PRAĆENJE PODATAKA INFRASTRUKTURE UZ POMOĆ BIM-A

INFRASTRUCTURE MONITORING DATA HANDLING WITH A HELP OF BIM

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Sažetak: Mostovi i tuneli ključni su dio željezničke infrastrukture, koji su izloženi različitim vrstama propadanja. Stoga je njihovo stanje predmet praćenja i izvora ogromne količine podataka. Podaci se generiraju tokom čitavog životnog ciklusa imovine i važno je prikupiti što više informacija u svakoj fazi kako bi se pouzdano predvidjeli njihov učinak u budućnosti. Iako pračenje infrastrukture je zaduženo za prikupljanje podataka, dodatno je upravljanje podacima jednako važno kao i njihova generacija. Istraživački projekt Assets4Rail koji financira EU Shift2Rail program, fokusira se na mjerenje, nadzor i rukovanje podacima za željezničku imovinu. U ovom radu prikazan je novi pristup potonjem.

Ključne riječi: nadzor, upravljanje informacijama, BIM, infrastruktura, most, tunel, Assets4Rail

Abstract: Bridges and tunnels are crucial part of railway infrastructure, both being exposed to various types of deterioration processes. Thus their state is subject of monitoring and source of enormous quantity of data. Data are generated during whole life cycle of assets and it is important to collect as much as possible information in every phase to reliable predict their performance in future. While information and data collection is in charge of monitoring, additionally data management is as important as their generation. EU funded Shift2Rail research project Assets4Rail is focusing on measuring, monitoring and data handling for railway assets. The novel approach to the latter is presented in this paper.

Key words: monitoring, information management, BIM, infrastructure, bridge, tunnel, Assets4Rail

1. INTRODUCTION

Assets4Rail is a 30 months EU (Shift2Rail) founded research project which will contribute to the modal shift to rail by exploring, adapting and testing cutting-edge technologies for railway asset monitoring and maintenance. Assets4Rail shares the Shift2Rail view of having an ageing European railway infrastructure that needs to cope with the expected increased traffic in the future. To achieve this, we need an improvement in technology and a cost-effective maintenance and intervention system for infrastructure inspection and monitoring.
Assets4Rail aims to contribute to the modal shift by exploring, adapting and testing cutting-edge technologies for railway asset monitoring and maintenance. To achieve that, Assets4Rail follows a two fold approach, including infrastructure (tunnel, bridges, track geometry, and safety systems) and vehicles. A dedicated information model (BIM) will be the keystone of the infrastructure part of the project. This model with integrated algorithms will gather and analyze the information collected by specific sensors which will monitor subsurface tunnel defects, fatigue consumption, noise and vibrations of bridges as well as track geometry. On the other hand, train monitoring will include the installation of track-side and underframe imaging automated system to collect data for detecting specific types of defects that have non-negligible impacts on infrastructure. The additional use of the RFID technology will enable the smooth identification of trains and single elements, associated with the identified rolling stock failures.

2. PROJECT CONCEPT

The project conists from two parts:
- Workstream 1 (WS1) dedicated to bridge and tunnel specific part of railway infrastructure, and
- Workstream 2 (WS2) dedicated to track-wehicle interactions.

WS1 aims to contribute improving the inspection, maintenance and upgrade methods for cost reduction and quality improvement of railway bridges and tunnels. It aims as well to the noise and vibration reduction in bridges. While it will deal with novel alternative monitoring techniques to evaluate defects in tunnels and on bridges such as: structural fatigue, incipient corrosion (steel and concrete), cracks, water/moisture, mortar loss in joints, detachment of lining surface, voids, concrete spalling, abnormal pressure, vibrations, temperature, etc., particular focus will be also on subsurface defects data collection with use of non-destructive detection techniques such as Ground Penetration Radar (GPR), ultrasonic tomography, impact echo, thermal camera and laser scanning.
On the other hand, WS2 aims to build a common measuring and monitoring data representation layer suitable to elaborate data coming from all source segments (onboard, wayside and remote), to correlate the different data and to obtain a holistic view of the railway system conditions. The characteristic features of two workstreams and the interrelation among them is shown on Figure 1.

