EFFECTIVE FACILITY MANAGEMENT AND OPERATIONS VIA A BIM-BASED INTEGRATED INFORMATION SYSTEM

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ABSTRACT

Purpose: The purpose of this paper is firstly to summarize the status quo of the building information management technologies applied in the facility management and operations (FM&O) sector and identifying prevailing issues; and secondly, to devise technical solutions for those issues based on an exemplar case.

Background: Considerable financial losses could occur as the result of insufficient interoperability issues among information systems. In order to minimize losses, Building Information Management (BIM) tools must be able to interoperate with a variety of digital FM&O systems.

Approach: This research applies the principles of grounded theory as well as conceptual constructs of a proposed BIM framework. Firstly, descriptions of information management systems of eleven projects in technical reports are analyzed and the prevailing technical issues extracted. Then, a narrative representation of an IT-implementation project together with its organizational context has been provided. Finally, the most important issues from recent projects have been presented together with their respective solutions provided by the case project.

Results: The results demonstrate that the most important issues in implementing BIM for streamlining FM&O activities are lack of guidelines and efficient technologies for capturing BIM models of existing facilities, coping with non-consistent terminologies and taxonomies, requirements specification in BIM applications, and identifying which information and what levels of detail are desired by the FM&O teams.

Practical implications: In addition to scholars, the results are useful to database implementers and database designers, as well as decision-making buddies in the FM&O sector.

Research limitations: More research in this area is needed with a focus on business processes and regulatory requirements.

Originality/value: No earlier research has so thoroughly described the overall architecture and functionalities of different components of an integrated BIM FM portal solution with regard to the latest findings in both theory and practice.

Keywords: BIM FM, facility management, FM&O, building information modelling, interoperability

1 INTRODUCTION

Facility managers of corporations are responsible for the operation and maintenance of assets. This constitutes a considerable share of their annual expenditures. In the building industry, 85 percent of life-cycle costs of a facility occur post construction (Jordani, 2010). Accessibility of the required information is essential to any efficient facility management and operations (FM&O) practice (Teicholz, 2013) i.e. lack of information dramatically lowers the efficiency of maintenance activities (Motawa & Almarshad, 2013).

In recent years, Building Information Management (BIM) technologies have substantially influenced information management practices throughout the entire building industry. BIM has demonstrated potential for tackling problems induced by insufficient access to information in all phases including FM&O (Sabol, 2008). Facility owners are now pursuing a variety of business objectives by using BIM including but not limited to reducing operating and maintenance costs, improving service delivery, streamlining business processes, underpinning and optimizing future building modifications, and consequently achieving higher return-on-investments (ROIs) (Aspurez & Lewis, 2013; Teicholz, 2013; Eastman, Teicholz, Sacks, & Liston, 2011; Khemlani, 2011; Jordani, 2010; Ding et al., 2009).

Nonetheless, there are three major obstacles against leveraging BIM for FM&O in its full capacity, namely IT provisions, business processes, and contracts (Parsanezhad & Tarandi, 2013; E. W. East, Nisbet, & Liebich, 2013). The three categories correspond to the three industry foundations constituting the IFC (Industry Foundation Classes) standard which are articulated by Owen (2009) as technologies, processes, and people, as well as the three fields of activity formulated in the BIM framework developed by Succar (2009), i.e. technology, process, and policy.

This paper is a qualitative work that is based on the principles of grounded theory. It mainly addresses how the first obstacle (IT provision) can be overcome. A summary of the literature on implementation of BIM for FM&O is provided, an example of such systems is described, and its components and functionalities are analyzed in relation with the findings of the literature review. The purpose of this paper is twofold: firstly, to summarize the status quo of the building information management technologies applied in the facility operation activities and identifying prevailing issues and impediments; secondly, to devise technical solutions for those issues based on an exemplar cutting-edge case.

