BIM for FM: Input versus Output data

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Abstract
In the last decade, the implementation of Building Information Modelling (BIM) in facilities management has significantly increased among practitioners. This has largely been due to the noticeable BIM capability in collecting, capturing and generating data/information during the lifecycle of assets through Open data standards such as the Industry Foundation Classes (IFC) and specifications such as the Construction Operations Building information exchange (COBie). However, accuracies of data and interoperability between facilities management and BIM software systems are still the main challenges for facilities managers. Thus existing applications of BIM for facilities management often output data that does not satisfy the facilities management requirements. Furthermore, the existing frameworks for overcoming the interoperability are generally inclined towards software oriented or theoretical procedures. The purpose of this paper is to develop BIM - based guidelines, which enable to integrate data between the facilities and BIM software systems to keep the data accurate and ensure the outputs achieve the required data/information for facilities management. To achieve the aim of the study, a critical review of peer - reviewed literature in BIM - facilities management and a case study are conducted. The critical review discusses the challenges, gaps and linking approaches of the peer - reviewed studies about BIM - facilities management integration. The case study is to assess the suitability of integrating a building modelling tool (e.g. Revit), Open data specification (COBie) and a facility management tool (e.g. Ecodomus) for exchanging data between BIM and facilities management environments. This paper provides practical evidence of both the challenges and the benefits of BIM in facilities management applications and also provides the requirements for successful proprietary middleware for BIM-FM interoperability.

Keywords: BIM, COBie, Facility management, Interoperability.

1 Introduction
The rise of building complexity has led to the investment of up to half the capital and operating building cost in services and facilities (Jaunzens et al. 2001). Meanwhile, Facility managers are searching for a new technology and process to face the challenge of collecting, categorizing, visualizing and updating the information for operation and maintenance and even to integrate with the design data. One technology that can facilitate the above tasks is the Building Information Modelling (BIM). BIM is emerging as a methodology for generating, exchanging and managing a constructed facility's data throughout its life cycle (Succar and Sher 2014). By visualizing the lifecycle data, BIM can improve the qualities and efficiencies of facility management functions (Motamedi et al. 2014). A BIM visualized database can increase of the efficiency of work order execution, in terms of speed, to accessing data and locating interventions (Kelly et al. 2013). Furthermore, the information stored within the BIM model can create a learning cycle, a deeper understanding and a constant improvement in the building facility life cycle (Carbonari et al. 2015). In other words, BIM can act as a data pool for all phases of the building, including the operation and maintenance phase. There is an agreement about potential applications of BIM in facility management. These applications can be

summarized to record modeling (locating building components), asset Management (creating and updating digital assets), building maintenance (planning and checking maintainability), space management (allocating and managing spaces), energy management, and emergency management (Becerik-Gerber et al. 2012, Program 2013, Eastman et al. 2011, Arayici 2015, ED Love et al. 2015). Agreed benefits and applications for BIM in facilities management practice should encourage the facilities management organizations and client to invest in BIM in their practice. However, according to a survey (Eadie et al. 2015), the implementation of BIM is rarely used with a very low figure (4.05%). There are some challenges that still need to be overcome such as identification of critical information required to be added during the operation and maintenance stage, identification of the processes for updating the designed model with as built information, lack of collaboration between stakeholders and interoperability between BIM technologies and current facilities management technologies. Research and prototype systems for facility management based on BIM are currently being developed with emerging issues of interoperability between heterogeneous data sources; however, accuracies of data and interoperability between facilities management and BIM software systems are still the main challenges for facilities managers. Thus existing applications of BIM for facilities management often output data that does not satisfy the facilities management requirements. In this paper, a contribution to the interoperability gap between BIM and facilities management technologies is added by investigating the challenges of BIM in facility management using an extensive literature review, comparing the difference methods of integrating the BIM and FM data. Furthermore, this paper evaluates one of the approaches on a real-world case study and develops a BIM- based linking approach guideline and requirements.

2 BIM-FM challenges

There is three main barriers to adopt BIM in facility management practice, which are business and legal, technical, and human and organizational. Table 1 summaries the challenges and the barriers (created by the challenges) facing the implementation of BIM in facility management practice.

