QA/QC FORMULATION IN BUILDING INFORMATION MODELS VIA STRUCTURAL DESIGN REVIEWS

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ABSTRACT

QA/QC FORMULATION IN BUILDING INFORMATION MODELS VIA STRUCTURAL DESIGN REVIEWS

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Building Information Models (BIMs) are being used widely in the construction industry, and a quality check should be performed in order to ensure the integrity and reliability of the models. Quality concern starts with the initial steps in modeling and continues through at the end of the lifecycle of a project. BIMs generally contain some errors and mistakes and 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 the projects and even the stakeholders within the same project, it is challenging to establish a standard quality check procedure. In order to focus on the quality of the models, 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 formalisms to identify and eliminate them in time. Currently, there are no guidelines and formalisms to determine the overall quality level of a Building Information Model and propose Quality Assurance and Control procedures. In this study, design reviews from the employer are used to determine the items to be checked for satisfying a structural model's integrity. The design and model reviews are classified and analyzed to understand the existing issues, and a quality control mechanism, including a checklist, is proposed. This study contributes to a better understanding of BIM quality issues and proposes a BIM quality assurance and control formalism that can be tailored by practitioners and design teams.

Keywords: Information Integrity, BIM Quality Control, Quality Checking, Design Reviews

ÖZ

TASARIM DEĞERLENDİRME YORUMLARI ARACILIĞI İLE YAPI BİLGİ MODELLERİNDE KALİTE GÜVENCESİ VE KALİTE KONTROLÜ FORMULASYONU

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Yapı Bilgi Modelleri (YBM) inşaat sektöründe yaygın olarak kullanılmaktadır ve modellerin bütünlüğünü ve güvenilirliğini sağlamak için kalite kontrolü yapılması gerekmektedir. Kalite kaygısı, modellemedeki ilk adımlarla başlar ve bir projenin yaşam döngüsünün sonuna kadar devam eder. YBM'ler genellikle bazı hatalar içermekte ve tespit edilmedikleri hallerde, işverenlerle beraber uzun inceleme süreçlerine, kod uygunluk kontrollerine veya yapım sırasında sorunlara neden olabilmektedir. Kalite gereksinimleri projelere ve hatta aynı proje içindeki paydaşlara göre değişiklik gösterdiğinden standart bir kalite kontrol prosedürünün oluşturulması zordur. Modellerin kalitesine odaklanmak için tasarım ekiplerinin ihtiyaçlarına göre özel prosedürler hazırlanmalıdır. Bu nedenle, YBM kalite konularını keşfetmeye bunları zamanında belirlemeye ve ortadan kaldırmaya yönelik formulasyonlar geliştirilmesine ihtiyaç vardır. Halihazırda, bir Yapı Bilgi Modelinin genel kalite seviyesini belirlemek ve kalite kontrol prosedürleri önermek için hiçbir

kılavuz ve formulasyon bulunmamaktadır. Bu çalışmada, yapısal bir modelin bütünlüğünü sağlama amacıyla kontrol edilecek öğeleri belirlemek için işverenden gelen tasarım değerlendirme yorumları kullanılmıştır. Mevcut sorunları anlamak için tasarım ve model incelemeleri sınıflandırılarak ve analiz edilerek, kontrol listesi de içeren bir kalite kontrol mekanizması önerilmiştir. Bu çalışmada, YBM kalite konularının daha iyi anlaşılmasına katkıda bulunmak amacıyla uygulayıcı ve tasarım ekipleri tarafından uyarlanabilecek bir YBM kalite güvencesi ve kontrol formalizmi önerilmektedir.

