Quality Management Processes and Automated Tools for FM-BIM Delivery

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Abstract –

Despite the significant benefits of Building Information Modeling (BIM) that can be potentially achieved during the operation and maintenance (O&M) phase, industry has so far mainly focused on its implementation in the design and construction phases. As-built BIM models cannot be efficiently used mainly due to a lack of expertise on the owners' and operators' side to update and use them. Moreover, industry standards do not contain precise guidelines to ensure the ease of use, interoperability, and maintainability, for an efficient and effective utilization of models. Additionally, as these models are mainly developed for the design and construction phases, they usually lack information required for the building's operations and contain many superfluous details. These issues constitute some of the main barriers to the adoption of BIM for O&M. In this light, this research investigates delivering correspondence between as-built models and O&M requirements, using procedures and automated tools to facilitate quality management activities for FM-BIM.

Keywords –

BIM; Quality Management; BEP; IFC

1 Introduction

Building Information Modeling (BIM) consists of the creation of a digital representation of the physical and functional characteristics of a facility as an integrated database of coordinated, consistent, and computable information (Ramesh, 2016). It serves as a shared knowledge resource for information about a facility and provides a reliable reference for decisions throughout its lifecycle, to maximize efficiency, improve information exchanges, and reduce costs (Vega Völk, 2017). The use of BIM has thus far mainly been focused on design and construction phases. However, its main benefits can be achieved during the Operation and Maintenance (O&M) phase.

Aside from aspects such as generating savings during the design and construction phases, BIM provides a repository of detailed information of the built asset that can be used during operations. Consequently, receiving a complete BIM model at the end of the construction project is becoming increasingly important for the owners. However, even though the commissioning and handover process of delivering physical assets is very well defined, the lack of standards or procedures for digital project delivery creates confusion for owners in terms of deliverables. As a result, the delivered models are not ready to be used by operators as they lack the relevant information and contain superfluous data.

Hence, it is crucial that the owner can constantly check the quality of the models before the delivery and during the handover, to monitor the progress of model development and to solve issues as early as possible. On the other hand, having standard procedures and tools will help the designers and engineers create useful models for operation, as it makes it possible for them to perform quality control before delivery. The main objective of this research is to investigate quality management aspects of FM-BIM models and to develop automatic quality improvement and control tools.

2 Literature Review

2.1 BIM for Operations and Maintenance

To efficiently perform its tasks, Facilities Management (FM) must centralize information from various fields under one roof. Information should be managed and analyzed in a structured and systematic way to facilitate decision-making. FM activities depend on the accuracy and accessibility of data created in the design and construction phases and maintained throughout the O&M phase (GSA, 2011). The BIM model can supply 3D geometry as well as the data of assets and spaces to FM databases to be used for activities such as planning for maintenance and renovation.

Although BIM models are successfully used in the design and construction phase, most models created for these phases contain significant quality issues including inaccurate, incomplete, or unnecessary information for facility managers (Zadeh et al., 2015). As a result, the use of BIM during the O&M phase remains limited as the models are not readily usable and require extensive modifications and quality improvement, which is costly and time-consuming.

In addition, industry standards do not contain guidelines to ensure the ease of use, efficiency, interoperability, and maintainability of FM models. Motamedi et al. (2018) stated that the FM models should evolve from as-built and as-designed models: they must include geometry and be lightweight. They further noted that models must include all relevant attributes for inspection, maintenance and simulation, as well as the relationship between elements. The quality of data and its availability is crucial as it enables the FM database to provide the information with the required level of detail.

2.2 BIM Quality Assurance and Control

The National BIM Guide identifies procedures to be defined and documented within the BIM Execution Plan (BEP), such as a QA approach for monitoring the modeling process and a QC approach to test the compliance of the final deliverables with quality standards (Motamedi et al., 2018). However, current BEPs do not feature comprehensive QC/QA processes. A continuous QA mechanism set up by the owner guarantees the quality of the model throughout the project lifecycle.