Table 1: BIM-FM barriers, challenges and their description

Challenge	Barrier	Description
Perception of BIM	Business and legal Human and organizational	Lack of benefits, real world projects Lack of proof of positive return of investment Lack of standards and guidelines
Fundamental difference between project and life-cycle management	Business and legal Human and organizational	Different methodology between BIM and FM BIM implementation for running existing projects/buildings
Contractual and legal framework	Business and legal	Model contents and required data for FM Model ownership and protection of data Model exchange format Model design liability Intellectual property ownership
Trainings, roles and responsibilities	Human and organizational	Trainings Shortage in skilled BIM-FM employees Unclear roles and responsibilities Lack of collaboration between project stakeholders
Cost	Business and legal Human and organizational	Cost of software and hardware Cost of training and BIM consultant Cost of hiring new employees
Interoperability	Technical	Diversity between BIM and FM tools and platforms Open standard limitations Lack of common interest between the software's vendor

The following comprehensive summary identifies all the challenges; these challenges can be the reason of a barrier or mix between barriers.

2.1 Perception of BIM

Engagement of BIM in planning, design and construction processes has shown real benefits and applicability. There is an agreement about BIM's potential applicability in the facility management fields, and clearly BIM can act as a data pool for all phases of the building. However, there is not still enough evidence of more benefits of BIM in facility management practice to convince facilities managers/clients to full embrace this new technology, and also it is still unclear how BIM can be used and what are the requirements for successful BIM implementation in facility management (Carbonari et al. 2015, Becerik-Gerber et al. 2012). These current lacks of standards, guidelines and evidence of benefits for implementing BIM in FM practice can lead to a lack of interest from the facility managers and a lack of demand from the client, which consequently is slowing the process of implementing BIM for operation and maintenance stage in contrast with what is happening in the rest of construction industry phases (Carbonari et al. 2015). This issue should be explored and assessed through real projects, and organizational BIM guidelines developed that define BIM usage in facility management practice and detail BIM project delivery requirements (Teicholz 2013).

2.2 Fundamental difference between project and lifecycle management

The fundamental difference in project-based business and lifecycle management is one of the main challenges in implementing BIM in the facility management practice (Kiviniemi and Codinhoto 2014). Most facilities management/client firms that own or operate and manage buildings in operation and maintenance phase have already existing guidelines and some existing tools and software platforms to handle the facilities management information. These guidelines, tools and software platform are developed and chosen to be compatible with different inventories of building information, which may include computer-aided drawings (CAD) scanned drawings, physical drawings, and point cloud files but definitely not BIM. Therefore, implementing BIM in facility management practice without a new strategy will lead to waste, redundancy and unsupportable needs of information maintenance (Teicholz 2013). In other words, facilities management contracts are historically bipartite agreements, while BIM is a collaborative process. The conflict won't be solved except with implementing new strategies, which fit both (McAdam 2010). Seventy percent of the buildings that will be occupied in 2050 are already existing now (eu.bac 2015) and these existing buildings represent the greatest opportunity to improve building energy efficiency and reduce environmental impacts. Implementing BIM within facilities management organizations that have already many existing buildings in their portfolios is seen as a big concern and will require a coherent road map and strategy as well. Researchers have raised several questions related to the adoption of BIM for existing buildings operation and maintenance: "*Should the existing buildings be modeled for the new system? What is the required level of information? How much would the modeling process cost? What are the measurable benefits? Is it possible to use a hybrid system managing existing and new buildings in different environment and using different data? What problems could cause this and how long is it feasible to maintain two different systems?*"

