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Real-time monitoring and analyses of sensory data integrated into the BIM platform

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Abstract

Bridges and tunnels, crucial elements of the railway infrastructure, are exposed to various types of deterioration processes. Their condition is a subject of monitoring, as it is important to collect as much as possible information in every life cycle phase to reliably predict their future performance. An enormous quantity of monitoring data is generated during the whole life cycle of these assets. EU funded Shift2Rail research project Assets4Rail which is focusing on measuring, monitoring, and data handling for railway assets, as data management is as important as their generation. This paper presents the major outcomes of the Assets4Rail project and its application to infrastructure projects.

Keywords: monitoring, data management, bridge, tunnel, Assets4Rail

1 Introduction

Building Information Modelling (BIM) is a model-based process of generating and managing building data during the building life cycle. The concept of BIM was first introduced by Eastman et al. [1] and explained in detail more by Van Nederveen and Tolman [2]. Real implementation and popularity of BIM started at the end of the millennium with various commercially available solutions, which first extended traditionally building design from two-dimensional drawings to 3D modelling (ArchiCAD, AutoCAD, MicroStation). BIM augments spatial dimensions with time as the fourth dimension and cost as the fifth [3]. Thus, nowadays BIM is defined as a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle (6D); defined as existing from earliest conception to demolition [4].

Compared to the area of the average building, infrastructure assets can span several kilometers in one direction while only a few meters in another dimension. Therefore, 3D representation of engineering infrastructure seems less attractive and GIS asset data were transferred to asset management systems for operation and maintenance for a long time [5]. 3D virtual design, construction, and facility management of civil engineering infrastructures are implemented into modern engineering practice to enhance collaboration of all involved stakeholders, resolve conflicts and improve cost-effective performance of infrastructure. Furthermore, a survey conducted by ASCE and associates reveals the recent accelerated application of BIM for Infrastructure, i.e. Infrastructure Building Information Modelling (I-BIM). Engineering firms adopt technology from vertical buildings for infrastructure projects most quickly, but to an extent, they are waiting for demand from their clients [6]. Although spatial visualization does not attract infrastructure owners so much as vertical building operators, it is evident [6] that infrastructure owners often tend to make far more effective use of the information once data is collected. In general, they increasingly recognize the benefits of 3D modelling using intelligent objects.

Globally, there are two major vendors; Autodesk and Bentley, and several minor vendors providing software solutions for infrastructure design supporting BIM workflows. Each provider has its data format and object models that are not compatible. Industry Foundation Classes (IFC) is a platform-neutral, open file format specification developed by BuildingSMART [7]. As such, IFC is the most commonly used vendor-neutral format to allow BIM data exchange between different applications and disciplines in the AEC industry. However, in its current state, IFC mostly supports building information with IFC for the infrastructure still being in development stages [8]. Nevertheless, the bulk of object model data such as geometry, properties, relations, etc. can still be transferred from I-BIM via existing IFC standards.

The objective of the EU (Shift2Rail) funded research project Assets4Rail is to contribute to improving the inspection, maintenance, and upgrade methods for cost reduction and quality improvement of railway bridges and tunnels. It aims to improve information gathering and analysis for bridges and tunnels by developing a Building Information Modelling (BIM) platform to optimize inspection, maintenance, and upgrade costs. The project, which started in December 2018, will develop an integrated platform for handling data based on the BIM concept. The BIM approach enables the data layer integration for bridges and tunnels (sensors information, infrastructure geometry, traffic data, loads and fatigue detection, graphical information, etc.) within a single platform. This promising technology will facilitate and optimize the decision-making process regarding maintenance issues and will improve the monitoring of the infrastructure.

2 Assets4Rail project approach

Assets4Rail aims to develop a holistic monitoring data handling procedure based on integrity inspection of railway assets (bridges and tunnels) and processing algorithms built into the information model. It consists of four steps: (1) Monitoring; (2) Information modelling; (3) Fatigue consumption assessment, and (4) Intervention measures. These four circularly related steps offer the development of novel technologies, which will be consequently tested and validated in relevant environments on selected test sections within the project. New alternative automated and enhanced inspection methods will allow faster and more accurate inspection of tunnels and bridges, including improved repeatability and reproducibility. The second step aims to develop novel central information models for data collection and further processing. The third step aims to provide a tool for realistic fatigue capacity assessment for individual structural components and thus to allow for larger axle loads and higher speeds of trains. The fourth step aims to provide a set of novel techniques (e.g., reduction of noise and vibration intensity on structures, cleaning of long tunnel drainage pipes, etc.) which permit an increase in rail traffic, less traffic disturbance due to intervention activities, reduce future problems and prolong infrastructure service life. When the last step is performed, the whole procedure is repeated, starting with monitoring to evaluate how the measures affect the asset performance.

