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Linking BrIM to BMS for bridges – validation of concepts

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ABSTRACT: Over the past two decades, Building Information Modeling (BIM) has emerged as a prominent facet of the digital transformation within the AEC sector. However, this transformational focus has predominantly centered on the design and construction of new bridges, overshadowing the critical realm of existing bridges constructed before the advent of BIM. The operational and maintenance phase of a bridge's lifecycle is the longest and most cost-intensive, heightened by the growing concerns of fatal accidents, climate change impacts, and the aging infrastructure of numerous bridges globally. This has sparked a global interest in shifting from a reactive to a preventive approach to bridge maintenance, entailing the seamless integration of digitalization into the operations and maintenance (O&M) lifecycle. The digital transformation of operation and maintenance processes carries the potential to significantly reduce costs and, most importantly, safety.

1 INTRODUCTION

The IABSE Task Group 5.6 has a dedicated mission: to bridge the gap between Bridge Management Systems (BMS) and existing BIM solutions. This initiative is grounded in Open BIM standards but accentuates the critical role of data models. The foundational concepts for this implementation were extensively deliberated upon at the IABSE Congress held in New Delhi, India (Aas-Jakobsen et al. 2023). The journey began with the identification and systematic categorization of use cases that facilitate the harmonious integration of Bridge Management Systems and BIM for existing bridges.

The pivotal stakeholders in this endeavor are the bridge owners and regulatory authorities, whose perspectives are paramount in shaping this market-oriented initiative. In our vision, the establishment of a universally accepted standardized framework for data exchange between disparate systems empowers bridge owners. This framework will grant them control over their bridge infrastructure's data, enabling informed and timely decision-making. The culmination of intensive interviews with bridge authorities and owners from around the world has led to the

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creation of a comprehensive review document. This review will serve as the guiding compass for recommending the future integration between Bridge Management Systems and Open BIM.

2 VISION OF LINKING BIM TO BMS FOR BRIDGES

Many bridge owners hope that BrIM (Bridge Information Modeling) will be used throughout the structure's life cycle, from initial design to building, operation, and maintenance, and finally removal and recycling at the end of service – a one-stop shop for information. As part of a BMS, operation and maintenance data are currently collected in various forms and kept in multiple repositories. To maximize maintenance of individual structural assets and manage the asset as a portfolio of structures, BrIM and BMS should be linked so that information may be shared effortlessly, even for existing structures that do not yet have a BrIM model.

The complexity of maintenance/inspection requires organized, automated, open and transparent digital processes, which should consider both structural and asset management data.

It is assumed that the BMS aims to integrate digital storage, exchange of data, cost as well as deterioration, optimization and analysis models and their interoperability with existing BIM solutions (Hajdin & Samec 2022).

The vision of this work aims to form a foundation for 3D/4D/5D/6D software and hardware independent data exchange between different software technologies during life cycle and beyond, considering also monitoring, sensor equipment and damages on the structure along time axis. Open BIM technology for the interoperability from technical, semantic and organizational point of view is of main interest. Thus, the work is based on the following formulation:

BIM model should be the driver and front end and will provide a link to the BMS system. The BIM model should allow for bi-directional information flow with the BMS system (and other systems linked to the BIM) such that information is not duplicated. The aim of our TG is searching for all requests from BMS systems (in form of use cases) in order to report missing attributes within exiting Open BIM systems.

It is in the following assumed that in addition to structural information the BrIM model include or reference the design basis, which include location, bridge type, traffic definition, metocean data, information on hazard, geotechnical design data, geological design data, seismic input, etc. The focus of this work has been to the structural system.

In order to prioritize the direction of the work the following workflow was defined as shown in Figure 1:

- Identify and systematize use cases for linking BMS and BIM for bridges.
- Prioritize use cases based on market input.
- Propose structure for connecting BMS and BrIM.

The first step (Use Cases identification and systematization) was completed and reported in (Aas-Jakobsen et al. 2023). Relevant use cases for a BrIM model over its lifetime are identified, including their potential and eventual extension of IFC standard. Currently, IFC standard (widely recognized and used Open BIM standard) is used as the reference data scheme. For the future it is important to underline, that IFC is not the only possible exchange format.

