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Exploring quality issues in building information models via structural design reviews

To cite this article: E Candir and G Atasoy 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1101** 092011

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Abstract. Building Information Models (BIMs) are being used widely in the construction industry. BIMs generally contain errors and mistakes, if not identified, might result in long review processes with the employers or cause issues during code compliance checks or construction. Since the quality requirements vary according to projects and even the stakeholders within the same project, it is challenging to establish a standard quality-check procedure. To focus on the model quality, custom procedures tailored according to the needs of the design teams should be prepared. Hence, there is a need to explore the BIM quality issues and develop formulations to identify and eliminate them in time. Currently, there are no specific guidelines and formulations to determine the overall quality level of a BIM and propose Quality Assurance (QA) and Quality Control (QC) procedures. In this study, design and model reviews from the owner are used to analyze the items to be checked for satisfying a structural model's integrity. The design reviews are classified and analyzed to understand the existing issues. This study contributes to a better understanding of BIM quality issues and proposes a direction toward BIM quality assurance and control formulation that can be tailored by practitioners and design teams.

1. Introduction

Building Information Models (BIM) are widely used in the Architecture, Engineering, and Construction (AEC) industry to generate, manage, and communicate project data. BIM usage for public works became compulsory for some countries, including the United Kingdom, Netherlands, and Singapore. Accordingly, the standards, guidelines, and general rules are still developing with the increase in BIM-based projects worldwide. There are several guidelines (e.g., LOD Specification by BIM Forum [1], BIM Guide by Penn State [2], and Singapore BIM Guide [3]) and standards that focus on BIM implementation process and modeling detail. BIMs have numerous uses, including model authoring, visualization, coordination, 4D planning, and cost estimation. One of the objectives of BIM usage is to enable the communication of project information. In other words, the models take the role of being an information hub of the project. Zadeh et al. [4] checked numerous BIM projects and deliverables and stated that most BIMs created for design and construction include significant quality deficiencies, including incomplete, inaccurate, and unnecessary information. Such problems emphasize the need for quality checking in BIMs for the AEC industry. The quality of information is a well-established topic in the information science domain; however, it has not acquired sufficient attention regarding BIMs. There is no specific and widely-used guideline or standard to check the quality of BIMs in the industry. In order to satisfy design and model quality, BIMs need to be continuously reviewed and updated as designing and modeling are continuous for the whole design stage. ISO 19650 [5] states that Quality

Assurance (QA) and Quality Check (QC) for BIMs should be performed; however, how to perform them in practice is not specified. With the increase in the number of BIM authoring, visualization, communication, and analysis tools, additional plugins (e.g., Corbissniffer) and tools (e.g., Dynamo, Solibri Model Checker) are also developed. Such tools enable users to scan their models in terms of the previously defined categories, including views, sheets, families, and worksets, and use readily available rule sets or customized rule sets. However, such tools/plugins are not comprehensive or populated with quality information requirements.

Unclear and incorrect information in BIM results in numerous Request for Information (RFIs) and prolonged communications between the project stakeholders [6]. Hence, the quality of BIM measured as the structure and the content of the information is of high importance for model checking [7]. After submitting the design drawings and project BIM models for review to the client, it would take some time to review both the model and the drawings. It would cause significant issues in the project design progress if unidentified errors or missing items exist in the BIMs. Hence, practitioners need a systematic way to identify the quality issues (e.g., inaccurate or missing information) in the existing BIMs, and develop in-house BIM QA systems. With this perspective, this study is a part of a research study that targets the development of an automated information quality checking system for BIMs. Capturing the preliminary works of the project, this paper aims to explore the design and model-related quality issues in BIM models in a formalized way so that the building stones for manual or automated quality checks can be developed. To achieve high quality BIMs, the requirements should be well-defined. In order to perform a research study in-depth, only structural models are considered within the scope of this study.