2.3 Contractual and legal framework

Most contract forms still require the handover in paper documents and 2D drawings containing the 2D drawing sheets, equipment lists, warranties and other information. This handover way of deliverables is 2D and manually, while the design stage is produced in the virtual, collaboratively BIM environment. These differences will create some potential of ambiguity, conflict and complexity. For example, the BIM model may contain more updated data than the paper documents (Arayici 2015). To avoid that challenge, a legal contractual agreement has to be created where all parties should outline, detail and agree on what data should be involved, the model ownership regarding an owner being able to re-use the information through the lifecycle of the facility, the data format to be transferred between building phases and how it is transferred between stakeholders to avoid any congestion with unnecessary data, any repetition of work and any legal risks (Teicholz 2013, Program 2013). Furthermore, the exchange of BIM model through the design, pre-construction, construction and operation phases also raises another challenge, which is the model liability. The model legal liability can hinder the adoption of BIM in facility management practice due to the other stakeholder's concerns (designer and contractors) related to their contribution in filling the facility management data (Teicholz 2013). Therefore, defining each stakeholder's contribution and authorities is so critical in the employee information requirements (EIR). Fortunately, professional groups, such as the AIA and AGC, are developing guidelines for contractual language to cover issues raised using BIM technology (Eastman et al. 2011).

2.4 Trainings, roles and responsibilities

The majority of facilities management personnel haven't had yet a comprehensive knowledge of the available BIM implementation guidelines, standards and processes in the facility management practice. This lack of knowledge of the potential of BIM in the FM practice will lead to less interest from the FM firms and client to invest money, time and effort to implement it, therefore losing future opportunities and benefits and hinders the adoption of BIM in FM practice (Carbonari et al. 2015). Training and up-skills will help the facilities management personnel to get familiar with the BIM 3D environment, to contribute in all the phases of the building and to understand what can be achieved using BIM models and how it can be helpful to accomplish the facilities management firm's goals. Meanwhile, BIM doesn't offer new technology only; it offers new methods of collaboration, which have to enforce all the stakeholders to collaborate for modeling and model utilization (Eastman et al. 2011, Becerik-Gerber et al. 2012). Integrating BIM in FM practice will address new roles and responsibilities as who will specify the data needed and control the entry of FM data into the model during all the building phases and be responsible for any inaccuracies in it and who will take the responsibility for updating BIM data and ensuring its accuracy. All these roles and its responsibilities and duties have to be identified and mentioned in the organization information requirements (OIR) and employee information requirements (EIR) (Manning 2014).

2.5 Cost

The cost of implementing BIM in the FM firms is considered to include: BIM software cost, hardware cost, training and up-skills cost for the new process and technology, hiring employees with BIM competence for the new roles, and even sometimes hiring a BIM consultant for implementation, integration and performing pilot project to assure the firm is on the right track. Adopting BIM in the FM process needs a change in the previous process and standards which will lead to an increase in the cost (Becerik-Gerber et al. 2012). Although these new costs may be more than offset by efficiency and schedule gains, they are still a cost that someone on the project team will have to bear. Thus, before BIM technology can be fully utilized, the risks of its use must not only be identified and allocated, but the cost of its implementation must be accounted for as well.

2.6 Interoperability

Interoperability is the ability to exchange data between applications to facilitate automation and avoidance of data re-entry. Due to the diversity between the BIM platforms and the FM platforms, the interoperability between them is one of the main challenges in implementing BIM in FM practice. There are huge efforts in introducing open data standards such as the industry foundation classes (IFC) and XML schemas, and structured specifications such as the construction operations building information exchange (COBie) to solve the interoperability issue (Azhar et al. 2015). However, these afore-mentioned approaches still have their inherent limitations. Well-developed practical strategies for the purposeful exchange, compatibility and integration of meaningful information among the BIM model components to the different FM information systems such as computerized maintenance management systems (CMMS), electronic document management systems (EDMS), building automation system (BAS), and energy management systems (EMS) are required for overcoming the interoperability challenge needed.

A number of researchers, practitioners, FM companies, software vendors and professional organizations are working hard to resolve these challenges; it is expected that the use of BIM will continue to increase in the FM practice. Most of the efforts are focusing only on the business and legal barrier and human and organizational barrier and neglecting the technical barrier. However, the entire theoretical framework of BIM data being used for facilities management is predicated on the assumption that data can be exchanged easily between software programs, specifically BIM and FM (Kensek 2015). Some software vendors and researchers worked to overcome the technical barrier (interoperability challenge) and provided different approaches to link easily and smoothly between the BIM data and the FM data. These linking approaches are discussed in details in the ensuing section.