This paper is describing the concept of BrIM and BMS linkage and its validation. For this purpose, stakeholders, bridge authorities worldwide have been answering a set of questions,



Figure 1. Workflow.

prepared by IABSE TG 5.6. Their point of view, requirements and practical needs will lead to the last step: development of missing parts within BrIM.

Our work is based on our hypothesis:

- The BrIM shall allow for bi-directional information flow;
- Information should not be duplicated in the connected systems.

3 USE CASES

In order to structure the work all tasks which BrIM, and BMS could be used for was sorted into use-cases. These were categorized into five groups: object data, data management, visualization, maintenance & repair information and user interface. All identified use case were described and the advantages with linking BrIM and BMS was identified, as well as necessary update of the IFC data scheme. The below discussion gives an overview of the main findings.

3.1 *Object data*

Object data is information needed for the object. The general bridge data should consist of existing documentation of the bridge from the construction site (including interventions after construction stage), geometrical model of the bridge as built (Isailovic & Hajdin 2022) or after retrofitting, geo location of the structure, hazard information, design basis, statical report, geological report, full set of drawings, reports from construction supervision (including deviations and vulnerable areas), bridge owner, designer, constructor, construction year, traffic class, traffic load, bridge class, generation of design codes, seismic zone, monitoring plan and instrumentation, time specification. Potentially all existing bridge data can be imported into the BIM tool.

Extended definition of structural and non-structural member specification shall be delivered on member topology, geometric extent and cross sections, materials, information of reinforcement, prestressing, surface treatments, environmental exposure, degree of strength utilization, geotechnical members like piles, anchors, appurtenances like bearings, expansion joints, etc., location of monitoring sensors and time dimension.

A mechanism is needed, which would identify the status of each element in the structure. The status should be able to reflect initial, unchanged, modified, replaced, added, and demolished entities. In addition, it should be able to reflect updated documentation in BMS system, including e.g. instrumentation. Storage should be organized such that historical data could be visualized and compared to similar structure and objects on other bridges.

Inspection and maintenance activity on bridge element should be stored in BrIM for planning and logging purposes. Damages must be stored in a way that it could be monitored and visualized and serve as input to a damage model. Modification, demolition, and construction of new elements need to be updated in BrIM and its geometric changes must be added such that visualization is possible. Thus, time stamp of changes is needed.

3.2 *Data management*

Data management is related to how the data and information in the model is used. The main purpose is to prepare the ground for fund optimization.

There are several BMS worldwide, all BMS have essentially a management process for all bridges, where one needs to identify the bridge, know its condition and act upon it when required. These three tasks are grouped into three main modules: i) Inventory; ii) Inspection; iii) Intervention. With evolution in technology and focus on the needs of bridge owners, these three main modules have been split into more specialized modules.

Since BMS in principles has to deal with a huge number of bridges, it is important to have a unique ID which can be used to link data relating to that particular bridge from other sources. BrIM model shall identify all the data fields that are essential for communication with BMS.

Currently existing structures are documented by 2D drawings. In the near future it is currently not realistic to automatically convert these drawings to full BrIM models. An alternative is to create simplified BrIM models that holds the information needed to communicate with BMS. Since BMS information contain information about how the structure develop with time, this parameter has to be added to the IFC scheme for seamless communication, as time and date stamp is critical in assessment of progression of deterioration within the bridge element. Deterioration modelling module is critical in BMS as it is based on the deterioration model created under this module that the management decision making during the Risk assessment and Priority and ranking tools are achieved. In addition to the 4^{th} dimension, we propose to add a 5^{th} dimension which describe the severity of distress in the element at that particular time zone.

3.3 *Visualization*

The visualization of information on a 3D numerical model of a bridge is crucial in the development of the link between BMS and BrIM. Indeed, an easy access to bridge information in its context, such as inventory data or bridge elements' conditions, can significantly improve maintenance workflows from inspection on site to prioritization of repair actions.