2. Literature Review

Blay et al. [8] emphasized that the quality of information is very important to the success of asset delivery, management, and performance in the Digitized Architecture, Engineering, Construction, and Operations (DAECO) sector. Amor and Dimyadi [6] stated that data quality in the BIM environment is the first unresolved issue. The study emphasized that the quality of the data comes before code compliance so that code compliance can be performed [6]. While primary motives for using BIM methodology in project planning include increasing planning accuracy, cost security, and quality, quality is the most deficient one among others [9]. Yang et al. [10] stated that data quality is somewhat difficult to define precisely, as it means different things to different user communities. How quality is defined may change according to the point of view in the industry. It might be design quality, modeling quality, drawing quality, or planning quality. Hjelseth [11] categorized compliance checking as validation checking and model content checking. While the most commonly cited key quality dimensions are accuracy, completeness, consistency, and currentness [12], various studies use different information quality dimensions. Arazy and Kopak [13] discussed that while many studies focused on the salience of dimensions (if a dimension better represents users' perception), measurability is a key trait (some quality dimensions are easier to measure). Regarding information captured in BIM, accuracy, consistency, and completeness are essential quality dimensions [14, 15]. For instance, according to their case study, Wang et al. [15] stated that BIMs created by the contractors do not comply with the completeness, accuracy, and consistency assessments despite the standards and proper training. Zadeh et al. [4] prepared a framework to check the information quality of a BIM model to be used for facility management. Those information quality dimensions are; completeness, value accuracy, consistency, well-formedness, and understandability. It can be seen that the selection of quality dimensions can be subjective, and the utilized set of dimensions varies in existing studies.

Researchers mostly used owner requirements at the beginning of the project to establish checks according to these predetermined requirements. Such requirements can be in terms of model quality or design quality and can be a part of the BIM Execution Plan (BEP). For instance, Cavka et al. [16] showed how owners' information requirements could be developed and formulated to enhance BIM-based project delivery. As a means of model content checking, Donato et al. [17] examined the information quality in the architectural design phase via checklists and queries. Focusing on LoG (Level of Geometry) and BOM (Building Object Model), the study focused on the Developed Design phase and the transition between Concept Design and Developed Design Phases. In such studies, information quality in the architectural design phase is commonly examined via predetermined queries and checklists based on the owner/client requirements. Such studies did not focus on understanding the inherent quality issues that arose as a result of the Quality Control Process and developing tools or methods to be used for Quality Assurance purposes, customized according to the needs of the design teams.

There are a few tools that mainly focus on clash detection and accessibility or enable a platform to enter predefined stakeholder requirements. However, not all projects come with detailed client quality requirement lists in the initial phases of the project, and many quality issues are identified by the clients during the design reviews. Kim et al. [18] assessed the design reviews for BIMs from many disciplines and divided the design review comments into five categories: general, query, suggestion, observation, and requirement, with a perspective of the owners to support BIM adoption. As Preidel et al. [19] stated, compliance checking is a manual and iterative process as it always has been based on 2D drawings. Respectively, the compliance checking procedure is time-consuming, difficult, and error-prone. With the increasing digitization in the AEC industry, especially improvements in information modeling, new technologies or tools have become available to improve and partially automate the compliance checking procedure [19]. Dimyadi et al. [11] stated that compliance checking is done as a separate procedure at predetermined times and phases during the design stage. Models are checked in different software tools according to already defined rules, and this checking procedure is defined as a part of the quality assurance system (QA). While quality checking is required, an understanding of the variations of quality issues should be acquired so that related quality checks can be performed. Identifying the quality issues for individual disciplines might give the opportunity to establish a quality checking framework for specific disciplines. The literature is limited in proposing a solution for design companies to develop quality assurance procedures using quality control processes (e.g., checking the quality of the submitted models through design review comments).

3. Research Methodology

This study follows a case study approach. As Yin [20] states, conducting case study research is one of the most convenient ways of doing research to obtain an in-depth understanding of an unexplored area in the literature. In this case study approach, the design and model reviews, which are given by an external reviewer from the client-side, of a project are examined in detail to generate a checklist to be used in other projects. Figure 1 shows the research methodology. The first step of the research is to collect design and model review comments from the owner and the design company. The second step is to clean the review comments as they may not be in an organized and clean form. The next step is to analyze the review comments.

