International Journal of Engineering & Technology, 8 (1.4) (2019) 492-499

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Development of Automated BIM Data Quality Pre-Check (BDQPC) System in Architectural Design Phase

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Abstract

Recently, the mandates on utilizing Building Information Modeling (BIM) implemented by the public institutions of many countries have had a great impact on the significantly increasing practices of BIM. BIM is a technology that supports a process of information exchange and communication by integrating, interchanging, and reusing data during the building lifecycle. The improvement of work efficiency and productivity that comes with BIM adoption depends on the consistency and accuracy of data. To maximize the benefit of BIM, interest in BIM data quality has been increasing all over the world. The delivery of BIM data is mandatory in advanced countries, and these countries are promoting automated BIM quality checking. The BIM data quality pre-check (BDQPC), which is conducted by a designer in the design phase, offers opportunities for quality improvement by continuously assessing BIM data. However, the BIM quality pre-check is being conducted under the arbitrary interpretation of users because of the absence of specific review factors and assessment methods for checking BIM quality. The purpose of this study is to suggest an automated BIM quality pre-checking system to improve BIM design quality effectively and efficiently. It is expected to meet the owner's requirements and to minimize the additional cost and time incurred from revising and reproducing data by ensuring its consistency and accuracy.

Keywords: *Building Code Checking, Building Information Modeling (BIM), Data Quality, Industry Foundation Classes (IFC), Pre-Checking*

1. Introduction

The building industry environment is a collaborative environment that requires repetitive data exchanges and high-frequency communication among different domains and applications [1]. Building Information Modeling (BIM) is a technology that supports a process of information exchange and communication by integrating, interchanging, and reusing data during the building lifecycle. Recently, BIM has been actively adopted in order to improve the productivity of the building industry. Furthermore, the public institutions of advanced countries, such as the US, the UK, Singapore, and South Korea, have applied mandates to implement BIM in design delivery. It has had a great impact on significantly increasing practices of using BIM [2]. The improvement of work efficiency and productivity that comes with BIM adoption depends on the consistency and accuracy of data. To maximize the benefits of BIM, interest in BIM data quality has been increasing all over the world.

The delivery of BIM data is mandatory in advanced countries, and these countries are promoting automated BIM quality checking, including compliance with regulations. In particular, regulation checks through an automated regulation checking system can reduce errors, time, and the inefficient use of human resources through objective verification. BIM data, as a final result of the design delivery contract, could lead to additional time and cost when quality degradation of BIM data occurs due to errors or the omission of information. In addition, it is a key element to be secured in the design phase, because it could raise legal issues. However, many problems have been faced while reviewing information of various fields comprehensively to meet the quality requirements in BIM application guides. The BIM quality pre-check is a frequent review of a BIM model performed by a designer in the design phase. It is suggested in BIM guides (BIM guide series of the US, COBIM of Finland, BIM guides of Korea, etc.) to ensure the quality of BIM data at the time of delivery. The BIM quality pre-check is also a process of reviewing essential items before implementing various analyses. It improves work efficiency and satisfaction with design quality through producing consistent and accurate information and increasing the reliability of analysis results. Currently, the BIM quality pre-check is being conducted under the arbitrary interpretation of users. There are no specific factors to be reviewed and no specific assessment methods for reviewing BIM quality [3]. Therefore, a BIM data quality pre-checking (BDQPC) system is required for systematically constructing BIM data and efficiently securing data quality.

The purpose of this study is to suggest an automated BIM quality pre-checking system to improve BIM design quality effectively and efficiently. Domestic and foreign BIM guides have been analyzed to construct a process and to derive items for the BIM quality pre-check. The derived checking items have been systematized and structured to enable the development of an automated checking system. We propose the direction of continuous quality management of BIM data by analyzing the possibility of implementing an automated BDQPC.

A BIM data quality check is conducted in various fields, such as code checking and energy analysis. This paper focuses on code checking, which is a costly bottleneck` in the building delivery process [4].

The methods and procedures in the following were performed to develop the BIM data pre-checking system.

