

# Chapter 3

## Development of BIM Management System



**Alberto Pavan, Vittorio Caffi, Alessandro Valra, Davide Madeddu, Diego Farina, Jacopo Chiappetti, and Claudio Mirarchi**

**Abstract** With BS 1192:2007 and even more so with BS PAS 1199-2:2013 and 1192-3:2014, the concept of Common Data Environment (CDE) of the order (project, construction or management that is). Originating from a standard dedicated to design (BS 1192:2007) and although its concept has been extended to information management in general: Capex (strategy, project, construction: PAS 1192-2) and Opex (exercise: PAS 1192-3), the CDE, as it is understood today in common practice, is still very much affected by the original link with the design and the design phase (and in particular the design in the new building). All this according to an information flow that is still very linear and sequential: client, designer, builder, manager, user; more than circular, as the so-called BIM methodology would like. The risk, therefore, is that the commercial software market is affected by this CDE approach, which is also useful for the very rich real estate market of the emerging economies, neglecting the construction market of the more consolidated economies (Europe for before), very built up, and aimed more at housing quality, sustainability, reuse, and renewal of the existing heritage rather than the new one. It is consequently necessary to define new information flows and a new type of information management environment (CDE) for the phases of use, conservation, and renovation of buildings for the European market. The need arises for a specific BIM Management System (BIMMS, overcoming the classic CDE) for asset management and their enhancement that collects information from the buildings themselves and its users (Digital Twins, IoT, sensors, etc.). A new CDE / BIMMS that uses semantics and open dialogue, via API, with multiple Tools rather than acting as a repository of files and models. BIMMS is a new concept of CDE created for the operation/renovation phases in mature real estate markets (such as the European one).

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A. Pavan (✉) · V. Caffi · C. Mirarchi

Department ABC—Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milano, Italy

e-mail: [alberto.pavan@polimi.it](mailto:alberto.pavan@polimi.it)

A. Valra · D. Madeddu · D. Farina · J. Chiappetti

One Team S.r.l., Milano, Italy

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## 3.1 Common Data Environment

### 3.1.1 Introduction to the Topics

The sharing and conservation of information are two critical issues that have always been present in the construction sector. They have been handed down over the centuries and have become increasingly important with the increase in regulatory, technological, requirements, etc. complexity. typical of our days.

Today, digitalisation offers new tools to solve this critical information throughout the construction chain, both in terms of containers (files) and in terms of content units (single information and data). With the BS 1192:2007, in the UK, the concept of the Common Data Environment in constructions is born, then resumed in a more digital sense in the PAS 1192-2: 2013. Since the CDE has been “subject”, of other standards, at national level (UNI, DIN), European (CEN) and international (ISO), and “object” of new tools (360DOCS, Aconex, BIM+, etc.). Tools that from simple document repositories have increasingly turned to the management of the “models” generated by the various “BIM Authoring” software, in their different component files (architectural, structural, MEP, etc.).

The writing of a new type of CDE, aimed mainly at the built environment, cannot therefore ignore a careful analysis of the standards that define its contours and the commercial software that characterize its operational use.

The creation of a CDE aimed at the construction supply chain, and which sets the life cycle of buildings (50, 100 and more years), also cannot omit even a general analysis of the systems for sharing and preserving “data” (and not just files). These systems have been in use for decades in other industrial sectors (Data Base Management System: DBMS; Enterprise Resource Planning: ERP, etc.) and must also be analysed to define the architecture of BIM4EEB’s new CDE system. In the same way one cannot forget all the new technologies that increasingly appear in the informative panorama also of the constructions: sensors (Internet of Things—IoT), DB to Objects, non-relational DBs, etc.

Finally, the same concept of CDE addressed to the single order, or intervention, is now losing more and more meaning towards that of digital platform, collaboration and sharing: organization, supply chain, national and transnational (see the DigiPLACE project, EU, H2020).

The architecture of the BIM4EEB CDE defined in BIM4EEB must take all these variables into account and give them an operational response.

Building Information Modelling (BIM) is gaining momentum in the AEC industry for design and construction and one of the most significant technological advancements in recent years that has been adopted by the design and construction industry (Khaja et al. 2016, Parlikad et al. 2019).

Traditional method is mainly concerned with 2D representation of information throughout all the entire project phase; however, Building Information Modelling leads to the re-shaping of the construction industry as it stands for the necessary evolution of the design approach linked to the increasing complexity of the building process. BIM lays down the transition from unidirectional and asynchronous workflows to integrated and shared models. Most research has agreed that BIM is a process of expanding 3D models to computable nD models to simulate the planning, design, construction, and operation of a facility. In particular, 3D BIM makes it possible to perform specific analysis based on the geometrical information of the model, such as 3D visualization, clash detection and code checking (Solihin et al. 2017).

To put it in a nutshell, the five most important benefits include: better cost estimates and control, better understanding of design, reduce construction cost, better construction planning and monitoring, and improvement of project quality.

Despite many advantages of BIM, the slow adoption to date has inspired researchers worldwide to investigate existing barriers; these barriers include technical problems (compatibility and reliability), fragmentation of the project team, the inherent resistance to change by construction stakeholders, lack of training, and business process related issues, inadequate organizational support and structure to execute BIM, and lack of BIM industry standards.