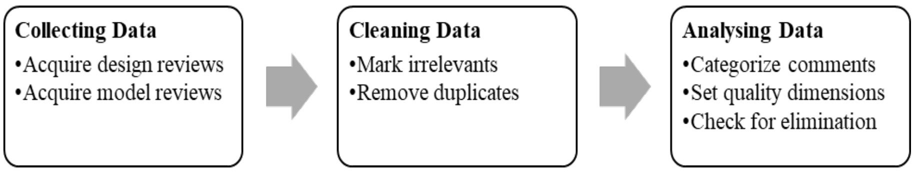


Figure 1. Process diagram.

3.1. Collecting Review Comments

Designs prepared by an engineering company can be reviewed internally or externally. Firstly, a design company can conduct an internal design review to check the quality. Secondly, an external entity can review the design and the BIM model. Design and model reviews might be obligatory according to the project types. Generally, state organizations or design consultants review structural designs. Since the design itself evolves over time, it is highly expected to have new design reviews and comments after each project submission. Change in design leads to change in BIM as well. Every project lifecycle composes of phases, including design, construction, and operation. While the design phase also has its sub-phases, they are subject to change since every project and design is unique. Design phases are mainly composed of six stages (Schematic Design, 30% Design Drawings, 65% Design Drawings, 95% Design Drawings, Construction Drawings, Bulletins/Revisions), and designers submit drawings/BIMs to the owner or the architect almost at every stage.

3.2. Cleaning Review Comments
It is very likely that data obtained from the review process cannot be used directly in the analysis. In general, data need to be filtered or cleaned before any treatment. Cleaning may be required for several reasons. First, there might be miss-assigned comments for the specific discipline. These need to be eliminated or re-assigned to the corresponding discipline. Second, there might be duplicated comments for the same issue in the review. It is possible that more than one person can review the design or the model. There might be issues that are pointed out by every reviewer so that comments have the same content, although they are given by different reviewers. These types of comments need to be merged as they are the same. After considering these points in the cleaning of the review data, the categorization and analysis phase can be performed for the review comments.

3.3. Analysing Review Comments
Since BIMs are reviewed along with the designs, comments are divided into two, indicating if it is a model review comment or a design review comment. First of all, design review comment location (plans, details, legends, or schedules) are determined. Location is vital to make a hierarchical order for the categorization. Categorizing comment locations might give clues about the point of focus to check the drawings and the BIMs. After considering comment locations on the drawings, comment content is checked. A single comment can imply multiple issues in the drawings. Comment contents are divided into single addressable units to increase control and workability.

After dividing comments into single addressable units, each item is checked to understand if they are fixable within the scope. Reviewers might assign a comment to a wrong discipline or ask a question that is not in the scope of the corresponding design team. Hence, the comments that can not be addressed or eliminated by the design team are noted as unfixable. Fixable comments need further analysis to determine the causes and if it would have been possible to prevent that comment. Indeed, some comments can not be prevented before the review process. One reason is that the comment might give a new suggestion about the project. Another reason is that the comment might ask for design confirmation. Similar to new suggestion, design confirmation comments can not be expected or prevented before the submission. Other types of comments could be eliminated before the review process. In case any owner and/or project requirements are stated at the beginning of the project, the designers are expected to comply with such design and modeling requirements. Another example of preventable comments includes missing or erroneous information. Model review comments should also be analyzed to observe the level of model quality. Similar to designs, model review comments are gathered after each design package submission. Although there are initial model requirements, most check items may be introduced during the design stage. For example, the workset structure that will be used in the project is generally provided by the owner at the beginning of the project.

4. Case Study
A structural design project that has model review and design review comments is selected as the case study project. The project is planned to be constructed in the US as a warehouse. The footprint of the building is about 175000 sq. ft. It is a two-story steel building with a composite slab and a steel roof. The design scope includes the structural analysis and the design of the main gravity and lateral load-carrying systems. The design company is also responsible for the structural BIM and drawings of the project. The design phase is conducted in the cloud environment on BIM360 platform. Structural design team has its own discipline-specific BIM on the cloud that is updated together with the other disciplines.