1. Review operational and technical definitions of BIM quality and BIM data quality pre-check
2. Analyze domestic and foreign BIM guides
3. Set BDQPC data items in accordance with BIM data quality management system
4. Construct an algorithm for the automated BDQPC system based on IFC format
5. Verify appropriateness of the automated BDQPC system using Solibri Model Checker (SMC) and KBim Veri

2. Literature review

2.1. openBIM

BIM is based on the concept of using electronic information to generate and express building information. BIM refers to the process and technology of acquiring and managing information electronically, which is important throughout the lifecycle of building planning, design, engineering, construction, maintenance, management, and demolition [5]. Through BIM, information related to a building can be managed and used electronically, enabling the application of the many advantages of computers, such as accuracy and storability. However, the construction industry is huge and complex, and a wide variety of software is used by different groups in the industry to handle computerized information. The omission of information and errors in transmission can occur in the process of information exchange between these different programs [6]. To address this issue, buildingSMART proposed the concept of “openBIM.” openBIM is a concept focused on independence from specific software or product groups and ensuring interchangeability and interoperability of information between different kinds of software. For this purpose, the IFC format was developed as an international standard data format in buildingSMART and is actively being developed. In 2013, IFC was adopted and published as an ISO 16739 standard [7]. IFC is an international standard neutral file format for BIM data exchange and information exchange between the BIM software used in many fields in the construction industry. In the IFC data structure, information about the building is expressed based on the relationship of the objects and the relationship of attributes owned by the objects.

2.2. Preceding research analysis

A review of previous studies was conducted, focusing on BIM data quality management and related subjects.
Koo and Shin (2017) explored ways to automate the mapping of IFC and BIM object data using a machine learning technique, namely anomaly detection [8]. Seo et al. (2012) proposed the requirements considering the quality of BIM data and demonstrated the efficiency of the requirements with SMC in a case study [9]. Kwon et al. (2009) suggested the IFC-based BIM data quality management system for quantity take-off and verified it by using SMC [10]. Song and Ju (2013) developed the rules of SMC to automatically check the quality of a BIM model against clauses in the BIM guide of Korea. They also defined the quality standard specification to support the quality check system [11]. Kim et al. (2015) suggested the typology method of building code and applied it to real regulations [12]. Zhang et al. (2014) developed a model view checker for the model instance validation of IFC models based on mvdXML and BIM Collaboration Format (BCF) [1].
According to the results of the review, the studies on BDQPC remain in the early stages of the research, including dealing with a very limited items of development and systems. Depending on the extent to which BIM is increasingly adopted, the construction of a BDQPC system is expected to become more important. In addition, it could be assessed as a well-timed and important research subject.

2.3. BIM quality

The Project Management Institute (PMI) of the US defined quality and quality control as shown below [13].

1. Quality: This is the degree to which the project fulfills requirements.
2. Quality control: It refers to creating and following policies and procedures in order to ensure that a project meets the defined needs intended.

A building information model (BIM) is a digital representation of the physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its lifecycle, from inception onward [14]. As stages in the architectural process proceed, information is added and merged continuously. BIM applies parametric technology, where intelligent building objects can represent the geometric information, spatial relationships, geographic information, quantities, and properties of building objects, material inventories, and project schedules [15, 16]. BIM is especially useful for quality control using building object properties, such as characteristic and relation information for various disciplines.
An aspect of BIM, quality control, encourages the correct utilization of data, and quality checks review the validity of the physical and logical information to increase productivity [17]. Quality control requirements based on BIM according to the goals and objectives of quality checks can be classified [18].
BIM-based design work can be interpreted as an activity to meet the requirements established in advance by a client. In this study, BIM quality is defined as the degree of meeting the requirements of the client on a BIM project. In addition, BIM quality management is defined as a whole system, which includes the policies and the processes on quality standard, assurance, and monitoring to create satisfactory BIM data.