The Common Data Environment was originally defined in BS 1192:2007, then in PAS 1192-2:2013, finally it has its own international standard, ISO 19650. There are also other standards from Italy and Germany with similar approach. The contents of the CDE are not limited to assets created in a 'BIM environment' and it will therefore include documentation, graphical model, and non-graphical assets. In using a single source of information collaboration between project members should be enhanced, mistakes reduced, and duplication avoided. The advantages of implementing a CDE include:

- Ownership of information remains with the originator, although it is shared and reused, only the originator can change it;
- Project team members can all use the CDE to generate the documents/ views they need using different combinations of the central assets, confident that they are using the latest assets (as are others);
- Shared information reduces the time and cost in producing coordinated information;
- Any number of documents can be generated from different combinations of model files.

BIM teams are those whose possibly geographically dispersed members from various organizations and disciplines, perform project tasks on BIM-enabled projects. even though achieving BIM's full capabilities relies on effective collaboration among the team members in BIM-based construction networks, it is still a struggle for these members to collaborate. Nonetheless, only a few studies have been conducted to identify the barriers to strengthening team collaboration in BIM-based construction networks.

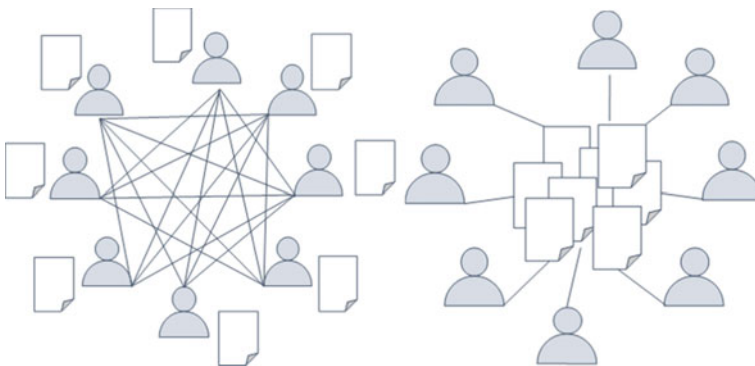
BIM methodology is mainly developed and applied for new building projects. Its use for renovation and retrofitting projects is still in its infancy. On the other side, there is a strong present need to improve the quality and the functionality of the existing building (Scherer 2018). To encourage BIM adoption for renovation project, there is a need to examine refurbishment project stakeholders' separate roles, responsibilities, relationships, and interactions among themselves of which can be hampered by internal or external environmental factors. Although BIM adoption environment requires a more multidisciplinary collaboration effort of different disciplines against information sharing, building design, construction techniques.

### 3.1.2 *Principal of CDE*

Traditionally, interdisciplinary collaboration in the fields of Architecture, Engineering, Construction (AEC) is based on the exchange of 2D drawings and documents. Although the different disciplines use 3D models for development, design, and visualization, the collaboration between them has developed especially in 2D. Traditionally used CAD tools have some significant limitations such as the separation between the design and the information associated with it.

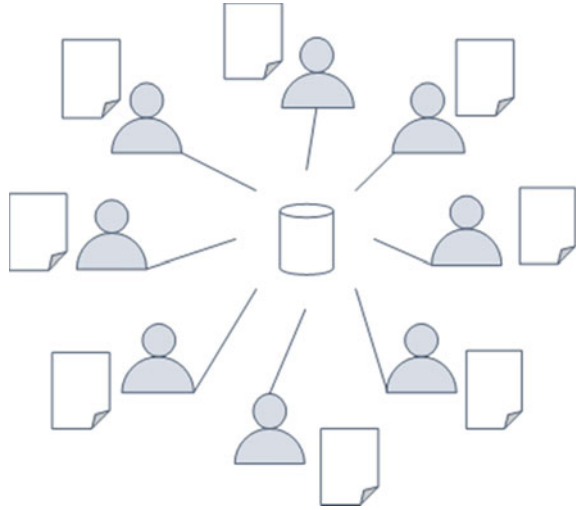
The creation of a common portal, a source of information, reduces exchange times and costs because it makes an easy collaboration between team members who can draw from a single source. In the traditional information sharing, each subject exchanges data with all the other subjects involved causing inevitable information losses (Fig. 3.1).

The structured use of a data-sharing environment requires rigorous discipline on the part of all members of the design team, in terms of adherence to agreed approaches and procedures, differently from what happens for more traditional procedures (Fig. 3.2).



**Fig. 3.1** Traditional approach versus ideal BIM-CDE

**Fig. 3.2** Stage 3 ISO 19650-1:2017—CDE schema



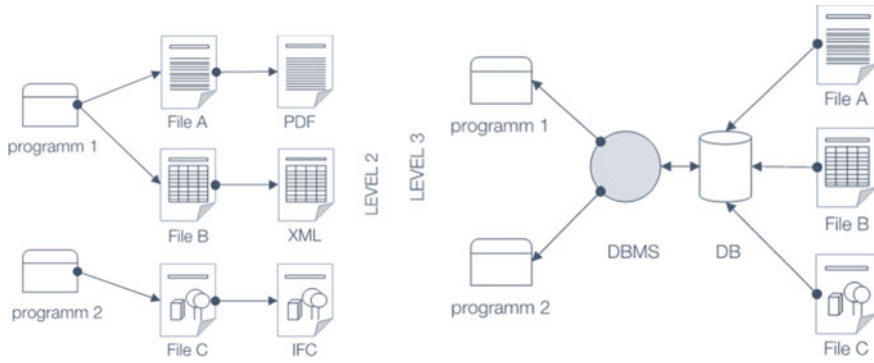
The BIM design was born as an evolution of the process that starts from the design of the 2D paper, to 2D and 3D CAD systems, parametric modelling up to digital modelling in a collaborative 3D environment. The BIM methodology in fact, in addition to requiring the use of specific modelling technologies for the various dimensions, must follow a flow of information that follows well-defined rules and standards.