In this case study, design review comments are given by senior structural engineers representing the owner, through the design phase of the project, and model review comments are given by the BIM consultant. It should be noted that some of the expectations from the design teams were listed on the

BIM Execution Plan (BEP) at the beginning of the project. The requirements were very basic. For example, every discipline needs to have a Revit model that is clean of warnings. There were no organized and detailed quality requirements for the project. Project quality requirements are mainly determined parallel to the project development. Design review comments were collected after every project review during the design stage of this project. There were 143 comments collected after 100% submission.

5. Findings and Discussion

All of the comments were organized in a single document to ease the categorization process. The first action was to eliminate the duplicated comments. In order to be able to cover up all the items flagged during the review process, single comments, including multiple issues inside, were divided into smaller addressable comments according to the content. After eliminating the duplicate comments and dividing multiple issues containing comments, 220 comments were acquired to organize and classify. Table 1 shows the comment distribution along with the design submissions.

Table 1. Comments based on the submission packages.

Design Package	#
30% Detailed Design	4
65% Design	139
95% Design	77

Every comment was categorized according to the locations on the drawings to see the points that needed more attention during the design stage. In order to determine comment distribution among the project drawings, Table 2 shows the list of locations on the structural drawings where design review comments originated. It can be seen that most of the comments are related to the plan views and notes, specifically for the Drafting Views, Foundation Plans, and Live Sections.

Table 2. Comment location list.

Location on the drawings	#
3D view on Cover Page	3
Detail - Drafting View	36
Elevation (Brace Elevation)	6
Elevation (Misc. Steel Elevation)	2
General Comment - Not based on a specific sheet	6
General Notes	7
Live Sections	20
Loading Sheets	11
N/A	1
Plan Notes (Foundation Plan)	9
Plan Notes (Framing Plan)	6
Plan Notes (Ground Floor Plan)	5
Plan Notes (Roof Framing Plan)	9
Plans (Foundation Plan)	36
Plans (Framing Plan)	17
Plans (Ground Floor Plan)	3
Plans (Misc. Steel Framing Plan)	17
Plans (Roof Framing Plan)	18
Plans (Site Plan)	1
Schedule (Structural Column Schedule)	2
Sheet List on the Cover Page	2
Special Inspection/Specifications	3

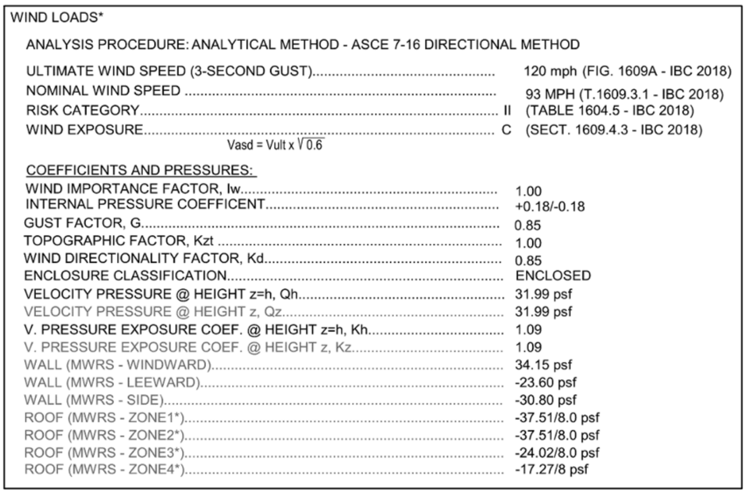
Then, the comments are tagged as fixable or not. As mentioned in the methodology section, although experienced discipline engineers review each discipline's drawings, some items can be miss-assigned to the structural profession. These types of misassigned comments were considered unfixable comments. Another example of the unfixable comments is that the reviewer asks for verification or a missing item, although it has already been provided in the drawings (the reviewer could not see the information). In the project, 12 comments were identified as unfixable comments.

