Automatic Verification of Facilities Management Handover Building Information Models

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ABSTRACT

Although Building Information Models (BIM) are increasingly recognized as a compelling tool for project delivery, the challenges of seamless model validation and the transition of BIM data to FM remains unresolved. BIM data interoperability issues, lack of a clear understanding of owner's Exchange Requirements (ERs), inconsistent syntax in developing discipline-specific models, and software limitations contribute to the difficulty of using Architecture, Engineering, and Construction-purposed BIMs for FM handover. This research explores a case-based example of implementing computational BIM for automatic verification of an FM-handover BIM at project close out. The relationships between, and properties of, model objects used to capture the required geometric and non-geometric information for the owner's FM handover needs is specified in accordance with the applicable IFC entities. The syntax of the model is formalized in conjunction with the buildingSMART Data Dictionary (bsDD) schema. Dynamo is used as a visual programming platform to work with the Autodesk Revit Application Programming Interface (API) to extend its parametric capabilities to verify the BIM data in compliance with the specified requirements. The results of the automated verification procedure highlight completeness, uniqueness, correctness, usefulness, and unambiguity of BIM data as critical quality dimensions for the purpose of project delivery.

Keywords: BIM, Facilities Management (FM), FM-handover BIM, IFC Model Views (MV), BIM data quality, BIM verification

INTRODUCTION

Considerable financial losses can occur as a result of insufficient data interoperability between construction and FM's Operation and Maintenance (O&M), as a result of such inefficiencies as staff productivity loss, rework and manual information verification (National Institute of Standards and Technology, 2004). Although BIMs are recognized as a compelling tool for facility's lifecycle information management with the potential to overcome these challenges, their implementation in FM handover and post-construction building operation remains rather limited (Cavka, Staub-French, & Poirier, 2017). Several studies have identified the quality of BIMs as a main barriers for that purpose (National Institute of Standards and Technology, 2004;

(Wawan Solihin, Eastman, & Lee, 2015). The quality issues of design- and construction-intent BIMs pertain to providing inaccurate, incomplete, or unnecessary information. Hence, assessment and implementation of these models for downstream FM tasks require significant adjustments, which is typically a manual, time-consuming and costly task (P. Zadeh, Staub-French, & Pottinger, 2015).

This paper adopts a case study approach to provide a framework for automatic verification of FM handover BIMs in support of sustainable data reuse. This study is a part of a longitudinal research which attempts to establish a modularized BIM-intensive framework for facility data creating and handover following downstream FM task- and system-needs in support of sustainable data re-use. The lessons learned in this process provide a deeper understanding of the critical aspects of BIM quality, which are important for facilitating automatic verification and transition of FM data from construction to operation.

LITERATURE REVIEW

BIM for FM handover

Facilities Management (FM) encompasses multi-disciplinary and independent disciplines with extensive information requirements (Patacas, Dawood, Vukovic, & Kassem, 2015). Examples of such information include building component's location, performance data, manufacturer and vendor data, installation, operation and maintenance requirements, etc. (Becerik-Gerber, Jazizadeh, Li, & Calis, 2011; Matarneh, Danso-Amoako, Al-Bizri, Gaterell, & Matarneh, 2018). For BIMs to facilitate automated and seamless information flow from construction to FM, ERs need to be identified, formalized, and clearly conveyed at the front end of the building lifecycle according to FM task- and system-specific needs (Kassem, Kelly, Dawood, Serginson, & Lockley, 2015; Kim et al., 2018; Patacas et al., 2015). This entails BIM content (what information) and format (content structure), as well as consistent terminologies and taxonomies (Parsanezhad & Dimyadi, 2013). A successful model exchange should incorporate the semantically required aspects used to define elements within the object-oriented, parametric environment of BIM-authoring tools (Eastman, Jeong, Sacks, & Kaner, 2009). Hence, lack of clear specifications for these aspects hinders automated validation of model data at project close out, requires rework (in terms of remodeling), mapping model data, and manual re-entry to FM systems (Nawari, 2012; W. Solihin & Eastman, 2015).