2.4. Quality pre-checking

The BIM quality pre-check is defined by the Basic BIM Guidelines for Facilities Project (Public Procurement Service) [19] and BIM Guideline for Design (Ministry of Land, Transport, and Maritime Affairs) [17]. The BIM quality pre-check is conducted by a designer before delivery. It checks the criteria that are essential for securing BIM data quality itself and the quality of the results of its application. The BIM quality check is conducted by the client after delivery, and it is based on the quality pre-checking report (a check on the addi-

tional items is performed as needed). The development of objective and clear BDQPC items is essential, especially in Korea, where the BIM quality is assessed largely based on BDQPC items.
Existing manual quality checking requires a lot of time and effort, and it has weaknesses in terms of the objectivity, transparency, and reproducibility of results. Currently, the quality of BIM-based quality checking is limited to domestic and foreign research, and it is necessary to present a plan that can be utilized in various fields according to the purpose of quality checking through this study.

2.5. Three criteria for BIM data quality management

A quantitative and objective management system is needed to continuously manage BIM data quality. To develop a standard for BIM data quality management, BIM data quality management criteria are defined according to the three management criteria of data quality [10] of the Korea Database Agency.

1. Quality Standard (QS): It is a criterion to assess the degree of BIM data quality. In other words, it is a type of measurement standard that is managed to secure the accuracy of data. The five types of quality standards are shown in Table 1.

Table 1: Five types of quality standards for BIM quality

Quality standard		Definition
Name	Sign	
Uniqueness	U	Data item must be unique and must not overlap with another item
Integrity	I	Critical data item must exist in the data model (no omission)
Correlation	C	Predefined relationship between data items should be formed
Validity	V	Data item must be represented in a prescribed form
Accuracy	A	Data item must have accurate required information

2. Critical Quality Criteria (CQC): It is an important criterion as a substantive management object in BIM data. It directly affects data quality.
3. Business Rules (BRs): They are the consistent and formalized rules that are applied to management or assessment activities. They include the detailed content with which each CQC should comply.

3. BIM quality pre-checking system

3.1. BIM quality pre-checking process

The BIM quality pre-checking process is developed based on BIM guides, including the Basic BIM Guidelines for Facilities Project, BIM Guideline for Design of Korea, and COBIM Series 06 of Finland. It reflects the domestic circumstances of design delivery shown in Fig. 1.

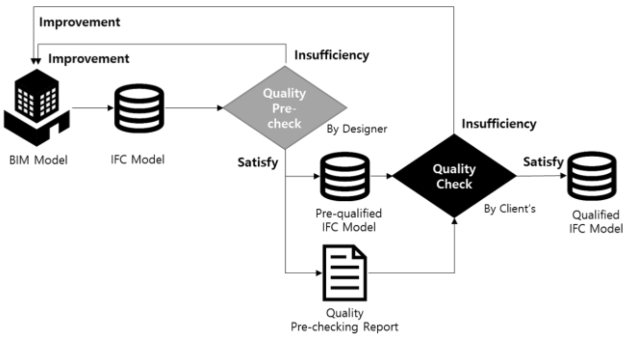

Fig. 1: BIM quality pre-checking process

In this process, the designer could continuously conduct the BIM quality check and revise any errors. By maintaining the target throughout the design project, the effects of BIM utilization could be maximized. After delivery, this process could provide an objective and rapid quality check to the client by an automatic review of the quantitative items on the quality pre-checking report.

3.2. BDQPC items

The required quality of BIM data of each project differs depending on the purpose and the field of BIM adoption. The needs of the client are also an important factor here. In this study, the common and critical BDQPC items that could be universally applied in various projects are derived. The BDQPC items are categorized into two groups: 1) General items: minimum standard that must be met for all BIM models and 2) Items in field: minimum standard that must be met to support the effective utilization of BIM in a specific field. In this study, the BDQPC items for code checking are developed, and the items for other fields, such as energy analysis, are planned to be developed later.
The Basic BIM Guidelines for Facilities Project (Korea) [19], BIM Guideline for Design (Korea) [20], BIM Guide Series 02 (US) [21], STATSBYGG BIM Manual (Norway) [22], and COBIM Series 06 (Finland) [23] were analyzed. A total of 35 items were extracted as the General BDQPC items.
Evacuation and fire protection regulations, which were the most frequently reviewed regulations among the law checklists of the four projects (two commercial buildings and two apartment buildings) in design firms, were analyzed. The analyzed articles of the building act enforcement decree [24] are as follows:

