

# The BIM Management System: A Common Data Environment Using Linked Data to Support the Efficient Renovation in Buildings <sup>†</sup>

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† Presented at the Sustainable Places 2020, 28–30 October 2020; Available online: <https://www.sustainableplaces.eu/>.

Published: 1 January 2021

**Abstract:** One of the main challenges of the construction industry is the management of the huge amount of data generated by the stakeholders during the whole lifecycle of the buildings. Data needs to be found, collected, shared, and updated minimizing the process and technological inefficiencies. Recent advances have been seen in the adoption of BIM-based approaches and in the implementation of CDE as an agreed source of information. This paper describes the development of the BIM management system as a platform to manage the building lifecycle data using the linked data paradigm to improve the interoperability and the interdisciplinary collaboration

**Keywords:** BIM; BIM4EEB; BIMMS; common data environment; linked data; SPARQL; IFC

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## 1. Introduction

Achieving optimal information management is one of the current challenges in the construction industry. The amount of data generated by a building asset through the entire lifecycle can be massive and poor management could hinder strategic decision and collaboration between parties. A way to resolve this issue is to create a common data environment (CDE) that works as an agreed source of information for any given project or asset, for collecting, managing, and disseminating each information container through a managed process [1]. Establish a CDE means to combine workflow procedures supported by technology solutions [2].

In this paper are described the features and the functionalities of the BIM management system (BIMMS), a platform built around a CDE that will support all construction stakeholders on the whole process, able to collect not only models and documents regarding designs, but also live data collected on site or from inhabitants to provide a wide perception of needs. The novel approach proposes to use the linked data paradigm to manage the data and exploit the relationship between them allowing to improve the interoperability and the interdisciplinary collaboration.

The BIMMS is developed by One Team within the BIM4EEB Project activities and integrates a set of digital tools developed by BIM4EEB partners (BIM4EEB toolkit) to support BIM-based building renovation [3].

## 2. Materials and Methods

The BIM management system (BIMMS) is a platform built around a common data environment (CDE) that stores all the data and information gathered through different sources and along the whole building lifecycle, acting as a single source of truth (SSOT). The BIMMS and its CDE allow to

collaborate and to store, share and visualize BIM and GIS (geographic information system) models, manage documents, energy performance data and link the data-streaming from sensors devices to the models to evaluate the comfort preferences of inhabitants. All the data is shared and accessed with pre-established rules, traceable with historical records and revisions, and interoperable through service-based software interfaces. Building related geometry is stored and viewed as BIM Models using an AEC industry-recognized standard as ISO 16739 Industry Foundation Classes (IFC).

All the contents of the CDE will be considered as resources using the resource description framework (RDF) [4] data model defined in the Semantic Web technology [5]. This emerging paradigm allows the creation of relationships between different information domains. Using the RDF, the resources can be read as a statement in the form of triples (subject-predicate-object). To describe a resource is possible to declare more triples that define the resource parameters, descriptions, and relations with other resources. The RDF representation may contain links to further objects whose content if it is considered relevant can be retrieved by following the links.

The schema in Figure 1 describes the main BIMMS' modules. In the middle the CDE stores the data schematically grouped in five different types of resources such as documents, BIM models, linked data, streaming data from IoT devices, and GIS data. The outer layers are the Services used to exchange data between CDE and applications and they are the main interfaces to exploit and exchange data. The CDE Services can be grouped mainly in the user management functionalities, the resource management functionalities, the SPARQL endpoint, and the BIM Viewer. The BIMMS software architecture is open and allows the integration of new tools to extend and further improve the functionalities of the platform. For these tools, is provided a set of application programming interface (API) and services specifically developed to give complete and interoperable access to the BIMMS project data. Developers can connect their applications to extend the data in any manner that could improve the renovation works activities and the processing of business logic.

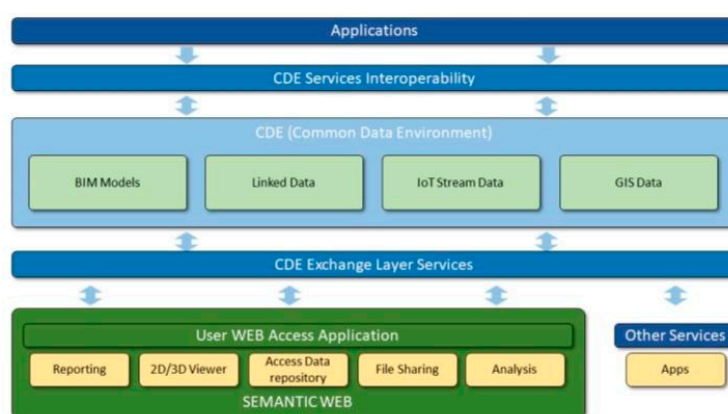


Figure 1. The BIM management system main modules.

