Integration of BrIM and BMS to support bridge life-cycle management

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Abstract The implementation of Bridge Management Systems (BMS) dates back to the 1970s and its adoption is nowadays generalized worldwide. Initially, they were used only as a database but, in the last decades, BMS potential is being highlighted. Tools to perform data analysis, integrating performance prediction models, have been added to the most advanced BMS. These are essential to support bridge managers in scheduling their maintenance interventions thus assuring their functionality conforms to the predefined expectations.

Most of the existing BMS are currently software tools able to integrate a set of stakeholders involved during the bridge management. Hence, the adaptation of BMS to a digital environment must consider that aspect. In this regard, choosing an information exchange format that allows taking BMS into a digital context yet maintaining the interoperability between different stakeholders and their tools of preference is mandatory.

In the context of construction's digitalization, Building Information Modelling (BIM) is the main method being adopted. However, BIM was initially conceived for buildings, thus adaptation efforts are ongoing to also include other types of constructions, namely, civil infrastructures to which the bridges category belongs. This led to the appearance of the Bridge Information Modelling (BrIM) concept, which represents for bridges what BIM represents for buildings.

The most widely used format in the BIM context for interoperability purposes is IFC. IFC is an open format that allows software vendor-independent data exchange. In this context, this paper presents an assessment of the existing knowledge about the applicability of the IFC for modelling bridge data. A review is made to verify the feasibility of using the current IFC version to describe the information contained in BMS. Main limitations are identified, and opportunities discussed, namely how the current IFC schema can be adapted to face the missing entities.

Keywords: Bridge Management System (BMS), Bridge Information Modeling (BrIM), Industry Foundation Classes (IFC)

1 Introduction

The entire transport infrastructure system that allows the movement of goods and citizens, as well as the quality of service provided by the system, is an important driver to support economic and social development. In most countries, due to the current population needs, there is a deficit of public service in what comes to infrastructures resulting in a problem known as the "infrastructure gap" [1]. This gap demands a larger transportation infrastructure system that means the expansion of the current networks and, on the other hand, pressures the maintenance of the existing assets to ensure the functionality under tight quality criteria. Although this topic brings several challenges and can be discussed from different standpoints, this work is focused on bridges. The latter are key assets inside the inland transport network due to the bottleneck effect they can have. That is, an eventual failure on a bridge or its components can interrupt totally or partially the network service.

On the other hand, according to the existing statistics, China presents more than 800.000 road bridges [2] and The United States recorded 731.964 bridges in 2021 – from which 619.622 are referred to as highway bridges [3]. In both cases, the economic development and the continuous increase in population were key factors to achieve such a level of urbanization. Even a smaller country such as Portugal, has railway and roadway networks composed of 9196 structures [4] and an increase in infrastructures is expected in the next years due to the current investments to extend the railway network (train and high-speed train). The increase of bridges is an effect reproduced on the global scale. At the same time, the management process during the operation stage tends to be more complex and challenging due to the huge amount of information produced as well as the consideration of new decision parameters (e.g., environmental and sustainability aspects).

Towards a completely digital, more intuitive, and more reliable business model to manage the current bridge stock, the use of BIM methodology is defined, by an extensive list of bridges owners [5], as a priority area for development to embrace innovation and emerging technologies in the management of structures. This priority has been highlighted worldwide. As an example, a report elaborated by PwC [6] revealed that the implementation of BIM Level 2 could save the British government £400m a year.

In this sense, some authors took the opportunity to study the integration of the information available in current BMS into Bridge Information Models. The main requirement is the digitization of all information which consists of the creation of digital representations of physical objects. As an example, to face this demand, Tanaka et al. [7] developed a strategy including scanners and scanning software to obtain PDF files from the existing paper inspection reports. In addition, the software is able to provide the bridge information model with metadata directly extracted from the PDF file such as text data, damage image data, degradation sketch data, among others.