2 STATE OF THE ART

2.1 Technological BIM FM integration solutions

Considerable financial losses occur as the result of insufficient interoperability issues among information systems in the building industry. A substantial proportion of these losses is attributable to the FM&O sector (NIST, 2004). Owners are willing to use BIM to enhance their operation and maintenance activities and to minimize or eliminate losses (Jordani, 2010). BIMenabled information systems are aimed to seamlessly convey the information from design and construction models and databases to actors within the FM&O sector. Such systems must be capable of interacting with other digital tools that are already used in the sector. FM&O staff work with a variety of tools ranging from paper and pencil to spreadsheets, Computerized Maintenance Management Systems (CMMS's), Computer-Aided Facility Management (CAFM) tools, Document Management Systems (DMS's), Building Management Systems (BMS's), Building Automation Systems (BAS's), etc. (Lewis, 2013a; Jordani, 2010).

CMMS's are deployed for asset management, generation of service requests, managing work orders of different types, calculating/tracking required/used resources for planed/executed jobs, keeping employees records, and inventory of managed assets (Sapp, 2013; Lewis, 2013a). FAMIS (by Accruent), IBM Maximo, Corrigo, WebTMA (by TMA Systems), and AiM Maintenance Management (by AssetWorks) are some commercial example of CMMS's. FAMIS uses an ORACLE database which is integrated with financial databases (Aspurez & Lewis, 2013).

CAFM systems are a combination of Computer-Aided Design (CAD) and relational database software aimed for space management i.e. administering room numbers, departments, usable heights, room areas etc. (Sapp, 2013; Lewis, 2013b; B. East, 2013). Most contemporary CAFM systems still acquire manual querying and updating routines such as overlaying polygons on drawings (Aspurez & Lewis, 2013). FM:Interact (by FM:Systems), Archibus, and AiM Space and Facilities Management (by AssetWorks) are some commercial examples.

Despite the widespread acknowledgement of advantages of implementing BIM technologies for operating facilities, the adoption of as-built BIMs within FM&O is still more a vision rather than a reality (Teicholz, 2013). This is partly attributed to the large variety of CMMS's, CAFM systems, and DMS's. Sporadic examples of such adoption have nevertheless emerged in recent years namely the Revit-compatible version of Archibus (Jordani, 2010).

The cutting edge technical solutions in the field can be categorized as seen in Table 1 (after Teicholz, 2013; Lewis, 2013a). Construction Operations Building information exchange (COBie) is an open data transfer specification developed by the U.S. Army Corps of Engineers which facilitates delivery of managed asset information by using low-level formats such as the Excel spreadsheet (E. W. East & Carrasquillo-Mangual, 2012; Sabol, 2008). In Table 2, a number of real-world applications of the above initiatives are briefly introduced.

Table 1: Today's technical solutions for optimizing information transfer from BIM to FM&O software

Solution	Technical approaches for linking information
Using spreadsheets as simple document indexing tools	Hyperlinking
Using spreadsheets according to COBie guidelines	Hyperlinking, exchanging and synchronizing data
Using the IFC format for exchanging building information among BIM and FM&O systems	Exchanging and synchronizing data (embedding and integrating data to the recipient system)
Coupling CMMS's with BIMs via Application Programming Interfaces (APIs)	"Portal solution"
Using proprietary middleware such as EcoDomus, Onuma Systems, and FM:Interact	"Portal solution"