### BIMMS Main Functionalities and Features

The resource management functionality allows to create, view, and download the resources stored in the CDE. The users can define a resource using a wizard that allow the uploading of a file, add a description, classification, and mappings with other existing resources. The resource can be also integrated with linked data selecting the domain, the properties, and the values of one or more ontologies available in the BIMMS. This feature allows the exploitation of the relationships of the resources with multiple information domains and datasets available in the semantic web.

Users, according to their role permissions, can see the list of resources stored in the CDE and carry out basic operations such as check their properties, download, and manage document versions. A specific section of the resource management lists all the BIM Models in the project with the links to download the original uploaded format and in the RDF ifcOWL [6] or BOT [7] ontologies. The RDF files are created by the BIMMS conversion functionalities and are available to exploit the IFC data in

the linked data context. For every resource uploaded in the CDE is possible to track changes and keep versioning and revisions.

The BIM Viewer (Figure 2) allows users to view the 3D IFC model with its properties. The viewer is capable of panning, rotating, and zooming the view and the items can be selected to view the properties, zoom in to selection, isolate, hide, and unhide the model elements. The elements in the 3D model can be also selected from a hierarchical tree view that will show the hierarchies between elements coming from the IFC file structure. Are available also some custom tree views that shows the IfcRooms, IfcSpaces, IfcGroups hierarchy to help the user to focus on space planning, renovation work locations, and sensors configuration settings (Figure 3).



Figure 2. The BIM management system BIM Viewer.

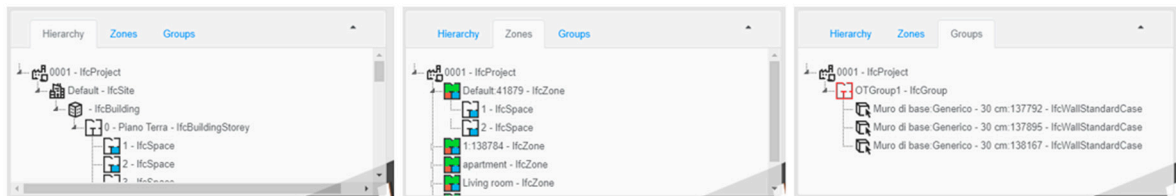
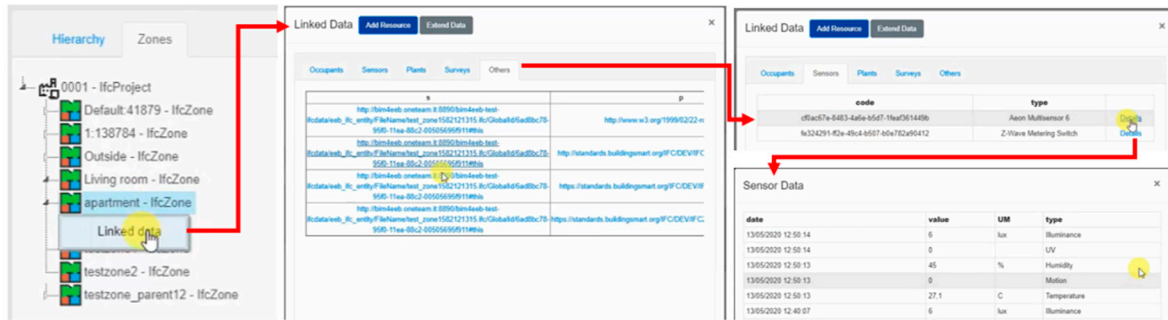


Figure 3. The different tree views available in the BIM Viewer.

Another functionality of the BIMMS related to the exchange layer services is the SPARQL Endpoint capable of receiving and processing SPARQL Protocol requests. The SPARQL Endpoint is a point of presence on an HTTP network that's capable of receiving and processing SPARQL Protocol requests [8]. Once the resources are inserted in the CDE, enabled user view roles can search and properly filter this information according to specific data connected to the resource itself (Figure 4). The endpoint enables users and applications to query a knowledge base via the SPARQL language [9]. Potentially a well-formed query can retrieve data across different domains and repositories allowing to make relationships beyond the information available in BIMMS.