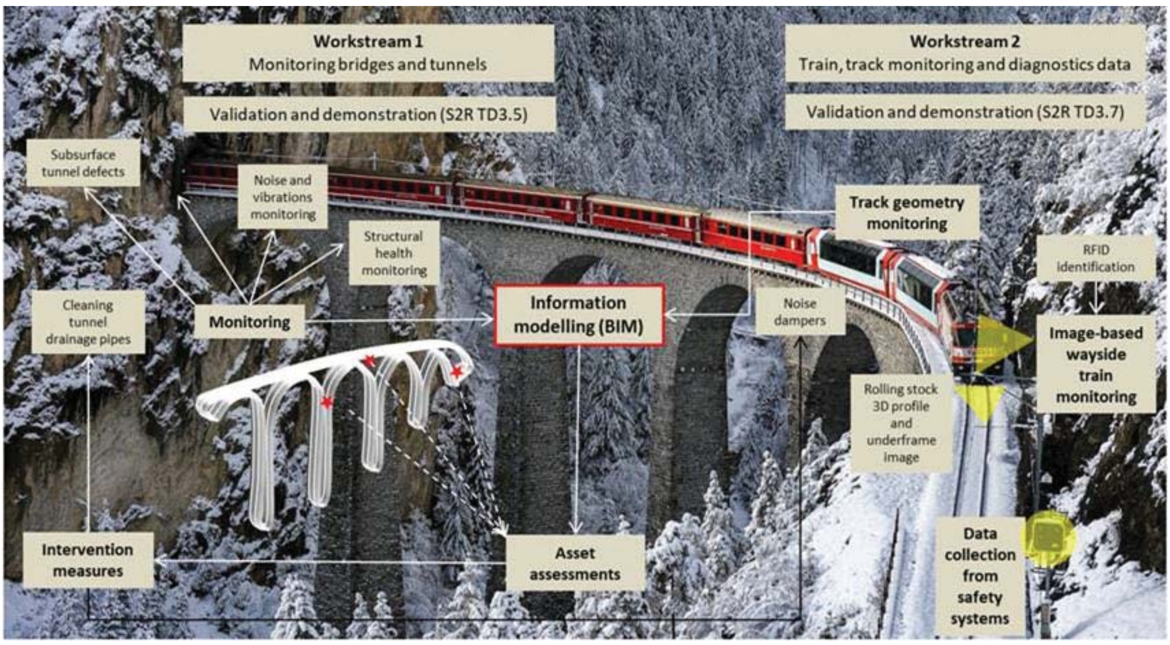

Figure 1: Assets4Rail concept

A common problem of the monitoring and inspection of railway assets is that the data that portrays the status of the items is very heterogeneous, making it difficult to be read and understood by a holistic system that would program the optimum maintenance of the network and vehicles. In addition, ageing codes and standards for infrastructures may represent a problem for the "administrative upgrading" of infrastructure. This may be solved by exact and reliable numerical calculations on fatigue and other critical aspects. In parallel, it is also possible to reduce noise and vibrations that meet future increased traffics. Thefore, it is an urgent need to improve information gathering and analysis for railway infrastructure.

Thus, Assets4Rail is developing an integrated Building Information Management (BIM) platform for handling data based on the BIM concept. 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 to maintenance issues and will improve the monitoring of the infrastructure. Such a holistic monitoring data handling procedure based on integrity inspection of railway assets and processing algorithms built-in into information model consists of four steps:

- Monitoring
- Information modelling
- Fatigue consumption assessment
- Intervention measures