Table 2 - A number of recent real-world applications of BIM for FM&O

Project	Approach and achievements	Issues	Source
Sydney Opera House	A unified central data repository was devised by integrating information from different resources.	There was no detailed methodology for capturing existing facilities as an accurate object-based building	(Ding et al., 2009; Moffat, 2013; Sabol, 2008; Schevers et al., 2007)
A pilot project by the US General Services Administration (GSA)	The objective was to transfer the records from the modelling tool (Revit) to the CMMS (Maximo).	Only 17 percent of the records in Maximo could be matched into Revit fields.	(Teicholz, 2013)
A federal project in New Jersey	It was planned to use COBie for transfer of data from BIM to the CMMS or CAFM systems. Onuma Systems was used for validating COBie deliverables.	The biggest problem was to identify which information was important for FM&O. Another challenge was to select a suitable CMMS in advance. The implementation of COBie has not been fully realized yet.	(Teicholz, 2013)
A federal project in Minneapolis	Their strategy was to engage the FM team in early modeling efforts.	Early identification of FM-specific systems and zones in the design model proved to be difficult, since the FM team was merely interested in as-built models and close-out documentation. The modeling team believed that there was no clear way to specify detailed data requirement in BIM compared with earlier drafting tools.	(Teicholz, 2013)
A project for integrating disparate BIM, CMMS, and BAS systems of a courthouse	OmniClass Table 13 and Uniformat standards were used to specify space types as well as the facility data classification levels i.e. spaces, zones, components, and systems. CMMS's and inventory spreadsheets were the sources for collecting data for the project.	Naming conventions and data structures developed by local key personnel hindered interoperability among systems.	(Teicholz, 2013)
Mathworks project	Information synchronization through FM:Interact-Revit integration and early presence of the FM&O manager in the conceptual design phase were the main strategies. COBie was used as a reference source and as a standard rather than a transfer format. The time spent for space planning was reduced to one-tenth.	Ambiguities with specifying the level of detail (LOD) of the FM model and use of non-standard internal naming, numbering, and classification conventions for spaces and assets by the client significantly hampered the project.	(Aldaham et al., 2013)
Information administration of an existing health science center	Importing submittals of an existing health science center to TOKMO (now EcoDomus) via COBie format helped reducing the average work order duration by 8.7%. OmniClas was used for classifying the assets.	No direct integration of the CMMS data with the BIM model or linking among them was realized.	(Beatty, Eastman, & Kim, 2013)
A construction project at the University of South California	Information from BAS, CMMS (e.g. assets records), and DMS (e.g. warranty documents) were decided not to be imported to Navisworks rather be linked to within the FM system. Equipment and component schedules were composed using parametric attributes rather than hard-coded Excel entries. They had to use a wide assortment of both industry-wide and internal standards i.e. OmniClass for equipment names, and National CAD standards for equipment abbreviations, types, and instances.	Varying information requirements according to the organizational role of the FM&O actors alongside with varying naming conventions, LODs, and the varied types of data available for different assets were major challenges in the data collection phase.	(Aspurez & Lewis, 2013, p. 197)
The construction project of Xavier University in Cincinnati, Ohio	FM:Interact Space Management module was deployed for synchronizing room and element data with Revit. A person-year of data entry was avoided.	The main challenge was integrating the CAFM system (FM:Interact) with the CMMS (WebTMA).	(Afedizie et al., 2013)
A residential hall at University of Wisconsin	Revit models were exported to IFC format and imported to the CMMS (TMASystems). A SQL database was then implemented for processing the information residing in the CMMS.	The equipment and room types were not defined prior to importing information to the CMMS. This slowed down the process. Another problem was that default values for the MEP equipment, e.g. airflow for the air handling units (AHUs) were inserted instead of real values. It was also difficult to specify whether the information was as-designed or as-built.	(Lewis, 2013a)
A renovation project in the University of Chicago	The participants firstly specified the types of information to be collected, how to organize the information, and how to map the information onto the CMMS (Maximo). A set of drop-down menus and pick-lists were maintained in the translational tool to handle inconsistencies among naming conventions used by design, construction, and FM&O practitioners	Since the fields mandated by COBie did not fully align with the needs of the project, COBie was replaced by a translational spreadsheet produced by a third-party database consultant.	(Lewis, 2013b)

2.2 Towards an integrated solution for a more effective FM&O practice

As evident in some of the examples introduced in previous section, the COBie initiative is helpful as a set of guidelines for identifying which data should be collected and by whom. Nonetheless, there are some downsides to implementing COBie as a standard format for conveying information to the FM&O team, e.g. mismatch of mandatory information fields in COBie with those necessitated by the business goals of each specific organization, and lack of incentives for manufacturers to provide their product information in a COBie-compatible format.

