DEVELOPMENT OF ARCHITECTURAL DESIGN QUALITY CONTROL REQUIREMENTS BASED ON OPEN BIM

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ABSTRACT: The construction industry consists of various and massive architectural information as an architectural process includes a variety of design stages with cooperation of many disciplines. Particularly, architectural information is generated and managed through the life cycle of a building, from conceptual design stage to the construction and maintenance. A Building Information Model (BIM) serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward. BIM technology accomplished quantitative development being utilized in various disciplines. However, it is necessary to develop environment and requirement for qualitative improvement of BIM based project. Particularly, requirement is very important for architectural design evaluations. The purpose of this study is to develop and apply of quality control requirement for improving the quality of architectural design in open BIM environments. To achieve this purpose, the authors have investigated case study for open BIM data quality control (software, guideline and application case) and classified quality control targets according to physical/logical quality and data quality. In addition, the authors have defined open BIM based quality control process and developed quality control requirements. Finally, the authors have developed rule based quality check system using requirements for efficient quality control based on open BIM.

Keywords: Building Information Modeling (BIM); Open BIM; Industry Foundation Classes (IFC); Quality of Architectural Design; Quality Control; Code Information Check

1. INTRODUCTION

The communication between the numbers of participants is required on collaboration by field and phase, because the construction industry co-works with various sectors of business. Therefore, the management and utilization of information that is used to communicate in complex and diverse business process are very important. Especially, design information that is generated in the early stages of the construction industry is utilized and modified at a later stages, a systematic management is required in the all construction stages.

For the efficient utilization of a various information occurred in the construction industry, the technology applied actively calls BIM (Building Information Modeling). In Korea, it applied or is planning at various public projects [1]. However, the improving of quality is necessary with design based on BIM and increasing of construction project. The effective quality control measures should be developed through the design evaluation and check for improving quality of design information based on BIM [2].

The purpose of this study is a development and a suggestion of quality control requirements and required elements for improvement of architectural design quality and systematic quality control in open BIM environment. For this purpose, in this paper, the status and research analysis (open BIM environment analysis, architecture process analysis based on open BIM, quality control analysis), development of quality control requirements, quality control application plan (including system) and verification of quality control application results discussed in standard and application are progressed.

2. ARCHITECTURAL DESIGN PROCESS BASED ON OPEN BIM

This paper identifies architectural design process based on BIM which is defined in domestic and international guidelines. Through this study, it will be able to identify the basic information and be the basis for prehension of quality management target on future process of architectural design.

2.1 Traditional Design Process

The building design process in the construction industry is shown in fig. 1. The design process in design stage can be classified according to the Feasibility Study, Programming, Conceptual Design, Design Development, Construction Documents, etc [3].

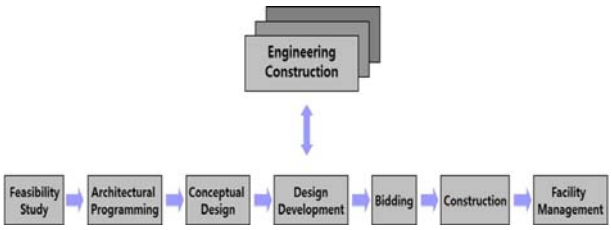


Fig. 1 Building design process in the construction industry [3]

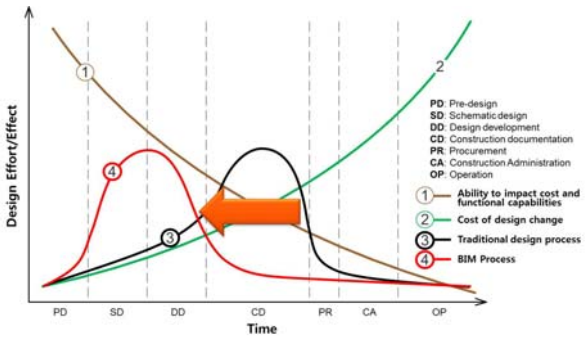


Fig. 2 Change of business environments [6]

2.2 Design process based on BIM

Because of complexity and diversification of construction industry, business process has been changed. Traditional design process has been changed in according to apply BIM. In traditional design process, there was large part of contents that should be handled in construction document stage. However, in the BIM process, all participants (owner, architect and contractor) collaborate works [4]. If the main operator or specialty contractor reflects construction know-how, design uncertainty and construction period can be reduced and also construction quality can be improved [5].

2.3 Phased Information Analysis in Architectural Design Process based on BIM

The quality management targets should be drawn first in order to develop the quality control standards for improving the quality of architectural design. For this purpose, the authors review the guidelines that include information about the application of BIM by work process phase. The term that defines the process phases differ, but the basic concept is largely the same. Table 1 presents quality control targets based on IPD stage through analysis of architectural design process.