3 BIM-FM Linking Approaches

Researches and prototype systems for the link between facility management and building information modeling are currently being developed to solve the interoperability challenge between BIM and FM (Kang and Hong 2015). Different approaches were developed and suggested using one of five methods or combination between some/all of these methods. The five methods are as following

- Design pattern and Application programming interface (API),
- Web service,
- Extract, transform & load (ETL) and data warehouse (DW),
- BIM-based neutral file format,
- Information delivery manual (IDM) and Model View Definition (MVD).

The main four approaches are based on one or some of these methods (Table 2). The four approaches are manually and spread sheets, Industry Foundation Classes (IFC), Construction Operation Building Information Exchange (COBie), and Proprietary Middleware.

Table 2: BIM-FM linking approaches and the corresponding methods to achieve the approach

Approach	Methods
Manually and spread sheets	Extract, Transform & Load (ETL) and Data Warehouse (DW)
Industry Foundation Classes	BIM-based neutral file format
Construction Operation Building Information Exchange (COBie)	BIM-based neutral file format Design Pattern and application programming interface (API) Extract, Transform & Load (ETL) and Data Warehouse (DW)
Proprietary Middleware	BIM-based neutral file format Design Pattern and application programming interface (API) Web service Extract, Transform & Load (ETL) and Data Warehouse (DW) Information Delivery Manual (IDM) and Model View Definition (MVD)

These approaches are explored in further detail as following:

3.1 Manually and spread sheets

Owners utilize either a CMMS or CAFM system to input information manually or costumed spreadsheets by the facility manager from the BIM data and paper documents into digital files compatible with the FM systems (Arayici 2015). With manually and spread sheets approach, inputting, verifying, and updating the information in FM systems is a costly and time-consuming process and meanwhile no validation on the quality of the data entered. However, the only advantage of this approach is the facility team can operate without any changes in their work process.

3.2 Industry Foundation Classes (IFC)

Industry Foundation Classes (IFC) is an open, vendor-neutral BIM data repository, specified and developed by buildingSMART, for the semantic information of building objects, including geometry, associated properties, and relationships to facilitate cross-discipline coordination of building information models, including architecture, structural, and building services, data sharing and exchange across IFC-compliant applications, and handover and re-use of data for analysis and other downstream tasks (Thein 2011). IFC is an object-oriented database of information that enables data sharing via ifcXML and aecXML. This is especially effective for interoperability among BIM authoring applications, such as AECOsim Building Designer, and analysis applications to calculate quantities and costs, heat loss, cooling loads, lighting requirements, etc., or to handover data to facilities management applications for operations and maintenance. However, this also means that when importing IFC, applications must interpret and transform imported objects to their native objects as best as possible. As a complete 1-to-1 match is typically not possible, imported elements differ from natively created elements. Therefore, round tripping (importing an IFC file into the application that exported it or any other IFC-compliant application without any loss of data or functionality) of IFC data is an unrealistic expectation. Additionally, there are some software applications are still not compatible directly or indirectly with IFC (Arayici 2015).

3.3 Construction Operation Building Information Exchange (COBie)

Construction Operation Building Information Exchange (COBie) approach is to enter the structured data as it is created during design, construction, and commissioning (Program 2013). Designers provide floor, space, and equipment layouts. Contractors provide model, and serial numbers of installed equipment. Much of the data provided by contractors comes directly from product manufacturers who also participate in COBie. At the early stages of design, the vertical and horizontal spaces that are necessary to fulfil the district's requirements for the building, facility, or infrastructure project are defined. Within these buildings, facilities, or projects are also defined the different types of systems, which can include electrical, heating, ventilating and air conditioning (HVAC), potable water, wastewater, fire protection, intrusion detection and alarms and other systems. COBie looks promising the interoperability bridge between the design and construction stages with the operation and maintenance stage. However, COBie hasn’t reached the maturity enough to be successful and encourage its implementation. The main problems with COBie implementation are it is seen as a spreadsheet instead of an xml based information exchange, it was developed in silos; it doesn’t work with software firms and guideline organizations to better integrate with systems and classification, and undefined outputs from COBie demanding organizations (John 2013).