IFC format and its associated Coordination Model View, on the other hand, have not been successful in providing consistent semantics for all stakeholders. The IFC schema is often deemed to be too rigid to be implemented during all life cycle stages of the facility (E. W. East et al., 2013; Tarandi, 2011). Another problem with IFC export as a means for information transfer to FM&O is the large file sizes and populated information that is not totally relevant or useful for FM&O (Lewis, 2013a). Such problems can be overcome in the future by development and implementation of Model View Definitions (MVDs) [1] specific to FM&O.

Middleware solutions are relatively expensive, but are commonly used successfully by sizable organizations such as NASA and GSA. "BIM for FM Portals", emerging some years ago (Jordani, 2010) are the most appraised FM&O information handling systems. Portals are simple and flexible from user's perspective. They provide windows to different FM&O systems and directly interact with CMMS's, DMS's, and BAS's. Technicians prefer to be able to use their own downstream systems for troubleshooting. Portals fulfill this requirement and perform queries on the model in the background (Aspurez & Lewis, 2013). Portals are flexible enough to comply with a wide variety of FM&O software, and are relatively inexpensive to develop and run (Sabol, 2013).

3 APPROACH

3.1 Theoretical framework

Among the variety of definitions of the acronym BIM (Eastman et al., 2011; GSA, 2011; Howard & Björk, 2008) and a number of proposed frameworks for research around BIM (Gu & London, 2010; Jung & Joo, 2011), the definition and research framework provided by Succar was deemed the most appropriate and clarifying one for the purpose of this study. He defines BIM as "a set of interacting policies, processes and technologies producing a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle"(Succar, 2009, p. 357). The definition is, in turn, based on an earlier definition articulated by Penttilä (2006, p. 403).

Succar regards BIM as a modern framework for organizing domain knowledge which is in turn based on the definition of "Frame" by Minsky. According to Minsky, new frameworks (in this case, Succar's BIM framework) may be invented for new conditions or substantial changes (in this case, development of BIM technology and tools) and applied by the researcher for representing stereotyped situations (Minsky, 1974). Among the three fields of activity within

[1] http://www.buildingsmart.org/standards/mvd (accessed 20 February 2014)

BIM, our research lies in the “Technology field” and is focused on the sub-fields of software and network solutions (Succar, 2009).

3.2 Methodology

The research field of building information management in general and information management tools for FM&O in particular, is rather new and overwhelmed by empirical findings and influences of new information technologies. Hence, theory-driven and linear models have been deemed inappropriate for the purpose of this study. Instead, the principles of grounded theory (Flick, 2009) have been followed and the knowledge derived from an exemplar case project has been used to complement existing literature in the field. Grounded theory is a method for qualitative studies which was introduced by Glaser & Strauss (1967) and is based on initiating the research with data collection and subsequently seeking codes, concepts, and categories that help further formulation of theories.

Firstly, the literature about some ad-hoc solutions has been consulted for presenting the status quo. Descriptions of information management configurations in eleven projects have been derived from technical reports and analyzed to extract technical issues prevailing in existing solutions.

Then, a narrative and illustrative representation and reconstruction (Flick, 2009) of a progressive IT-implementation project in the field together with its organizational context has been provided. One of the advantages of an original analysis of case studies over other methods for collecting data about information systems, e.g. interviews and surveys, is less subjectivity (Bakis, Kagioglou, & Aouad, 2006) and less distortions (Harris, 2001). The choice of the case study is a purposive sampling. This approach improves the efficiency through collecting the data that is relevant to the objectives of the research (Morse, 1998).

