An IFC-based interoperable framework for building linked-data

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Abstract. Nowadays, interoperability is one of the biggest challenges in the integration of technologies. In order to ensure interoperability, data models are pivotal. In this sense, this paper presents an IFC (Industry Foundation Classes)-based interoperable framework for building linked-data, where static and dynamic data are integrated in a harmonized way for the CARTIF-III building. For this purpose, a BIM (Building Information Modelling)-centred framework has been designed, where BIM contains all the static information modelled from the building, including sensors. A dynamic database is modelled under the IFC paradigm to be able to link data between both repositories and, thus, keep record of dynamic data that the building periodically generates. With the aim of demonstrating its functionality, CARTIF-III building has been used where, on one hand, BIM model deals with thermal zones and sensors. On the other hand, dynamic database stores data coming from the "modelled" sensors, as well as Key Performance Indicators (KPIs). The key point is the integration of both data resources so that self-inspection procedures could be applied in buildings.

Keywords: Interoperability, static and dynamic data, BIM, IFC, self-inspection, INSITER.

1 Introduction

Currently, Europe directive is to achieve a critical mass of Energy-efficient Buildings (EeB) by 2020 through sustainable industrialization of high-performance architectural, structural and building-service components [1]. Approximately, 40% of the consumed energy around Europe is due to the building stock, therefore, it is critical to improve the energy efficiency [1]. However, most of the inefficiencies are hampered by critical shortcomings during on-site construction and refurbishment, whose consequence is low quality buildings. That is why INSITER project (Intuitive Self-Inspection Techniques using Augmented Reality for construction, refurbishment and maintenance of energy-efficient buildings made of prefabricated components) [2] aims to reduce the discrepancy in quality and energy performance between design and real behaviour by applying self-inspection techniques.

For that end, INSITER relies on Building Information Modelling (BIM)-based construction projects, which supports the decision-making process and allows easier management along the building lifecycle [2]. BIM is complemented by intuitive and cost-effective AR (Augmented Reality), which connects the virtual building model and the physical building (or the building under construction) in real-time [3]. During construction or commissioning phases, both techniques are very helpful to prevent errors in-advance, which usually imply high repair costs, or when left unattended to, they can have large, negative consequences on the building's technical, and subsequently, financial performance [3].

Nevertheless, the concept of BIM is applied and understood in many ways (e.g., a simple information repository, a complete data model, etc.) [4]. When dealing with self-inspection processes, BIM application needs to be adjusted. In practice, common BIM models are too complicated; there is a plethora of information that is not structured in a step-by-step process for on-site construction workers. It is difficult to inspect details and technical quality by comparing the BIM model and the realized building. Moreover, data for comparison with the BIM models are acquired via three-dimensional (3D) measurement devices adjusted for self-inspection [5][6], which present issues with robustness, and user-friendliness. Other challenges also arise in the form of differences in geolocations, building typologies and materials, working cultures, methodologies, software tools and data registration [5]. Complementary, industry can also benefit from this BIM concept in order to increase the reusability of data between all the stakeholders involved in the construction process.

BIM model needs also to be enriched with dynamic information so as to apply self-inspection methodologies, which require dynamic data to calculate KPIs [7]. Nevertheless, the main challenge is the implementation of the appropriate interoperability standards for data exchange [8], such as it is also being proven in PERFOMER project [9]. Their approach is similar to the one presented in this paper in terms of dynamic data. That is to say, integrating data in-situ from sensors through a TimeSeries server and provide the data through BIM viewers where static sensor and dynamic data are linked. Also DIMMER project integrates BIM with real-time data and extends to the district level, leading to District Information Models (DIM) [10].

For the aforementioned purposes, this paper presents an interoperable framework to facilitate the integration of heterogeneous data sources under the Industry Foundation Classes (IFC) standard [11], an open industry standard format. Then, under the INSITER approach, the various necessary data and information can be merged to provide useful data; the combination of all these resources improves the construction process by reducing the costs and time, while concurrently and pre-emptively detecting potential errors. In this way, by means of the IFC ontology, the various linked building data may be integrated to provide a homogeneous understanding.

2 Interoperable framework

As stated before, self-inspection tools support the evaluation of building construction and energy performance. For that end, data are required to assess the building facilities, although multiple and heterogeneous data formats are available depending on the device vendor [8]. Hence, it is required the harmonization of the information in a common language that increases the interoperability level in the system-to-system communication (e.g. BIM and database in the INSITER context). In order to face this challenge, it is proposed the framework depicted in Fig. 1 [3][12] where four layers are intended to ensure interoperability and harmonize the information flowing through the multiple entities and enabling self-inspection procedures.