This use case aims to allow the visualization of generic data of the bridge: bridge type, geometric position of elements, material specifications, number of spans, dimensions, etc. These data can be presented under two forms: 3D view or table view. Besides, several milestones of the bridge life should be available: "as-built" model, "as-is" model, etc. (Tomczak et al. 2022).

3.4 *Maintenance and repair information*

Being fully aware of the complexity of various types of bridge damages (and their underlying deterioration mechanisms), the focus of our interest are not just its visible symptoms. In fact, rather than reinventing the common perception of damages in BMSs, the idea is to find the way to use BrIM for documenting damages which are identified in a traditional routine inspection process, based on a visual observation. Additionally, the focus might be extended to parameters for the damage evolution prediction.

In an object-oriented system, such as BrIM, each damage will be represented by an instance of certain class (i.e. type), described by certain set of attributes (i.e. properties). In principle damage classes are already implicitly defined in damage catalogs of various BMSs. The sets of properties describing damage types are included in catalogs too. Although similarly organized, damage descriptions differ between various BMSs. To make data communication between different BMSs easier, finding a consensus on damage description is necessary. This means that any damage type should be described by a set of properties which is a common denominator for majority of BMSs.

In BrIM terms, modeling of damage means enabling the new BrIM functionality of modifying the intact geometry of the damaged element by introducing damage location, affected area of an element, damage photos, relationship between the damage object and the affected element, etc.

For the bridge management, historical information is crucial both for documenting the historical development of damage, as well as for documenting element replacement, addition, and/or geometry adjustment. For this purpose, an extension of IFC schema is required.

Damage evolution prediction, performed by BMS, should be associated with particular BrIM element or the entire model. It can be done by externally referencing the damage evolution data and, perhaps, assigning a time attribute to it.

3.5 *User interface*

In the context of efficient maintenance of motorways and tunnels as-built drawings have been reworked to show the exact location of maintenance items and quantities for planning of maintenance rotations, tracking progress and tracing the history of interventions (e.g. refurbishment and partial replacement). The digital availability of detailed asset documentation simplifies the distribution and update of information (Sacks et al. 2018).

Exact and current asset information is even more vital for rescue teams. Also, for the online documentation of maintenance, immediate status update, quantity surveying and the billing workflows the use of portable tablet computers greatly improves the speed of processing and mobility of teams. The ultimate vision of utility managers is an augmented reality tool to look through solid material (pavement, concrete) onto hidden assets with their exact coordinates, network topology and status information.

Another advanced use of real-time interfaces with a digital twin is the use case of structural monitoring, either in temporary installation to measure the structural response for decision making, or in permanent big-data applications such as detecting changes in temperatures, humidity, forces, strains or vibration frequencies identify latent deterioration processes. The monitoring platform may just record data for later interpretation by postprocessing, or it may permit configurating new interfaces in the field, and even allow (by virtue of cloud computing) to run structural simulations and interpret the measurement data on the spot.

4 EXTENSION OF IFC FORMAT

Linking BrIM and BMS through extension of the IFC format opens up for seamless communication between the system. This will give the bridge owner the possibility to combine information stored during the design phase with data collected in the operation phase, thus, opening up for more informed and effective operations of individual structures, as well as easier comparison between structures.

The following key extension of IFC were identified:

- Introduction of time stamp to track change on elements and information.
- Introduction of unique IDs for elements.
- A mechanism which can store status of elements such as initial, unchanged, modified, replaced, added, and demolished entities. This could be done through a *IfcLifetime* entity type with attributes like *BirthDate* and *DeathDate*. By introducing IfcLifetime entity, the current as-is geometry of a bridge would be determined at any moment in time, as shown in Figure 2.
- Place holder for inspection and maintenance plans.
- Maintenance and repair functionality including deterioration prediction, costing and optimization.
- Connection to structural assessment software.
- Definition of damage properties and damage information modelling.
- A system that handles visualization of current status of the structure including accurate position of damage and vulnerable zones.