3.4 Proprietary Middleware

Proprietary middleware is a computer software that designed by a single company which provides services to software applications beyond those available from the operating systems. This approach finds a link between the BM and FM systems, sometimes a bi-directional link, using programing languages and application programming interfaces (API), design pattern, web services, and BIM-based neutral file format such as open data standard (IFC) and data structure specifications (COBie). The benefits of this approach are enabling two separate systems (BIM and FM) to interact, providing a single source of information, reducing the human errors, and updating the information dynamically. However, it has high cost, complex process and the implementation is fixed during programing in proprietary middleware approach (Kang and Choi 2015). One of the most successful proprietary middleware for BIM-FM integration in the real-world market is Ecodomus.

4 Case Study

The research aim posed at the start of this paper was to investigate the challenges and linking approaches of BIM in FM for assets. A case study was collated and aimed to investigate one of the most successful proprietary middleware for BIM-FM integration in the real-world market (Ecodomus). EcoDomus has been used on Sydney opera house and other important lifecycle BIM projects in the world. Ecodomus consists of two applications, which are EcoDomus PM and EcoDomus FM. EcoDomus PM (“Project Management”) is a versatile software solution dedicated to enabling the usage of Building Information Models (BIM) and lean processes for new construction or renovation of existing buildings. EcoDomus PM helps collecting and cleaning BIM data and supports project data management in a web-based platform. Meanwhile Ecodomus FM a software application that provides for real-time integration through hyperlink and data integration of BIM with Building Automation Systems, like Siemens, Honeywell, Johnson Controls, or others, with CMMS/CAFM/IWMS software like IBM Maximo, ARCHIBUS, AssetWorks AiM, Accruent FAMIS, TMA Systems’ webTMA, Corrigo, or others, and GIS from ESRI (ArcGIS) and Google (Google Earth). EcoDomus FM can serve as a part of Central Facility Repository (CFR) helping owners keep data always up-to-date across the applications and databases. In addition to Ecodomus and Revit in this case study, Dynamo was used to create 3D rooms to visualize the rooms’ volume in 3D views. Dynamo is a visual programming language that can interface with Revit for the creation of custom tools (Figure

1b). The case study was conducted on town house villa in United Arab of Emirates (Figure 1a). In order to create the model, the researcher used the as-built floor maps, elevations and sections provided by the main contractor and the mechanical specifications and types. The model was completed with filling the shared parameters and Ecodomus attributes in approximately 40 hours, with an average of 20 m^2 completed every hour.

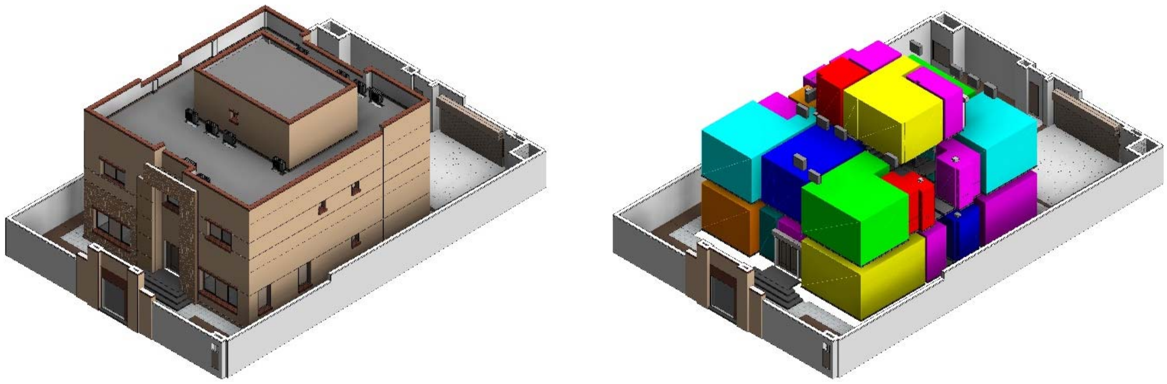

Figure 1: Town Villa 3D model created on Revit 2016 and 3D automatic volumes created by Dynamo.