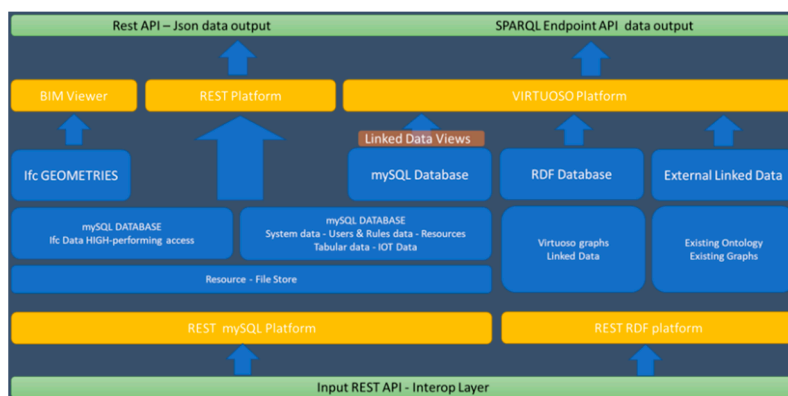


**Figure 4.** The linked data shortcut in the BIM Viewer gives access to interactive SPARQL and sensors data.

Finally, the access to the data by the external tools is done by the interoperability and exchange Layer service that works as an interface between applications and the CDE. The applications are the tools developed during the BIM4EEB Project by the Partners and all other tools and services that will be developed later and that will be used to exchange data with BIMMS. The interoperability and exchange layer services integrate tools and services using REST principles [10]. That exposes a set of API available on the BIMMS Web Portal under the Endpoints at <https://bim4eeb.oneteam.it/BIMMSWS/Help>. The Endpoints are available to the developers, upon registration on the BIMMS [11].

### 3. Results

There are different kinds of data that will be stored and managed by the BIMMS. Some data is structured and well defined by a schema that allows the storing and management by the most common relational databases. Moreover, the data may be linked to different sources and then the BIMMS can be able to retrieve relationships and give the opportunity to link the resources together. The CDE is implemented using two different databases, a relational DBMS SQL based as MySQL and a hybrid ODBMS that supports RDFs to triple store as Openlink Virtuoso (Figure 5). The chosen triple store platform works as middleware with a hybrid database engine that not only supports the semantic web of data but extends the existing data on the relational DBMS through live linking. In this way, the entity relationships will extend beyond SQL tables to RDF graphs allowing reasoning and inferences rules performed by Virtuoso Platform also on the MySQL data.



**Figure 5.** Database and interoperability layers.

The MySQL DBMS is used as a main data store that manages all 3D BIM Models, documents, drawings, and data streaming from sensors. MySQL also manages the website backend with tables and views to manage interface, user, and roles management. The Virtuoso Platform is used as a data store for linked data resources directly uploaded as RDF, triples creation and modification, geo linked data store, and to store resource graphs and ontologies. Virtuoso is configured also to enable SPARQL

queries through the resource graphs in the Virtuoso SPARQL Endpoint available on the BIMMS Web Portal.

### 3.1. IFC File Management in BIMMS

The 3D BIM Models are stored and shared in the CDE using the IFC file format. The IFC is defined by an EXPRESS based entity-relationship model organized into an object-based inheritance hierarchy. When an IFC Model is uploaded in the CDE, a batch process will start to parse the IFC file and store all the items in the MySQL database. When the model is processed it can be accessed by the 3D Viewer and by the Virtuoso Linked Data View definition. The IFC items as Linked Data are converted in the two most common ontologies that support IFC: ifcOWL and Building Topology Ontology (BOT). The conversion is done using the open source IFctoLBD converter [12].

Thanks to the data access drivers, Virtuoso will access tables and views in the MySQL and will be mapped entities, properties, and values in the linked data graph. Drivers connect both databases acting as middleware that gather all data on external databases without the cost of developing a specific data conversion for every need. This solution improves the efficiency on long-term use of the BIMMS. Is expected an improved performance on big models because the file is not parsed on the fly and it is not necessary to load the whole data before getting the results of complex queries. Furthermore, MySQL was used as file storage and to manage the versioning, permissions, and user management. These tables and views are translated in RDF using the capabilities of the R2RML module of Virtuoso Server. Finally, the BIMMS expose the Virtuoso SPARQL Endpoint as an internal Endpoint under the SPARQL functionalities in the BIMMS web portal.