2.1 Infrastructure monitoring

Various monitoring technologies represent the source of data for the assessment of the infrastructure's condition. They can be listed into following groups: (1) manual inspection - visual or using some apparatus, (2) traditional sensors - strain gauges, geodetic instruments, inclinometers, etc., (3) safety and security (S&S) sensors, (4) remote sensing technologies, (5) distributed fiber-optics sensing, (5) wireless sensor networks (WSN), (6) low power micro-electromechanical system sensors (MEMS), and (7) citizens as sensors. The first three monitoring approaches engage manual inspection or installation of S&S and traditional monitoring sensors. They are still constantly evolving and producing new instruments (models). The remaining five emerging sensor technologies have only recently gained more and more attention. According to [9], sensor and communications research has been going through dramatic innovative changes resulting also in numerous remote sensing technologies including photogrammetric image platforms (drones) and laser or radar sensing systems (scanners, ground-penetrating radar, etc.). Sensing is rapidly becoming part of everyday life not only for health and living but also for the environment and security. Effective use of existing and new smart monitoring systems with a better understanding of how people use the infrastructure services would lead to the realization of resilient adaptable infrastructure systems.

Of the above-listed emerging technologies, we highlight the optical fiber sensing technology because the standard optical fiber becomes the sensor that can be installed to cover even large infrastructure elements to assure continuous and distributed measurements of conditions around the optical fiber (e.g., temperature, strain, acoustic noise, etc.). Its' simple and quick installation and low production cost compared with point measurement sensors, make it ideal for long-term monitoring once the fiber is permanently embedded in a structure.

Wireless sensor networks (WSN) transmit sensor data using radio frequencies. This allows rapid deployment of monitoring instrumentation due to the elimination of some of the cabling. Combined with micro-electromechanical system (MEMS) sensors it is possible to significantly reduce the overall costs for large-scale monitoring purposes. WSN sensors are typically small-sized and low-powered enabling on-the-fly on-board calculations to derive acceleration, inclination, and displacement in real-time without human intervention. Thus, sensor data is not only collected but can also be processed and interpreted using custom-made algorithms that can be embedded into these sensors. This way, users can access final WSN outputs on any Internet-enabled device. MEMS are the product of the ever-increasing miniaturization trend in the design and processing capabilities of emerging sensor systems. MEMS are small integrated devices or systems that combine electrical and mechanical components varied in size from micrometers to millimeters (or even smaller for the next generation nanoelectromechanical systems), which can merge the function of computation and communication with sensing and actuation. These miniature systems can perform measurements ranging from acceleration, strain, inclination, temperature, and pressure. In combination with other sensors, MEMS are integrated into novel instrumentation systems able also to monitor surface defects, e.g., cracks [10].

Structural health monitoring (SHM) has greatly benefited from rapid sensor advances in recent years. But, no matter novel monitoring approaches the question of data management and handling with a huge amount of data remains. Data processing technologies, as well as advances stemming from sophisticated computer aided construction management tools, can help on that significantly. Successful implementation of any SHM system depends on employing the appropriate technical instrumentation and equipment. First, the monitoring data acquisition approach (i.e. choosing the appropriate sensor technology and configuration) is selected to meet the established monitoring requirements. Furthermore, data acquisition and data analysis tools and methods for structure state evaluation are also chosen. Finally, a detailed installation and monitoring operation plan is prepared. Next, monitoring database requirements are defined (if needed) and procedures for data handling and communication should be described in detail to optimize the monitoring system's long-term function avoiding possible data redundancy occurrences. The physical architecture of the SHM system can be very different, depending on various factors, e.g. investigative structure’s size, data acquisition rate, level of automation, etc. In Fig.1 an example of the monitoring system architecture is shown into which BIM is integrated as the final data repository unit.

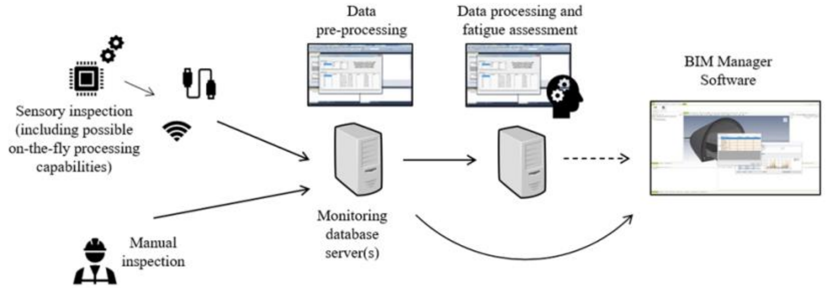


Figure 1. SHM general architecture units

This kind of approach was used for Assets4Rail project. The monitoring results are typically imported on demand via the BIM software’s sensor data integration module. Hence, the oversaturation of the BIM model with the monitoring results can be prevented, especially when dealing with SHM of higher data acquisition rates. Thus, BIM environment becomes an optimal environment for visualization of monitoring data and results of analysis based on those data. BIM capabilities enable the convenient presentation of various parameters related to the structure being monitored and they enable an effective decision-making process.