As mentioned, Ecodomus consists of two modules, having two workflows, to process the building data. To evaluate the performance of this software for various applications of FM, an analytical analysis was performed. A checklist of various features was prepared. The Ecodomus PM has an add-in for Revit, which generates virtual rooms and detects the assets inside these rooms. These information are added to the related parameters and exported into the web-based interface automatically and instantaneously as they are generated using the application programming interface (API). The API encapsulates data processing procedures into a simplified interface. The user interface of Ecodomus is divided into six main parts: COBie, Reports, BIM server, Activities, Project setup, and integration. The COBie parts are divided almost like the COBie sheets. Data can be entered on the web-based application and synchronized with BIM native model (Bi-directional). Figure 2 illustrates different tabs in the COBie part in the EcoDomus interface and shows that all the types and floors are collected and sorted automatically, meanwhile the instance equipment (components) are automatically located, and a parameter added for its location based on the virtual rooms generated in the Revit model.

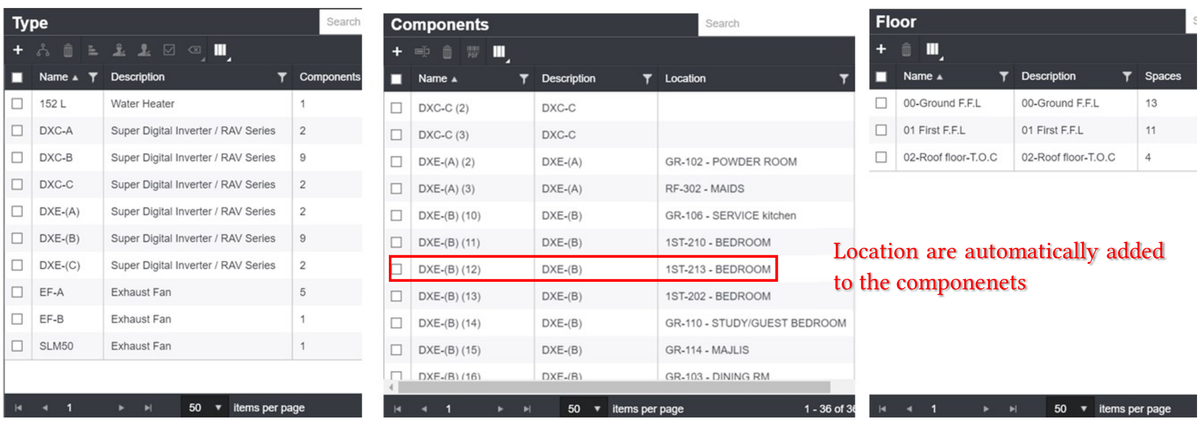

Figure 2: Ecodomus COBie interface

The input data entered in the Revit model is completely the same like the exported data in the COBie spreadsheet through Ecodomus (Figure 3). However, Ecodomus can't work with Revit linked files, although the BIM experts agreed that most probably the Revit rooms are in different models (architectural models) than the mechanical equipment ones (MEP models). Furthermore, the shared parameters are not automatically added to Revit model, and the author encourages adding them automatically for overcoming the lack of knowledge of the BIM team for the required parameters for operational and maintenance phase.