As referred by Wan et al. [2], the use of current bridge management systems is limited given that the information is fragmented and isolated making it hard for the visualization of information as well as the information exchange among stakeholders. Thus, to improve the efficiency of data collection and information management processes, Wan et al. conceived a BIM-based bridge management system in which inspections and interventions information are directly inserted in the digital geometric representation.

Once all information is digitized, the bridge information model can be enhanced with additional features such as automation of processes (e.g. quantity take-off) and engineering simulations (e.g. structural analysis). Additionally, as shown by Samadi et al.

[8], data analytics feature can be integrated into the framework to assist bridge managers in the decision making process. In this specific case, Samadi et al. provide a graphical user interface containing the bridge digital model and the results from genetic algorithms.

The previous works are related to the metadata mapping from BMS into BrIM models. Nevertheless, some research efforts have been done to improve and provide powerful visualization using procedures such as photogrammetry. Hüthwohl et al. [9] show the assignment of defect information including the representation of damage texture from a 2D image (collected in visual inspection) in the 3D geometry. Isailović [10] investigates the digital damage representation in more detail presenting a software tool to enrich the BrIM model by attaching the damage as-is.

In this work, the authors intend to understand and analyze the information typically available in bridge management systems and the corresponding mapping with the entities defined in the IFC schema to be possible for the pairing of BrIM models and BMS. Thus, interoperability issues will be faced regardless of the BIM authoring tool used by the different stakeholders involved during the operation stage.

2 Bridge Management System as a valuable information tool

2.1 Bridge Management System: Purposes and features

An asset is defined by the asset management standards series (ISO 55000) as being an item, thing, or entity that has potential or actual value to an organization. Bridges are included in the definition and are considered physical assets. Moreover, the information generated by themselves is considered information assets because such information supports the management process of bridges [11]. In this way, BMS have been implemented by organizations around the world to ensure a safe, reliable, and effective operation. To support decision-making in its fulness, a BMS needs to be integrated with information technology such as information systems (databases), logistics, operations, finance and human resources, among others. At the same time, there is a set of stakeholders with interest on the data included in the BMS. Thus, the establishment of a BMS requires understanding the needs and expectations of each stakeholder. In summary, the main bridge stakeholders are: i) Owners; ii) Managers; iii) Inspectors; iv) Operators that can be grouped according to the functions in charge; and v) Suppliers which can also be grouped according to the material and/or components they provide (e.g. bearings, expansion joints, steel elements, among others).

Based on the report produced by the IABMAS Bridge Management Committee [12], which focuses on the identification and comparison of existing BMS, differences in the purposes and features of each one are visible. These differences result from the different organization´s objectives and plans [11]. To face the variety of features in existing BMS, IABMAS [12] suggests the need for standardization in the field of bridge management.

Most of the BMS developed over the last years were originally proposed as simple inventory databases. Since then, other modules have been developed and tested in academic institutions and, posteriorly, incorporated into a BMS. Nowadays, the current BMS implemented in the industry of bridge management are composed of several modules, including the inventory (database) module, deterioration prediction module, optimization module, cost module, condition assessment module, and structural assessment module [13]. The new modules were conceived to support managers and owners during data analytics to help them to find patterns from predictions and, consequently, to define a strategic interventions plan.

This work is focused on the inventory module that is essentially filled by managers, inspectors, and operators. The main purpose is to identify the relevant information from the operation stage for mapping it to the IFC standard later.

2.2 Data generated throughout the bridge´s life-cycle

The acquisition and storage of long-term data is a complex process due to the huge amount of information produced for bridges as well as the need to ensure a feasible system for long time history. Indeed, to meet future demands of extending the service life of large infrastructures, understanding the relevant information and making it accessible for future generations is a key step in bridge management.

From the first moment in which the idea to build a new bridge arises, information starts to be produced, namely investment feasibility, tender documents, and environmental impact assessment. Nevertheless, the information amount tends to exponentially increase in design, planning, and construction phases. According to Wan et al. [2], the information model is expected to be established during the design and construction phases, namely geometrical information including cross-sections, dimensions, longitudinal profile, and relationships and connections between elements. Additional data, inherent to the structure and described as non-geometrical information, is also produced. Examples include administrative and technical data including location, surrounding environment parameters, materials and its properties, suppliers, among many others.