1. Article 34 (Direct stairs)
2. Article 46 (Fire protection district)
3. Article 56 (Fireproof structure)

4. Article 90 (Emergency elevator)

In total, 13 BDQPC items for code checking were extracted.
The 36 BDQPC items (23 General items, 13 Code checking items) that could be expressed with object, attribute, and relation of the BIM model were extracted from 48 items. These items are subjects of this study and are utilized as items for the automated BIM quality check later.

3.3. Systematization of BDQPC items

A total of 36 BDQPC items derived in the previous section were classified according to the BIM data quality management criteria. First, the BDQPC items were categorized by CQC and given the QS type depending on the characteristic of its check rule, as shown in Fig. 2. To systematically manage the BDQPC items, the BR of CQC was given a five-digit code, as shown in Table 1. Code assigning was conducted, considering an additional expansion later.

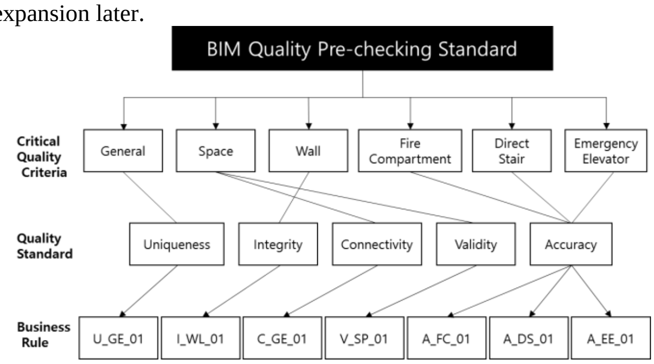

Fig. 2: Systematization of BDQPC items

Sign of QS(1 digit)_Abbreviation of CQC(2 digit)_Order(2 digit) (1)

This code is comprised of the sign of the QS type, the abbreviation of CQC, and its order, as shown above. Through this code, users can easily understand the characteristics and the kinds of information related to the BR.

3.4. Structuring of BDQPC items

In order to enable an automatic quality pre-check, the BDQPC items that consist of natural languages should be translated into computer-readable language. Structuring of BDQPC items into the IFC structure was conducted for this reason. In total, 36 BRs were quantitatively represented as object, attribute, and relation of IFC format (the standard data format of design delivery). In order to clarify the quality pre-check, precise criteria are required, and the system developed in this study can be automatically checked based on the criteria. Therefore, the definition of the criteria as shown in Table 2 is very important. In addition, the algorithms for performing the quality pre-check are defined as a flowchart and pseudo code. Fig. 3 is the flowchart of the following item: "Each space with an area more than 0.5 square meters in a building is necessarily represented as a single space object (V_SP_01)." To review this item, required information of IFC entities and the evaluation method of each step is defined. The structured BDQPC items are used as a rule of the BIM quality pre-checking program.

Table 2: BDQPC items (example of whole items)

	Critical quality criteria	GS	Business Rule				
			Code	Contents	Structuring according to IFC format		
					Entity	Required property	Value
GENERAL	General	U	U_GE_01	All BIM objects must have a GUID	IfcElement	GlobalId	IfcGloballyUniqueId
		C	C_GE_01	Building elements must be connected to the space they belong to	IfcRelSpace Boundary	RelatingSpace Related BuildingElement	IfcSpace IfcBuilding Element
	Wall	I	I_WL_01	External wall must have an attribute value of outside exposure	IfcWall	Pset_WallCommon - IsExternal	IfcBoolean
	Window	I	I_WD_01	External window must have an attribute value of outside exposure	IfcWindow	Pset_WindowCommon-IsExternal	IfcBoolean
	Space	V	V_SP_01	Each space with an area of more than 0.5 square meters in a building is necessarily represented as a single space object	IfcQuantity Area	AreaValue	IfcAreaMeasure >0.5 m^2
		I	I_SP_01	Type of space must be defined	IfcSpace	ObjectType	IfcLabel
CODE CHECKING	Fire compartment	A	A_FC_01	Main structures and walls surrounding fire compartments must have a fireproof attribute value	IfcBuilding Element	Pset_Common - FireRating	IfcBoolean =True
		A	A_FC_02	Space included in fire compartment must have a related attribute value	IfcSpace	Pset_SpaceFireSafety Requirements-FireExist	IfcBoolean =True
	Direct stair	A	A_DS_01	Direct stair must have a fire compartment attribute value	IfcStair	Pset_SpaceFireSafety Requirements - FireExist	IfcBoolean =True
	Emergency elevator	A	A_EE_01	Emergency elevator must have a fire compartment attribute value	IfcTransportation	Pset_SpaceFireSafety Requirements - FireExist	IfcBoolean =True
	Ramp	I	I_RP_01	The ramp slope value must be defined	IfcRamp	Pset_RampCommon - RequiredSlope	IfcBoolean =True