Industry Foundation Classes (IFC)

The Industry Foundation Classes (IFCs), developed by buildingSMART, for data standardization, cover a wide range of domains within the AEC and FM industry. IFCs address data interoperability by specifying an open data schema and neutral file format to promote object-oriented data exchange among heterogeneous BIM platforms used by various participants in the AECFM industry (Bedrick, 2019; Kell, 2015; Laakso & Kiviniemi, 2012). This schema specifies exchange format definitions, including data structures, modeling constructs, and syntactic and semantic requirements. (Lee, Eastman, & Solihin, 2016).

Although the IFC standard is increasingly being used by software vendors and practitioners, the significant extent and complexity of a full IFC model results in technical difficulties and redundancies (e.g. exporting asset data which is not required), unless this overgeneralization is overcome by means of reducing the scope for specific needs of an exchange scenario – this is called a Model View (MV) (Steel et al., 2012)(Eastman, Jeong, Sacks, & Kaner, 2009). On the other hand, the "lack of formal definitions on a semantic level" hinders efficient implementation of iFC models (C. Zhang, Beetz, & de Vries, 2013). The openBIM schema corresponding to this aspect of BIM data interoperability is the bsDD that operationalizes BIM exchange information terminology in an attempt to establish a common understanding among various industry experts, end users of BIMs, and solution providers. The bsDD seeks to provide universal definitions for BIM data for the purpose of interoperability and data exchange (National BIM Standard, 2017). The schema defines the syntax and data types for individual properties or property groups, which can be assigned to objects or object types (buildingSMART, 2016).

BIM data verification

As owner organizations increasingly become interested in BIM-intensive delivery of facility data, assessing the quality of model data at the time of project close out becomes more critical (Mayo & Issa, 2015)(Akcamete, Akinci, & Garrett, 2010; Terreno, Anumba, Gannon, & Dubler, 2015). Further, this task is mostly essential since downstream FM users depend on the quality of models developed in previous phases of the project (P. A. Zadeh, Wang, Cavka, Staub-French, & Pottinger, 2017). Existing literature on the subject of BIM data verification typically have been working on development of methods and mechanisms for checking 1) model data quality in terms of such aspects as completeness, clarity, accuracy, usefulness, and interchangeability; and 2) model conformance quality to pre-defined requirements, such as those of IFC MVs or organization's BIM standards (Kasprzak, Ramesh, & Dubler, 2013; Lee, Eastman, & Lee, 2015; Lee, Eastman, & Solihin, 2018; Lee, Eastman, Solihin, & See, 2016; Wawan Solihin et al., 2015; P. A. Zadeh et al., 2017) (Farghaly, Abanda, Vidalakis, & Wood, 2018). Studies suggest that the current uncertainty on the quality of IFC MVs have been recognized as a barrier in its adoption among end users. The concerns on quality of IFC MVs range from validating the syntax of the model to satisfying programmatic requirements. Therefore, the need to develop robust and rigorous test criteria, processes, and tools is inevitable. However, this is a challenging task since it needs to take into account various characteristics of data (Wawan Solihin et al., 2015).

Although a few checking methods have already been developed and implemented, they are based on proprietary methods which cannot be easily accessed, used and extended by end-users (Zhang, Beetz, & Weise, 2014). This paper proposes a practical framework customized following owner's specific needs in support of sustainable creation and transition of data. Verification tests are developed in an object-oriented environment that are accessible to end-users with limited programming language skills.