### 3.2. BIMMS Linked Data Views

All the contents of the BIMMS CDE will be considered as resources using the Resource Description Framework (RDF) specifications. As an example, we can consider here as resources different types of entities such as a 3D model, a building element, a user, a task, a sensor, or a document. Each resource will be referenced in the CDE by a unique identifier. This unique reference will be used to retrieve the representation of the resource and to establish links among other resources stored in BIMMS CDE and across the Web. When a user creates new resources in the BIMMS the uploaded files or the properties assigned during resource creation will be used to define a set of relationships based on triples. The triples are defined as Subject, Predicate, and Object, where Subject and Object are nodes linked together by a Predicate. In the example shown in Figure 6 is defined as a resource (Subject) that hasResourceFile (Predicate) a file (Object). If the resource is linked with an entity in a BIM Model, it can be defined as isResourceOf predicate that defines the relationships between them. This could be a common example where a PDF document, for example, a datasheet, could be linked to an IfcWindow item in an IFC Model previously uploaded by another user. In the same way, could be made a relationship between the properties of the resource. These properties could be labels defined as objects literals, or other node references. This kind of reference could be done for example between devices and their characteristic features, such as measurement properties, measurement list, and so on. Another common example is shown in Figure 7 **Error! Reference source not found.** about the relationships between a device with its measurement data, such as a temperature sensor with its streaming. The devices, the measurements, and the location where the measurements took place are all resources identified by their URIs. In the web of linked data, these kinds of things are defined and managed by different kinds of ontologies. A sensor device in the BIMMS could be defined by default as srf4bldg:Sensor [13]. The predicates isContainedIn defines that this device is contained in an IfcSpace, makesMeasurement defined in saref:Measurement [14] with dateTime and value as objects.

In Figure 8 is shown also the relationship between the record of the single IFC Model item in the MySQL database, its triple definition in the graph database and the net of relationships that will define its versioning, and relationships between other IFC items and the rest of the resources stored in the database. The linking could be expanded also outside the database bringing other external public access databases.

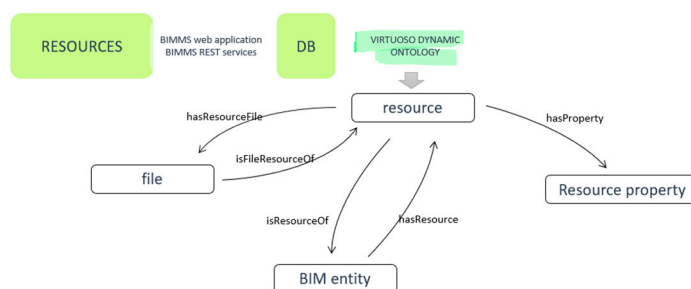


Figure 6. BIM management system resources linked data view.

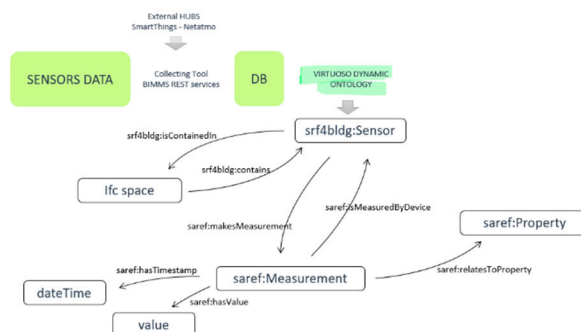


Figure 7. BIM management system sensors linked data view.

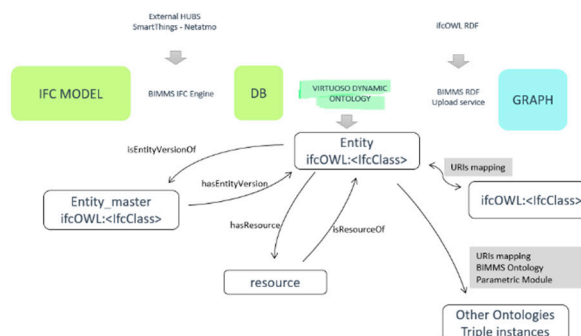


Figure 8. BIM management system IFC linked data view.

## 5. Conclusions

The BIMMS is part of the BIM renovation Toolkit developed in the BIM4EEB Project and currently is still under development. The work described reports the achievements obtained in the first phase that has been focusing on the design and development of the main framework and functionalities to support the development of the tools in the other tasks of BIM4EEB Project. Further developments are expected, and the BIMMS will be tested and validated with the complete BIM Toolset in the demonstration sites defined in the project. The use of the Linked Data principles applied to the CDE have opened new paths in research and development that are worth investigating. The next step in the development will be the improvement of the ontological representation features and the development of a better integration between the different functionalities, to give the end user easy access to the linked data environment.

**Author Contributions:** Conceptualization, methodology, validation, formal analysis and investigation, paper writing, review and editing: A.V., D.M., J.C., D.F.; software development: A.V., J.C., D.F. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research is part of BIM4EEB Project funded by EU Horizon 2020 Research and Innovation Framework Programme, grant number 820660.

**Acknowledgments:** The authors want to acknowledge great support of all our BIM4EEB Research Project partners listed here: <https://www.bim4eeb-project.eu/partners.html>.

**Conflicts of Interest:** The authors declare no conflict of interest.

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