Anahtar Kelimeler: Bilgi Bütünlüğü, YBM Kalite Kontrol, Kalite Kontrol, Tasarım Kontrolü

Dedicated to my beloved family…

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ABBREVIATIONS

AEC	Architecture, Engineering and Construction
BEP	BIM Execution Plan
BIM	Building Information Modeling
BOM	Building Object Model
CAD	Computer Aided Design
FM	Facility Management
IFC	Industry Foundation Class
LOD	Level of Detail
LOI	Level of Information
LOG	Level of Geometry
NDA	Nondisclosure Agreement
QA	Quality Assurance
QC	Quality Control
SMC	Solibri Model Checker
YBM	Yapı Bilgi Modeli

CHAPTER 1

INTRODUCTION

1.1 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 of the countries, including United Kingdom, Netherlands, and Singapore. It has also become a contractual requirement in the bidding phases since the owners are aware of the contribution of BIMs to the entire project lifecycle. Government institutions and private sector companies started to change their methodologies to adopt BIM in their projects. As Häußler et al. (2020) stated German Federal Ministry of Transport and Digital Infrastructure has committed itself to the digitalization of projects within its area of responsibility in three successive steps:

1- Set-up phase (2015–2017)

2- Extended pilot phase (2017–2020)

3- Broad implementation for all new projects (starting in 2020)

Ministry of Transport and Infrastructure in Turkey also prepared BIM Technical Specifications and Tender Documents to be used for Transportation Projects Construction works (T.C. Ulastirma ve Altyapi Bakanligi, 2021). Moreover, some municipalities require BIMs for underground metro projects. It spreads more and more among the AEC professionals since it significantly increases the collaboration and decreases the cost and time for many aspects of the projects. Accordingly, the standards, guidelines, and general rules are still developing with the increase in BIM-based projects worldwide. There are a number of guidelines (e.g., LOD Specification by BIM Forum (Bedrick, Ikerd, & Reinhardt, 2020), Design & Construction Standards by Penn State (UK BIM Alliance, 2006), Singapore BIM Guide (Building and Construction Authority, 2013) and standards (e.g., (UK BIM Alliance, 2020; UK BIM Framework, 2019) that focus on BIM implementation process and modelling detail.

BIMs have numerous uses, including model authoring, visualization, coordination, 4D planning, and cost estimation. Mass usage of BIMs requires additional precautions as it changes the way jobs are done. One of the objectives of BIM is to enable communication of project information. In other words, it takes the role of being an information hub of the project. 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 not any guideline or standards to check the quality of BIMs in the industry. Quality requirements start from the design stage, follow the construction and operation stages, and end with the demolition/end of life stage. With the new way of business, adoption of BIM, the nature of quality requirements, and the process of quality checks start to alter.

Zadeh et al. (2015) checked numerous BIM projects and deliverables and stated that the majority of the 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 effective use of BIM depends on the accuracy and quality of the models. Although it relatively decreases human impact due to an increase in digitization compared to the CAD, there is still a need to check the designs and models to make sure they satisfy the stakeholder requirements. The need for quality does not decrease, even increases, as the models and designs become smarter and more collaborated. BIM changes the way projects are designed, modeled, and coordinated. Hence, in order to satisfy quality in the design and the model, BIMs need to be continuously reviewed and updated as designing and modeling are continuous for the whole design stage.

ISO 19650 (International Organization for Standardization, 2018) states that Quality Assurance (QA) and Quality Check (QC) for BIMs should be performed; however, does not specify how to perform that in practice. Instead, it refers to the automated and semi-automated quality control procedures inherit in the BIM authoring tools. However, such tools/ plugins are not comprehensive or populated with quality information requirements. There might not be a widespread method to check the quality of BIMs, but every company can develop a procedure that fits their operation the best. One of the main requirements of construction projects is satisfying the pre-determined quality requirements. Quality requirements start from the design stage, follow the construction and operation stages, and end with the demolition/end of life stage. With the new way of business, adoption of BIM, the nature of quality requirements, and the process of quality checks start to alter.