Revit and Dynamo

Autodesk Revit is well established as an IFC-compatible, object-oriented, parametric modeling tool for collaborative BIM development given its Application Programming Interface (API) compatibility (Pazlar & Turk, 2008; Eastman et al., 2011). The Revit API allows third-party developers to create custom tools that can integrate with Revit through different programming languages. Dynamo is an opensource, visual programming platform developed by Autodesk that can work as a visual scripting interface with the Revit API to extend its parametric capabilities (Autodesk Dynamo Studio, 2017). Applications of such functions include data creation, editing, retrieval, and documentation (Preidel et al., 2017b). The visual programing interface is a significant advantage of Dynamo as it allows users with little computer programming knowledge to carry out various project lifecycle analyses on BIMs (Danhaive & Mueller, 2015). Within Dynamo's workspace, data flows through "wires" to support input and output ports to "nodes", establishing the logical flow of data in the visual program. Nodes process and execute the input data by performing an operation to create the output and represent the sequence of executed actions(Autodesk Dynamo Studio, 2017, Preidel et al., 2017b).

CASE STUDY DESCRIPTION

The proposed FM-handover BIM verification framework in this paper is a result of an extensive study of the FM practice and FM data handover process employed at a large owner organization in the Midwest United States. The owner organization under study employs an internal FM group, including several departments, that oversee the development, operation and maintenance of the buildings. The asset portfolio of the organization comprised a diverse range of buildings with different characteristics, economic life, maintenance costs, rehabilitation timeframes, and mission criticality. The pilot project selected for this case-study research is a five-story academic building comprising classrooms, offices, and research and laboratory spaces. This project was delivered using the Design-Build (DB) project delivery methodology. The focus of the proposed framework in this research is on elements of Heating, Ventilating, and Air Conditioning (HVAC) systems within this building.

Current practice: Handover of Facility Data

Within the organization of study, the close out deliverables typically consist of record documents (2D drawings), project information, stakeholder contact information, warranties, installation, operation manuals, maintenance manuals, and performance test reports. The organization of study also requires project teams to deliver an AEC-purposed BIM. However, these models are developed for design and construction purposes and typically lack the specific information required for downstream O&M tasks. On the other hand, since the owner does not provide detailed guidelines for developing discipline models, various AEC firms on different projects follow their company-specific modeling and naming conventions. This makes the task of adjusting the model for FM purposes, mapping and retrieving BIM data time-consuming and manual.

Phases of the research

Data collection and analysis in this research consists of multiple methodologies and phases. In the initial phase of the study, the authors conducted semi-structured interviews with the key stakeholders from the owner's FM department to have a clear understanding of the facility data handover process as well as task- and system-specific needs. Further content analysis on project close out deliverables was carried out to identify ERs for the exchange model. This includes required building elements, as well as semantic and geometric information. In the second phase, the authors formalized the identified ERs in conjunction with the IFC schema. This includes model objects representative of the building elements and components (e.g. instances of duct, duct type, systems) and appropriate properties to capture required semantics and geometrics. Further the authors established detailed guidelines in conformance with the bsDD schema to unify the syntax of the delivered model. The two schemas were chosen to achieve greater acceptance among developers and end-users of the BIM.

This paper presents on the third phase of this research, which followed a four-step process in which the owner formalized ERs (Phase 1 and 2) were 1) populated in the exchange model in Autodesk Revit, 2) necessary quality dimensions were determined in a use-case based approach with focus on the HVAC systems, 3) appropriate tests were developed using Dynamo to assess the model data with respect to the identified dimension, and 4) the tests were implemented on the pilot project. While the proposed framework could be implemented on numerous model objects, HVAC-specific examples of the work completed for phase one and two as well as the four-step process conducted for phase three are provided in the following section.

RESULTS

Phase 1: Identification of Exchange Requirements (ERs)

The content analysis comprises the review, cross referencing and isolation of required data for commissioning, maintaining, and operating elements of HVAC system in the case building. For instance, the HVAC Performance Test Report (a 2D PDF handover deliverable) included numerous pieces of information that could be provided within the FM-handover BIM in an integrated manner. Table 1 provides the ERs retrieved from the leakage test report carried out on duct elements of the HVAC distribution system for commissioning purposes.