Some parts of the construction stage are excluded because information is considered in terms of architectural design.

Table 1. Quality control targets by stage through analysis of architectural design process

IPD Stage \ Case	Korea KIA (Architecture design work procedures) [7]	USA AIA (IPD) [6]	Finland Senate Properties [8] (BIM Requirements)	USA CIC (BIM Project Execution Planning Guide) [9]	Quality management target
Conceptualization (Expanded Programming)	• Pre-survey • Regulation, Review of purpose and size	• Setting goal • Cost • BIM environment	• Cost • Space program • Regulation information	• Programming • Site analysis	• Pre-check regulation
Criteria Design (Expanded Schematic Design)	• Functional analysis(Space Programming) • Deliberation and building permit	• Spatial relationship • Pre-design of major building system • Regulation(fire, Safety plan)	• Space model(Spatial BIM) • Building draft model (space based) • Crash check • Cost estimation • Energy simulation	• Architecture, Structure, MEP, additional model • Energy analysis • Structure analysis • Lighting analysis • Mechanical analysis • Regulation check	• Space programming check(Spatial BIM) • Model check • Model crash check • Energy analysis • Regulation check(Deliberation and building permit)
Detailed Design (Expanded Design Development)	• Prior review of basic design • Regulation check • Writing basic drawing and specification by stage	• Complete building components(including building system) • Construction schedule • Regulation analysis	• Building model(Building Element BIM) • Modeling by field • Crash check • Final energy simulation		• Checking final model by stage • Model crash check • Energy analysis • Regulation check(Deliberation and building permit)
Implementation Documents (Construction Documents)	• Reexamine basic design drawing • Writing project drawing by field • Deliberation and building permit	• Writing construction document • Shop drawing(including regulation document)			• Regulation check(Deliberation and building permit)

3. CASE STUDY AND ANALYSIS (OPEN BIM BASED QUALITY MANAGEMENT)

In this chapter, details separated by quality control software, guideline and case study for quality control based open BIM analysis are presented. In addition, limitations of the current applicable and additional requirements are reviewed.

3.1 Overview of open BIM based Quality Control

An aspect of BIM, quality control encourages utilizing data correctly and quality check means reviewing the validity of the physical, logical information to the main course for the increase of productivity. The quality check standards based on BIM in according with the goals and objectives of quality check can be classified as shown in the following Table 2 [10].

Table 2. Classification of quality control based on BIM

Classification	Description
Physical Information Quality	Adequacy requirements of the shape of model • Minimum requirements for shape representation • Suitability of model location • Crash check of space model
Logic Information Quality	Adequacy requirements of the logic of model • Minimum/Maximum requirements check (based regulation) • Path analysis of components/space for evacuation and fire
Data Quality	Adequacy requirements of the data of model • Representation check of component • Checking properties of input data • Checking space program

3.2 Case Study of Quality Control

The cases classify coverage of detail target for quality control of open BIM-based. The cases are separated as follows: quality control software, application cases that reflect quality control guidelines.

3.2.1 Quality Control Software

The quality control software which is based rule is able to crash check physical BIM model accurately and detailed. The Navisworks and SMC (Solibri Model Checker) are leading software in the construction industry that can check model quality based on BIM. The Navisworks that have strength for 4D can only review physical check such as crash check. The SMC is the most common tool for BIM quality control in the GSA of United State, Senate Properties of Finland and BIPS of Denmark widely used. In addition, the SMC also is used at headquarters building design of Korea Power Exchange