Generally, BIM requirements and standards are identified early on in the tender phase through project specification documents. However, yet the quality-related requirements of BIM are not defined by standards or communicated through widely accepted guidelines. Design management teams should have in-house systems to make sure the information in the BIM environment is of the required quality. To achieve high quality BIMs, the requirements should be well-defined. There are different approaches to the quality of BIM from different perspectives. The first track is code compliance. Design earthquake codes, accessibility codes, fire safety codes and municipality codes can be examples for the code compliance checking in BIMs (Eastman, Lee, Jeong, & Lee, 2009; Kincelova, Boton, Blanchet, & Dagenais, 2019;

Malsane, Matthews, Lockley, Love, & Greenwood, 2015; Y. C. Lee; C. M. Eastman; and J. K. Lee, 2015). The other check is information integrity. It is checked if the information provided is accurate, correct, and complete (Cavka, Staub-French, & Poirier, 2017; Gu, Zhang, & Gu, 2016; Zadeh, Cavka, & Staub-french, 2015). Researchers generally focus on code compliance in order to automatize the checking and eliminate the errors (Choi & Kim, 2017; Eastman et al., 2009; Macit İlal & Günaydın, 2017; Nawari, 2012). However, the priority should be assigned to making sure the information entered into the BIM environment is accurate. For instance, the location and sizes of objects, the design details, usage of correct annotations, and cross-sections should be controlled. Otherwise, code checking would yield incorrect and inapplicable results. On the other side, unclear and incorrect information in BIM results in numerous Request for Information (RIFs) and prolonged communications between the project stakeholders (Amor & Dimyadi, 2020). Hence, the quality of BIM measured as the structure and the content of the information is of high importance for model checking (Hjelseth, 2015a). After submitting the design drawings and project BIM models for review to the client, it would take at least a week for the review process and another week to incorporate the review comments in the designs and in the BIM for a structural engineering company. It would cause significant issues in the project design progress if there are errors or missing items in the BIM that cannot be identified before the submission. This study highlights that the design and model information provided in the BIM is an important aspect and explores how the quality of the models can be assessed and whether a quality review process can be formulated.

There are only a few studies that specifically tackle information quality in BIM. Solihin (2015) focused on validating IFC files, Zadeh et al. (2015) used Facility Management users' information needs as a requirement, and Donato et al. (2018) focused on Employer Information Requirements (EIR) as a requirement. Information quality in the architectural design phase is commonly examined via pre-determined checklists and queries. Neither of the previous studies focused on understanding the inherent quality issues that arose as a result of Quality Control Process and developing tools or methods to be used for Quality Assurance purposes, customized according to the needs of the design teams.

The objective of this research is to first explore the data quality issues in BIM models in a formalized way so that the building stones for manual or automated quality checks can be developed. Understanding the quality issues as a result of the QC process, the second objective of this study is to develop a QA system for information quality in BIMs. In order to perform a research study in depth, only structural models are considered within the scope of this study. With the increase in digitization and IT usage in the AEC industry, most of the items will have the opportunity to be automated since the direction in the industry goes on that way. For this reason, this study includes discussions that are based on how much of the BIM quality checking procedure can be automated and how much of it remains manual.

1.2 Research Questions

There are a few studies (Cavka et al., 2017; Kim et al., 2018; Zadeh et al., 2015) that tackle the information quality of BIM. These studies either focus on information integrity based on the owner/client requirements or focus only on the architectural models to signify the need for quality control. While quality checking is required, an understanding of the variations of quality issues should be understood so that related quality checking mechanisms can be developed. 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). Within this perspective, this study aims to answer the following research questions to fill the gap in the quality checking of BIMs:

- RQ1: What kind of a procedure can be applied to BIMs to determine the quality-related issues of BIMs?
- RQ2: How can the information quality checking of BIM be formulated?