Table 1. Owner information requirements

Close out deliverable	**FM handover Exchange Requirements**
Performance Test Report	Project name, project number, test type, test date, (test) performed by, (test) witnessed by, subject duct name and Uniformat classification, air system type, leakage class, subject element location (room#), surface area, duct construction pressure class, specified test pressure, actual CFM, actual pressure, comments

Phase 2: Formalization of Model Requirements

In phase two, the authors formalized model content, structure, and format in conjunction with the IFC and bsDD schemas. This mainly is to clearly convey 1) what information needs to be provided in the model (e.g. which model objects and what geometrics and semantics to be included in the model); 2) the relationships between objects (e.g. the element and its surrounding room); 3) the syntax (e.g. property and data types, and naming conventions). This is critical for providing complete, useful, and unambiguous data, and to facilitate automatic data mapping and retrieval from models populated by various DB stakeholders. As an example, the property "AssessmentDate" from the IFC schema, represents the "test date" listed in Table 1 as one ER. Table 2 provides detailed guidelines regarding the syntax for this property.

The goal is to establish a common understanding among DB teams and the end-user of the model.

Table 2. Formalized model requirements

Property Name	Property Type Data Type	Definition	Unit	Predefined values
AssessmentDate	P_SINGLEVALUE IfcDate	Date on which the overall condition is assessed	N/A	N/A

Phase 3: Automatic Verification and Transition of FM Data

Step 1: Populating the FM-handover BIM

Following the established syntax in the second phase of the research, the authors created Shared Parameter files in Revit. Figure 1 shows the details on the "AssessmentDate" parameter. Since there is no "Date Type" available within Revit, the authors and FM staff experts in BIM within the owner organization agreed to create this parameter of type text.

```
# This is a Revit shared parameter file.
# Do not edit manually.
*META   VERSION MINVERSION
META    2       1
*GROUP  ID      NAME
GROUP   1       Pset_Condition
*PARAM  GUID    NAME    DATATYPE        DATACATEGORY    GROUP   VISIBLE DESCRIPTION     USERMODIFIABLE
PARAM   14909500-3442-4119-bab9-27f6dc1f3865    AssessmentDate  TEXT            1       1               1
```

Figure 1. Shared parameter files

The owner can easily share these files with project teams responsible to populate discipline models in future projects. Further guidelines specify the relationship between these parameters and the appropriate model object to which they need to be assigned. For instance, the "AssessmentDate" needs to be an "Instance" parameter, the value of which can vary for different elements. This is critical for providing consistency for model data populated by different experts.

Step 2: BIM Data Quality Dimensions

The developed framework seeks to verify 1) completeness and correctness of the BIM data; and 2) compliance of the provided data to the established requirements. Following the comprehensive literature review on the subject, the purpose of this framework following FM handover needs, and the authors' experience with Revit API and Dynamo, the data quality dimensions deemed necessary within the object-oriented environment of BIM are as follow:

Format: At model level, appropriate software interoperability needs to be met so that discipline BIMs created by various stakeholders using different BIM-authoring tools can be exported to IFC format and aggregated in a federated model in Revit. Therefore, the software platforms need to be object-oriented, parametric, and IFC compatible.

Content: The content of the model needs to be comprehensive, meaning the elements need to be modeled, parameters need to be assigned and populated with value for model objects. Furthermore, the data provided in the model needs to be unique, for instance no duplicate elements or parameters are acceptable. Finally, the data provided in the model needs to be accurate. For instance, model elements' geometric data (e.g. dimension, or location) shall represent the characteristics of the respective building element.

Structure: The BIM data provided shall conform to the pre-defined syntax (e.g. no in-place or generic models are acceptable, and elements should be associated with the appropriate category and type). This is to establish a common understanding among the creators and end-users of the data, to avoid unambiguity of data.