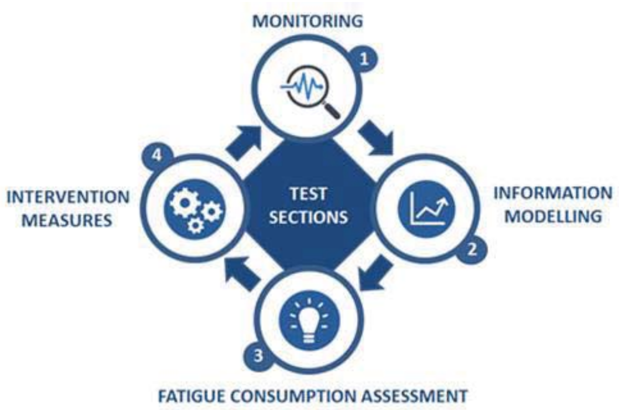

Figure 2: Four steps of the iterative procedure used within the project

These four circularly related steps offer novel technologies development, which will be consequently tested and validated in relevant environment on selected test sections within the project. When the last step (intervention measure) is performed the whole procedure is repeated, starting with monitoring to evaluate how the measures affects. Thus, an overall concept of project can be graphically presented as on Fig. 2.

3. INFRASTRUCTURE DATA HANDLING

3.1. BUILDING INFORMATION MANAGEMENT (BIM)

Building Information Management/Modelling (BIM) is model based process of generation and managing building data during building life cycle. The concept of BIM was first introduced by Eastman et al. [1] and explained more in details 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].

BIM concepts and workflows are accepted quite well in the AEC industry (Architecture – Engineering – Construction), while infrastructure managers have been initially less ambitious but try to catch up recently. Compared to finite area of average building, infrastructure assets can span several kilometers in one direction while only few meters in other 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 long time [5]. Anyway, 3D virtual design, construction and facility management of civil engineering infrastructures is implemented into modern engineering practice with an aim 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 recent accelerated application of BIM for Infrastructure, i.e. Infrastructure Building Information Management (I-BIM). Engineering firms adopt technology from vertical buildings for infrastructure projects most quickly, but to extent they are waiting demand from their clients [6]. Although spatial visualization does not attract infrastructure owners so much as vertical buildings operators, it is evident 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 modeling 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 own 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 most commonly used vendor-neutral format to allow BIM data exchange between different applications and disciplines in AEC industry. However, at its current state IFC mostly supports building information with IFC for infrastructure being still in development stages [8]. Nevertheless, bulk of object model data such as geometry, properties, relations etc. can still be transferred from I-BIM via existing IFC standards.

3.2. INFRASTRUCTURE MONITORING

Traditional infrastructure monitoring is based on contact sensing approach. Sensors are installed directly in contact with the structure in that case [9]. Thus, innovative infrastructure contact monitoring technologies are mostly based on various sensors, consist of data logger, which transfer data via world wide web to a database. Sensors, which measure various physical parameters (e.g. strain, moisture, temperature, etc.), can be installed on the surface or inside the structure. Although physical contact with the object of monitoring is needed, advanced sensors which allow wireless data transfer are sometimes named also remote or autonomous monitoring system. Various systems allow the interrogation of large numbers of sensors by dedicated data logging equipment.
On the other hand, based on the degree of interaction with the structure, there exist also non-contact monitoring methods [10], based on the analysis of various waves travel (e.g. visible, infrared, microwaves). Two types of sensors can be used. Active sensors, emit a wave and receive the reflection of the emitted wave from the ground/structure (e.g. ultrasonic and electromagnetic pulse). Passive sensors receive the wave naturally emitted by the ground/structure following an emission from nature (e.g. photography and thermal imaging). To capture existing physical conditions of infrastructure, remote monitoring data can be successfully supported also by the use of simple web-cam for additional visual analysis.
Using a BIM process infrastructure managers have access to very rich information streams. Information includes detailed data from the post-construction model and information from real-time sensors that continuously update the model during operation. For reliable infrastructure asset it is critical to capture real-time infrastructure existing physical conditions at every point in the life cycle. This can be done by traditional contact surveying and also from reality-based point clouds captured via non-contact methods (i.e. laser scanning, ground-penetration radar or digital photographs by photogrammetry etc.) briefly mentioned above. The remaining question in case of asset management is how to handle these data.