After eliminating unfixable comments, reasons for a comment origination were investigated. Instead of applying a predefined category, data-driven categorization was followed. Table 3 presents the emerged categories and related comment examples. As opposed to Kim et al. [18], no comments were categorized as general, observation, or requirement. Query, which is named as design verification in this study, asks for confirmation from the other party. For instance, a structural framing or a structural element may seem to be under-designed or overdesigned to the reviewer. The new suggestion category presents new ideas. The coordination category asks for coordination items to be resolved with the other design disciplines in the next issuance of the design drawings. Also, the reviewer may want the design to be double-checked in certain cases. The errors category alerts the existence of errors in the drawings (e.g., design error) or the model (e.g., modeling error). The missing information comments are issued when required information is not provided. An example of missing information is presented in Figure 2. According to the governing code for the project, wind loads and parameters need to be referenced from ASCE 7-16. However, a wind loading parameter, Ground Elevation Factor, which needs to be stated in the drawings, was missing.

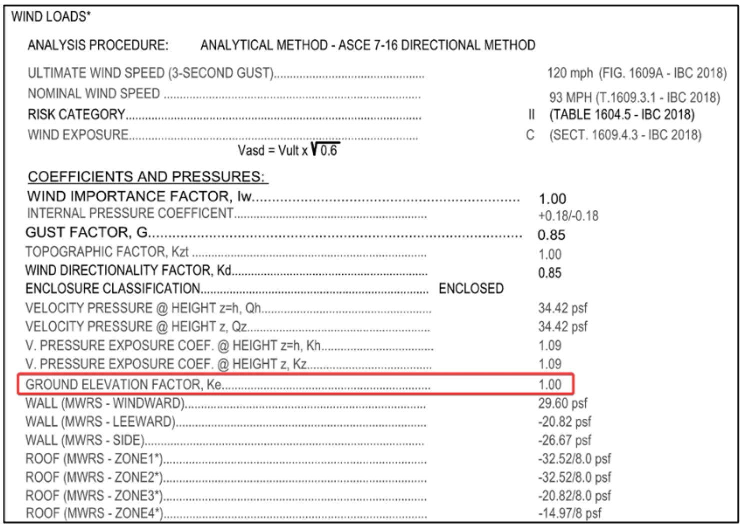
Table 3. Example comment list.

Category	*Description*	*Example Comment*
Missing Information	Required information is not given	(#193) "Footing tag missing at Q line continuous footing."
Errors	An error occurred in the drawings	(#60) "Structural Steel - use latest ASTM designation for bolts."
New Suggestion	New suggestion for the design team	(#134) "Consider supporting precast panel directly on footing in lieu of the additional cost to form and place short grade wall."
Design Verification	Given design is needed to be checked	(#122) "Check effectiveness of bracing between column lines J and K."
Further Coordination	Further coordination is required with Owner/Other disciplines	(#6) "Alternate sheet names for Steel Plans S-202E, S-202F and S-220E and S-220 E that are not in series with main 1/8th scale part plans A-D is recommended - Similar perhaps to reflected ceiling plans."

Although the governing code ASCE 7-16 and wind loading references were correct, the loading parameter was missing in the wind loading sheet. This comment is labeled as missing information and fixed for the next submission.



(a)



(b)

Figure 2. Example for missing information a) 65% Design Drawings b) 95% Design Drawings.

Table 4 shows the distribution of the comments according to their categories. It is seen that 46% of the comments were categorized as missing information, while 28% were categorized as error. Since errors and missing information can be prevented, they are assessed in more detail.

Table 4. Categories of comments.

Category	*# of Comments*
Missing	101
Error	61
Coordination	2
New suggestion	14
Design confirmation	30
N/A	12

Table 5 shows the comments that were grouped as missing (annotation, a piece of design information, a label, or a code reference) and erroneous (modeling error, design error, and annotation error) information. Table 5 reflects that while the majority of missing information is annotations, the majority of errors were made related to designs.

Table 5. Missing sub-categorization.