1.3 Scope of the Study

This chapter presents the scope and outline of the thesis. Chapter 2 reviews the existing research studies made in the area of quality checking of BIMs. Chapter 3 explains the methodology to be applied to design reviews to obtain an organized and reviewable overview of the quality of BIMs. Chapter 4 depicts how to apply the above-mentioned methodology to an existing project. Chapter 5 reveals the results and discussion after completing Case Study. Chapter 6 represents the validation study of the checklist. Chapter 7 summarizes the thesis and focuses on the limitations and the possible future researches on the area of interest.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Bryde et al. (2014) examined and compared different projects to see the effects of BIM on project success. The study shows that using BIM methodology positively influences time, coordination, communication and quality (Bryde, Broquetas, & Volm, 2014). Since the implementation of BIM is still in progress, and different companies are in a BIM environment for different purposes, the standards or general rules are still developing with the increase in BIM-based projects around the world. One of the main requirements of construction projects is that it satisfies the predetermined quality requirements. There are different approaches to the quality of BIM from different perspectives. One is code compliance, and the other is information integrity. In recent years, many research studies focused on design phases for code checking or facility management/operation phases for information checking. Research on both information checking and code checking of construction projects has increased due to the digital improvements in construction information technology, and necessity emerges from the transformation process from traditional CAD environment to BIM environment. This chapter presents background information on code compliance, information quality in BIM, existing tools and identified literature gap.

2.2 Code Compliance

Although code checking of building designs is a time-consuming, error-prone and costly process, code checking is done manually (Ghannad et al, 2019). Automated code-compliance checking has been a hard problem for the AEC industry for the last 50 years (Ghannad et al., 2019). There are different tools/platforms for automated compliance checking, as shown in Figure 2.1.

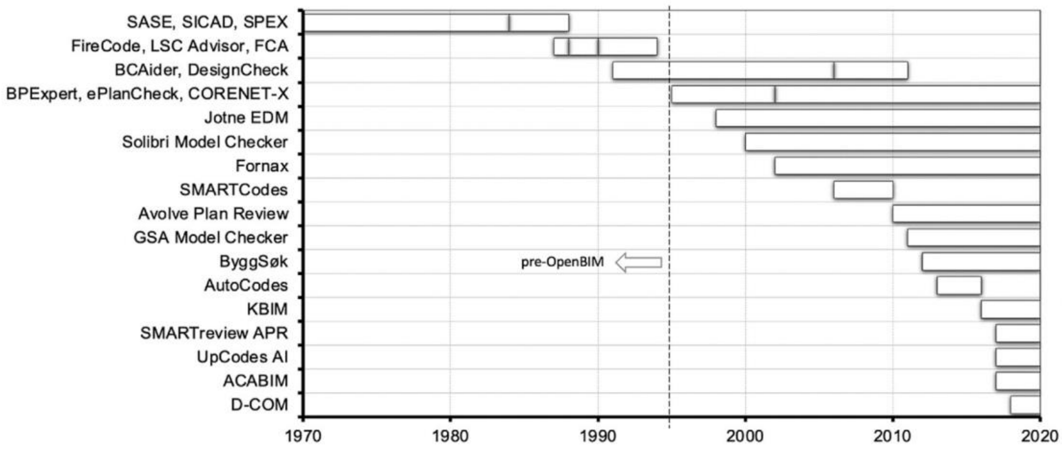

Figure 2.1. Timeline of Major Automated Compliance Checking Systems (Amor & Dimyadi, 2020)

A widely known approach for automated code checking systems was established in the middle of the 1990s. Already existing building code is embedded in a code checking system in Singapore and named as CORENET e-PlanCheck. Singaporean government used this platform for compliance checking of digital building models according to initially determined requirements in the areas of fire safety, barrier-free access, and building control. The system is not open to third parties, so that verification of the code is not possible. Methods used in this system are summarized in the FORNAX library (Preidel & Borrmann, 2017).

Another way of checking digital models is SMC (Solibri Model Checker), used for code checking and model quality checking. It is compatible with the IFC platform, and users have access to predetermined rulesets and have the ability to alter the default requirements according to their specific needs.

Ismail et al. (2017) approach the subject from an automated code compliance perspective and prepare a review on BIM-based automated code compliance checking systems. In this review, ease of collaboration between construction parties and information change is emphasized, and IFC (Industry Foundation Class) is shown as the main data format for BIM software. Building codes are represented in a programing language, and compliance checks are carried out automatically. By doing this, an automated quality check is performed, and the quality level of the model is determined according to governing building codes (Ismail, Ali, & Iahad, 2017).