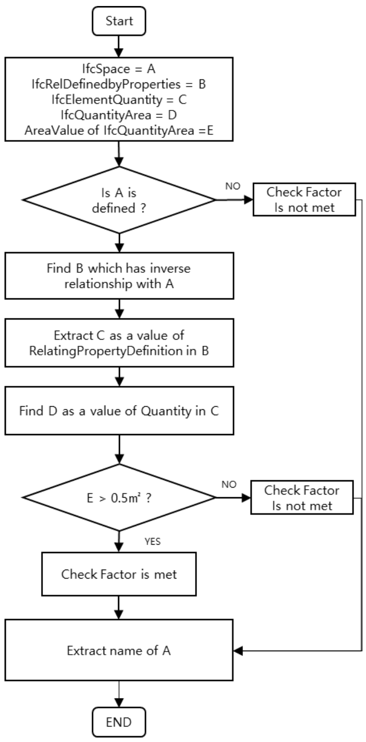

Fig. 3: Flowchart of item of BDQPC (V_SP_01) (example)

4. Verification of BIM pre-checking system

4.1. Case application for verification

To verify the adequacy of the developed BIM quality pre-checking system and the possibility of implementing an automatic BDQPC, SMC was utilized. The rules of SMC, a similar concept to BR of BDQPC items, are made by Ruleset Manager in SMC. SMC is a leading software program in the construction industry that can check model quality based on BIM. SMC is the most widely used tool for BIM quality control in the GSA of the US, senate properties in Finland, and bips in Denmark. SMC was also used during the building design of the Korea Power Exchange headquarters as a quality check tool. SMC can perform various functions, such as space, accessibility, structure, constructability, and regulation checks, through a rule set that the user defines [4]. The code was entered as the name of each rule.

The verification of the developed BIM quality pre-checking system was conducted using the BIM model of the 15-storey design firm's headquarters building located in Seoul, Korea. Verification was carried out in two aspects: 1) Conformity of algorithms of BDQPC items and 2) contribution to increased BIM data quality.

1. Conformity of algorithms of BDQPC items:

Six errors were created intentionally in the BIM model to confirm whether these could be found by the developed algorithms. The results of BIM quality pre-checking showed that all six errors were recognized. It was also confirmed that the results of passing rules were obtained correctly.

2. Contribution to increased BIM data quality:

The code checking on the fire compartment standard of the detailed article of facilities evacuation was performed, targeting an original BIM model and revised BIM model according to the result of quality pre-checking. In the revised BIM model, there was one error, while in the original BIM model, eight errors occurred (shown in Fig. 4).