The main CDE standards are:

- BS 1192-1:2007
- BS PAS 1192-2:2013
- UNI 11337-1:2017
- UNI 11337-4:2017
- UNI 11337-5:2017
- ISO 19650-1:2018
- DIN SPEC 91391-1:2019
- CEN TR 442031/442032
- (ISO 19650-4: WIP).

### ***3.1.3 Practice Applications BIME4EEB–BMS***

The DBMSs (Data Base Management Systems) have been created to make a coherence between the independent data and created by different applications. However, this improvement in data management has led to the emergence of independent databases originating from individual organizations that do not talk to each other. The situation remains devoid of a unified vision where data from different databases



**Fig. 3.3** Independent files versus integrated database+DBMS

can communicate quickly and strategically, bringing the process to a higher level (Fig. 3.3).

The ACDat is information content represented by data and data structures (files or containers). Despite wanting to distinguish itself from a file and file sharing system and from a document manager it performs the same function. In general, they are relational databases, but there are ACDat prototypes based on non-relational DBs. The main objective of the ACDat is to guarantee over time the digital sharing of the data created by the various subjects that collaborate in the construction process.

Originally the use was based on the sharing of graphic models (generated by BIM authoring software) within the design team elaborated by the various disciplines: architectural, structural, plant engineering, mechanical, hydraulic, electrical, etc.

“Issues relating to the coordination of (graphic) files, federation of models, verification of geometrical interferences (clash detection), processing of files at the same time by more operators, etc. (see BIM Plus, Trimble Connect, Collaboration for Revit, BIM 360 Team, BIMX, etc.)” (Daniotti et al. 2020).

Today there are platforms that have generated or are evolving into real ACDats /CDEs in which the original function is added to the management of data, files, and documents of various origins; moreover, the coordination will not only be of 3D models but also of time management (4D), costs (5D), maintenance (6D), etc.

Every time a new job is opened, the organization creates a new CDE. The various CDEs (of the various orders) are organised in a collaborative platform. The client is always responsible for the CDE as the owner of the results of the order (Appointing Client, Owner). The designated subjects, who will intervene in the job, interact directly in the CDE. The designated parties and the Lead Appointed parties operate in their own WIP and make their own models and documents available to the other parties. The appointed party approves the documents located in the WIP space and makes them visible in the conditional space for the coordination of all parties. Once the coordination is concluded, the appointed party authorizes the publication (models and documents can be reused by others), and for the appointed party they are ready to be deposited in the Appointing party’s CDE.

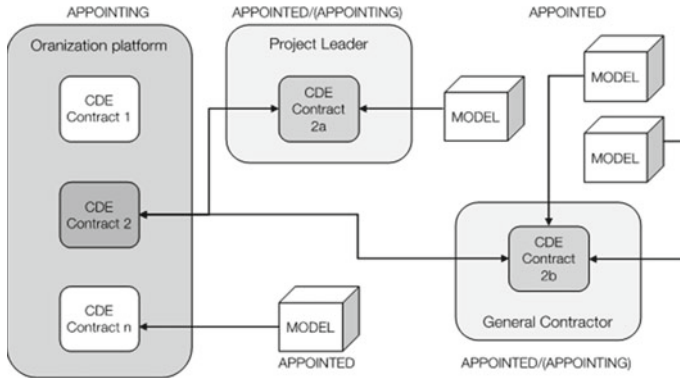


Fig. 3.4 CDE flow

“Therefore, the CDE managed by the Appointing Party receives the definitive data coordinated in advance between the Appointed parties in the Lead Appointed Party’s CDE. The entry of the Appointed parties’ coordinated data in the CDE job order takes place in the Sharing environment, it assumes value of deposit for the client, and is always subject to the client’s approval and verification. The CDE data—coordinated, approved and verified, upon the client’s prior authorization—can therefore be shared with third parties (Publishing) or in conclusion archived (Archive) for their following possible mining, should they be re-processed” (Daniotti et al. 2020) (Fig. 3.4).

The main scope of the BIM4EEB BMS is the development, starting from a Common Data Environment, a management platform able to collect and manage the amount of data useful for BIM4EEB project. Such a platform should be open, interoperable and provided of a specific toolkit to optimise the management of information (collection, share, update, and exchange) during the different stages of a BIM-based renovation process. This for making it more efficient with respect to traditional processes. The open and interoperable platform will be based on a BIM management system (composed of different BIM tools) allowing different stakeholders (as designers, architects, construction companies and service companies, owners, and inhabitants) to exchange data and to efficiently manage renovation works.

The BIM4EEB BIM Management System aims to be an open integrated BIM-based collaboration environment, enabling the continuous updating, enhancement, improvement, and enrichment of available models by the AEC industry stakeholders based on robust modelling guidelines that will be provided by the project, to ensure sustainability of the project developments and enhance its exploitation potential even after the end of the project.

The BIM management system will host a variety of applications to ensure timely and uninterrupted realisation of standardised renovation processes and smooth collaboration between the different stakeholders in a cost-efficient and timesaving manner.

Initially, the first one (field survey) will be accelerated thanks to a specific tool for fast mapping that apply the latest information technologies to create BIM models of

existing buildings in a quick and accurate way. Then, the second one (initiation and design) will be improved thanks to a tool that support decision-making and a BIM-assisted energy refurbishment assessment tool. Moreover, the third one (construction) will see a BIM-enable tool for the renovation intervention management to organise, plan and track site operations.

The BIM management system will have a set of Application Programming Interface (API) and Services specifically developed to give complete and interoperable access to the BIM4EEB project data. It will be realised as a web platform, and it will serve to all project partners to connect their tools and applications used and developed during the project.