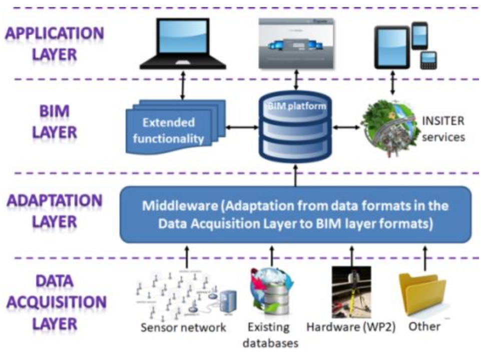

Fig. 1. Architecture framework for the self-inspection tools based on IFC.

From bottom, the data acquisition layer represents the devices for obtaining data related to the building [7]. In this case, it is associated with hardware and documents for applying the self-inspection methodology. Basically, sensor network to capture dynamic information of the building (i.e. energy and comfort parameters), existing databases of the building, hardware (laser scanner, thermography and sound probes for quality checks [5]) and other sources (e.g. data sheets) are included [3].

Adaptation layer is the next one and is dedicated to harmonize data coming from the data acquisition layer [3]. The idea behind this layer is the implementation of a middleware able to translate the specific data formats from the devices into the common IFC representation [8] used in INSITER. It is important to remark data-sheets and documents are not translated because they do not provide structured information, but they are included within the BIM platform, as it will be explained later. Basically, the main translations are based on how to adapt the communication protocols from building automation to the IFC database that is described in section 2.2. Additionally, middleware also treats acquisition hardware data though combination of measurements, importation into Revit and extraction to IFC, as explained in section 3.

The main layer in the INSITER architecture framework is the BIM layer that contains the data repositories. It is composed by three repositories: the Open Source BIM Server for static building data, a Postgres database for dynamic data and the sharepoint to store the documents [12]. This three-entities repository is implemented under the concept of extended BIM (xBIM) or dynamic BIM (dBIM) [8], which combines static and dynamic data under the same format (i.e. IFC). That is to say, it is a "single data-resource" containing both the static information linked to the building and the dynamic sensor data. Additionally to the BIM Server and its extended functionality, BIM services are also contemplated, such as clash detection and model checks.

At top level, the applications are deployed. This Application Layer integrates information from the services that check building quality, as planning and cost tools, local monitoring visualizers, or BIM viewers. It also allows the construction workers to perform quality analysis of the building by extracting information from the BIM model, as well as performance monitoring on dashboards and interaction with experts via remote communication, effectively cross-checking solutions in a timely manner. This layer obtains data from BIM Server in IFC format to be exposed and exchanged.

2.1 Static data model

As stated before, the main topic is how to integrate static and dynamic data. Starting with the first data model, within the world of Information Technologies (IT), there is an ever-growing number of information exchange standards, each with its own purpose and scope. The INSITER project selected standards take into account the possibility that existing standard(s) may not fulfil the needs and requirements, and could possibly require the combination of several standards. Mature and often-used exchange formats, such as DraWinG (DWG), AutoCAD and Revit native file formats, are closed (or proprietary) formats which introduce a major dependency on software vendors. Standard alternatives are also available, like Drawing Exchange Format (DXF) and Green Building Extensible Markup Language (gbXML) [13], however, both standards have a much more limited scope. For instance, with gbXML, the scope is only related to energy performance. For many requirements of the INSITER framework, this is not sufficient. Consequently, the standard IFC [9] was the most relevant candidate for INSITER selection [3].

Within the building and construction industry, the choice regarding exchange standards is straightforward. There is only one open standard (IFC, also called ISO16739) that is widely accepted, mature and covers most of the disciplines within the sector [9]. From the first real practical version, i.e. IFC2x3 TC1 (first technical corrigendum), major improvements have come with more recent releases. In this way, IFC4 [14] has been available for several years and has many new features of importance for selection by INSITER, including key defining factors for being selected. These factors include, but are not limited to:

- Improved representation of curves and surfaces through non-uniform rational B-spline (NURBS), B-Spline and Bezier algorithm definitions (Rational).
- Improved scheduling capabilities, such as storing content representing scheduling information very close to the capabilities or freedom available with commercial packages like Microsoft Project.
- Usable texture embedding capabilities.
- Newer, more compressed ways of storing geometrical data through vertex index arrays and sets of triangles, with or without normal information.