Step 3: Development of Verification Tests

Within the context of the employed object-oriented approach, the developed tests are to retrieve data from the model and check it with respect to the quality dimensions determined in step 2. These tests are developed using Dynamo as an add-in to Revit. As an example, Table 3 lists the developed tests for entities of the IFC model to verify the quality of BIM data from the performance test report.

Table 3. Required BIM verification tests

	Tests	
Entity	Content	Structure (syntax)
Instances of duct	Object exists, is unique, object has associated material and classification	Element is modeled as view-independent; object name conforms the syntax; object category and type are assigned; each geometric building object is associated with the appropriate building level; groups are (zone, system) assigned
Rooms	Rooms are modeled and bounded, elements are tied to their surrounding room	Room name and number are assigned and follow the syntax
Properties	Parameter exists, has value, and is unique	Property name, property type, data type, unit conforms to the syntax, value is accurate, enumeration types equal to predefined values

Step 4: Implementation of the Framework

This section provides a few examples to demonstrate the results of implementing the developed tests (refer to Table 3) on the BIM for the pilot project.

1. Verification of content for room objects

As an example, Figure 2, shows a part of the Dynamo graph that retrieves the type parameter "Assembly Code", which represents the Uniformat classification for duct types and identifies ones with no value to report back within the model.

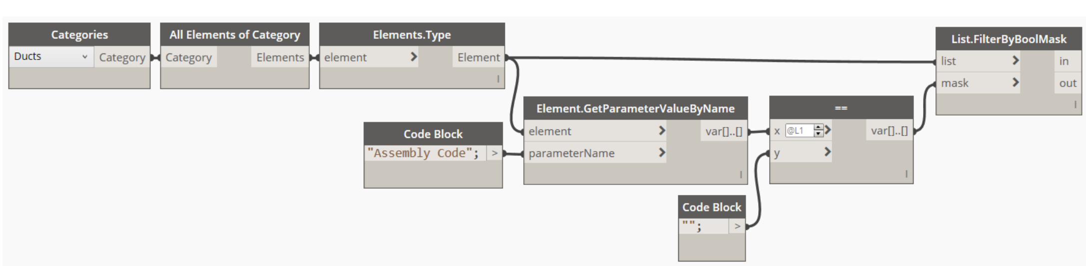

Figure 2. Dynamo graph for verification of object classification

2. Verification of syntax for model objects

Tests classified under this category seek to verify the model content conforms to requirements for the object-oriented, parametric environment of the BIM. For instance, Figure 3 shows the Dynamo graph to identify in-place families in the model and reports all instances of such type. Within the same context, the authors developed more tests to identify instances of category Generic Models and Model Groups. This is to ensure the parameters from the shared files are assigned to all appropriate model elements.