The BIM Management System will be built around a general schema of Common Data Environment (CDE) that will store all the data and information gathered through different sources and along the whole building life cycle, acting a single source of truth (SSOT), with dedicated interfaces and capabilities that will work as a central repository enabling the data exchange with connected tools for providing better coordination among users and process phases.

Common Data Environment (CDE) with dedicated interfaces and capabilities that will work as a central repository enabling the data exchange with connected tools for providing better coordination among users and process phases. All the data will be shared and accessed with pre-established rules, traceable with historical records and revisions, and interoperable through service-based software interfaces. Building related geometry will be stored and viewed as BIM Models using an AEC industry recognized standards as ISO 16739 Industry Foundation Classes IFC.

### **3.2 Collaborative Workflow and Information Exchange Requirements**

The building renovation works, involve several stakeholders, each of them having different and specific needs in terms of information they request and produce for their activities.

To identify how the information workflow has to be organised to support at best the renovation process, it is crucial analyse the relationship among the different actors and their interactions. This becomes even more important when the process is BIM enabled: identifying the information exchange process is a must to fully exploit the potential benefit offered by the new technologies.

This section highlights the relationships and interactions over the whole process, it identifies the actors' profiles and clarifies their interaction. Some general schemes and use cases are presented to highlight how to determine the information exchange requirements and workflow.

The methodology that has been followed to define the stakeholders' profiles and the phases of the workflow they are involved in are described. Visual schemes are presented to highlight sequences and relationships among actors, tasks, phases.



The specific graphical schemes that have been designed to illustrate the relationship at each stage of the workflow, among the actors and with the tool categories are here presented and explained. 21 actors were identified in the former paragraph, using such diagrams. Each profile is accompanied by a table showing the relationship among BIM tools categories that might be involved in the process, the information flow among the actors, the performed actions.

A Use case Matrix is suggested, to establish a general method to define User profiles.

### 3.2.1 Methodological Approach

To achieve the goals of identifying how the information flow has to be organised to support at best the renovation process, the building renovation process has been analysed through all its stages including initiative, initiation, concept design, preliminary design, developed design, detailed design, construction, use, and end of the life cycle. The steps of the analysis are highlighted in Table 3.1.

The workflow is analysed to define the relevant stakeholders, the relevant input and output information for each possible activity, the related BIM tool available on the market, the priority level of BIM technology adoption for each action or activity. The users' profile for a BIM management system, are eventually determined in relationship to the information workflow, and required function, required BIM tool categories for each stakeholder.

A further study and analysis related to the process workflow has been carried out in order define the relationships between the different actors, how actions are connected and connect the actors and if and how BIM tools are involved in the process, according to a priority scale. The outcome has eventually produced the

**Table 3.1** Sequential methodology of the work

Step 1	Collecting detailed data for all activities in all stages of building renovation workflow
Step 2	Identify the stakeholder in each stage, and the relationship between the stakeholders in each activity in the perspective of information analysis. For example, in a single task, who is the information provider, who is the information receiver
Step 3	Identify the input and output information for each action in detail
Step 4	Determine the priority of using BIM technology in each action with the scale from 0 to 5. In detail, 0 is not necessary to use BIM, 1 is useful but not recommended, 2 is recommended, 3 is desirable, 4 is highly desirable, 5 is mandatory. The priority is explained based on research hypothesis and BIM benefit for each action
Step 5	Determine the BIM tools and BIM tool category available in the market that fit for using in each activity in the workflow
Step 6	Based on previous analysis, summary the data for user's profiles including information, BIM category and required function

User profiles identification or a method to identify other User profiles following the workflow, actors involved, required actions, tools categories.

### 3.3 The BIM Management System

The BIM Management System (BIMMS) is a software platform designed to manage all the buildings' data and to perform as a single source of truth for the stakeholders involved in the renovation project. The platform was developed around a common data environment (CDE) used to store data coming from different sources and along the whole building life cycle. The CDE allow users, to upload, share and manage information containers and provide functionalities to visualize their properties, download, rename and manage document versions. The BIMMS' CDE manages different kind of resources and file formats, and let the user to define properties, set classifications, assign mappings with ontologies according to their role permissions and resource status. A BIM Viewer supports the 3D IFC BIM resources with functionalities to pan, rotate, zoom the models, select geometry items, and view their properties both in 3D and in a hierarchical tree view. The BIMMS' IoT middleware retrieve and save sensor measurements from a Samsung SmartThings Hub (Samsung 2020) collecting the data streaming from the devices placed in the demonstration buildings.

The measurements are stored in the BIMMS and shared, with authorization and permissions defined, to the end-user tools and applications. The BIMMS provides a SPARQL Endpoint to receive and process requests to the resources stored in the CDE using SPARQL queries. The SPARQL Endpoint is compliance with SPARQL 1.1 (W3C 2012) and allow connections to other SPARQL Endpoints to retrieve data from different repositories using the federated queries. To facilitate the visualization of the ontology relationships between classes and properties, the BIMMS implement a graph visualization of the ontologies. Finally, the developers can connect their tools to exchange data with the BIMMS using the BIMMS' REST API.

#### 3.3.1 *The BIMMS Architecture*

The Common Data Environment (CDE) is the core of the BIMMS, and a service interoperability interface works as a module that enables all the functionalities to be performed like upload, view, manage versioning, sharing, and permissions management. To guarantee the access to the data, an exchange layer service has been developed working as an interface between the external applications to exchange data directly from the application.