2.2 Database model: Building automation ontology

Still, the question remains, does the static data model cover all requirements? Although IFC is very complete, the INSITER framework is still required to offer support for multiple file formats, as well as dedicated semantic structures. This is the case of dynamic data, whose aim is to integrate periodic data measured from devices. For that end, an IFC-compliant database has been used [12]. Basically, the database schema follows the relationships between IFC classes, mapping the IFC classes and their relationships to create a repository, where the object TimeSeries is re-defined to represent all the data samples coming from the sensor network. Then, the relationship between the sensor and the timeseries objects generates the way to store dynamic data. Moreover, the concept of sensor and timeseries is replicated to KPI entities, being thus able to store not only raw data, but also aggregated data.

The mechanism to link static and dynamic data relies on the GlobalIDs that each object has in the BIM. That is to say, they are used as primary keys in the database to represent sensors, creating a single access to the object. There is a direct correlation between the objects in the BIM and the elements inserted in the database.

Having this approach in mind, building automation systems can be directly linked to the BIM of the building, extending the concept of BIM. Hence, the usable ontology is IFC to represent the objects in a dynamic database. Thanks to this re-definition of the IFC classes, building data is linked between the static and the dynamic “worlds”.

3 Data integration and interoperability mechanisms

One of the challenges to overcome for buildings self-inspection is to interconnect the different measurement instruments with BIM [15]. This is an interoperability challenge due to the multiple formats that need to be combined in the common IFC standard. A specific methodology was developed to merge useful digital information for self-inspection purposes within AutoDesk REVIT as BIM worldwide representative software. Suitable digital information sources are 3D point clouds (laser scanning or photo-based scanning), and also 2D images (thermal cameras and sound brushes) [3].

Hence, a specifically tailored plug-in for REVIT has been programmed and supported by the Point Cloud Library (PCL) as standalone, large scale, open software project for image and point cloud processing. The plug-in is a dynamic-link library (DLL) named INSITER-DLL and is able to precisely display the PLY files by layers in a unique working project. The method to integrate this information is drawn in Fig. 3 [14], where the user loads the base file into REVIT, and the INSITER-DLL automatically loads all related files meeting the requirements previously described. The PLY files serve as 3D templates to extract useful parametric features for self-inspection through fully manual/semi-automatic delineation, or just using complementary AEC (architecture, engineering and construction) plug-ins.

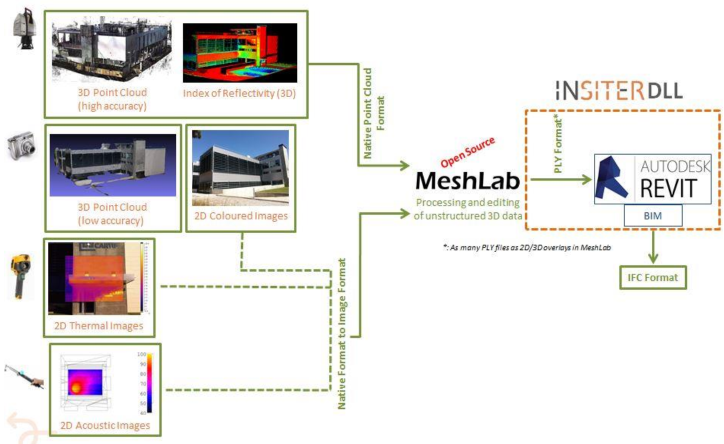

Fig. 2. Linked Data integration methodology

3.1 BIM data enrichment: Linked data method

As stated before, a tailored plug-in is in charge of enriching the BIM data through the PLY files with measurement equipment. A practical result will be detailed in section 4 about field validation in CARTIF-III building. Here, the theoretical approach is explained, which is based on the following steps, such as Fig. 2:

1. Creation of the BIM model including all the constructive elements that are going to be enriched or mapped into the dynamic database.
2. Obtain the images: thermal, cloud points and sound brush from the building.
3. Apply the algorithms to extract parameters like reflectivity, conductivity, RGB and other features of interest.
4. Introduce the results into the Revit plug-in.
5. Overlay the results of the INSITER-DLL and the BIM model to characterize the building, as well as export the IFC file.