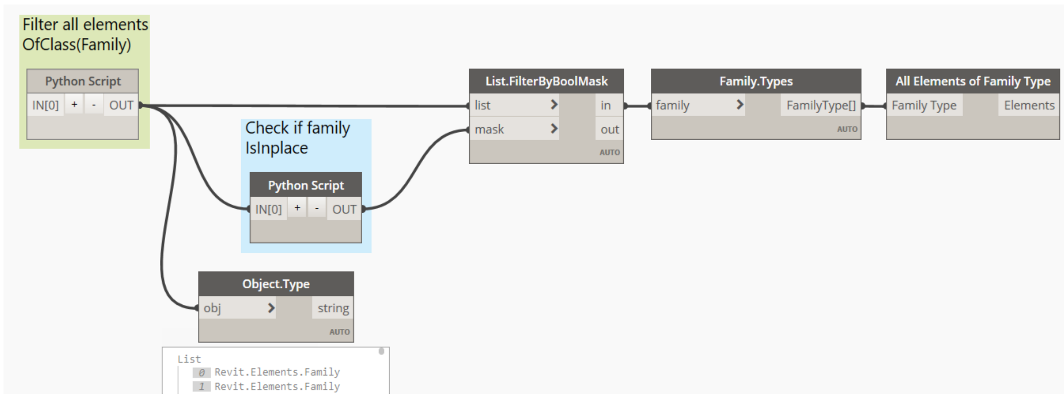

Figure 3. Verification of syntax

3. Verification of content for properties

Tests under this category intent to verify the parameters have been assigned and have a value. Revit provides a general mechanism for users to assign parameters to model objects. Parameters have a definition, which describes such details as name and data type for the parameter, and a value. Shared parameter files store information on user-defined parameters in an external document. Once a shared parameter is loaded into the model and assigned to elements, information about it can be retrieved. Figure 4 shows a part of the graph developed to retrieve and filter the "AssessmentDate" parameter and to further verify its type follows the established syntax.

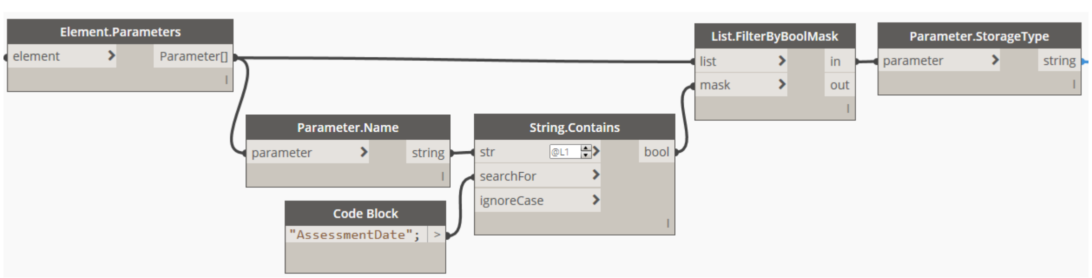

Figure 4. Verification of Property types

DISCUSSION and CONCLUSION

FM needs to build upon accurate, reliable, and timely information for various building systems, components, and component elements of the individual buildings in the asset portfolio. As owners increasingly become interested in implementation of BIMs for facility data handover, the quality of model data developed prior to project closeout becomes more critical. The framework and associated tests discussed in this paper advance the state of knowledge about the different aspects of BIM quality specific to FM handover exchange scenario. The framework is structured based on critical entities following the owner organization needs, including elements of HVAC systems, space, project, etc. The tests are developed to verify conformance of the model data (both semantics and geometrics) with pre-established guidelines. Results reveal that sustainable AEC-BIM data reuse during FM handover requires systematic and robust identification, clarification, and conveyance of the model requirements including syntax, semantics, and geometrics in early stages of the project lifecycle. This is critical in addressing BIM data interoperability issues of heterogeneous modeling and naming conventions, hence, establishing a common understanding of the ERs to facilitate seamless verification and transition of AEC data to FM. Prior to the development of this framework, AEC-intent BIMs were developed with little regard to downstream FM handover needs. This model verification procedure revised this process and developed a use-case based approach to the creation and validation of FM handover BIMs. This method is an alternative approach to manual quality assurance of FM data which minimize the risk while adding value to BIM workflows. This project's outcome continues to support streamlining facility information flow across the lifecycle of a building for various discipline models.

As noted, the owner organization under study owns and operates a large, complex and varied group of buildings. Therefore, the transition of FM data from an AEC-BIM at project handover is of utmost importance to this stakeholder. The framework developed herein should be interpreted based on this owner profile. Owner groups that do not operate buildings after the construction phase (e.g. those that follow a build and sell development model) might place less importance on BIM data transfer at building commissioning and/or handover. The focus of this research is mainly on providing a solution for sustainable data reuse within the context of building information modeling. Hence, the semantic and geometric information requirements for model elements were limited to the owner's needs from the close out deliverables. Future study based on the results of this research will focus on acquisition of as-built data in a more integrated and interactive format (e.g. point clouds) and extending the proposed framework for automatic verification of as-built conditions.

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