The BIMMS database architecture is composed of two main databases, a relational database management system based on MySQL and a hybrid triple store database system based on Virtuoso.

The MySQL database is used to manage and store data for the File management, Users' management, Roles management, 3D BIM Model IFC entities, Building activities, alerts, and occupancy, Sensor's data streaming, Application errors and logs. The Virtuoso database is used to manage and store RDF data for the BIMMS resources, IFC models, sensors data, geospatial data, and the RDF data directly saved by the tools.

The BIMMS provides different functionalities that allow the users to manage all the resources, being unaware about the complex technical workflows happening in the backend.

In a typical workflow the user logs in and is authenticated as profiled account in the BIMMS and then, using the BIMMS' "New resource" functionality, he can upload files, set properties, classification, and mappings with other resources. When a new IFC resource is created, the 3D IFC model is uploaded and the BIMMS, in background, starts a batch process to parse the model and store the items in the MySQL RDBMS, and the RDB-to-RDF conversion. The process does not block the users' activities and can continue to work in the BIMMS. At the end of the conversion, the user will be notified by email about the availability of the BIM Model ready in the resource list.

The resource data is immediately available in the BIMMS' Resource list, ready to be referenced.

When the BIM Model is ready, the user can navigate through the model and view the model's element properties in the BIMMS' BIM Viewer.

The data stored in the MySQL RDBMS are also available in the Virtuoso triple store as ontological representation and stored in specific Virtuoso named graphs.

The data is then available also through the BIMMS' SPARQL endpoint.

### ***3.3.2 Data as Resource***

All the contents of the BIMMS' CDE can be considered as resources using the Resource Description Framework (RDF) specifications. A resource is an any physical or virtual entity connected to a computer system. 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. In the triple, the subject denotes the resource, and the predicate expresses a relationship between the subject and the object. As an example, we can consider 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. The RDF representation may contain links to further objects whose content—if considered relevant—can be retrieved by following the links.

The data of the BIMMS' resources, the sensors streaming, and other data stored in the MySQL database is also represented as RDF data through the Virtuoso Linked Data Views functionality (OpenLink 2018). The Virtuoso Linked Data Views is a feature of Virtuoso server that allows to generate RDF views over SQL Data using "machine-readable relations semantics via terms defined in a vocabulary or ontology" (Heward-Mills 2018). The data stored in the MySQL relational database can be available in Virtuoso database as RDF, through a mapping of the MySQL table views with terms and ontologies schemas. This configuration allows to bring all the benefits of using the two platforms and made available as Linked Data the information stored on the relational MySQL database.

The feature can be accessed through an application wizard in the Virtuoso Server that create the mapping definitions in R2RML standard language, that can generate a Quad Map Definition using an ontology based on the data headers available on the source tables and the RDF Schema vocabulary. The R2RML language is a W3C recommendation that define a language that allows to create mappings from relational databases to RDF datasets (W3C 2012). The Quad Map refers to the Virtuoso storage schema that uses quads instead of triples using a field to refer to the source application or resource (OpenLink 2018).

The ontological representation of the resources is defined using the Virtuoso Linked Data View through the R2RML mapping from MySQL logical tables to RDF. The Virtuoso's R2RML processor generate the R2RML default mapping based on the input database schema: the logical tables are mapped as `rdfs:Class` with the same name, the contents are mapped in data properties defined with `owl:DatatypeProperty`, and object properties defined with `owl:ObjectProperty`. The mapping generates an internal ontology that support the generation of the triples composed by a subject map and multiple predicate-object maps, that is used to map each row in the logical tables. The internal ontology is stored in Virtuoso Server and is checked with the OOPS! Ontology Pitfall Scanner! (Poveda-Villalón et al. 2014), the University of Manchester OWL Validator (Horridge 2009), and the Vapour Linked Data validator (CTIC 2011). The result is a Direct Mapping that is further customized to include classes and properties defined in the Digital Construction Ontologies (DiCon). The DiCon ontologies are modularised and cover the digitalized construction processes domain. The resources stored in the BIMMS are first covered by the Information ontology module, that provide classes and properties for the information content entities, information containers, designs, plans, events, and issues. The integration was done defining some classes as `rdfs:subClassOf` and properties as `rdfs:subPropertyOf`.

For the resources, the mapping uses both classes and properties of the custom ontology based on the MySQL table column headers, the Digital Construction Information ontology that "defines the representation of information content entities in construction and renovation" (Törmä 2020), and the ISO 21597-1:2020 Container ontology (ISO 2020).

For the IFC models, the mapping uses both classes and properties of the ifcOWL ontology (Pauwels 2019), the Building Topology Ontology (BOT) (Linked Building Data Community Group 2021), and the Digital Construction Entities ontology that

“defines the basic classes and properties needed for the representation of construction and renovation projects” (Törmä 2020).

For the sensor’s data, the mapping uses both classes and properties of the custom ontology based on the MySQL table column headers, and the Digital Construction Ontologies (DiCon) that “act as an enabler of semantic interoperability between systems in the construction and renovation domain” (Törmä 2021).

### 3.3.3 Working with IFCs

The BIMMS’ CDE manages different kind of files that ranges from the 3D BIM models, drawings, reports, spreadsheets, to images and other kind of medias used to store the building documentation. The 3D BIM models are stored using the interoperable IFC file format. The IFC file defines an EXPRESS based entity-relationship model, consisting of several hundred entities organized into an object-based inheritance hierarchy. The structure of the IFC allows to parse the files to extract all the IFC entities, their properties and relationship and save them in the MySQL database maintaining the relationships of the original file.