The proposed extension will work for both new structures with BrIM models and structures without BrIM models. For the latter, very simplified models can act as place holders for information and exchange with BMS, and then be expanded into the realistic models when needed.

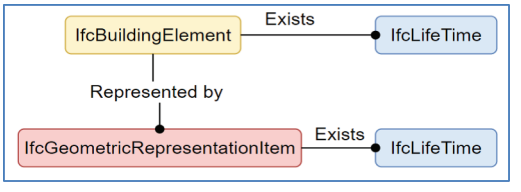


Figure 2. EXPRESS-G diagram illustrating the use of the proposed *IfcLifeTime* entity type.

5 BMS IN KOREA

In Korea, the BMS is meticulously tailored to cater to the distinct information needs of cable-supported bridges and conventional bridges. Specifically, for cable-supported bridges, the BMS incorporates sophisticated information systems such as a comprehensive health

monitoring system and a condition rating system equipped with detailed damage records. On the other hand, common bridges are overseen by an information system that meticulously tracks inspection and repair records for the entire bridge structure. The BMS dedicated to common bridges systematically accumulates invaluable inspection data, repair records, and essential information for the comprehensive assessment of bridge conditions and safety. This meticulous management extends to bridges owned by public agencies, ensuring a holistic approach to monitoring and maintaining the integrity of critical infrastructure.

Following the government's mandate for mandatory BIM adoption in public construction projects, the as-built BIM deliverables have assumed the role of foundational data for a BIM-based BMS (Nguyen et al. 2021). The IFC models submitted must undergo a conversion process to establish proper data links and optimize memory for seamless visualization. As maintenance tasks generate diverse data, encompassing images and Non-Destructive Evaluation (NDE) data, the primary objective is to efficiently transfer existing data to the new BMS, minimizing the need for manual input during this transition. Simultaneously, transitioning from the existing file-based maintenance system to a data-driven model, enabling Database-to-Database (DB-to-DB) transfers, presents a formidable challenge for bridge owners. This shift underscores the complexities inherent in modernizing maintenance systems while adhering to evolving technological standards (Won et al. 2021). In recent developments, public authorities have instituted a systematic approach for data accumulation throughout the project delivery, with the adoption of ISO 19650 as the standardized framework for handover data delivery (Shim et al. 2019). The architectural and data specifications of the as-built BIM must now factor in the specific requirements for new data and tasks that arise during the maintenance period as shown in Figure 3. Given the imperative of accurately assessing the key performance metrics of existing bridges facing deterioration, the new BMS is poised to offer a well-federated and dependable stream of data, ensuring comprehensive and reliable insights throughout the entire lifespan of the bridges. This strategic alignment ensures that the BMS is not only responsive to immediate project needs but also anticipates and addresses the evolving demands of bridge maintenance and performance assessment over time.