2.2 Bridge and tunnel information modelling system

BIM methodology has seen a rise in adoption across different types of construction projects, and throughout the entire project lifecycle, both isolated and in an integrated manner. BIM software platforms offer a wide variety of use cases, analyses, and scenarios supported by the BIM model, from design development and review, through tendering and construction planning, to construction management. Operations and facility maintenance planning and tracking is the newest addition to BIM, and it is still being developed and improved. Consequently, sensor information within the BIM model has been scarce, especially with a focus on real-time data, and appropriate case-studies with infrastructure projects have been even more scarce. Currently, the state of the art provides a limited subset of the above-mentioned functionalities, as discussed in some recent articles regarding the combination of BIM and sensor data [11]. However, no solution offers an industry-scale, integrated BIM environment with information from the entire project lifecycle (the “single source of truth” approach, with design, construction, cost, asset, operations, and maintenance data) together with real-time sensory data and analyses. Current solutions offer either only 3D geometry and sensor data without asset information and other BIM integrated data, or offer no sensory information in the asset model.

It is a BIMs task to help in collecting, analyzing, and aggregating the huge amounts of data necessary to connect the design of assets to the context of the surrounding environment and its future performance. Employment of parametric engines to make the connections between design and reality is possible [12]. The design model needs to be connected to reality (via monitoring), so that huge amounts of data can be accessed, analyzed, and adapted over time. A possibility of artificial neural network (ANN) employment for decision-making is recognized. Building a neural network forecaster for a particular problem is a non-trivial task. ANN suffers from knowledge extraction and extrapolation uncertainty. Data contained within BIM models about influencing variables should be available based on FEM/FDM of an asset from its structural analysis. Sufficient predictions of infrastructure asset performance can thus be achieved using the feedforward ANN and to consider adaptive-network-based fuzzy inference systems (ANFIS) [13]. By using a hybrid learning procedure one can construct an input-output mapping based on both human knowledge (in the form of fuzzy if-then rules) and stipulated input-output data pairs.

Multiple iterations of very complex analysis also need very powerful computational tools, which can be recognized in today’s penetrating cloud-based computing approach. Using virtually infinite power of cloud-based parallel processing it will be possible to simulate analysis of multiple factors in a shared model environment [12] and thus reliable real-time prediction performance of infrastructure assets, particularly bridges and tunnels, impacted by various load cases soon.

The platform being developed within Assets4Rail will incorporate the integrated BIM approach, with real-time and historical sensory data and related analyses. This means that the currently available integrated BIM – tunnel and bridge geometry, element properties, quantities, linked documents, drawings, and other information such as cost, scheduling, operations and maintenance plans and data which can be tracked and managed, will incorporate a new layer of information - sensory data. Specifically, it will include sensory readings, both real-time and historical, enabling this data to be displayed side-by-side with all other relevant asset and maintenance information, 3D model data and properties, already present within the BIM environment (**Error! Reference source not found.**).

Additionally to the reading and visualization of sensory data, analyses of that data will be improved by new algorithms based on Bayesian networks, taking full advantage of the gathered information with the help of sensors and making use of synergies derived from the use of BIM approach. Analyzed monitoring results will be present as well, within the same BIM platform, from simple color-coding, alarms, and warnings based on sensory data thresholds, to other more sophisticated analyses. To enhance different visualizations of the information, the goal will also be to work on optimizing the usability of the user interface system, as well as in scenarios of high visual quality for dissemination and communication based on the BIM models and data generated within the framework of the project. Although the IFC standard is not yet at the wanted maturity level for infrastructure, open data exchange can still be facilitated using available schemas and custom model view definitions (MVDs). By establishing well-defined mappings and utilizing already existing element class structures such as IfcSensor and IfcSensorType, as well as time-stamped data types such as IfcTimeSeries, the combined I-BIM and sensor data can be exported in an open, vendor-neutral format, further enriching the open BIM ecosystem.