There are other researches on automated code checking that use different approaches and languages to represent the code rules in specific programming languages. However, specific approaches are limited because rule representation of complex information in the coding language is not an easy task, and it requires extensive programming language since the aim is to make the whole process fully automated. Rule checking for all parts of the building is not an easy task. Building model checking applications can be developed for use in architectural design, detailing and building renovation (Eastman et al., 2009).

Making an adjustment or a correction for an error might be very difficult after the design phase had some progress, since it will require changing multiple model items. There are also studies to make comparisons between the concepts of automated design check and generative design in order to minimize the design errors by checking the model. As Sydora et al. (2020) did not limit the research scope with the code checking, it is also shown that design and information input also progress parallel with the code checking (Sydora & Stroulia, 2020). Information integrity directly affects the code checking in BIMs. Hence the information integrity needs to be satisfied prior to the code checking process.

2.3 Information Quality in BIM

Blay et al. (2020) 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. They presented an information resilience framework by drawing on the theories of resilience, information quality, and vulnerability (Blay, Yeomans, Demian, & Murguia, 2020). Amor et al. (2020) stated that the first of the unresolved issues is the data quality in BIM environment. The study emphasized that quality of the data comes before the code compliance so that code compliance can be checked (Amor & Dimyadi, 2020). In order to see the data quality level, information integrity should be satisfied.

Hjelseth (2015) classified the levels of model checking in a BIM as shown in Figure 2.2. The study used these levels to identify the maturity level of the Building Information Models (Hjelseth, 2015a). As rule complexity and the information provided in the BIM increases, one can see that more detailed checks need to be performed in order to improve the quality of BIMs. The last level is named as "Compliance Checking."

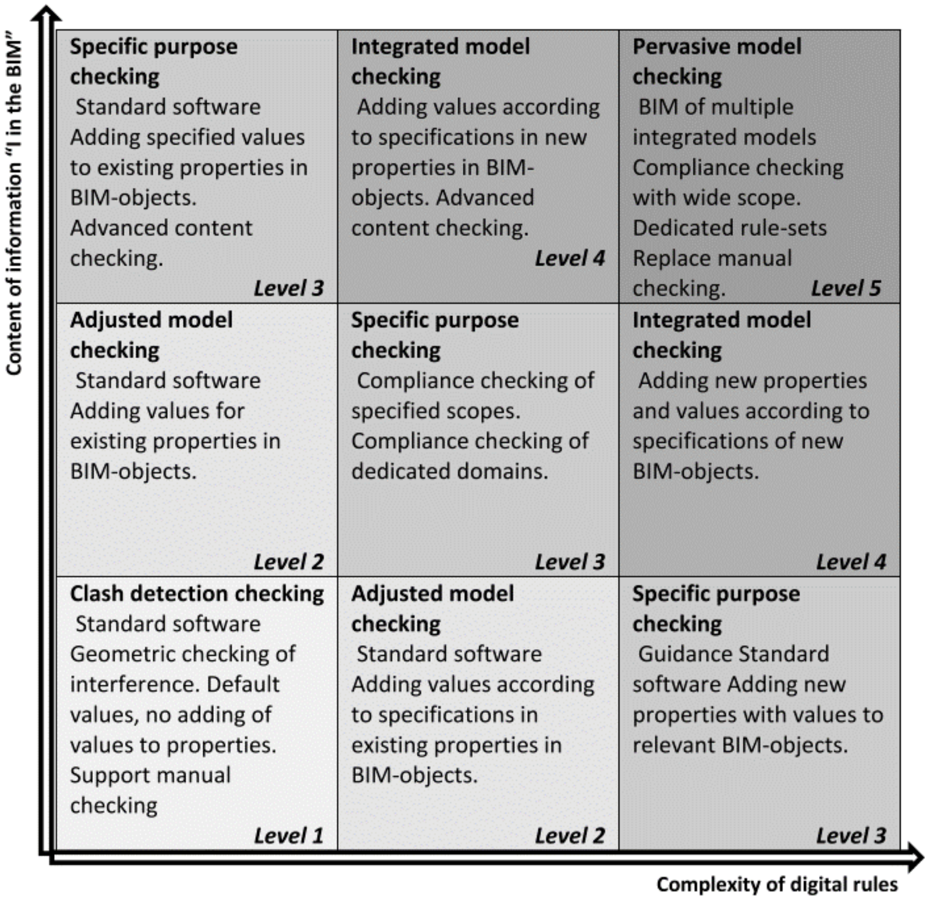

Figure 2.2. Classification of BMC Level for Compliance and Content Checking (Hjelseth, 2015a)