Zadeh et al. (2015) identified different types of BIM data quality issues (e.g. incompleteness, inaccuracy, incompatibility, incoordination, incomprehensibility) and categorized them according to different perspectives (e.g. entity-, model-, or user-level) and relevant facility management perspectives (e.g. assets, MEP systems, spaces). Furthermore, Ramesh (2016) proposed comprehensive quality attributes (i.e., availability, consistency, accessibility, timeliness, relevancy, completeness, accuracy) and a QA and QC planning procedure. The procedure allows owner organizations, along with project teams, to systematically identify areas of concern when documenting and delivering facilities information, and to eventually define ways to manage them. This procedure consists of 1) identify facility information users; 2) understand user needs; 3) translate needs to quality attributes; 4) establish process controls; 5) define product controls. The procedure identifies the goals of owner organizations, lists their concerns and enables the development of a strategy for quality management, enabling the exchange of usable information. However, Ramesh's procedure does not include the model's assessment method.

Regarding QC, the designers' work is reported at project meetings and a report is prepared for project-specific official checkpoints, describing the priority issues that require attention. At these checkpoints, QC include several steps, such as a self-check, carried-out by the designer, internal check, by the project manager, and client assessment (Kulusjärvi, 2012).

However, the goal of the model preparation process is to have a lightweight federated model that complies with a standard format and is enriched with FM data. To achieve this goal, Motamedi et al. (2018) proposed a QC checklist, yet, it needs to be further expanded. To automatically assess the model, automatic model-assessment tools are available on the market (e.g. Solibri, Revit Model Checker), but the applicability of these tools for FM purposes regarding the owners' requirements must be evaluated, especially for COBie deliverables (Patacas et al., 2014).

2.3 COBie

Construction Operations Building information exchange (COBie) is a non-proprietary data structure that enables the creation and transfer of asset information. It is used as a data handover tool for transferring the data taken from the BIM models. However, COBie is only a platform for data capture and transfer and does not include specific data requirements for each asset type. Additionally, BEPs are generally imprecise regarding data requirements, delivery schedule, and data quality of COBie deliverables.

2.4 Research Gaps and Research Steps

The literature highlights a lack of comprehensive checklists and procedures to assess the quality of the BIM model for FM. There is also a need for an automated method for identification and correction of quality issues. The research proposes a comprehensive list of required items and information that must be present in the model for the operations of the facility, alongside a list of unnecessary items that must be purged from the design and construction models. The research proposes automated checking and purging methods. Model-checking tools and visual programming are used to develop an auditing tool useful for the construction firms and the Facility Managers. Moreover, a QA process flow to be used by owners and constructors regarding the requirements for FM is proposed. The developed tools and procedures were used in a real project to assess their applicability and to gather feedback for future improvement.

3 Proposed Solution

3.1 Checklist for BIM Model Quality Control and Purge

Alongside the specific data required by the owner, which vary from one project to another, the overall quality of an FM-BIM (e.g. data format, assets relationships, room definition) must be evaluated. Since this model derives from either an as-build model or a design-intent model, a preliminary preparation step is needed to ensure that all the required data are included in the model following a comprehensive checklist.

Tables 1 and 2 show the extended version of the tables developed by Motamedi et al. (2018). They include items that are generic for all BIM models, regardless of the authoring software. Additionally, they include highlighted items related to a specific authoring tool (i.e., Autodesk Revit). Although the terminology used to describe the highlighted items is tool-specific, it can be transposed for other tools. Finally, the items were categorized.

Since the as-built model contains unnecessary information for the purpose of O&M (e.g. structural elements, assembly, parts), the model should be purged. As a result, the model is more lightweight and, if possible, federated. Table 2 shows the proposed items to be purged from the model. Finally, once the model containing all the necessary information (owner's requirements) attains a sufficient level of quality and all superfluous information has been removed, it can be exported in an interoperable format, such as IFC. The model's data is then transferred to CMMS or CAFM platforms.