The observed case fulfills the requirements of a “primary selection” in that the required information is readily available to the authors. One of the authors is the designer of the system and thus has the double roles of researcher as well as the participant in the case project. This is also a retrospective study since it uses secondary data collection in an after-the-fact manner. As a criterion for studying the case project and based on the descriptions of the third dimension of the BIM framework suggested by Succar (2009), i.e. BIM Lenses, a mesoscopic lens within the FM&O domain has been applied as a mental construct for research in this field. BIM lenses are applied to Fields and Stages and are defined layers of analysis that “allow the domain researcher to selectively focus on any aspect of the AECO industry and generate knowledge views that either (a) highlight observables which meet the research criteria or (b) filter out those that do not” (Succar, 2009, p. 367). A Mesoscopic Lens implies medium coverage, focus and detail (Succar, 2009).

Finally, the most important issues from recent projects have been presented in three categories together with their respective solutions provided by the case project.

4 CASE STUDY: FM&O AT UNITEC INSTITUTE OF TECHNOLOGY (UNITEC)

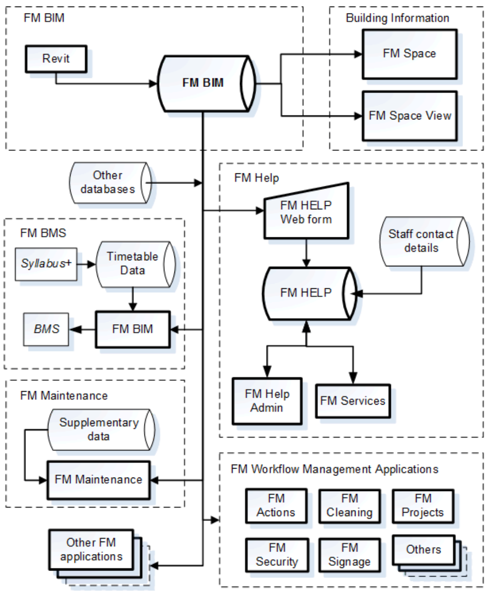
In this section, the technical specifications of a BIM-driven solution developed at Unitec are studied and illustrated in their organizational context. This project has been selected for the study as it exhibits excellence in several aspects. The Unitec’s FM System integrates BIM with FM&O processes; it facilitates FM&O actors’ access to information sourced from the BIM models by sharing it with downstream applications; the implementation of the system and its applications have led to improved workflow, more effective communication of the facility information to the end users, as well as considerable costs savings in several areas.

Unitec is a tertiary education facility with three campuses in Auckland, New Zealand, serving more than 23,000 students each year, and with about 800 staff members. Its Facilities Management (FM) department is located in the main campus and is managed under the directorate of Finance & Infrastructure, which is responsible for assets with a current total replacement value of approximately US$300 million.

4.1 BIM and FM Information Integration at Unitec

The BIM project started in 2008 following a decision to undertake an in-house development of an integrated suite of FM software applications to assist with the day to day operations and to support more efficient information management. One reason behind the decision was the unavailability of a suitable off-the-shelf product for this purpose. "FM Desktop" was a promising tool, but it was discontinued soon after being acquired by Autodesk. Archibus only dealt with 2D plans and was not BIM-compatible at the time. Also, the available commercial software applications all used proprietary database systems and did not allow for user customization. Furthermore, none of them provided any BIM integration with the FM&O workflow, which was one of the main criteria behind the project. Within the project, two mainstream activities were carried out consecutively: constructing information-rich object-based models of the campus, and leveraging IT solutions for connecting those BIMs to the FM systems and databases.

Figure 1: Unitec's FM System Overview



Using an earlier repository of CAD files called "base drawings" and complementary site surveys, a total of 191 buildings were modeled in Revit over 4 years and in three different stages, i.e. building shells; internal walls, fixtures & fittings, and roofs; space objects and other properties. The next phase is to add building services, and to incorporate underground infrastructure and above-the-ground assets such as trees, roads, and lamp posts into the campus model that is being developed.