Although the BIMMS store the original IFC files in the file system, the availability of the content of the IFC files stored in the database improved the speed performance to read and write IFC data, and to retrieve object data in real time to support the visualization in the BIM viewer. Moreover, the applications can define complex queries in the database and retrieve data faster than reading the IFC files on the fly. An application “IFC to Relational DB” runs as a service on the BIMMS’ server, that parse asynchronously the IFC files uploaded in the Common Data Environment (CDE) and write the contents in the MySQL database. The application is scheduled and can catch the file version changes, updating the data stored in the database in near real time as the IFC files being updated. The service uses the xBIM Toolkit, a software development toolkit (SDK) that allows to read, write, and view the BIM models in the IFC format (xBIM 2020). Another application “IFC to RDF” runs as a service in the BIMMS’ server, to parse the IFC files uploaded in the BIMMS’ CDE and to convert them into RDF graphs. The conversion was carried out using an application that convert IFC files in RDF using ifcOWL ontology (Pauwels 2019) and the Linked Building Data (BOT) ontology (Linked Building Data Community Group 2021). The original source code of the application is made by Jyrki Oraskari, Mathias Bonduel, Kris McGlinn, Anna Wagner, Pieter Pauwels, Ville Kukkonen, Simon Steyskaland, and Joel Lehtonen, is also based on some third-party dependencies, and refers to the work of Pieter Pauwels for the main Java components like the IFCToRDF converter (Oraskari 2020). The source code had been modified to adapt the URI to the BIMMS URI and are automated to be run asynchronously after the IFC has been uploaded in the BIMMS. Once the converted RDF files are available, are stored in the file system, available in the MySQL database as resources, and then loaded in the Virtuoso Server as RDF triples in the named linked data graph.

The BIMMS' BIM Viewer allows to view and navigate through the IFC BIM models, selecting the elements and view its properties. The BIMMS embedded the xBIM Toolkit Libraries to manage the viewing, reading, and modify the IFC files (xBIM 2020). To speed up the visualization, the IFC files are converted using the xBIM libraries in an optimized xBIM WebGL format (wexBIM). The WebGL format is widely used and supported as web standard to visualize 3D geometry in the web pages (Khronos 2020). As described before, an internal BIMMS' application (namely IFC-to-DB) parse and store the IFC data of the model items in the MySQL database.

The data is used to speed up the visualization of the properties in the BIM Viewer and to support the creation and editing of the IFC spatial elements like IfcZones and IfcGroups. This feature allows to edit the spatial hierarchy of a IFC model adding or modifying IfcZones and IfcGroups used to manage thermal zones for energy simulation, spatial zones for location-based activities, locations for sensors positioning, and element grouping for activities and resource management. All changes are saved in real time in the MySQL database and are available immediately in the BIM Viewer, in the IFC model when downloaded, and in the Virtuoso triple store. All functionalities to add, delete and modify IfcZones and IfcGroups are available via REST APIs for the applications (BIM4EEB 2020). The IFC hierarchy panel in the BIMMS' BIM Viewer with the IfcZones defined to group IfcSpaces for the apartment sensors setup: all IfcZones are defined using the BIMMS' APIs (Fig. 3.5).

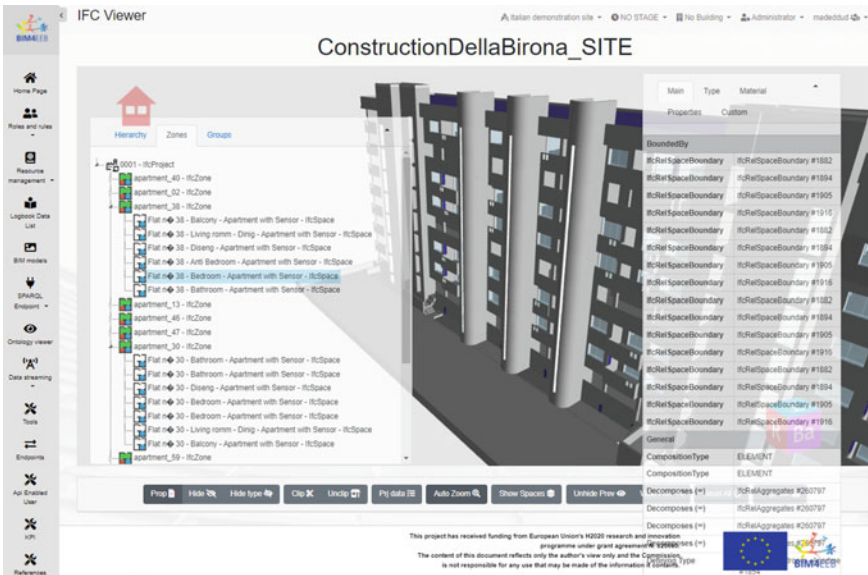


Fig. 3.5 The IFC hierarchy panel in the BIMMS' BIM viewer

### 3.3.4 Working with Linked Data

The BIMMS’ “Geo Linked Data” functionality allow to define one or more positioning of a resource or a thing in the world through its latitude and longitude. This feature allows to search a resource by its location and retrieve additional information of its neighbour’s geographic elements like cities, towns, buildings, hospitals, streets, factories, shops, points of interest, etc. The user can navigate in the map panning and zooming, and then clicking on a specific point on the map can define the positioning. The positioning data is defined with the Digital Construction Entities ontology (dice) developed in WP3, with dice: Location and dice: SpatialPosition and the data properties hasLongitude, hasLatitude, has Altitude, and isLocatedIn. The dice ontology is aligned with the WGS84 Geo Positioning Ontology.