Table 1. FM-BIM quality control checklist

Cat.	Item	Description
Delivery	Standalone models	FM-BIM models should be delivered standalone with multiple models combined.
	Completeness	Delivered models should be complete, including: Floor plans, Reflected ceiling, Mechanical ductwork and piping, Lighting, Electrical power, Electrical panel diagrams, Fire protection, Data system.
File Management	Compatibility information	Details about the compatible version of the viewing and editing applications should be provided per model.
	Geolocation	The model should be geolocated.
	Model alignments	The architecture, structural and MEPF models should match and align.
	Folder structure	Models are organized in a standard and consistent directory structure.
	Pinned links	Links should be pinned in place.
	Nested links	Reference nesting should be avoided.
	Link path	Links should have relative paths.
General	URL	URLs must only be used when it is impossible to provide the content locally.
	Asset modeling	Assets should be placed only in their associate models.
	Elements visibility	There should not be hidden elements.
	Phase elements	Each object should be modeled in the proper phase.
	Units	Consistent units should be used for the properties of assets.
Spatial element creation	Space completion	There should not be any missing spaces.
	Room location	Rooms should not be located on the roof or outside.
	Room tags	Room tags should be displayed in the center of each room in a floor plan view.
	Room level hosting	All rooms/spaces should be hosted at the level in which they contribute to the net and/or gross building square footage.
	Room and space definition	Rooms and spaces should be in a properly enclosed region.
	Room duplication	There should not be multiple Rooms in the same enclosed region.
	Room height	Room volume should go from its current level to its above ceiling.
	Space height	Space volume should go from current level up to above slab.
Spatial element properties	Room identification	Unique name and numbering should be used for rooms in the building.
	Room finishes	Surfaces of rooms should have finishes.
	Related space naming	Space names should correspond to room.
	Definition of areas	Areas are defined for grouping by function purpose.
	Gross area definition	The calculation method should comply with a guideline.
	Zone definition	Zones should be created.
	Zone assignment	Every space should be assigned to at least one zone.
Relationships/Assignments	MEP equipment location definition	Location relationship should be based on the space from which the equipment is accessed.
	Object duplication	There should not be duplicate objects.
	Architectural components location definition	Architectural components should be associated to the room where they are located/from where they will be maintained.
Systems	System modeling	There should not be any components with no system definition (Unassigned System).
Levels and ceilings	Floors definition	Floors should be properly defined and should not exist as ceilings.
	Ceilings definition	Ceilings should not be cut by a room.
	Room bounding	Ceilings should not be room-bounded to enable correct space height.
	Duplicate levels	There should not be multiple levels at the same elevation.
	Helper levels and floors	Helper levels and floors should be removed.
Naming convention	File naming	Model file names should conform to a standard.

View/Sheet naming	Model view and sheet names should be consistent and conform to a standard.
Level naming	Level names should be consistent and conform to a standard.
System naming	System names should be consistent and conform to a standard.
Family naming	Family names should conform to a standard.
Type naming	Type names should conform to a standard.
Room/Space naming	The names of rooms and spaces should be consistent and conform to a standard.
Room/Space classification	Rooms and spaces should be classified following a standard classification scheme.
Equipment naming/identifiers	Equipment names should be consistent and conform to a standard.
Equipment classification	Assets should be classified following a standard classification scheme.
Annotations	All annotations and title blocks should be consistent and conform to a standard.

Table 2. Purge checklist of items to be removed from the FM-BIM

Cat.	Name	Description
Annotative elements	Annotations	All unnecessary annotation should be deleted, specifically related to structure, installation, assembly or construction.
	Revisions	Revisions information should be purged from the model. Revisions cannot be deleted, but they must be "un-issued".
	Line styles	All unnecessary line styles should be removed, specifically related to structure, installation, assembly or construction.
Views	Legends	All unnecessary legends should be removed, specifically related to structure, installation, assembly or construction.
	Schedules	All unnecessary schedules should be removed, specifically related to structure, installation, assembly or construction.
	Sheets	All unnecessary sheets should be removed.
	View templates	All unnecessary view templates should be removed, specifically related to structure, installation, assembly or construction.
	Scope boxes	All unnecessary scope boxes should be removed.
	Views not on sheet	All views not on any sheet should be removed (e.g. plan, section, elevation, detail, test, work in progress and drafting views).
Customization	Design options	All unnecessary design options should be removed.
	Area space schemes	All unnecessary area space schemes should be removed, specifically related to structure, installation, assembly or construction.
	Worksets	Worksets should be discarded.
	Browser organization	Keep only one browser organization for views, sheets and schedules ("all")
	Visibility	Turn on all model objects, all annotation objects, remove all filters, and turn on the visibility of all worksets and links.
el integ	Generic models	All unnecessary generic models should be removed. They should be avoided in general.
	In-place families	All unnecessary in-place families should be removed. They should be avoided in general.
	Unused elements	All unused objects should be purged and removed.
	Mass elements	All unnecessary mass elements should be removed. They should be avoided in general.
	Detailed components	All unnecessary detailed components should be removed.
	Groups	All groups used to model the building must be ungrouped.
File	Purge	The models must be purged multiple times before being shared.
	Linked files	All non-transmittal linked-in files (CAD/Revit) should be removed from the model.
	Images	All unnecessary images should be removed.
	Warning count	Warning count should be reduced to zero.
	Merging files	If possible, architectural, mechanical, electrical, fire protection and specialized equipment should be merged into one file.

