An Information Quality Assessment Framework for Developing Building Information Models

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Abstract –

Information Quality Assessment (IQA) is an important, but often overlooked aspect, of the Building Information Modeling (BIM) process. Models with information quality issues, such as incomplete and incorrect information, may cause rework during the design process if detected early. Otherwise errors may propagate downstream, leading to significant cost consequences to stakeholders in the Architecture, Engineering and Construction (AEC) industries. Current approaches of IQA show significant efforts on addressing information completeness issues but are limited when addressing information correctness. Greater understanding of the features of these quality issues is necessary to begin to detect these issues. This paper addresses this problem by proposing an IQA framework that incorporates three identified features: IQ Dimensions, Arity and Data Characteristics. From this framework, 3 classes of algorithms are further defined to detect these features. A validation test was conducted against current modeling guidelines used for BIM quality assurance in both architectural and structural disciplines. The results indicated more than 80% of the rules were able to be categorized using the framework. Guidelines that were not categorized included those that were overly ambiguous, or did not directly involve BIM. The outcome of the paper will enable BIM managers to ensure a fit-for-purpose, quality assured model that can reduce rework, and engender greater trust in the model creation process.

Keywords –

Information Quality Assessment; Features of Quality Issues; Building Information Modeling

1 Introduction

Building Information Modeling (BIM) simulates the construction project in a virtual environment. It provides a platform for collecting building-related information and allows information collaboration between different disciplines [1]. Due to its information-centric characteristics, models with poor information quality may cause significant cost consequences and rework [2][7]. Thus, Information Quality Assessment (IQA) for BIM is essential for stakeholders in the Architecture, Engineering and Construction (AEC) industries to realize the full benefits of BIM.

However, quality assessment is still a crucial and challenging task in BIM project delivery processes. Current ways of auditing for model quality control are manual, and usually involves visual checking of the model [8][9] or comparisons using check lists [6][7]. Such auditing processes tend to be time-consuming and difficult to avoid errors. Other than the tedious process of manually checking the models, there is still a lack of a general framework for defining some information quality criteria such as information correctness or accuracy. This consequently causes ambiguity, and difficulties in identifying model quality issues may arise [3]. Hence, implementing a quality assurance process for BIM requires a significant amount of time and effort from qualified personnel, and despite best efforts, may still lead to errors that may propagate to downstream activities, causing unnecessary rework during design. This then may lead to significant cost consequences to stakeholders. The aforementioned challenges may explain why IQA is often overlooked in the BIM process.

The objective of this paper is to propose an information quality assessment (IQA) framework, by identifying three sets of features related to the IQ dimensions of completeness and correctness, arity, as well as data characteristics. Specific algorithmic approaches can then be identified to detect the model quality issues. Section 3 describes the proposed framework, and section 4 describes the algorithm classes in detail. Validation of the proposed IQA framework is then carried out on a set of BIM modeling guidelines/ quality assurance requirements laid out in the Singapore BIM Guide [7].

2 Literature Review

The information contained within BIM should be complete and correct to support different BIM use cases such as structural analysis, cost estimation and quantity take off [5]. Therefore, the assessment of BIM information quality is essential to evaluate whether the model is fit-for-purpose. In the following section, a review of the literature will be conducted to show current research efforts on BIM quality assessment.

- **IQ frameworks and quality issues in BIM:** Information Quality (IQ) dimensions help to categorize and identify model quality issues. However, the ambiguity in characterizing IQ dimensions exists in current practice of information quality assessment (IQA) [3]. There is a lack of a general consensus regarding the identification of information quality dimensions as well as an agreed-upon taxonomy of information quality issues. Berard [8] evaluated building design information from 8 quality dimensions: relevance, consistency, correctness, precision, availability, distribution, flexibility and amount of information. Zadeh et al. [9] analyzed facility information quality focusing on information incompleteness and well-formedness. Wang et al. [10] developed a model fitness system to evaluate model quality based on information inconsistency. The differences in IQ dimensions between different studies arise due to the different considerations arising from differing BIM uses. For example, the quality issues such as incorrect placement of model elements and inconsistent naming of attributes are more important during the design collaboration process [10]. On the other hand, during construction management, model information such as scheduling and fabrication type are more important to ensure correct quantities are obtained [11].
- **Information completeness:** Although significant ambiguity exists in current IQA practices, information completeness is one of the most consistently mentioned IQ dimension in the literature [9]. There have been a few of research efforts on checking information quality arising from information completeness. Early studies show that manual checking methods such as using checklists [6][7][12], visual checking [5] and photo-analysis [4] were applied to check for missing information in models. BIM applications such as Solibri Model Checker and iTwo are available to detect missing attributes in building elements. However, a review of previous studies shows that a systematic framework for checking information completeness in BIM has not been discussed widely, and constitutes a research gap to be addressed.
- **Information correctness:** Correct information is vital to fulfil the purposes of building information modeling. It plays a critical role as an IQ dimension in the IQA framework. However, information correctness is a concept with widely varying definitions and meanings. Zadeh et al. [9] discussed information correctness issues as inaccuracy of model attributes specifically for facility management. Berard [8] described correctness as "extent of missing, incorrect outdated design information".