Yang et al. (2013) stated that data quality is somewhat difficult to define precisely, as it means different things to different user communities. Hjelseth et al. (2010) studied concepts for model checking and divided the checking in BIM into several parts; which are (1) validating model checking (geometry-based checking/clash detection and compliance checking/rule checking), (2) guiding model checking, (3) adaptive model checking, (4) model content checking. Table 2.1 shows the framework for model checking concepts proposed by (Hjelseth & Nisbet, 2010).

Table 2.1 Framework for Model Checking Concepts (Hjelseth, 2015b)

Intention with model checking	*Result*
Validating	Pass/Fail
Guidance	Proposal
Adaptive	Adapted object
Content	Present/Missing

Dimyadi et al. (2016) stated that compliance checking is done in 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).

Compliance checking is composed of two categories, which are Validation Checking and Model Content Checking (Dimyadi, Solihin, & Hjelseth, 2016). As a means of model content checking, Donato et al. (2018) examined the information quality in the architectural design phase via checklist and queries. Focusing on LoG (Level of Geometry) and BOM (Building Object Model), the study focused on the Developed Design (DD) phase and the transition between Concept Design Phase (CD) and DD. As shown in Figure 2.3, the quality checking procedures require the quality assurance criteria to be identified as one of the first steps. While a predefined checklist is used, employer information requirements for the quality of BIMs are not addressed in this study.