However, the handover of such information to the in-service phase is not common and it is an actual obstacle to implementing BIM methodology in the existing bridge stock. Recently, *fib* [14] released a new bulletin with the purpose of creating a *Birth Certificate* to assist owners during the management process. Moreover, such a certificate will improve the handover of "as-built" information (real cover depth, concrete strength, permeability and transport properties of concrete, porosity, among others) and the current loss of data. The bulletin refers that the certificates are intended to work as a complement to the three documents currently kept by most owners, as-constructed drawings, routine inspection reports, and load capacity ratings.

The information enrichment during the in-service phase is essentially related to a series of actions carried out to ensure the bridge´s safety and functionality. Thus, the data collection can be divided into four distinct modules: i) Condition Assessment Module including inspection planning, information collected from inspections such as pictures, condition states and damage information, data from monitoring systems, data from specific tests, among others; ii) Interventions module comprising repair and maintenance activities, and operational works; iii) Structural Assessment Module oriented to the safety assessment depending on the bridge condition; and iv) Financial module containing costs of an extensive list of activities, estimation of capital needs, among others.

3 Bridge Information Modeling (BrIM) based on IFC standard

3.1 IFC, BrIM, and BMS

It is worth mentioning that the creation of BrIM models is not depending on the IFC standard. BIM authoring tools – known as software that intuitively allows to model information from commands/icons – have their own data structure and semantics defined by the software developers. However, the interoperability without IFC is very limited. Thus, over the last years, buildingSMART has continuously improved the IFC schema through a collaborative workflow that has involved the major stakeholders of the industry. This huge effort is seen as one of the largest in the industry but, at the same time, it opens several opportunities for interoperability on a large scale. IFC by itself does not ensure interoperability, there is a need for it to be implemented in BIM authoring tools.

For that purpose, both data structures of BIM tools and IFC need to be mapped to establish an interpreter (dictionary) able to read and write in both directions. An appropriated mapping is a key aspect and includes the recognition of entities, attributes, properties, among others. In some cases, defining which IFC entity should be used is a fundamental concept. The right categorization has implications on what properties are expected to be found in an object. As a simple ilustrative example, a column is associated with the IfcColumn and, for this entity, the IFC standard has a set of properties which are relevant for columns. Moreover, IFC was conceived to be retro-compatible, that is, with the release of new versions there are principles kept, e.g., the nomenclature used is not modified and all deprecated entities continue to be part of the schema based on the assumption that it may be imported but shall not be exported by software [15].

In the same way that IFC data structure and BIM tools data structures are combined and mapped, the expansion of the concept to BMS is an opportunity to semantically enrich BrIM models and to enhance and provide the bridge life-cycle management with digital tools.

3.2 IFC capabilities to store BMS information in a standardized way

All physical objects and corresponding information (attributes, properties, …) must be correctly mapped but it depends on the IFC version. Although IFC has been evolving to cover infrastructure projects, one of the principles is the use of the current schema since it is defined to be as wide and flexible as possible. Thus, the number of new entities should be minimized through the use/adaptation of the existing entities for the actual needs [16]. The IFC version supported by the BIM tool can limit the interoperability because the use of advanced versions comprises more entities than the older ones.

As an example, if the bridge model is built in a BIM tool that supports IFC4.0.2.1 the bridge deck will be likely interpreted as slabs and the abutments as walls or foundations.

The IFC-BRIDGE project started in 2017 and was incorporated into the IFC specification (IFC4.2) in 2019. The project developed an extension of the IFC schema to cover the most common bridge typologies including slab bridge, girder bridge, slab-girder bridge, box-girder bridge, frame bridge, rigid frame bridge, and culverts. The remaining types were not directly considered but are expected to be represented by the current IFC version. The extension of the infrastructures-oriented IFC was started by a common element that is inherent to infrastructure projects, the IfcAlignment [17]. This entity allows defining the geometric perspective on the proper placement of horizontal and vertical segments to connect certain points along a proposed path. It was considered the start point for IfcBridge, IfcRail, IfcRoad, and IfcTunnel.