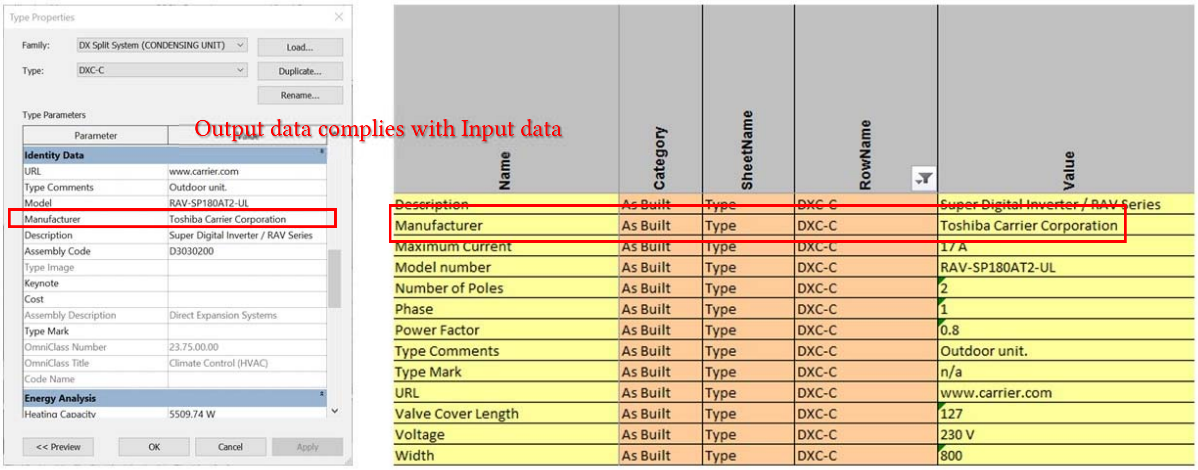

Figure 3: Ecodomus exported COBie spreadsheet (Output Data) VS Entered data in Revit shared parameters (Input Data)

In summary, Ecodomus package (PM and FM) provides a smooth data export from Autodesk Revit to a secure online database (more BIM authoring apps support is on the way), online data entry and editing for all COBie entities, documents uploading and attaching to BIM objects, 3D model navigation; COBie excel files importing and exporting, and the integration of BIM with systems and processes used to maintain and operate the facility, such as CMMS, CAFM, BAS, GIS, and ERP. Ecodomus provides a methodology for capturing and transferring critical design and construction data (input data) at closeout directly into operation and maintenance systems (output data).

5 BIM-FM linking guideline

A proprietary middleware BIM based guideline for facility management integration is illustrated in Figure **4**. The platform is composed of bi-directional add-in for the BIM platform and a web-based application. The add-in has to achieve the required functions such as automatically creates 3D rooms, automatically detects the object is contained within which room and fill the convenient parameter, runs a quality check, and works and detects the linked objected from other files. Meanwhile, the add-in has to create the required parameters for FM, defines the Uniclass-2 classifications and defines the stage where each parameter has to be filled. On the other hand, the web-based part has to integrate with geographical information systems (GIS, visualizes the data in 3D views and 2D plan views, comprehends the ability to use the defined facilities in different projects and upload and attach documents to each facility, and its database works with SQL and Non-SQL and integrates with different databases like BMS and CAFM. This guideline can be used by BIM vendors and construction companies that want to perform BIM-based FM integration and ensure the output data for the facility management systems comply with the input data in the BIM systems by designers and contractors. This conceptual guideline is still in its infancy stage as this is an on-going research project, it is hoped that this framework will be further refined and validated.