A software tool was written using Revit's API to automatically update or synchronize the model data at the end of each modeling session with a centralized database in a SQL Server DBMS (database management system). This is the core component of the in-house developed client/server FM Applications Suite, some of which are described in the following sections. The tool also generates Portable Document Format (PDF) floor plans, images of each space, and a normalized representation of the building geometry in Extensible Markup Language (XML) format for post-processing, e.g. energy analysis. An IFC file of each model is saved together with the Revit model in the repository and used for general post-processing and visualization.

A number of downstream applications can access the centralized database linked to the BIM models and update various information as required, which would then automatically update the models when they are subsequently opened for editing. A brief description of the Unitec's FM System is given in Figure 1. A number of key components of the system are described below.

4.2 FM Help and Workflow Management Downstream Applications

FM Help is a help desk system developed for managing the unique work flow requirements within FM&O. The system provides a simple online form accessible on the intranet across all campuses, which is prepopulated with the essential information sourced from the BIM models, e.g. building and space numbers, departmental charge codes, and contact details of the person logging the job. Anyone on campus can log a job to request general repairs and maintenance, to notify health & safety issues, and to keep track of each job's status. Upon submission, the information is immediately available on the FM Help Admin system for moderation purposes. Once checked and verified, the job request is then assigned to the appropriate sections within FM&O and becomes available on their respective workflow management applications, e.g. FM Actions, FM Security, FM Cleaning, FM Vehicles, and FM Signage which are all web-based and accessible on desktop or portable devices anywhere on the campus.

4.3 FM Space and FM Space View for communicating building information

FM Space and FM Space View are web applications that provide access to spatial information and a set of BIM-generated floor plans in various scales. For teaching spaces such as classrooms or lecture theatres, the available equipment in each space is also listed so that the user can look up what teaching facility is available, e.g. data-show, PC, etc. At the moment, the list of equipment is derived from a database that is managed manually via an application called FM Equipment. Eventually, the equipment data will be incorporated into the BIM models, which will provide another means of updating the information automatically. Space utilization data derived from the BIM models are used for the institutional finance and accounting purposes, but also for automatically generating various regional FM statistical reports, e.g. Tribal, TEFMA, etc.

4.4 FM BMS

FM BMS application interfaces with the BMS to control the HVAC in bookable spaces. The application continuously checks the room-booking timetable database for any scheduled or one-off booking information. It sends an instruction to the BMS to turn on the ventilation or air-conditioning system half an hour before a room is scheduled to be occupied, and an instruction to turn it off 5 minutes before the end of the booking period. This has provided a huge energy saving in comparison with the previous preset daily on/off mode of operation.

4.5 FM Projects

FM Projects application provides the Projects office with an online tool to manage capital projects, e.g. new and major building works, and relocation projects. As part of the new project setup, a new record is created in the BIM models maintenance schedule, which will remain active until it is ticked off after the model is updated with the as-built information handed over to the FM office. FM Projects also provides workflow management as well as costs management functionalities. Currently, information handed over to the FM office is still in the form of printed drawings or CAD files. However, work is in progress to implement a method of assimilating as-built information directly into existing models.

4.6 FM Maintenance Costs

FM Maintenance Costs application extracts interior and exterior surface areas, and condition ratings from the BIM models, and allows managers to specify various parameters such as repair or replacement costs, and then generates maintenance cost schedules. Space condition audit is carried out visually by observation as required, but at least once every couple of years. Space condition rating is then determined by using the weighted average of all interior surface condition ratings of that space as per NAMS (NAMS, 2006) in the scale of 1 to 5.