Table 3. Case status of quality control

Project name	Overview / Purpose	Development organization	Quality control standard	Content
USA GSA BIM Enabled Design Guide Automation [11]	• Automation of BIM technologies specified in the guidelines for planning, design, construction, and maintenance of court building.	GSA, Georgia Tech Design Computing Lab	U.S. Courts Design Guide	• Checking space program and level of security about designs from the architect through BIM technology • Development of egress evaluation system according to the level of security
Finland MUSIC CONCERT PROJECT [12]	• Promote the possibility of plan checking in pre-design stage • Using BIM for reducing the error in the site.	Senate Properties		• Space visualization for user • Cost estimation • Energy calculation and life cycle simulation • Acoustic design
Denmark Rambøll Headquarters [13]	• Case that applied BIM technology in Rambøll head office	Rambøll	3D CAD Manual 2006 Digital Construction	• Crash check with SMC as a IFC file(AutoCAD Architecture, Tekla, MagiCAD)
USA Wisconsin - 13 BIM Pilot Projects [14]	• Using BIM in architecture and structure design (some sectors of MEP)	Wisconsin state	Wisconsin (BIM) GUIDELINES	• Components crash check • Space crash check
Norway National Museum Design competition [15]	• National Art Museum International competition held in the Vestbanen, Oslo, Norway. • Automatic model validation and quality control for BIM model in step 1	Statsbygg, Jotne EPM Technology	Statsbygg General Guidelines for Building Information Modeling v1.1	• Verification IFC structure • Automatic verification using EDMmodel ServerLite • Space check (space arrangement and check) • Energy analysis (heat loss calculated automatically)
Power Exchange Headquarters building construction Design competition [16]	• Application BIM and quality assessment of BIM design (Functional quality, Energy efficiency)	Korea Power Exchange	Power Exchange Headquarters building construction Design competition Guideline	• Submit original BIM model, IFC 2X3format, and design report about environmentally friendly building(Energy performance) • Multidisciplinary assessment about the design quality based BIM • Visual checking, Functional quality checking, and Analysis of energy efficiency

as a tool for quality check. The representative feature of SMC is space check, accessibility check, structure check, constructability check and regulation check, as the user define a rule set, the various physical and logical checking and extracting needed information are possible.

3.2.2 Application Cases of Quality Control

Several guidelines are deriving actually application cases that reflect relevant guideline's contents. The quality control cases are as follow, table 3.

3.3 Conclusion

The additional requirements and limitations are arisen on the part of the overall status as a transitional process of continuously develop and apply measures deduction, because of awareness about the importance of quality control. Design software and viewer software are available for checking while creating BIM models directly in design stage, but it is inadequate for complex quality check. The thing complemented these shortcomings is rule-based quality control software. This software which is internal quality control rules can apply the rule easily when it necessary. And also the rules can be extended to reflect the additional design requirements. For these reasons, rule-based quality control software is used in a variety of ways for quality control cases.

The most part of analyzed cases of quality control are for physical checking (crash checking) yet. For more effective quality management, the logical quality checking, including the development of related system is being planned and in progress. In addition, various case studies that can verify standards of quality control will be ongoing process in order to evaluate the design information and work environment.

4. DEVELOPMENT OF ARCHITECTURAL DESIGN QUALITY CONTROL REQUIREMENTS BASE ON OPEN BIM

To increase the reliability of design assessment and quality check result, defining of the design phase work and standard that reflect the business requirements is necessary first. And then environment that can be applied to this system should be established. Therefore, this chapter presents that quality control standards based on open BIM through reviewing the target of quality control and development of checklist for checking the details.

4.1 Review of Quality Control Target based on open BIM

The research review the detailed quality control targets that covered by the software based rule for the guideline and quality control through information analysis of architectural design process based on BIM. To reflect the domestic situation, targets of quality control that reflected Korean regulations are derived additionally. Next, the derived targets are classified as the physical information quality, logical information quality, and data quality.

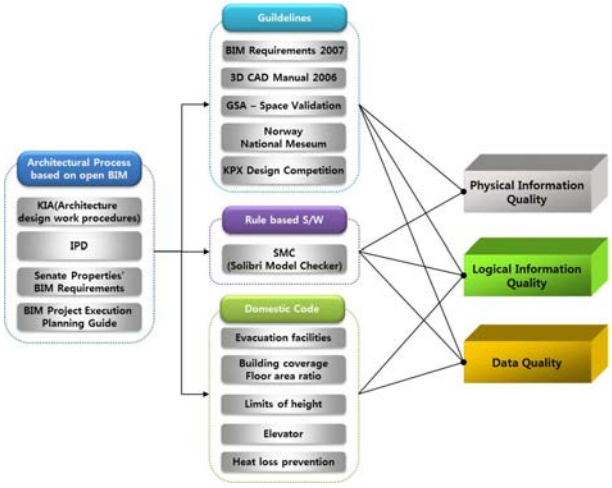


Fig. 3 Scope and procedure of quality control target

The applied targets of quality control are preferentially selected applicable generalized quality control target rather than a specific item. The current contents are the basic step yet. The targets should be checked and taken into account the applied target in accordance with the goal of a specific project through identification of additional check target in the future. In case of logical quality information based regulation check especially, quality control target checking work should be progressed continuously.