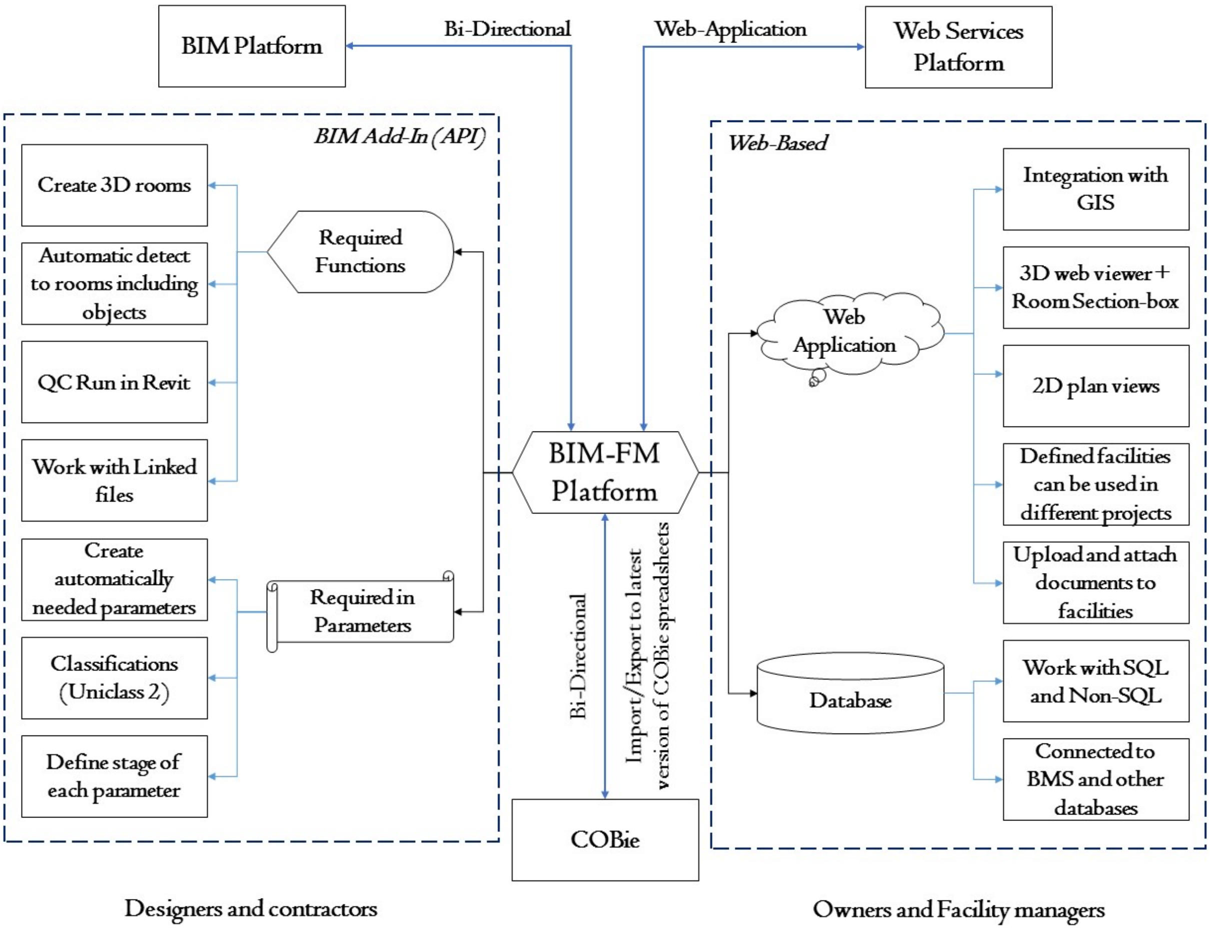

Figure 4: BIM-FM proprietary middleware platform guideline

6 Conclusion

This paper aims to generate and visualize effectively information required and ensure the accuracy of information (output information complies with input information) for facility management decision making by realizing BIM-based mining of data per connecting it to more various heterogeneous systems based on the proposed architecture of the proprietary middleware. To achieve this goal in this paper, two research methods that build on each other – i.e. review of existing studies and a case study approach using one of the successful systems in the BIM-FM integration – was conducted. The findings from the literature review provided the evidence that there are challenges that are hindering the exploiting of BIM in facility management. The six main challenges are perception of BIM, fundamental difference between project and life-cycle management, contractual and legal frameworks, trainings, roles and responsibilities, cost, and interoperability. Meanwhile, the literature review defined the difference approaches for linking data between BIM and FM systems and their benefits and barriers. The main four linking approaches are manually and spread sheets, industry foundation classes, construction operation building information exchange, and proprietary middleware. The case study was piloted using Ecodomus software (one of the successful proprietary middleware systems in linking BIM and FM). The findings from the case study provided, the evidence that there are plenty of benefits in using proprietary middleware such as providing information on web-based application, visualizing FM data on 3D elements, providing a single source of information, reducing the human errors, and updating the information dynamically. However, it has high cost, complex process and the implementation is fixed during programing in proprietary middleware approach (For example, Ecodomus can't read linked elements in Revit files and doesn't define the needed parameter in the BIM platform). Finally, this paper based on the literature review and case study suggests the overall architecture and functionalities of different components of an integrated BIM FM system to ensure input-output data comply based on the portal solution with regard to the status quo of the subject area in both theory and practice.

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