  This inconsistent definition of correctness makes detection and validation of incorrect information in models a difficult problem to solve. Kulusjärvi and Heikki [12] described information correctness checking as "to compare and measure information contained in a BIM against reference information". This reference information can be related documentations, or physical reality [3]. In general, this literature review shows that methods to perform correctness checks are limited to visual checking and use semi-automated ways [9][13].
- **Information Delivery Manual (IDM) and Model View Definition (MVD):** In the study of information systems, the quality of information is a characteristic that should be checked against the information consumers' requirements [14]. Analogously, the aforementioned has been adapted for use in BIM: A good quality model is one with useful information specified by BIM users that is fit-for-purpose. During the BIM development process, model information is typically exchanged downstream for different BIM uses. The current best practice is to specify these exchange requirements in the Information Delivery Manual (IDM). This is a standard methodology for BIM users to specify the information required in BIM for different scenarios [15].

  The current implementation of IDM is to represent information exchange requirements in the format of paper-based documents [16]. Based on the exchange requirements, Model View Definitions (MVDs) would be developed to streamline information specific to the BIM use. However, MVD itself does not guarantee whether the data extracted from model is correct or consistent. Validation still needs to be carried out to check if it conforms to the information constraints or rules specified in exchange requirements [17]. Several research efforts have been made on the development of MVDs from IDM specification [16][18], however the validation of the exchanged information is still an open research question.

3 IQA Framework

The components of the proposed framework for information quality assessment (IQA) of building

Table 1. The proposed framework for information quality assessment

IQ Dimensions	Arity	Data Characteristics	An Example of Quality Issue	Algorithm Classes
Completeness	Element level	Geometry Attributes	Missing and incomplete attributes	class 1
		Non-geometry Attributes	Missing and incomplete attributes	class 1
	Model level	Element	Duplicated elements	class 3a
			Missing elements	class 3b
Correctness	Element level	Geometry Attributes	Length of analytical wire is zero	class 1
		Non-geometry Attributes	Physical-analytical model distance exceeds tolerance	class 2
	Model level	Element	Interference clashes	class 3a
		Relations	Elements are not connected	class 3a
			Mismatch between mapping files in different BIM applications	class 3b

information models (BIM) are as shown in Table 1. The objective of this framework is to categorize quality issues from the perspective of the information requirements of the model. Three features of quality issues are identified: IQ dimensions, Arity and Data Characteristics. Subsequently, specific IQA scenarios may be defined using these three features, and consequently classes of algorithms can be identified to address the quality issue raised. Specific examples of such quality issues are provided in Table 1 as well, where these are common issues faced by experienced structural engineers and BIM managers in actual projects.

- **Information Quality Dimensions:** In the proposed framework, information completeness is defined to mean an element must have complete attributes and values, or a model must contain all relevant elements. In other words, incomplete information refers to missing or incomplete attributes or values in the element or missing elements in the model that should exist according to the design scheme.

  For information correctness, this framework considers elements or models that contain incorrect information such that when they are passed downstream, it affects the performance of the model. For example, a model may contain complete information for structural analysis but if the information is incorrect, then during structural analysis, this may result in incorrect analysis.
- **Arity:** The proposed framework recognizes that quality issues on information completeness and correctness can exist on two levels: on single elements (or a single group of multiple elements) and on a model level. This framework refers to this IQ dimension as its arity. To categorize the arity of these issues clearly, this framework refers to these as Element Level issues and Model Level issues, respectively.

  Information quality on element level focus on the data quality in a single element (or a singular group of elements). This means that some values of the attributes or properties in a specific element in BIM will be checked.

  Model level quality issues refer to issues that exist between multiple elements. In this scenario, the quality auditing task here may involve the checking of the relationship between multiple elements or the existence of several elements in a model.