5 RESULTS

The Unitec's FM System is a web-based portal solution which serves all functions of CMMS's, CAFM systems, and DMS's, and at the same time integrates and seamlessly and reliably synchronizes the underlying FM&O building information databases with the BIM models. In Table 3, most significant problems in the field (derived from literature and presented in Table 2) are presented together with their respective solutions provided by the Unitec's FM System.

Table 3: Issues with current FM&O information systems versus provisions in the Unitec's FM System

Issues with current FM&O information systems	Provisions in Unitec's FM System
Issues with as-designed and as-built information	
▪ Issues with identifying which data are important for FM&O	The solution has been developed by the FM department of Unitec and thus directly addresses the requirements of their FM team on information types and LODs.
▪ Issues with specifying LODs required for the FM model	See above.
▪ Varying information requirements according to the organizational role of the FM&O actors	See above.
▪ Non-useful information coming from design- and construction-intent models	BIM models were constructed and populated in conformity with the needs of the FM&O staff.
▪ The variety of industry-wide standards, local naming conventions, and data classification structures, and established colloquial names deployed in various FM&O information sources of the facility	An in-house developed BIM Standard and Conventions handbook is used, which is based loosely on commonly used industry standards.
Issues with FM&O systems	
▪ Lack of knowledge for specifying a CMMS early in the design phase	Not applicable to this project since the system was developed for existing facilities.
▪ Proprietary database systems not allowing for customization	An industry standard, DBMS (SQL Server-ISO/IEC 9075), has been utilized to maximize data interoperability and to facilitate system maintenance. Further efforts for using IFC more centrally in the system are in progress.
▪ Information fields in the CMMS's not matching those in the BIM authoring tool	The same SQL DBMS that is derived from the BIM model also feeds information to the FM&O applications.
▪ Lack of direct integration or linking among the CMMS data with the BIM model	Unitec's FM applications suite has bidirectional links with the BIM models.
▪ Lack of interoperability among the CAFM system and the CMMS	Functionalities of both CMMS's and CAFM systems are incorporated into the web-based FM solution.
Inefficient workflow processes	
▪ Manual and time-taking querying and updating routines in CAMF systems such as overlaying polygons on 2D drawings	FM Space and FM Space View provide access to a set of BIM-generated floor plans in various scales.

▪ The BIM systems and models not fully integrating with the FM&O workflow	FM Help controls soliciting the information required for streamlining workflows from the BIM information resided in the SQL database, and channeling the query results to respective workflow applications, e.g. FM Actions, FM Security, FM Cleaning, and FM Vehicles. More specific applications such as FM Maintenance Costs and FM PropLease extract accurate and current information from BIM models for each FM&O task.
▪ Issues with updating as-built models after construction	A custom-made software synchronizes the Revit model with the SQL DBMS after each construction project. FM Projects performs the synchronization procedure.

6 PRACTICAL IMPLICATIONS

In addition to their theoretical significance, the results provide in-depth insight into prevailing issues with BIM-based IT solutions for the FM&O sector as well as examples of how those technical issues can be resolved. The results will be useful to DBMS implementers and database designers active in the FM&O sector, as well as decision-making buddies in the field.

7 CONCLUSION

According to our findings, the most important issues in implementing BIM for streamlining FM&O activities are lack of guidelines and efficient technologies for capturing BIM models of existing facilities, coping with non-consistent terminologies and taxonomies used by different actors, accurately defining and specifying requirements in BIM applications, and identifying which information and what level of detail is desired by the FM&O teams. Current open formats for transferring building information (e.g. IFC and COBie) should be enhanced and complemented or new open formats be developed for maintaining interoperability among the wide variety of proprietary tools and systems used through the entire life cycle of the building in an efficient and sustained manner.

No earlier research has so thoroughly described the overall architecture and functionalities of different components of an integrated BIM FM system based on the portal solution with regard to the status quo of the subject area in both theory and practice. Nevertheless, more research with a focus on FM&O business processes and regulatory aspects of building information hand-over are required so as to complement the findings of this paper on efficient use of BIM for FM&O.

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