Regarding the geometry, both IfcSweptAreaSolid and IfcSectionedSolidHorizontal are considered to define alignment-based geometry [16]. The spatial structure elements are useful elements to capture the spatial hierarchy within a project but, as the previous versions were oriented to buildings, the IfcSpatialElement was reconfigured to include the IfcBridge. Thus, IfcBridge is currently a subtype of Ifcfacility, and IfcBridgePart is a subtype of IfcFacilityPart. Borrmann et al. [16] shows in more detail all the entities added to the IFC schema to cover bridge structures. Physical systems such as IfcBearing, IfcCaissonFoundation, among others were added to the previous entities.

Due to the lack of geometric information in BMS, most of the information contained in existing BMS will be associated with the IFC standard through user-defined property sets. The IfcPropertySet is defined outside of the schema to allow flexibility in the process (see Fig. 1). In other words, the IFC standard does not need to be extended to include specific information about a certain national management system.

When applicable, the use of property set templates (*Pset_X*) already available in the IFC standard can be considered, e.g., *Pset_Condition*. Currently, there are 640 property sets established in the IFC schema.

IfcProcess and IfcClassification are also relevant entities. IfcProcess is the supertype of IfcTask which is useful to map information from the inspections. On the other hand, IfcClassification is an entity able to link to external resources such as the national classification system.

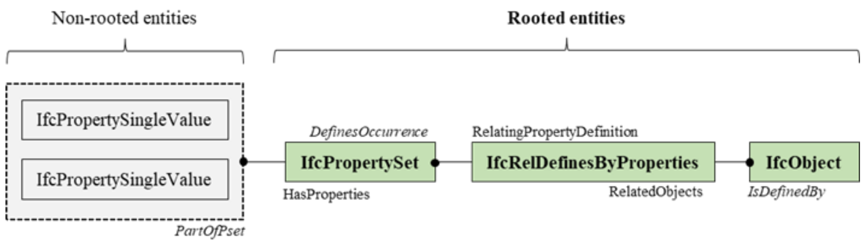

Fig. 1. Establishment of user-defined property sets and assignment to the IfcObject

4 Conclusions and Future Developments

The authors have presented the most important entities established in the current IFC schema to receive the information from the bridge management systems (BMS). Although IFC does not support specific entities to collect data from BMS, it provides sufficient flexibility based on well-defined mechanisms to integrate user-defined properties without affecting the schema. In general, the current version of the IFC standard is prepared to support bridge management during the life-cycle. However, the use of different BMS and inspection manuals worldwide demands single implementations from national authorities. In the same line of mapping information from BMS to IFC entities, it is worth noting that it is useful for new structures which are designed under the BIM methodology.

For the existing bridge stock, designed and constructed at a time when BIM methodology was not implemented, there is a need to own geometrical information to build the 3D model – that is a critical step – and then associate all relevant information to manage bridges. In the case of BMS containing geometrical information, the modelling process can be automatized to save human and financial resources. Otherwise, the individual creation of BrIM models, which requires the conversion and analysis of all information available for each bridge, will be a laborious and time-consuming process.

BrIM appears to solve current problems of bridge management, namely, to improve the effectiveness of information management as well as to enhance a collaborative workflow based on the information exchange from a central model. One of the most important and discussed aspects remains in how much information should be directly associated with the BrIM model and how much information should be associated as external references to ensure good handling of IFC files. It leads to the need of specifying use cases, understand information delivery manuals, and exchange information requirements to define the level of information needed.

In summary, BrIM and BMS complement each other given that handling and sharing of BrIM models are affected by large IFC files and BMS is useful to work as an external library. On the other hand, BMS are affected by the way data is inserted and presented to the users and geometric models can simplify tasks. Moreover, the current bridge management systems provide decision-makers with modules oriented to data analytics and it requires the analysis of big data normally stored in BMSs. That aspect should also be addressed in the future.

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