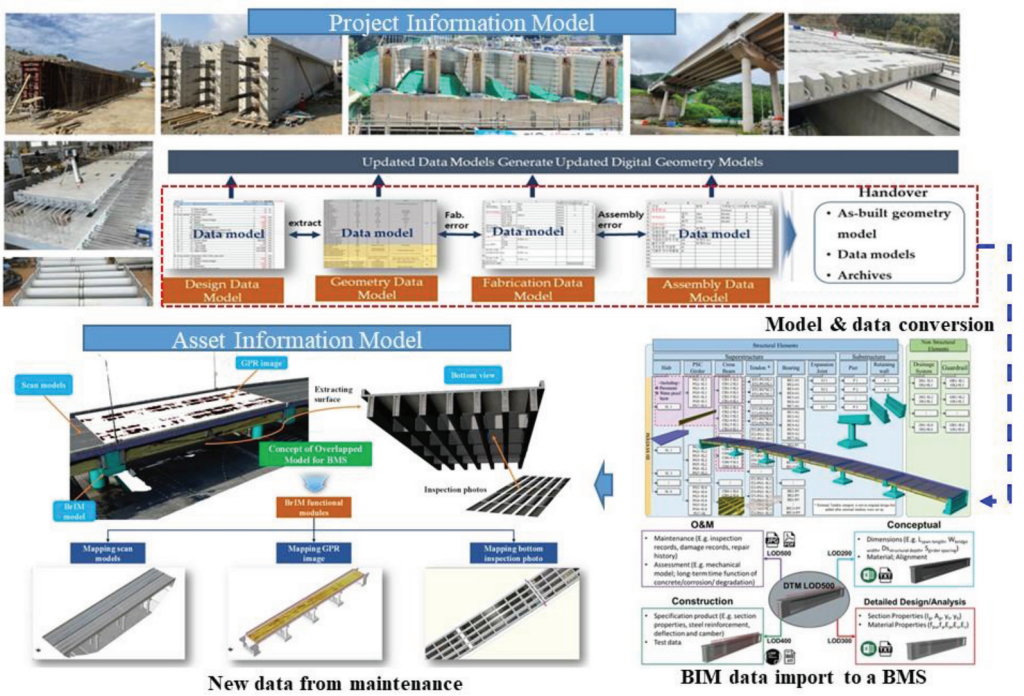


Figure 3. Information delivery from as-built BIM to BMS.

6 BMS IN SOUTH AMERICA

At the onset of 2015, the Technological Development Corporation established the BIM Forum in South America as a technical and permanent platform. This forum unites key professionals and institutions associated with Building Information Modeling (BIM) to channel technical concerns, knowledge, and information. Its purpose is to contribute knowledge and experiences from companies and professionals. The primary goal is to disseminate, develop, and foster best practices in all aspects of BIM, encompassing road infrastructure and bridges (Valenzuela et al. 2023).

The main countries involved in the BIM Forum include Argentina, Brazil, Colombia, Chile, Ecuador, Peru, among others, providing a foundation for various initiatives in each country. For instance, in Chile, the national strategic program "Construye 2025", under the "Plan BIM", aims to ensure that companies participating in future public tenders develop projects that are constructible and operable. These projects should contain integrated modeling and databases, demonstrating a comprehensive understanding of the BIM concept.

In alignment with this, the Roads Directorate, as part of its Bridges 2020-2030 program, has incorporated the BIM methodology within the lines of development and implementation (MOP 2022). The focus is specifically on the implementation of BIM in road infrastructure works, particularly in bridges, during certain project phases.

Academic support has played a crucial role in developing BIM, enhancing the technical capacity and skills of professionals. The primary application of BIM is evident in the design stage, especially for complex or unique bridges (cable-supported), under a master plan of road infrastructure, or specific requests during construction (e.g., Maipo bridge Pan-American route).

Highlighted projects include the "Trincheras Structural Project Concesión Américo Vespucio Oriente AVO1 (2018-2019)" in Chile, which was developed in BIM by the Concessionaire. Notable projects in Colombia include the "Intercambio vial San Juan con la Carrera, Medellin (2021)" and the "Troncal Alimentadora PLMB, Cali (2022)", both involving comprehensive BIM applications from site study and design coordination to visualization using VR + AR.

Costa Rica showcases studies involving the interaction between road infrastructure and bridges, such as the coordination of design on national road 1.

Currently, BIM implementation has extended to Operations and Maintenance (O&M), integrating methodologies for inspection and data review of pathology. Examples include Colombia's application to footbridges and initiatives in Chile by Municipalities, the Ministry, and EFE (Railway authorities) to digitalize O&M activities for existing structures (Seguel & Seguel 2021).

In conclusion, South America has developed several standards aligning with international requirements, as proposed by BIM Forum Argentina. These standards encompass fundamental concepts applied to design, construction, and operation, defining dimensions from 3D to 7D, implementation phases, and areas of application (architecture, infrastructures, including bridges), each at different stages of adoption in various countries and structures.

7 VALIDATION OF CONCEPTS

Various authorities, in total 22, in different countries have been interviewed over six months, using therefor developed questionnaire.