The definition of the location of a resource can be done during the creation of the resource using the BIMMS’ “New resource” and “New Linked Data object” functionalities. These functionalities are based on a step-by-step wizard that include a step dedicated to the GeoLinked Data. The GeoLinked Data are then available for consultation through the BIMMS’ “Geo Linked Data” functionality that shows all the locations in a map with single points or clusters depending on how much locations are defined near each other. When the point is selected (clicking on it), a new panel will be shown. This panel shows a map with the results of a federated query done using the Wikidata Query Service to retrieve information about geographic elements located near the location. This feature allows to exploit the data distributed on the Web and improve the knowledge of the neighbours where the project resource is located. The query uses the wikibase service in Wikidata Query Service, passing the Latitude and Longitude of the dice: Location as center of interest that, combined with a radius (by default 1 km), will get the results shown in the map as coloured points.

This feature allows to select the points that will open a descriptive label with a few links to the main Wikidata web page where are listed all the property statements available (Fig. 3.6).

The Wikidata Query Service was chosen among others thanks to the high availability of their datasets and for the high reliability of their endpoints and servers. Unfortunately, most other interesting open data sources in the field of geospatial information that were available with their SPARQL Endpoints in the beginning of the project have their services temporarily down due to long maintenance downtime or capacity problems.

## 3.4 The BIMMS Tool-Kit Integration

The BIMMS REST APIs allow the connection of external tools to the BIMMS environment promoting the development of specific applications that can work in the different areas of the renovation process responding to the specific needs of the



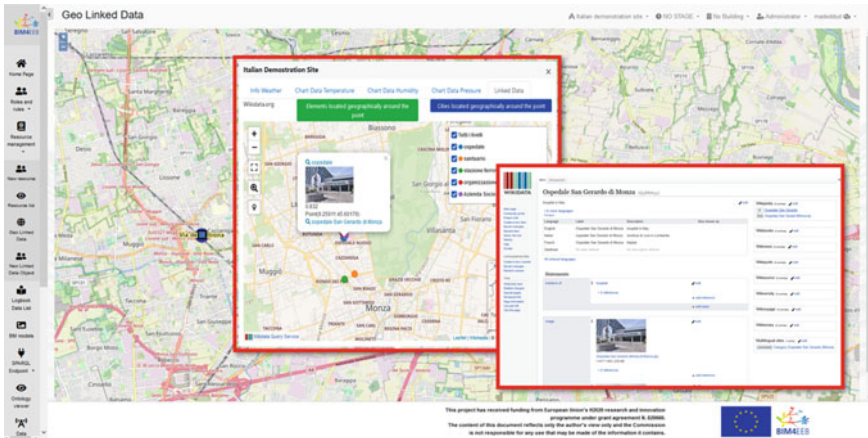


Fig. 3.6 Wikidata query service

stakeholders involved in the process itself. In the BIM4EEB project different tools have been developed according to this schema while the BIMMS REST APIs can be used to develop further applications after the BIM4EEB completion. This approach sees the integration of BIMMS and tools and requires the development of dedicated testing and validation activities that, on the one hand can assess the function of the single tools and, on the other hand, can test and validate the integration between tools and BIMMS guaranteeing the correct information flows between the two.

### 3.4.1 Tools Definition and Integration with BIMMS

As already mentioned, the BIM4EEB project sees the development of a BIMMS that allows the integration of different tools through REST APIs. The structure of the BIMMS and the integration with the dedicated tools developed in the project can be described through the following image (Fig. 3.7).

The BIM toolkit comprehend six tools integrated around the BIMMS. The tools are following listed.

- BIMPlanner.
- BIMEaser.
- Auteras.
- BIMcpd.
- Fast Mapping toolkit.
- BIM4Occupants.

The first step in the testing and validation activities consists in the identification of the main components in terms of both functionalities of the single tool and integration