  One difference between element level and model level issues is the source of information to be checked. In the element level, checking can be done by using information from within a single element, such as the attributes or parameters. While in the model level, checking is performed successfully only when the information from multiple elements are available and, in some cases, data outside BIM maybe required for checking.

From the viewpoint of quality control, dividing IQ issues into element and model level is an important feature to distinguish the specific IQA scenario. These scenarios are important to identify the appropriate algorithm approach to use.

- **Data Characteristics:** Data characteristics refers to the type of data. From the perspective of data characteristics, this framework considers the following:

1. **Geometry attributes:** properties showing geometry information of physical elements;
2. **Non-geometry attributes:** properties showing non- geometry information of physical elements;
3. **Element:** physical elements in the model;
4. **Relations:** relationships between physical elements;

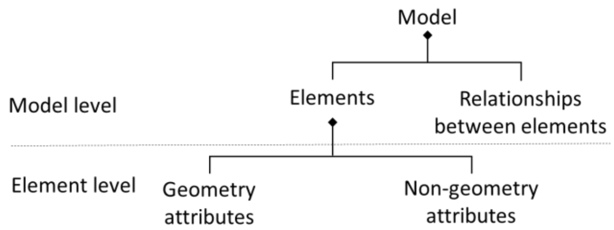


Figure 1. Model Hierarchy

In the model hierarchy shown in Figure 1, “Model” refers to the building information model, and this resides on the highest level. Elements in the model and the relations between these elements are child entities that lie on the second level. Attributes contained within the elements are on the lowest level. Both geometry and non-geometry attributes exist in the element level while existence of the element and the relations between these elements lie on the model level. As IQ issues may arise from different circumstances, issues caused by element attributes can be considered as element level issues and corresponding algorithms can be devised to check this kind of issues.

- **Quality Issues:** In Table 1, examples of common quality issues are listed for different IQA scenarios arising from the structural analysis BIM use. These were identified by experienced engineers and BIM managers in real-world BIM projects. The quality issues mentioned in this framework are categorized according to the features of IQ dimensions, arity and data characteristics. By identifying the features of these quality issues, general approaches for algorithms to detect such quality issues can be developed.

4 Algorithm classification for different IQA scenarios

From the features identified in the framework of Table 1, three classes of algorithms were developed to provide guidance for information quality assessment. Each class of algorithm provides a general approach to detecting the quality issue.

The three classes of algorithms are described in more details below. The description for each algorithm class is also summarized in Table 2, and it is organized by introducing the flowcharts for each algorithm, its features and the IQA scenario it is applied to. Examples are given to illustrate how the assessment can be conducted using the algorithm classes.