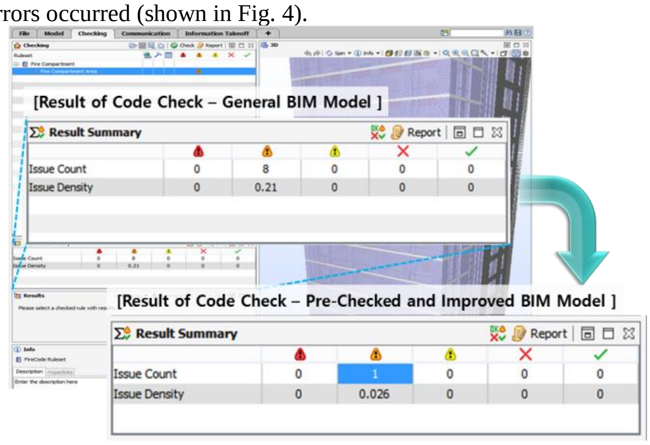

Fig. 4: Results of code check on fire compartment standards

(UP: Results of original model, DOWN: Results of revised model)

4.2. Development of pre-checking system for BIM data quality verification

Before submitting the BIM model data to SEUMTER (e-Submission system in Korea) [25] for project approval, the BIM model quality assessment module, KBim Veri, is used for verifying regulatory compliance. KBim Veri functions as a part of the BIM Quality Center service, which is the proposed web-based service for authenticating BIM models for SEUMTER submissions [26].

KBim Veri performs preliminary checks on data quality of BIM models during the design phase. It provides quality validation to meet the minimum requirements of the BIM model on code checking, energy simulation, and standards of the BIM guide with consistency and accuracy of data. After logging into the BIM Quality Center website, KBim Veri is executed when a user clicks the "BIM design quality verify" button.

The BIM design quality verification process consists of four steps. First, a user uploads a BIM model to verify. Second, KBim Veri verifies the uploaded BIM model when the user clicks the "Verification" button. Third, the user checks the verification result. The user can check the verification result for a pass or fail and can review the detailed results on quality criteria in the "Report" window. The verification results can be printed out. Fourth, the user issues a certificate for the BIM model, only if the result is a pass. When clicking the "Issue BIM quality certificate" button, the user can check the verification record and print out or download the issued certificate (See Fig. 5).

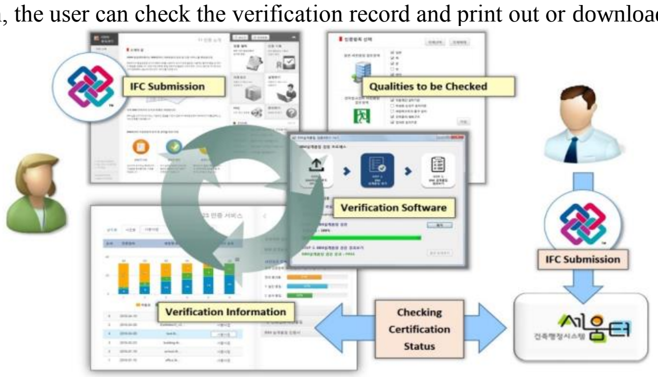

Fig. 5: Process of pre-checking system for BIM data quality verification

Key functions include:

- BIM model evaluation for file errors, such as invalid IFC version or wrong format
- Preliminary checking of BIM models prior to using KBim Assess for proper input of model objects and attributes necessary for automated code checking
- Basic quality assessment of model objects' dimensions, location, type, and object relations
- Report generation of checked results

4.3. Result analysis

Through verification, the developed BDQPC system and checking algorithm can correctly review design errors and provide users a high confidence level. In addition, by detecting errors in advance by performing pre-quality checking, it was confirmed that design quality could be considerably improved by modifying them. The authors concluded that this system is suitable for the systematic management of BIM data quality by providing an environment of advanced prevention of data errors and omission.

For a design office, because of the simplicity and systematization of the design permit process for small- and medium-scale design firms, it can improve productivity. It can also improve the design quality and engineering technology of the design offices and engineering companies and strengthen the collaboration among construction industry members by standardizing information exchange.

5. Conclusion

The design information found throughout the architectural industry is varied and extensive. In particular, the quality of BIM data applied at the design stage should be assessed and checked to ensure that the design meets the related design requirements. In addition, continuous checks in the design or development phase must be made to ensure that this continues to be true despite the frequent design changes. This study suggested the BDQPC system by verifying the possibility of improving the quality and reliability of BIM data. As a fundamental research study for developing an automatic BDQPC program, a quality pre-checking process, item, and checking algorithm have been developed based on the definition of BIM quality, BIM quality pre-check, and BIM data quality management criteria. The code system has been adopted to efficiently manage the BDQPC items that are planned to be extended to various BIM adoption fields.