In general, bridge owners face the dual challenge of managing unique assets and determining the most effective inspection means. Various methods and systems are used for this purpose. The documentation of bridges with their conditions due to bridge inspections and the management of structures is generally done in a structured and digital manner. Either specially developed or commercially available systems are used for this purpose. It can be concluded that digital structure management with the recording of structure conditions has already arrived in principle in the institutions surveyed. Still, it must be assumed that different approaches to structuring, processing, and presenting the data exist.

The data that is or should be included in a bridge management system mainly relates to documenting conditions or condition developments. On the one hand, the relevance of

categorized and thus generalized condition descriptions in the form of condition grades, point- or scoring systems becomes apparent. These provide essential decision-making aids in higher-level management by making structures comparable. On the other hand, the survey of visualization requirements shows that component-related condition information and documentation, particularly damage and damage development, are also of considerable relevance. The respondents showed a clear preference for a representation that enables a linked representation of, e.g., damage details and affected components. While a photorealistic representation of buildings or parts of buildings is predominantly not considered necessary in this context, a significant proportion of respondents consider this valuable information in damage documentation. This underlines the heterogeneity of the data to be processed. There are different levels of consideration at which different types of condition descriptions become relevant. The required condition descriptions range from generalized categorization to highly detailed reports of individual damage incidents with additional documents such as photos or sketches. Neither BrIM nor BMS systems alone can fulfil all these requirements suitably. Instead, a flexible combination of the two approaches seems promising.

Another critical point is the provision of the collected bridge data. The challenge here lies in the different data users with varying legitimate interests. In addition to authorization levels that may become necessary due to administrative structures, a small proportion of the data is often publicly accessible. In Europe, for example, this requirement results from the INSPIRE (Infrastructure for Spatial Information in the European Community) directive of the European Commission. According to this directive, all 34 member states have been obliged since 2007 to make certain geodata sets (including transport networks and associated infrastructure facilities) available to the public. For many authorities, this makes the possibility of differentiating the provision of data according to different rights even more relevant. This is also reflected in the interviews conducted, in which most respondents stated that various levels of access control are also implemented in the existing systems.

The findings underscore the challenges in developing a system that combines a Bridge Management System (BMS) and Bridge Information Modeling (BrIM). The sector's complexity, varying needs, and preferences highlight the need for a nuanced and flexible approach to bridge asset management systems.

8 HIERARCHY OF BRIM AND BMS

BrIM is expected to significantly minimize errors, accelerate project delivery time, and cut implementation costs. However, research indicates that, despite the wealth of data generated using building management systems (BMS) of varied degrees of sophistication, the building operation and management stage is falling behind. Our survey includes the challenging question about hierarchy between BrIM and BMS, including GIS based system. It is consequently important to understand both frameworks, BrIM and BMS, as future linked data bases, improving the evaluation of bridge performance in use and provide feedback to the design stage, perhaps resolving design-related performance issues.

9 CONCLUSIONS

The current challenge for majority of existing bridges represents the fragmented data: data describing the structure and historical information on how the bridge has been managed is stored in many different formats and location, thus, it is fragmented. There is a lack of standardization of obtaining information about the state of the structure and its structural properties. For existing bridges currently data is stored in several formats. Several BMS systems exist worldwide, but not incorporated in Open BIM systems.

The BrIM model should allow for bi-directional information flow with the BMS system (and other systems linked to the BIM) such that information is not duplicated in the connected systems.

Short overview of BIM-BMS situation from Korea and South America was presented.

The aim of IABSE TG 5.6 is searching for all requests from BMS systems (in form of use cases) to report missing attributes within exiting Open BIM systems. Open BIM technology for the interoperability from technical, semantic, and organizational point of view is of main interest. We need to consider as-built BIM deliverables for new bridges. In our vision, the establishment of a universally accepted standardized framework for data exchange between disparate systems empowers bridge owners. The culmination of intensive interviews with bridge authorities and owners from around the world will serve as the guiding compass for recommending the future integration between Bridge Management Systems and Open BIM. Survey results from bridge owners and authorities worldwide will help us in prioritization of use cases and serve as further development input for software authorities. Further steps about will be reported in the next papers.

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