Table 4. Quality check targets arrangement by classification

Classification	Targets
Physical information quality	Window and door fixed on the opening
	Required interval between objects
	Crash, structure, MEP elements
	Cross check between equal elements (architecture/architecture, structure/ structure, service/service)
	Cross check among other elements (architecture/architecture, structure/ structure, service/service)
	Connections of space and components
	Position of the components
Logical information quality	Evacuation facilities
	Building coverage ratio, Floor area ratio
	Height restrictions
	Elevator installation
	Prevention of heat loss
	Regulation of space area
Data quality	The required property, depending on the level of detail
	Space name, group name
	Type of space and each components
	Skin property (wall, slab, door, window)
	Height of space
	Whether space area makes sure it match with space program
	Whether each floor space area makes sure it match with total area

Definition of space location
Review all space group(spatial groups), including the type
Space number
Obstruent checking of space consisting external wall
Door, window, slab area calculation
Total area checking

4.2 Development of Quality Control Standards based on open BIM

In this section, quality control standards are developed through reconfiguring of derived quality control targets by items.

As described above, quality control targets based on open BIM can be classified physical information quality, logical information quality and data quality. In case of application in practical work, it can be separated by space check standard, design check standard, and construction check standard depending on applicable goals and way. The derived quality control target and relevance of standard, developed in this study, are as follow, fig 4.

The goal of this study is presenting the standard of quality control that can be used at the pre-design stage. The targets are spatial checking and design checking for improving the design quality and space standard, design standard and construction standard. In addition, criteria of escape stairs installation standard and heat loss prevention standard are presented for the purpose of using detailed BIM of design standard.

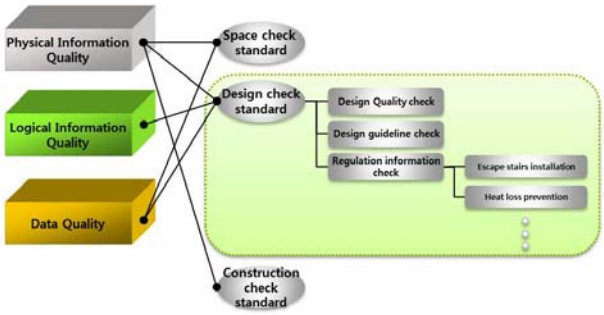


Fig. 4 Relevance of quality control targets and standard

(1) Space checking standard

It means checking of space components, space name, area, and crash in BIM model according to space program the client required. The spatial BIM model includes space information and spatial BIM is checked whether spatial plan is reflected appropriately [8].

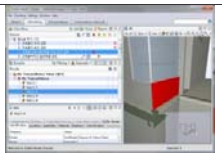
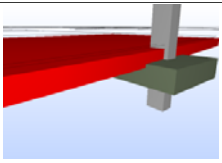
(2) Design checking standard

It means BIM model quality checking that progresses in the architectural design process and reflects additional contents such as design guideline in case of design competition. Furthermore, it contains regulation information, related design directly. In this research, the installation standard of escape stairs and heat loss prevention standard deal in detail. The regulation can be modified and supplemented additionally depending on the intended use of the BIM.

(3) Construction checking standard

It means the physical quality checking of BIM models and is applied constructability checking of BIM applicability generally. The crash checking between

Table 5. The quality control target and cases

Classification	Checking target	Cases	Description
Space check standard	Space components area and quantity check		• Space area checking within the error range • Error range can be changed according to the criteria of the project • Each floor space area / quantity checking
Design check standard	The absence of the components type in the BIM model		• Definition of the specific types and required properties checking • Ex) object's material
	Building skin/ Heat transmission coefficient property check		• Definition of the building skin/heat transmission coefficient property checking
Construction check standard	Crash check (each components)		• Crash checking between each components (Ex: Column and Slab)

building components and other type of objects is in this part.

Table 5 presents quality control standards, suggested in this study with major targets and some of the cases.

5. APPLICATION OF ARCHITECTURAL DESIGN QUALITY CONTROL BASED ON OPEN BIM

5.1 Suggestion of Process for the Application of Quality Control

For the application of quality control based open BIM, quality control software that is reflected the quality management standard and generated BIM model according to the BIM guideline have to be configured as shown in the following fig 4. The quality control software can apply the modified rule according to the criteria of developed quality control but the users should develop the rule directly for the automatic quality assessment as change of criteria (ex: regulation revised)

Therefore, the way of utilizing the quality control software and additional development are process in this study for the applying suggested standard of quality control.