The results of this study have significance for providing a quantitative and objective BIM-based environment to secure design quality. In addition, the developed system, which enables the continuous pre-checking of quality in the design phase, could minimize the additional cost and time incurred from revising and reproducing data by ensuring its consistency and accuracy. This study is expected to contribute to improving the efficiency of BIM-based design work and to meeting clients' quality demands.

Architects and designers who wish to check design quality in the design process or during evaluation can expect improvements in quality by a systematic approach with respect to the detailed checking of results. The automated quality pre-checking system can support quality checking according to quality pre-checking requirements and reduce inefficiencies in the use of time and human resources. Errors noted in quality checking results could be minimized by improving the performance of the checking system with respect to the requirements. It is expected that software would maximize the reliability of results and the efficiency of quality pre-checking.

The scope of the quality pre-checking requirements applied in this study is limited to the design process, and it may be impractical to apply quality pre-checking throughout the project's lifecycle. To overcome this limitation, the application scope of quality pre-checking should be expanded to various phases, such as construction and maintenance.

Acknowledgement

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NRF-2016R1C1B1014915).

References

[1] Zhang C, Beetz J & Weise M. (2015), Interoperable validation for IFC building models using open standard, *Journal of Information Technology in Construction*, Vol.20, 24-39.

[2] Kim IH, Cho GH & Choi JS (2010), A case study of BIM quality assurance for the target of super-tall buildings, Proceeding of the 18st Journal of the Architectural Institute of Korea, Vol.30, No.1, 23-24.

[3] Choi JH & Kim IH (2014), A study on the application of pre-processing of develop the open BIM-based code checking system for building administration process, *Journal of the Architectural Institute of Korea (Planning and Design)*, Vol.30, No.9, 3-10.

[4] Eastman C, Lee JM, Jung YS & Lee JK (2009), Automatic rule-based checking of building designs", *Automation in Construction*, 18, 1011-1033.

[5] Kim IH, Kim MC & Choi JS (2015), Improvement of Open BIM-based Building Permission Process Using EPI (Energy Performance Index), *Korean journal of construction engineering and management*, Vol.16, No.6, 124-135.

[6] Choi JH (2014), A Study on the Development of Code Checking System for Building Administration Process Applying Open BIM-based Process, M.A. Thesis, Kyung Hee Univ.

[7] buildingSMART International, http://www.buildingsmart.org

[8] Koo BS & Shin BJ (2017), Using Geometry based Anomaly Detection to Check Integrity of IFC classifications in BIM Models, *Proceedings of the Society for Computational Design and Engineering Conference*, 534-536.

[9] Seo JC, Kim HJ & Kim IH (2012), Open BIM-Based Quality Control for Enhancing the Design Quality in the Architectural Design Phase, *Korean Journal of Construction Engineering and Management*, Vol.14, No.4, 3-15.

[10] Kwon OC, Jo CW & Cho JW (2012), A Study on the Systematization of Open BIM Data Quality Management, *Journal of the Architectural Institute of Korea (Structure & Construction)*, Vol.28, No.2, 105-112.

[11] Song JK, Ju KB (2013), Development of Rule for Quality Checking Items to Raise Quality of BIM Model-Focusing on the Domestic BIM Guidelines-, *Korean Journal of Construction Engineering and Management*, Vol.14, No. 5, pp.131-143.

[12] Kim IH, Kim YH & Choi JS (2015), Building Code Typology and Application for Open BIM based Code Checking, *Transactions of the Society of CAD/CAM Engineers*, Vol.19, No.3 224-235.

[13] Project management Institute (2004), Project management body of knowledge, 3rd Ed., USA, p.413.