Missing	*Number of Missing*	*Number of Error*
Design Related	8	40
Annotation Related	81	16
Modelling Related	3	3
View Related	9	0
Naming Related	0	2

Examining the comments on whether there is missing information or an error in the drawings is not enough for a quality check. Hence, whether such comments could be prevented even before the review process (eliminated in an earlier stage or not) was evaluated. Initial checks before the submission can eliminate missing information. An initial automation assessment is performed on the case project to see the variety of required checks, including design check, visibility check, code reference check, duplication check, spell check, element tagging check, and nomenclature check. For example, Item #193 in Table 3 could be eliminated by checking all structural elements to make sure they had tags. Also, Item #60 could be eliminated by checking if the latest standards are used in the design. Item #134, Item #122, and Item #6 could not be eliminated as the first one is a new suggestion for the design team, the second one is a design confirmation, and the third one is a coordination item requested by the reviewer.

As it was indicated in the introduction section, this study presents the findings regarding the quality issues stated in the review comments. It will be followed by the development of a checklist, extension and verification with new cases, and the assessment of automation of the review process. Based on the currently collected information, it is foreseen that the checklist to be developed will have three main parts: (i) Model review, (ii) Design review/General Checks: Generic items to be checked in every review process, and (iii) Design Review/Project Specific Checks: Project-specific items. The model review checklist will have the main sections of general items, project information, links, views, sheets, warnings, worksets, families, groups, design options, hatch styles, legends, schedules, and clash detection. The general checklist will have the main sections of abbreviations, codes, design, general notes, reporting, schedule, sheet, and view. The automation is planned to be examined in three categories: automated (with a built-in, add-in, or third-party tool), semi-automated (checking or editing can be done automatically, but the remaining part needs to be done manually or vice versa), or manual. During the initial automation assessment, all missing and erroneous information that are design-related (code references, loading information), annotation-related (dimensions, framing tags), modelling-related (duplicate views/sheets), view-related (visibility, plotting settings), and naming-related (sheet names and numbers) were assessed. Accordingly, 25% of the items were marked as manual checks that could be prevented. The rest, 75%, were marked as semi/fully automated. These preliminary findings will be verified, and automation workflows will be developed. Such workflows include model checking with the help of Dynamo, APIs, and other scripting languages that can be integrated into the model authoring tools.

6. Conclusions and Further Research

BIM affects the construction industry in many ways, including the roles, responsibilities, and workflows within projects and organizations. The design and model related QA/QC procedures must adapt and keep up with such changes. Existing research studies on the information quality of BIMs propose a process that is structured on predefined requirements. However, it is not always the case that every project has previously well-defined quality requirements. In addition to that, current BIM issues might be beyond the project requirements. For this reason, every design team may feel the necessity to develop QA/QC systems from their mistakes on the projects in their own profession. QA/QC formulation in

BIMs with the help of the structural design and model review comments is introduced in this research study. Review comments are collected through the design phases of the project. They are cleaned, categorized, and analyzed in order to create a checklist to eliminate the review comments for future projects. In this study, a data-driven comment categorization is proposed, five comment categories are acquired: missing information, errors, new suggestions, design verification, and further coordination. Similar studies that highlight the quality issues in BIMs and the importance of quality checking are performed in the literature. This study builds up on them and extends the issues with a new set of categorization and assessment. Indeed, the analysis revealed that almost 50% of the review comments acquired from the owner representatives and design consultants are due to missing information, and about 30% of them are due to errors in the drawings.

This study contributed to the understanding of the quality-related issues in BIMs via review comment categorization and analysis procedure. The categorization and analysis processes can be taken as a guide for the potential users on how to apply similar procedures to their projects. This will increase the managerial contribution of the study to the design companies. This study has some limitations. A structural project mainly composed of steel and composite frames is used as a case study. There might be other items to be checked for other types of structures like concrete, wood, or composite structures. Checking just one project is not enough; further checks should be performed until saturation is reached. By doing a data-driven analysis, information quality dimensions completeness and accuracy are used based on the missing information and errors. It can be considered that different information quality criteria (e.g., level of detail) can be added for a more detailed analysis. Finally, RFIs and similar queries from other stakeholders can facilitate further assessment of the quality of BIMs, as well as constructability issues. The construction phase for the case project has not started yet; hence, this study is limited to the design and model review comments. Future studies can use such information to improve the BIM QA/QC processes.

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