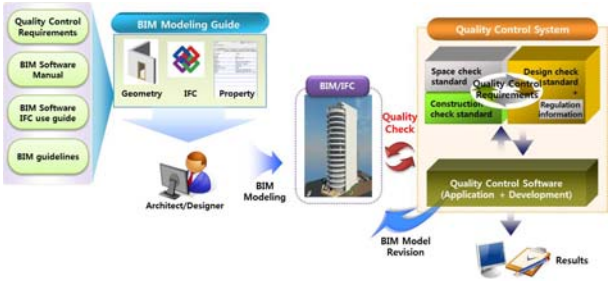


Fig. 4 Process and elements technology for the application of quality control

5.2 Quality Checking using the Software

In order to precede an effective quality control based on standard of quality control, evaluation through quality check software is very important. Depending on the purpose and nature of the quality control standard, some standards can check with provided existing rules in software.

Table 7. Use of quality control software

Standard	Software	Description
Spatial Check	SMC	• Spatial program check is available with reflected rule • Spatial program that changes according to the projects also can be reflected
Design Check	SMC	• Design basic quality and design guideline check are available with reflected rules. • Design guideline that changes according to the projects also can be reflected
Construction Check	SMC Autodesk Navisworks Tekla BIMsight	• Crash check is available for review to reflect the conditions of the interference and collision.

As described above, SMC can be utilized to all of the developed quality control standards. Therefore, in this research, the authors focus on the SMC software for quality control.

The standard of spatial check, design check, and construction check can be utilized with some modification as modification of SMC rule. SMC provides various rules and type of rule set by grouping depending on the types and purpose. The new rule set can be created by combination of various kinds of associated rules.

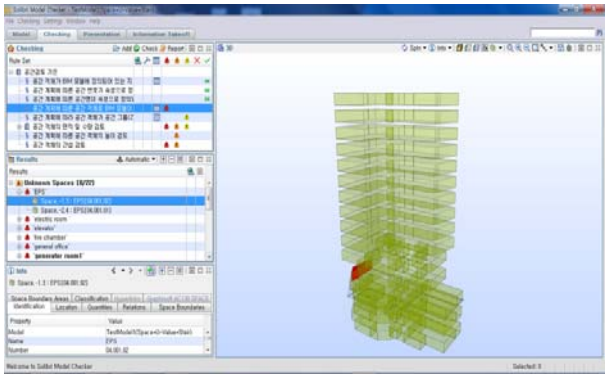


Fig. 5 Example of quality control according to the criteria of spatial check

First of all, regulation information should be structuralized in conjunction with IFC for using rules that related to regulation in the SMC (Fig. 6). The rules have to be defined as a separate class (Java file) in the SMC Java API environment and also the required properties and checking order have to be defined with IFC structure and regulation contents. This research focus on the installation of escape stairs of design check standard and generates the coded Java file from delimited rules (building use check, storey check, and type of stair check).

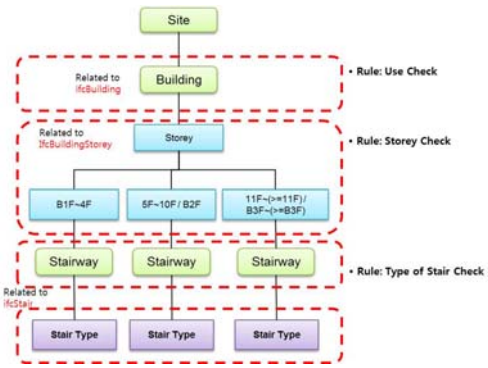


Fig. 6 structuralization of the escape stairs installation standard – IFC structure interaction

A new rule set that corresponds to a heat loss prevention standard is generated with developed one of the rules (Java file) in the Rule set Manager of SMC. And then quality check is conducted in conjunction with the BIM model. Through continuous modification of errors of the checking, a final draft is able to derive. In particular of the regulation information standard, the legality of the presence can be checked through the review of regulations in terms of licensing when the part of final result cleaned up.

6. CONCLUSIONS

The design information of occurred throughout the construction industry, targeted in this study, include a vast amount of information and it should be done the design assessment and quality control. The activation of BIM is progressed for the reorganization of design information utilization and evaluation but the current quality control work based on BIM cannot be made systematic quality management due to lack of standards, detailed instruction, and application measures (system side).

This research held that the purpose to present development of element technology and application plan for systematic quality control and improving the quality of architectural design in open BIM environment. In detail, the research analysis the output information and design phase work in design process, then detailed quality control targets are derived from some cases (guidelines, software) and Korean regulation. These quality control targets are developed for standard of spatial check, design check, and construction check depending on the nature and purpose of the works. The regulation check contents of these standards are included in the design check standard.

In addition, definition of the process and development of required various element technology are suggested for application of architectural design quality control based on open BIM. The results of these quality control is verified by quality check software (include developed contents) based on rule.

The quality control standards, applied in this study, are conducted by common tasks that can be applied. Depending on the purpose of applying with regulation checking, additional research will be expected to easily for extending a range of applying.

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