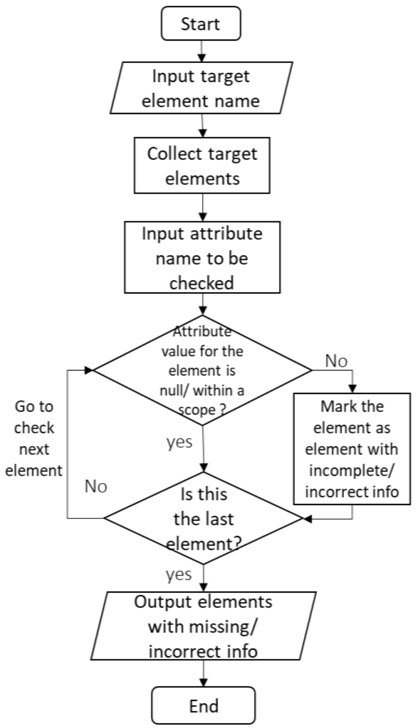
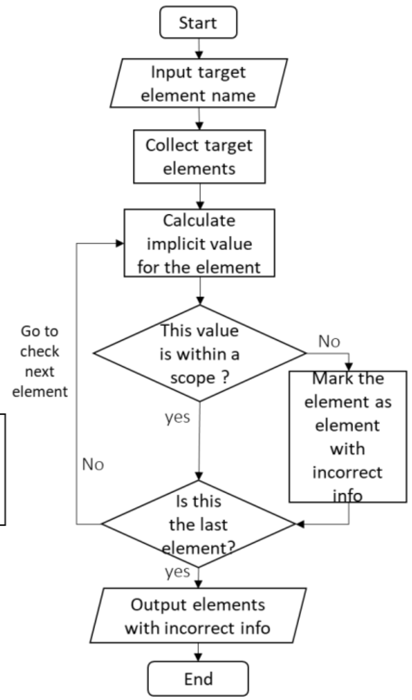
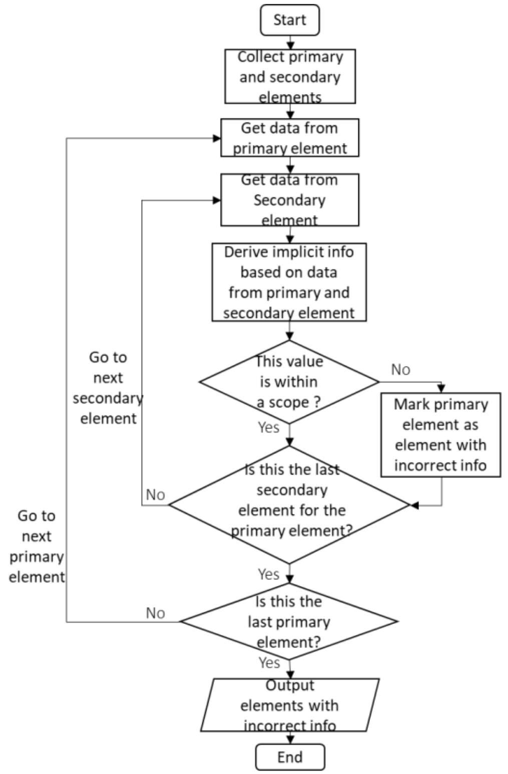
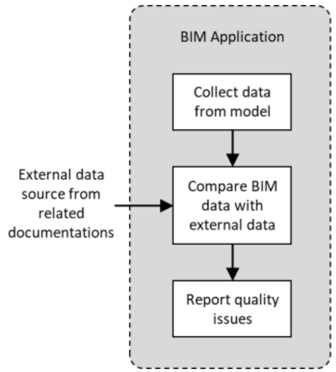
- **Class 1 -- Algorithm to check explicit data in a single element:** This class of algorithm can check the explicit data such as values attributes or properties in a single element. Here “explicit data” means the data can be accessed from element directly without any calculations or derivation. It can be applied to check quality issues on information completeness and correctness on element level.

  The procedure of using this algorithm class for checking model information starts from collecting target elements and then examining the specific attributes values for each element. Examples are given here to show how this class of algorithm can be applied to checking model quality issues in two IQA scenarios. When checking information completeness, the algorithm checks whether a specific attribute for an element is missing or the value of the attribute is null. The correctness issues are limit on checking data which are numerical or from string type. When checking correctness issues, it checks whether the value of attributes is within a predefined scope (numerical data) or corresponds with a specific value (string data).

- **Class 2 – Algorithm to check implicit data in a single element:** Checks are based on the implicit data which requires further calculation or derivation from explicit data existing in a single element. This class can be applied to check quality issues on information correctness on the element level.

  The procedure of using class 2 algorithm is very similar to that of algorithm class1, but more complicated with an extra step of calculating the implicit value for the element. Therefore, the function of checking information correctness here is limited to check whether a numerical data is within a predefined scope.

Table 2. Summary of algorithm class

	Algorithm Class 1	Algorithm Class 2	Algorithm Class 3a	Algorithm Class 3b
Description	To check explicit data in a single element	To check implicit data in a single element	To check between multiple elements with native data source within BIM	To check between multiple elements with external data source outside BIM
IQA Scenarios	Information completeness on element level; Information correctness on element level	Information correctness on element level	Information correctness on model level	Information completeness on model level; Information correctness on model level
Flowchart or Conceptual Schema				

- **Class 3a – Algorithm to check between multiple elements with native data sources within BIM:** This class of algorithm checks information involving multiple elements inside BIM. Checks focus on information correctness issues on model level. Since this class of algorithm checks between multiple elements, it is important to specify the relationship and sequence of elements to be checked. Therefore, a concept shown in Figure 2. specify the "primary and secondary" elements to be checked in this scenario.