With regard to the dynamic data, the process is based on the middleware (adaptation layer in Fig. 1). Then, the sensor network is interfaced thanks to the communication protocol (e.g. BACnet) and the objects are thus translated into the IFC database. It is important here to remark, a connection between the unique identifier of the sensor in the network and the GlobalID is necessary to link both “worlds”.

4 CARTIF-III demonstrator

CARTIF-III building is an office building located in Boecillo, Spain made of prefabricated models and according to nZEB (near Zero Energy Buildings) premise. It is 4.075 m^2 of floor space for CARTIF Technology Center activities. The main construction errors detected in this building are related to thermal bridges, lack of insulation in some of the zones (mainly one industrial area) and overheating in summer.

4.1 BIM enrichment and dynamic data integration

The integration was two-fold: firstly, field-tested for inspection tasks directly linked to the long term maintenance planning and, secondly, related to the dynamic data integration. With respect to field tests, 3D laser scanning of representative elements of this building were carried out both by a Leica HDS-3000 (TOF (time-of-flight) technology), and a FARO Focus3D X330, trying to evade voids. As illustrated in Fig. 2, data consist of geometry (XYZ coordinates); colour (RGB); reflectance (L index: materials and humidity) and reflectivity through the algorithms described in [16]. Thermography (to assess heat gain/loss and thermal bridges); and acoustic imaging were also obtained in parallel and inserted in MeshLab (see Fig. 2). The resulting enriched 2D/3D blending is illustrated in Fig. 3 [16] where the Revit BIM model of CARTIF-III is shown and the overlapping of the graphical information, being the left part the reflectance values and the right side the thermal information.

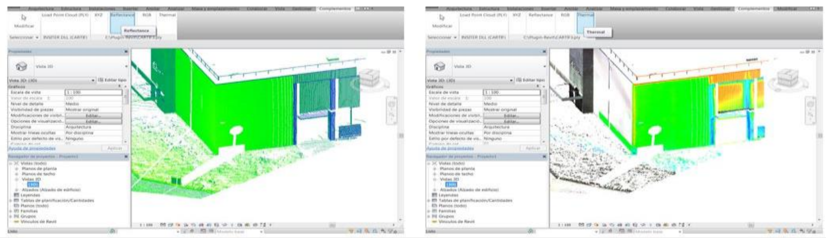

Fig. 3. Integration of 2D/3D enriched information into the CARTIF-III BIM Revit model

With regard to the dynamic data from sensors, the aforementioned framework was deployed in the building to collect data from the sensor networks in the building. Moreover, the BIM serves as data source for mapping the IFC objects into the database elements. After several months of data collection, information collected from sensor with IFC-ID = “0VE1OxL6b0nAnaUiygQBij”, which corresponds to temperature sensor, is shown in Fig. 4, as well as the associated KPIs. The approach is, as explained, connect sensor network, map sensor into the IFC and store its data.

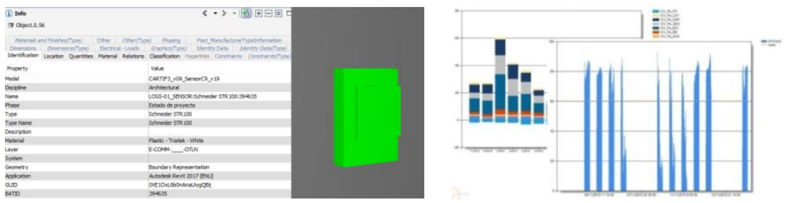

Fig. 4. Dynamic data example from the data integration

5 Conclusions

During this paper an interoperable framework has been described whose aim is to be able to integrate heterogeneous data sources in a common data model. Interoperability is a key aspect nowadays and it is a technology challenge. Furthermore, building context is especially critical where data are necessary to assess performance and multiple vendors are involved in the process. For this aim, IFC, as widely standard used in the AEC industry, has been selected as the INSITER ontology for linked-data. Thanks to the presented framework, the interoperability capabilities are increased by means of integrating data into BIM and, then, apply self-inspection techniques to avoid construction errors during the lifecycle of the building. The major benefit is being able to predict, prevent and solve errors in advance, and, then, increase the energy efficiency.

Related to future work, dynamic time series are expected to be continuously gathered in order to provide a full data repository. As well, additional buildings are planned to be included so as to validate the presented approach.

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