4. INTEGRATION OF MONITORING DATA

4.1. IFC FORMAT

As a neutral open file format platform, IFC is the most commonly used vendor-neutral format to allow BIM data (objects, geometry, associated properties and relationships) to be exchanged between different applications and disciplines in AEC industry throughout the whole lifecycle, from feasibility and planning, through design (including analysis and simulation), construction, to occupancy and operation. It is registered by ISO and is an official international standard under ISO 16739, which has many iterations.
The IFC specification includes terms, concepts and data specification items that originate from the use within disciplines, trades, and professions of the construction and facility management industry sector. Terms and concepts use the plain English words, the data items within the data specification follow a naming convention. The data schema architecture of IFC defines four conceptual layers, each individual schema is assigned to exactly one conceptual layer. Figure 3 shows the schema architecture.
IFC data schema is defined using EXPRESS data modeling language through hierarchically organized entities in an object-oriented fashion. It is computer interpretable. IFC may be encoded in various electronic formats, each having benefits and trade-offs of software support, scalability, and readability. As typical BIM model data can be quite large (i.e. gigabytes), the choice of format may have practical considerations. The officially supported formats are STEP, XML and ZIP

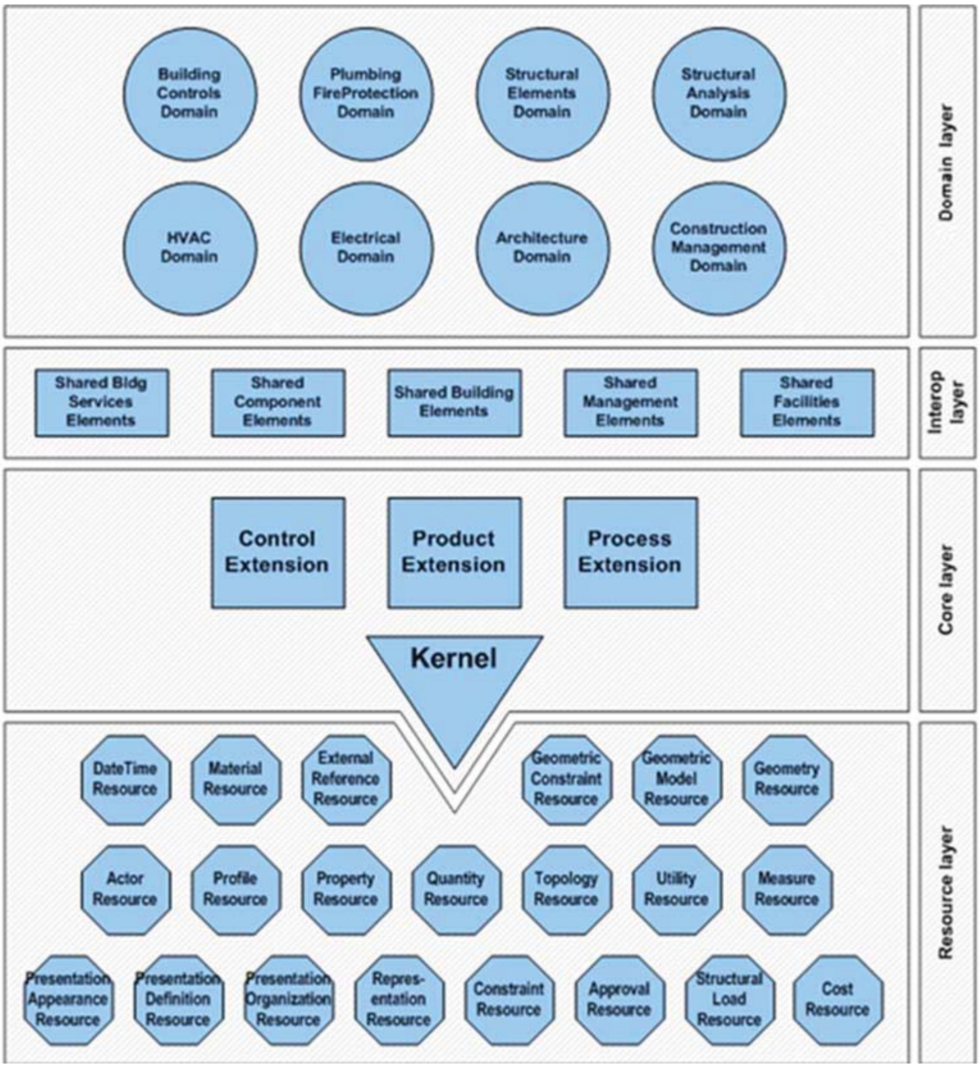

Figure 3: Data schema architecture with conceptual layers

4.2. IFC CONCEPTUAL LAYERS

4.2.1. **Resources layer** - the lowest layer includes all individual schemas containing resource definitions, those definitions do not include a globally unique identifier and shall not be used independently of a definition declared at a higher layer. Basic properties such as geometry, material, quantity, measurement, date and time, cost, actors, roles are defined in this layer;