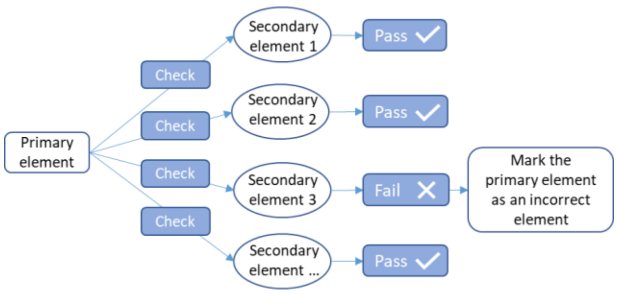


Figure 2. Schematic of checking between primary and secondary elements

The identification of these two element groups depends on what specific quality issues needs to be check. For example, in connection checks, the primary element may be any object which can be connected to other elements. Then the secondary element will be the one close enough to the primary element. During the checking process, primary elements will be collected in the first round. Then in the second round, secondary elements will be collected for each primary element. Checks will be proceeded by obtaining information based on data from the primary element and its secondary elements. Connection checks require the information such as distance between two nodes from different elements. In this case, coordinates of all nodes from both primary and secondary elements will be collected and be used to calculate the distances. The number of checking results depends on the number of secondary elements and if there is at least one result showing two elements did not pass the check. This primary element will be considered as an element with quality issues.

In this algorithm class, checking correctness issues involve the identification of numerical data derived from BIM.

- **Class 3b – Algorithms to check between multiple elements with external data source outside BIM:** Class 3b requires external data source outside BIM to perform checks. Such algorithms can be applied to check information completeness and correctness on model level. One example can be checking whether there is any missing element in the model. In this case, external data such as 2D CAD drawings may serve as reference information.

Due to the generic nature of procedure, a conceptual schema was given for the instructions of implementation of class 3b algorithms.

5 Validation and discussion

To test the validity of the proposed IQA framework and the algorithm classes derived, the framework was applied to current guidelines for BIM quality assurance. The validation was applied against a set of rules for quality assurance given in Singapore BIM Guide [7]. Both architectural and structural BIM elements were considered in this evaluation. Each rule would be classified according to the specific IQA scenario as well as its corresponding algorithm class. Then the algorithms would be applied to check quality issues against the rules.

A validation set consisting 30 rules from both architectural and structural BIM modeling guidelines was identified and tested on. The applicability rate of the proposed IQA framework to each BIM discipline was calculated (seeing Equation (1)).

$$R_a = \left(1 - \frac{N_u}{N_t}\right) \times 100\% \quad (1)$$

R_a – Applicability rate (%)
N_u – Number of rules categorized to unknown
N_t – Total number of rules tested

The results tabulated in Table 3 indicate more than 80% of rules can be classified through the proposed framework, for both architectural and structural BIM. Results from architectural BIM guidelines show a higher rate of applicability due to greater number of rules on checking spatial information.

Rules categorized as belonging to algorithm class 1 focused on checking existence and correctness of elements attributes such as ID, category, and level information. Compared with the rules in class 1, there were fewer of rules considered to be in class 2 that checks implicit data in elements. The reason can be that quality assurance in this BIM guidelines considers general cases whereas there are no statements on which specific information should be checked. Thus, it would be difficult to decide whether the information to be checked is explicit or implicit. However, in some cases, it was obvious. For example, rules involving checks on distance, areas, and coverage rate etc. were categorized in class 2.

According to the proposed IQA framework, the

Table 3. Validation results

Algorithm Classes	Algorithm Class 1	Algorithm Class 2	Algorithm Class 3a	Algorithm Class3b	Unknown	Applicability Rate, R_a (%)
IQA Scenarios	Information completeness on element level; Information correctness on element level	Information correctness on element level	Information correctness on model level	Information completeness on model level; Information correctness on model level		
Number of architectural BIM rules	6	1	6	2	2	88.2
Number of structural BIM rules	4	0	6	1	2	84.6

quality issues exist not only on element level but also on model level. The validation results demonstrate the current modeling guidelines have many rules for checking information quality on model level. These rules were categorized as class 3a which checks information correctness issues between multiple elements in BIM. Apart from checking data sources within BIM, some rules involving external information source outside BIM were included in class 3b. This indicates checking within single elements on element level is not enough for IQA. Quality issues existing between elements are also important.

Some rules were not able to be classified to any of the IQA scenarios, nor the algorithm classes. One of the reasons is that rule is worded too generally, which may cause ambiguity. For these rules containing general statements, it is not implementable with specific checking methods, nor is it possible to recommend specific instructions. Another reason observed is that some rules have a scope of checking that goes beyond the framework. For example, checking the quality of 2D drawings before exporting to BIM.

6 Conclusion

Good information quality in BIM helps owners in AEC industries realize the full benefits of BIM. Models with poor information quality may cause significant cost consequences. This paper proposed an information quality assessment (IQA) framework to systematically categorize information quality issues existent in BIM. Hence, recommendations for quality control implementation can be formulated. This framework collected quality issues on information completeness and correctness from the perspectives of data arity and data characteristics. Given these features, the quality issues were categorized into IQA scenarios, then corresponding algorithm classes were developed to check said quality issues.