3.2 Solution for implementing the checklist

In this research, several commercial quality control tools were assessed, such as schedules in Revit, Revit Model Review, Revit Model Checker, Solibri, and Dynamo. Aside from Solibri, these tools are embedded in Revit. However, it is possible to import an IFC file generated in other tools to Revit and then perform the quality control. As no single tool adequately supports all the required checks, a combination of them is required to achieve a sufficient level of quality control implementation.

Revit Model Checker is identified as the tool in which a large portion of the quality control checklist items can be programed. Table 3 shows a sample model-checker script that reports the spaces where their names and numbers do not match the names and numbers of their corresponding room. Revit Model Review is then used to complement Model Checker for specific checklist items (e.g. it checks that each enclosed region in the model has a defined space or room).

Table 3. Example of check code using Model Checker

Check Name	Check Code
Space matches room	(Category OST_MEPSpaces Included Code:True AND Type or Instance Is Element Type = Code:False AND Parameter SPACE_ASSOC_ROOM_NAME Does Not Match Parameter Code: ROOM_NAME) OR (CATEGORY OST_MEPSpaces Included Code:True AND Type or Instance Is Element Type = Code:False AND Parameter SPACE_ASSOC_ROOM_NUMBER Does Not Match Parameter Code: ROOM_NUMBER)

For purging, Dynamo scripts are used to implement most of the cleanup checks in a semi-automated way. Most codes list all the elements corresponding to an item of the checklist and allow the user to remove the unnecessary elements by filtering through a keyword or chain of characters (e.g. all view templates that contain “struct”). The process requires a human input to identify the keywords or take the final decision on the deletion of the data. This method is efficient for viewing a list of potential unnecessary similar items and removing them once.

Finally, an Excel dashboard was created to keep track of the improvement of the model’s quality. This dashboard is populated by the results of the assessments of Model Checker, displaying figures both related to quality control and purgeable items. It makes it possible to quickly visualize the model’s quality status.

3.3 Procedure for the Use of Developed Tools

Figure 1 shows the proposed procedure for FM-BIM model preparation. The assessment of the models occurs at two levels: 1) the modeler carries out self-checks using the above-mentioned auto-evaluation tools (self-check boxes in Figure 1); 2) at specified milestones—to be determined in the BEP—the project manager executes a control of the models using a combination of the developed tools. The generated report populates the dashboard to monitor the quality status and to determine any necessary improvements. After a number of iterations, the FM model is exported in an interoperable format, such as IFC, and delivered to the client. It is important to convert the model to the IFC format when it is of a sufficient quality, as the checks are carried out in the authoring software using the native format.

4 Case Study

he developed tools and procedures were assessed in a project of a general contractor based in Quebec. A building of a care center mandated by a major provincial owner organization was selected for the case study. The purpose was to assess the usability of the tools and the process and to gather feedback from stakeholders for future improvements. The project delivery mode was design-build and the company was in charge of managing the production of as-built BIM content and a customized COBie file.

In the complete COBie standard worksheets, the client requested only the design-related sheets (i.e. Contacts, Facility, Floor, Space, Type, Component, System). The required rules defined in the COBie standard and some optional properties to be transferred to the operations database were listed in the initial contract. A further analysis of the standard, contractual documentation, and interviews were performed to complete the data requirements of the client.

