset within a vaster network.

9 Conclusions

In today's technological landscape, organizations must digitize their infrastructure to remain competitive and improve efficiency. Digitalization can streamline operations and reduce costs by automating tasks, accessing and analysing data, and enhancing the customer experience. Even civil engineering infrastructure systems are moving towards digitalization. This paper proposes the creation of a Cyber-Physical Bridge. This vision is the result of a multidisciplinary joint effort related to the development of physical-to-virtual pipelines of information for the design, construction, and maintenance of infrastructure systems in the form of digital twins. The creation of an adequate Digital asset represents a crucial milestone that will increasingly be needed as digitization progresses. Efforts related to structural analysis, 3D modelling, measurements, documentation, performance analysis and geo-localization are currently executed in a disaggregated form. However, a comprehensive digitization of all generated information can be organized for maintenance purposes. A flexible, scalable digital twin of the bridge developed during load testing may provide added value and crucial aid to maintenance planners during the bridge's life-cycle.

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