The validation was conducted against current modeling guidelines used for BIM quality assurance in both architectural and structural disciplines. The results indicated more than 80% of rules were able to be categorized using the framework. Further, the rules were shown to fit the IQA scenarios and its corresponding algorithms classes. From the detailed results, it was observed there were fewer rules in class 2 than rules in class 1. This indicated that quality assurance in this set of BIM guidelines consists of general statements on which specific information could not be checked. Thus, it was not possible to determine if the information to be checked was explicit or implicit. It was also observed that there were some rules which were not able to be classified according to any of IQA scenarios. Reasons for this included that rule statement were too general, or that the content of the rules did not focus on the model or BIM itself, going beyond the scope of this framework.

Thus, the future improvements to the framework should focus on testing more BIM guidelines for quality control to further extend this framework, as well as identifying more classes of algorithms, particularly those identified within class 3b.

In general, the proposed IQA framework is shown to be adequate to guide modeling process, as well as to provide practical guidance for implementation of BIM quality assessment. It enables BIM managers to ensure a fit-for-purpose, quality assured model that can reduce rework, and engender greater trust in the model creation process.

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References

[1] Zadeh P.A. , Cavka H. B. and Staub-French S. BIM Information Quality Analysis for Space Management. Osaka University, 2016.

[2] Gallaher M. P., O'Connor A. C., Dettbarn J. L., Gilday L.T. *Cost Analysis of Inadequate Interoperability in the us capital facilities industry*. U.S. Department of Commerce, Maryland, U.S., 2004.

[3] Zadeh P.A. , Staub-French S. and Pottinger R. Review of BIM Quality Assessment Approaches for Facility Management. *11th Construction Specialty Conference*, Vancouver, British Columbia, 2015.

[4] Tang P., Anil E. B. Akinci B. and Huber D. Efficient and Effective Quality Assessment of As-Is Building Information Models and 3D Laser-Scanned Data. 2011.

[5] Sacks R., Eastman C., Lee G. and Teicholz P. BIM Handbook – A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers. 2018.

[6] General Services Administration (GSA). GSA Building Information Modeling Guide Series: 08 - GAS BIM Guide for Facility Management. U.S. General Services Administration (GSA), Washington DC, U.S. 2011.

[7] Building and Construction Authority (BCA). *Singapore BIM Guide*, version 2, Building and Construction Authority, Singapore, 2013.

[8] Berard O. BIM for Managing Design and Construction Assessing – Design Information Quality, PhD Thesis, Technical University of Denmark, 2012.

[9] Zadeh P. A., Wang G. Cavka H. B., Staub-French S. and Pottinger R. Information Quality Assessment for Facility Management, *Advanced Engineering Informatics*, 33:181-205, 2017.

[10] Wang J., Wang X., Shou W., Guo J. and Hou L. Development of BIM Model Fitness Review System for Modeling Quality Control, *Computing in Civil and Building Engineering*, 577-584, 2014.

[11] Chen L. and Luo H. A BIM-Based Construction Quality Management Model and Its Applications, *Automation in Construction*, 46:64-73, 2014.

[12] Kulusjärvi H. COBIM: Common BIM Requirements, series 6, 2012.

[13] Becerik-Gerber B., Jazizadeh F., Li N. and Calis G. Application Areas and Data Requirements for BIM-Enabled Facilities Management, *Journal of Construction Engineering and Management*, 138(3):431-442, 2012.

[14] Wang R. Y. and Strong D. M. Beyond accuracy: What Data Quality Means to Data Consumers, *Journal of Management Information Systems*, 12(4): 5-33, 1996.

[15] International Organization for Standardization (ISO), ISO 29481-1:2017 Building information models - Information delivery manual. Part1: Methodology and format, 2017.

[16] Lee Y.C., Eastman C. and Solihin W. An Ontology-Based Approach for Developing Data Exchange Requirements and Model Views of Building Information Modeling, *Advanced Engineering Informatics*, 30(3): 354-367, 2016.

[17] BuildingSmart, Model View Definition (MVD). https://technical.buildingsmart.org/standards/ifc/mvd/, Accessed: 29/05/2020.

[18] Lee G., Park Y. H. and Ham S. Extended Process to Product Modeling (xPPM) for integrated and seamless IDM and MVD development, *Advanced Engineering Informatics*, 27(4): 636-651, 2013.