4.1 Utilization of developed tools

For the purpose of assessing COBie deliverables, two available tools were assessed. COBie QC Reporter, a java-based program, is used to assess the content of COBie files, however, the tool is complicated to work with and is not capable of verifying all the fields required for the project. Revit Model Checker is an alternative tool in the BIM Interoperability Toolset. A functionality comparison of these tools was performed and is presented in Table 4. The numbers in each column indicate the number of assessed rules for each COBie sheet. The results show that none of these tools is capable of assessing all the rules and they need to be used in parallel.

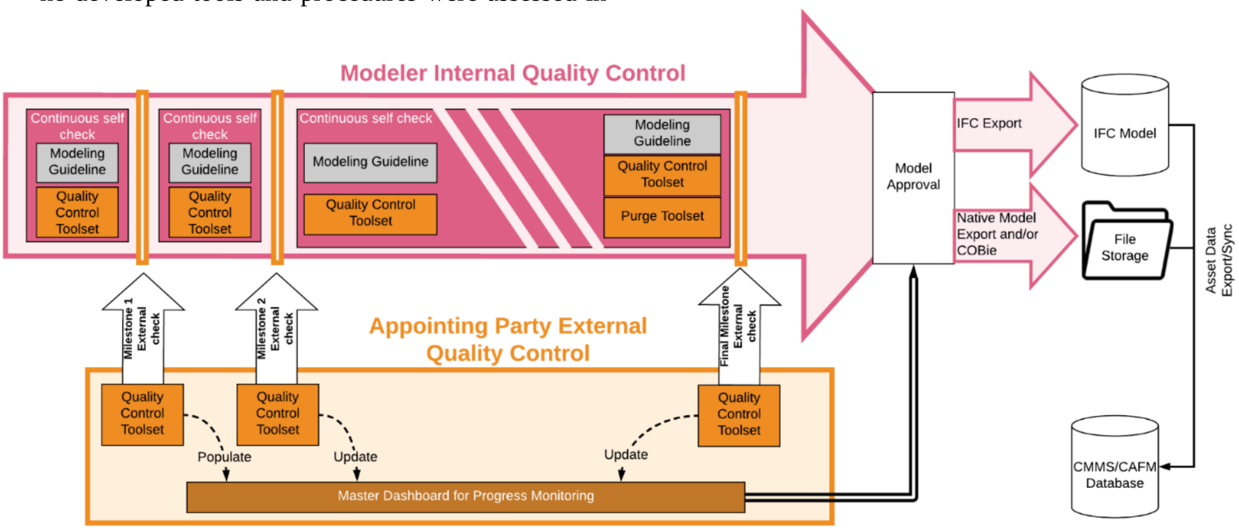

Figure 1. Overall workflow view of FM-BIM preparation showing checks performed at milestones

Table 4. Comparison of number of rules assessed by each COBie control tool

COBie Sheet Name	Only Model Checker	Only QC Reporter	Shared between tools
Contact	0	20	0
Facility	6	2	14
Floor	1	1	10
Space	2	1	15
Zone	1	3	7
Type	6	7	32
Component	0	6	14
System	3	3	8

The Model Checker template for COBie assessment does not include all the required rules and fails to detect many existing errors. Additionally, the format of the values (e.g. classification parameter or picklist) cannot be assessed by the template. Thus, a new set of checks was implemented and both tools were successively run. Finally, the data is exported in an Excel format and the QC Reporter is used to assess the remaining rules (e.g. contact rules, or sheet cross-referencing). Additionally, some non-COBie related checks proposed in this research were run to improve the quality of the model. For example, the developed Dynamo code to assess the height compliance of rooms and spaces was used to ensure that each COBie component is correctly included in a space or room volume.

4.2 Process design for the use of tools

A detailed process map was proposed regarding the use of tools. Figure 2 shows the process flow for the generation of COBie data and the utilization of the developed QC tools. The process includes a detailed identification of COBie requirements (i.e. sheets, fields, assets, classification standard and naming conventions). At the beginning of this project, the process and the required data items and formats were not adequately defined, which made the process of updating the model very tedious.