4.2.2. **Core layer** - the next layer includes the kernel schema and the core extension schemas, containing the most general entity definitions, all entities defined at the core layer, or above carry a globally unique id and optionally owner and history information;

4.2.3. **Interoperability layer** - the next layer includes schemas containing entity definitions that are specific to a general product, process or resource specialization used across several disciplines, those definitions are typically utilized for inter-domain exchange and sharing of construction information. For example, Shared Building Elements schema has entity definitions for a beam, column, wall, door etc.;

4.2.4. **Domain layer** - the highest layer includes schemas containing entity definitions that are specializations of products, processes or resources specific to a certain discipline, those definitions are typically utilized for intradomain exchange and sharing of information.

4.3. SENSOR DATA APPLICATION

Examples of practical use-cases of IFC in sensor-based maintenance and monitoring are very scarce, existing only as a part of academic research papers [11], [12] and [13]. The underlying structure of IFC allows for a sensor to be defined using IfcSensor element of which specific types are defined using IfcSensorType entity. Both IfcSensor and IfcSensorType are new entities introduced in IFC4 and are defined in Domain layer (Figure 3), specifically under Building Controls Domain schema. As a rooted entity (inherits from IfcRoot), IfcSensor has associated GUID (globally unique identifier), name, description etc. By also being an IfcProduct, sensor can have geometric representation and object placement associated with it, as well as relations to other elements and numerous property sets attached. This means that data read from the real sensor can be processed and attached to it's digital twin in BIM model which is represented by an instance of IfcSensor.

Constant	Description
COSENSOR	A device that senses or detects carbon monoxide.
CO2SENSOR	A device that senses or detects carbon dioxide.
CONDUCTANCESENSOR	A device that senses or detects electrical conductance.
CONTACTSENSOR	A device that senses or detects contact, such as for detecting if a door is closed.
FIRESENSOR	A device that senses or detects fire
FLOWSENSOR	A device that senses or detects flow in a fluid.
FROSTSENSOR	A device that senses or detects frost on a window.
GASSENSOR	A device that senses or detects gas concentration (other than CO2)
HEATSENSOR	A device that senses or detects heat.
HUMIDITYSENSOR	A device that senses or detects humidity.
IDENTIFIERSENSOR	A device that reads a tag, such as for gaining access to a door or elevator
IONCONCENTRATIONSENSOR	A device that senses or detects ion concentration, such as for water hardness.
LEVELSENSOR	A device that senses or detects fill level, such as for a tank.
LIGHTSENSOR	A device that senses or detects light.
MOISTURESENSOR	A device that senses or detects moisture.
MOVEMENTSENSOR	A device that senses or detects movement.
PHSENSOR	A device that senses or detects acidity.
PRESSURESENSOR	A device that senses or detects pressure.
RADIATIONSENSOR	A device that senses or detects pressure.
RADIOACTIVITYSENSOR	A device that senses or detects atomic decay.
SMOKESENSOR	A device that senses or detects smoke.
SOUNDSENSOR	A device that senses or detects sound.
TEMPERATURESENSOR	A device that senses or detects temperature.
WINDSENSOR	A device that senses or detects airflow speed and direction.
USERDEFINED	User-defined type.
NOTDEFINED	Undefined type.