[14] NIBS (2006), Overview Building Information Models.
[15] Choi JS & Kim IH (2015), Development of an Open BIM-based Legality System for Building Administration Permission Services, *Journal of Asian Architecture and Building Engineering*, Vol.14, No.3, 577-584.
[16] Azhar S, Nadeem, A, Mok, J & Leung B (2008), Building Information Modeling (BIM): A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects, *First International Conference on Construction in Developing Countries (ICCIDC–I)*, 4th-5th August, Pakistan.
[17] MLTM (Ministry of Land Transport and Maritime Affairs) (2010), BIM Guide of Ministry of Land Transport and Maritime Affairs.
[18] Choi JS & Kim IH (2011), Interoperability Tests of IFC Property Information for Open BIM based Quality Assurance. *Transactions of the Society of CAD/CAM Engineers*, Vol.16, No.2, 92-103.
[19] PPS (2015), BIM Guide of Public Procurement Service v1.3.
[20] KPX (2010), Korea Power Exchange Headquarters building construction Design competition Guideline.
[21] GSA (2007), 3D-4D Building Information Modeling BIM Guide Series.
[22] Statsbygg (2011), Statsbygg Building Information Modelling Manual Version 1.2.
[23] Henttinen, T (2012), COBIM Common BIM Requirements 2012 Series 6: Quality assurance
[24] Ministry of Government Legislation, http://www.moleg.go.kr
[25] SEUMTER, http://www.eais.go.kr
[26] Choi JS & Lee MJ (2016), Findings from the Korea Government-funded BIM R&D Project. *The BIM*, Vol.16, 12-14.
[27] Ding L, Drogemuller R, Rosenman M, Marchant D & Gero J (2006), Automating code checking for building designs, in: K. Brown, K. Hampson, P. Brandon (Eds.), Clients Driving Construction Innovation: Moving Ideas into Practice, *CRC for Construction Innovation*, Brisbane, Australia, 1-16.
[28] Kim YR, Lee SH & Park SH (2012), Development of Rule-Set Definition for Architectural Design Code Checking based on BIM - for Act on the Promotion and Guarantee of Access for the Disabled, the Aged, and Pregnant Women to Facilities and Information, *Korean Journal of Construction Engineering and Management*, Vol.13, No.6, 143-152.
[29] Jeong JY & Lee G (2008), A Study on the Possibility of using BIM in Automated Building Code Checking for Egress and Anti-disaster Regulations for Large-scale Buildings, *Proceeding of the Korean Journal of Construction Engineering and Management*, 871-872.
[30] Moon HS, Kim CY, Cho GH & Ju KB (2016), An Object Quality Verification Method for BIM Libraries based on Standardized Drawings in Civil Projects -Focusing on Retaining Wall Case, *Journal of the Korea Academia-Industrial cooperation Society*, Vol.17, No.4, 129-137.
[31] Jo CW (2016), A Study on Information Systematization of Detail Drawings for Connectivity between BIM Libraries and Technical Contents based on Information Framework, *Journal of the Korea Academia-Industrial cooperation Society*, Vol.17, No.10, 54-60.
[32] Lee SH, Park SI, Jang YH & Choi KW (2017), IFC Model Data Retrieval and Regeneration Method through Property Set-based Query Language, *Journal of the Korea Academia-Industrial cooperation Society*, Vol.18, No.2, 38-46.
[33] Park SH & Hong CH (2017), A Study for BIM based Evaluation and Process for Architectural Design Competition -Case Study of Domestic and International BIM-based Competition-, *Journal of the Korea Academia-Industrial cooperation Society*, Vol.18, No.2, 23-30.
[34] Choi JS & Kim IH (2017), Development of Rule-based Building Code Compliance Checking System for BIM-based Quality Improvement, *Information – An International Interdisciplinary Journal*, Vol.20, No.4(B), 2929-2936.
[35] Shekhawat K (2017), A computer-generated plus-shaped arrangement and its architectural applications, *Journal of Computational Design and Engineering*, Vol.4, No.4, 318-329.
[36] Vimal JS, Ghanshyam GT, Vivek KP & Poonam S (2017), Modified meta-heuristics using random mutation for truss topology optimization with static and dynamic constraints, *Journal of Computational Design and Engineering*, Vol.4, No.2, 106-130.