Once the COBie requirements definition is completed by the client/owner, the project manager, together with the designers, can set up the models of various disciplines accordingly by creating the parameters and choosing the appropriate classification system. The task of populating the model with the COBie data is to be carried out by the corresponding designer. Quality control is then performed by the project-manager, using COBie schedules embedded in Revit and the Model Checker. Once the model is complete, the COBie file can be generated and assessed using QC Reporter. Finally, the COBie file and the report are shared with to the client for evaluation.

Since multiple iterations are likely to occur in the COBie generation process, a dashboard, is developed to monitor the progress of the quality assessment. The dashboard is intended to provide a better visualization of the result of the checks implemented in Model Checker, as they can be directly exported in Excel. The tool was validated in the project and will be used (together with the workflow) for upcoming projects of the company to improve the delivery of COBie.

5 Conclusions and Futurework

This research project addressed the lack of methods to control and improve the quality of BIM models for O&M by proposing checklists of necessary items to be included in the FM-BIM, as well as superfluous items to be purged from the model. Additionally, a new method

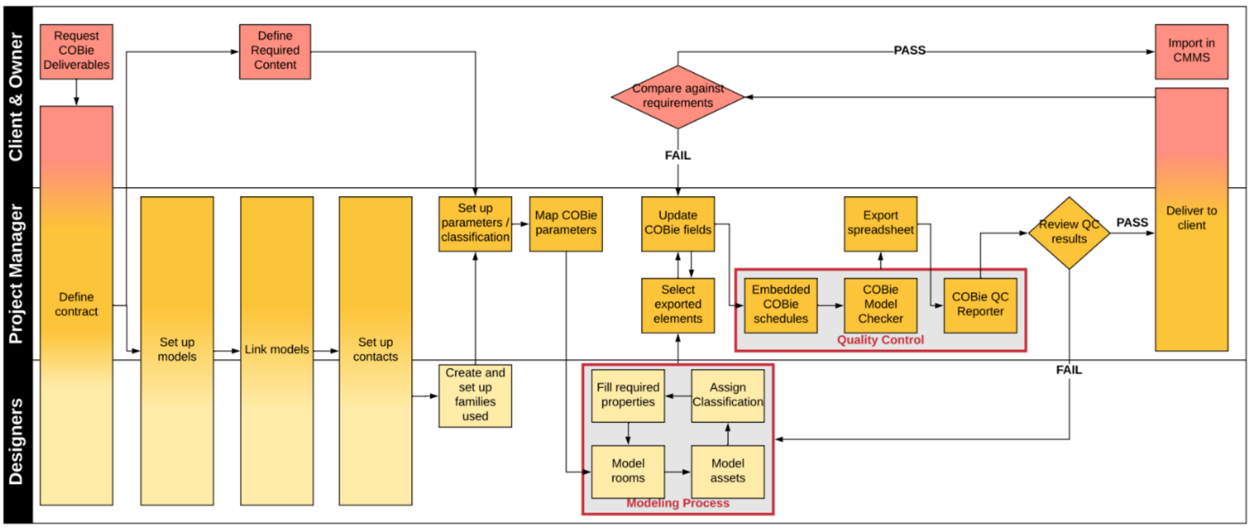

Figure 2. Proposed workflow to deliver a high-quality COBie

and tools to evaluate the quality of BIM models for the O&M phase were proposed. They facilitate the delivery of complete and usable FM BIM models. The applicability of the tools and methods were assessed in a real project by applying the rules related to the quality of COBie data in a BIM model.

The results of this research contribute to creating more useful BIM models for FM, which will eventually increase the quality of operation. High-quality BIM models help to increase the efficiency of building operations and to achieve major cost reductions. Ultimately, the effective management of buildings will also help to increase the comfort and quality of life of their inhabitants.

Although the developed tools addressed multiple items of the checklist, there is still quality control items that their assessment can be automated. Additionally, the checklist can be further extended by considering new requirements in the industry. The developed tools can be further improved to automatically fix the problems in the model (e.g. space and room height auto adjustments). Moreover, changes to contract templates or BEPs should be proposed to precisely define quality assurance procedures.

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