Figure 4: Four steps of the iterative procedure used within the project

The actual sensor data binding can be achieved in several ways through IFC format, generally by associating the sensor element (and/or the element(s) the sensor applies to) with properties and property sets. This includes entities defined in Resource layer such as:

4.3.1. **IfcPropertySingleValue** - Defines a property object which has a single (numeric or descriptive) value assigned. It defines a property - single value combination for which the property Name, an optional Description, and an optional NominalValue with measure type is provided. In addition, the default unit as specified within the project unit context can be overridden by assigning a Unit;

4.3.2. **IfcPropertyListValue** - Defines a property that has several (numeric or descriptive) values assigned, these values are given by an ordered list. It defines a property - list value combination for which the property Name, an optional Description, the optional ListValues with measure type and optionally a Unit is given. An IfcPropertyListValue is a list of values. The order in which values appear is significant. All list members shall be of the same type;

4.3.3. **IfcTimeSeries** - A time series is a set of a time-stamped data entries. It allows a natural association of data collected over intervals of time. Time series can be regular or irregular. In regular time series data arrive predictably at predefined intervals. In irregular time series some or all-time stamps do not follow a repetitive pattern and unpredictable bursts of data may arrive at unspecified points in time.

4.4. DATA FORMAT

The specific choice of data type to be used may be subject to practicality, ease of implementation, software support, file-size differences etc.
With all of the above taken into consideration, IFC could be used as an output format, allowing the BIM model (elements, geometry, properties, relations) with all additionally integrated sensor data information to be accessible in an open, standardized, vendor-neutral way across all IFC supported software.
Within the scope of the present project, all the sensors information acquired will be integrated to the BIM interface to be further post-processed and analysed in a future stage. Following the recommendations described in [14] it is clear that this digital information will be, by nature, software dependent. Hence, the digital information from sensors, information that will be embedded to the BIM interface, may be endangered by the obsolescence of the software environment related to the visualization

and process of the acquired data. While many software suite offer backward compatibility to ensure interoperability, the most practical solution to guarantee long-term data access is the use of open standard formats that can easily be processed and that are suitable for data interchange and transformation.

4.5. TIME SERIES DATA

The concepts of monitoring and inspection usually imply the acquisition of a given state variable fluctuation over time. The measurement of time variant physical phenomena, driven by the acquisition process, usually leads to a data output in the form of a time series. A time series is a sequence of values, representing a single or multiple measured data points, in chronologic order. With the increased implantation of the internet-of-things and its ubiquitous use of sensor, time series databases are growing in importance, and new solutions offer an unprecedented level of reliability, data storage capability and flexibility.

Acquiring and storing the data flow from multiple sensors of different nature require the use of some form of database. In the context of the present project this database could handle the bulk of the storage needs while performing, if required, data pre-processing (e.g. down-sampling, statistical processing, etc.). The acquired data can be handed over to the BIM infrastructure where it will be further processed to obtain the relevant SHM information. The amount of process needed and the volume of data storage in the BIM system will vary depending on the nature of the time series and the intended use. The temporal interval spacing of the time series can be constant or variable and is highly dependent on the nature of the measured parameter. Some physical phenomena, such as noise, are acquired with high and constant sampling rates, in the order of milliseconds, that allow for detailed post-processing in the frequency domain. Relevant signals related to structural dynamic data also require high sampling rates, such as vibrations or stress variations for structural fatigue. In other cases the nature of the phenomena will require the data to be sampled with a periodicity of minutes, hours or even days, such as temperature or humidity measurements.

No matter oftenly encrypted format provided by data acquisition hardware manufacturers, the vast majority of providers offer the possibility to export the time series to some form of standard format, either ASCII, CSV, or industry-related formats. Only few hardware manufacturer offer a direct integration with complex time series data such as the ones mentioned earlier (SQL, etc.). In any case, the ultimate goal in terms of data conversion within Assets4Rail project consists in transferring the information into the IFC time data format (known as the IfcTimeSeries).

5. CONCLUSIONS

The presented paper focuses on the mechanisms needed to adequately integrate the data provided by the HSM sensing solutions identified for monitoring of bridges and tunels into a Building Information Model (BIM) environment. Specifically, the challenges of streaming the data output of the sensors into an existing BIM database. The proposed vehicle for this integration is an open Industry Foundation Class (IFC) format as defined in the ISO standard 16739. Different types of data flows, inherent to the different technologies considered, are analysed as well as the procedures to integrate the resulting information stream into the data repository in the BIM environment.

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