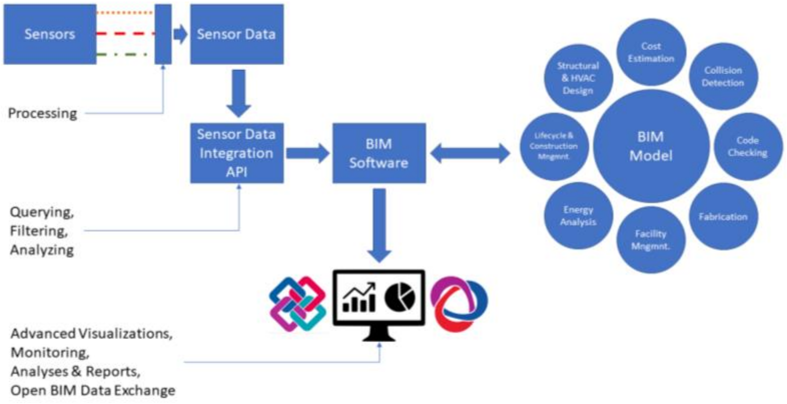
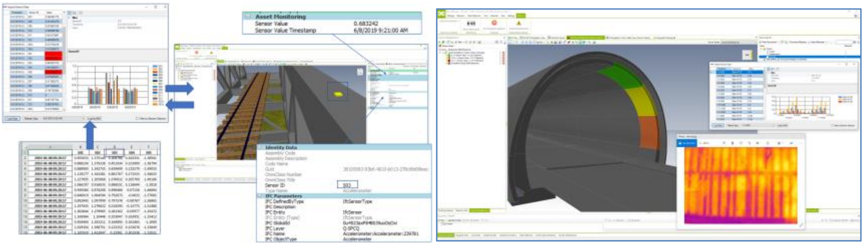


Figure 2. An overview of the Assets4Rail integrated BIM platform solution

2.3 BIM integration example

The following example was developed as a part of “Information Modelling” (WP2) in Work Stream 1 of the Assets4Rail project for demonstrational purposes. The entire solution is built on top of Bexel Manager BIM software platform using its Application Programming Interface (API) to develop a sensor data integration add-in. This extension allows the user to connect to an arbitrary data source (xml and csv files are used in the example) to import the processed sensor readings into the BIM environment. The imported values can then be linked to related assets (e.g. sensor elements or parts of the infrastructure model) by using a 1-1 mapping schema through a unique sensor identifier. On the BIM side, this identifier is defined as an attribute (property) on the BIM element itself, while on the sensor data side it is defined as a data column (Figure 3, left). This kind of mapping enables an automatic bi-directional relationship between the BIM elements and the related sensor data which allows for rich visualizations, advanced filtering, and more. For example, the add-in allows loading sensor data into BIM only for the specified timestamp, but this will be expanded upon further in development. The add-in has a dedicated User Interface (UI) which displays loaded sensor data as a bar chart based on selected BIM element or a specified time range. Once the data is loaded into BIM environment, all the benefits of the BIM software can be utilized. In this particular example, Bexel Manager's dedicated 3D color-coded view allows the user to easily distinguish between various sensor readings in 3D space and quickly locate a section of the infrastructure which requires attention. Additional documentation can be attached to these elements to provide more details on the issue (e.g. thermal scan images) using the concept of BIM element document linking (**Error! Reference source not found.** right). All of the integrated data can be exported into an open BIM format using Bexel Manager's IFC and BCF exchange capabilities to allow information flow between different BIM applications.



Asset Monitoring
Sensor Value 0.683242
Sensor Value Timestamp 6/8/2019 9:21:00 AM

Identity Data
Sensor ID 303
IFC Parameters
IFC DefinedByType IfcSensorType
IFC Entity IfcSensor
IFC Layer Q-SPCQ
IFC ObjectType Accelerometer

Figure 3. An example of the Assets4Rail integrated BIM platform solution on a railway bridge (left) and tunnel (right)

3 Conclusions

Traditional monitoring includes periodically prepared reports including all necessary information to assist in the planning of the future infrastructure operation. Unfortunately, a large number of data sets become uncontrollable as the number of sensors and frequency of data logging increases. Therefore, despite (or even due to) the huge amount of information, reliable prediction of future performance of infrastructure assets becomes very difficult. Big data needs to be put into context. Thus, BIM should become a central hub for all information about the infrastructure assets from its design and construction onward. At its heart is a computer-generated model that contains all graphical and tabular information about the asset since its design, construction, and operation.

This paper presents the background of the BIM approach in the field of infrastructure management and the issue of proper handling through monitoring data. Decision-making processes based on the data obtained from real-time monitoring are also included. Data generated during the whole life cycle of assets, in the presented case - railway bridges and tunnels, are important information for the prediction of an asset’s future performance when combined with the proper expert system. Monitored data management supported by various API for data analysis can be provided by BIM. The use of IFC standards is highly important in these processes.

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