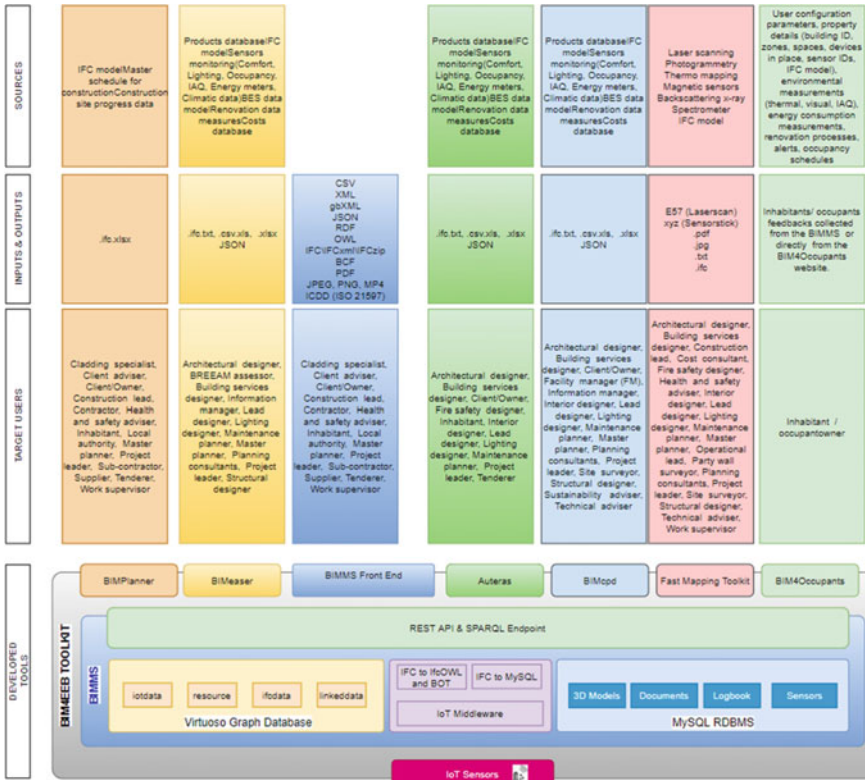


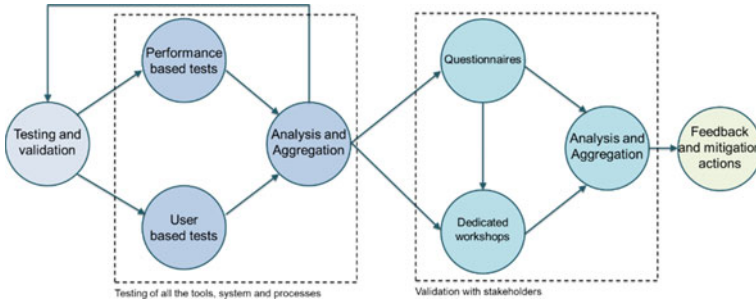
Fig. 3.7 Overview of the BIM4EEB toolkit framework

process between tools and BIMMS with the aims of assuring that these components can fulfil the project KPIs and can work with the expected performance in real environments.

### 3.4.2 Tools Testing and Validation

The testing and validation activities are based on a structured methodology that contains two main components, namely the testing actions of all the tools, system, and processes of the BIMMS toolkit, and the collection of the feedback by the stakeholders for the different components of the BIMMS toolkit with the aims of identifying mitigation actions applicable for future developments of the system. The main elements of this methodology are depicted in the following image (Fig. 3.8).

According to the series of standards ISO 29119 the testing activity has been organized according to two parallel dimensions. On the one hand performance tests have been developed considering the specific time and resources constrains of each



**Fig. 3.8** Methodology structure

toolkit component. On the other hand, the so called “*use based tests*” represent a set of tests that are related to the procedure and scenario testing developed through the definition of dedicated test cases documented according to a specific shared template defined in this methodological section and used for the development of all the activities. All the tools and the BIMMS have been tested according to this structure to guarantee both the IT performance and the capability of responding to specific use-based scenarios that can simulate the foreseen uses of the tools.

The testing activities should be considered as circular ones where thanks to the results of the testing the tools are progressively improved and re-tested to reach their final version ready for the validation activities. Hence, after the development of the testing activities and the positive results of all the testing considering both the performance based and the used based ones it is possible to move to the validation activities with the stakeholders described in the following section.

### 3.4.3 *User Feedback and Improvements*

The validation activities are based on the development of structured workshops dedicated to the different components of the BIMMS toolkit. The workshops aim at collecting the feedback of the stakeholders that may use the toolkit components to understand their perception in terms of usability, improvement of the performance, collaboration, etc. according to the KPIs identified in the BIM4EEB project. Each workshop has been organized according to the specific functionalities and application of the tools presented in the workshop itself. Nevertheless, to optimize the feedback collection from the stakeholders the workshops will use a standardized questionnaire where the questions are then scaled according to the specific needs and objectives of the workshop itself.

The feedback collection is based on a liker scale to identify the agreement or not of the respondents to specific statements about the presented tools and functionalities (Fig. 3.9).



Fig. 3.9 Linkert scale identification

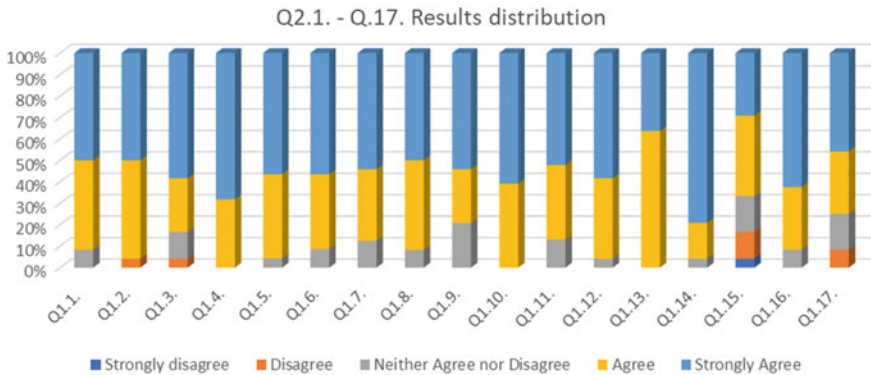


Fig. 3.10 Overview of the questionnaire results

The feedback of the user will be then used to understand if the BIM4EEB toolkit is able to answer to the needs of the involved stakeholders and to identify possible issues that should be corrected improving the toolkit itself. In the following is reported an example of the results obtained from the BIMMS workshop held in November 2021 (Fig. 3.10).

The results clearly represent that the BIMMS responds to the stakeholders’ expectations showing an alignment with the majority of the proposed statements. Only four points report a disagreement (even if with a very low percentage—around 3–5%), namely:

- Q.1.2: I find that the User Interface of the BIM4EEB solutions and their user applications have intuitive design.
- Q1.3: Thanks to BIM4EEB solutions I can easily monitor the construction works and schedules during the renovation, compared to a traditional renovation approach.
- Q1.15: I believe that I can use the BIM4EEB solutions with no technical support.
- Q1.17: I believe that my knowledge is sufficient to use the BIM4EEB solutions.

Hence future actions can be activated to provide user guides and resources that can support the stakeholders in using the BIM4EEB toolkit mitigating the highlighted points.

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