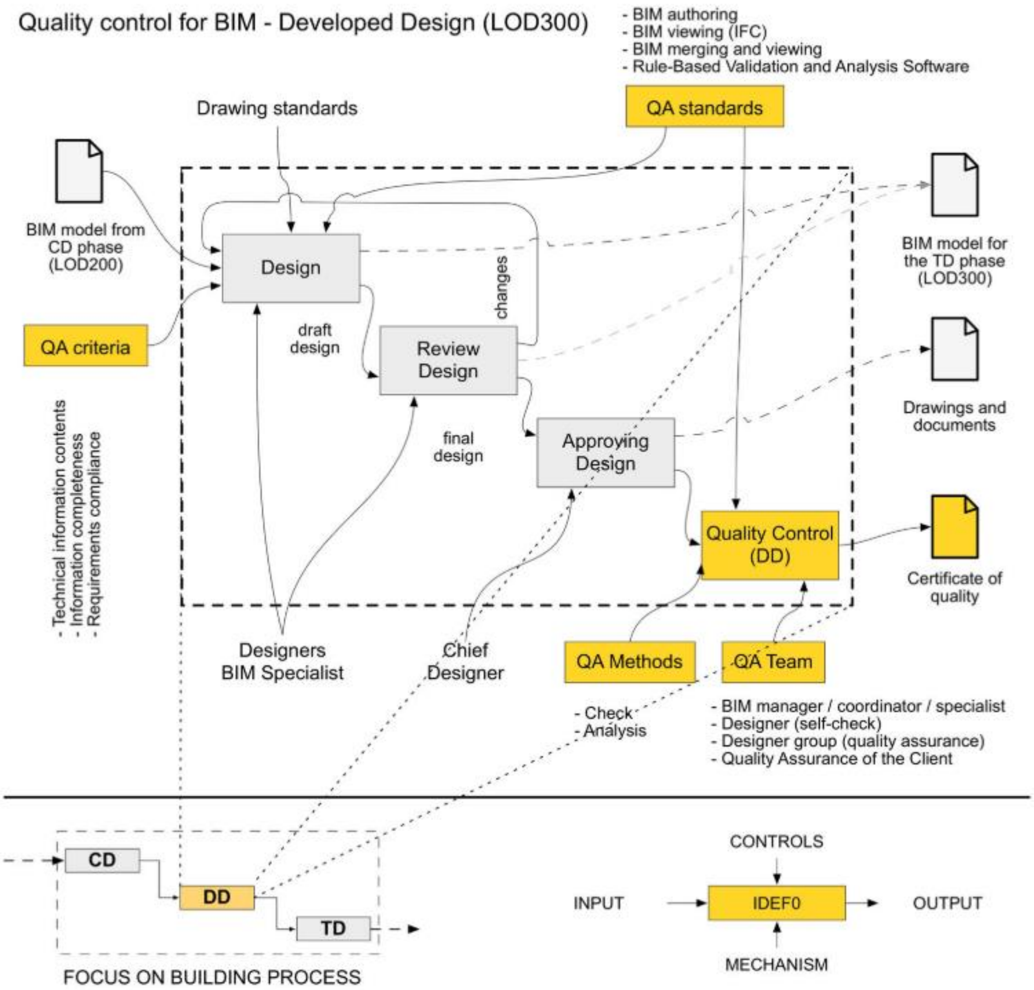

Figure 2.3 Quality Check Procedure (Donato, Lo Turco, & Bocconcino, 2018)

How quality is defined may change according to the point of view in the industry. It might be design quality, modelling quality, drawing quality or planning quality. One of the primary motives to use BIM methodology in planning of the projects is to increase the planning accuracy, cost security and also the quality. Quality is the most deficient one among the others although BIM increases the planning accuracy and cost security (Häußler & Borrmann, 2020). Quality has still space to be filled by the developments in the industry. Mainly researchers used owner requirements at the beginning and established their checks according to these pre-determined requirements. There might be owner requirements in terms of the model quality or the design quality. There might also be a BEP (BIM Execution Plan) for the company or for the project specifically. For instance, Cavka et al. (2017) showed how owners can develop and formulate their own information requirements to enhance BIM-based project delivery.

Zadeh et al. (2017) focused on the information integrity of a Building Information Model for facility management purposes. In order to continue to use BIM during the facility management/operation stage of a facility, information contained in BIM should satisfy several requirements. These requirements can be changed according to owners and facility types, but they are determined at the beginning of the design stage or modeling stage.

While the most commonly cited key quality dimensions are accuracy, completeness, consistency, and currentness (Fox, Levitin, & Redman, 1994), there are various studies that use different information quality dimensions. Arazy & Kopak (2011) 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 (Patacas, Dawood, & Kassem, 2020; Wang & Zhang, 2021). For instance, according to their case study, Wang et al. (2021) stated that BIMs created by the contractors do not comply with the completeness, accuracy, and consistency assessments in spite of the standards and the proper training. Zadeh et al. (2015) prepared a framework to check the information quality of a Building Information Model that is going 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.

As Preidel et al. (2018) stated, compliance checking is a manual and iterative process as it always has been and is 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 modelling, new technologies or tools become available to improve and partially automate the compliance checking procedure (Preidel & Borrmann, 2018).

2.3.1 Quality Check Tools/Software

BIM platforms have become increasingly popular for the design teams in the AEC industry. There are several reasons for that, but the main ones are increased collaboration and quality in the design. Time spent on the design stage is very important for the project since the design itself is an iterative process. With the increase in the number of BIM authoring, visualization and communication, and analysis (e.g., energy analysis, sustainability analysis) tools, additional plugins and tools are also developed to check the different cases in the BIM environment. Since this study focuses on BIM quality checking, some of the tools that are used widely in the industry are briefly explained here.

Design checking is different from the model quality or design drawings quality checking. In order to check the design, rule checking needs to be done per the applicable design codes. Figure 2.4 represents the flowchart for an automated code compliance checking procedure. According to the flowchart, rules are interpreted and converted into computable forms. Then, rules are executed in an environment that model data is also transformed and rule checking is established.

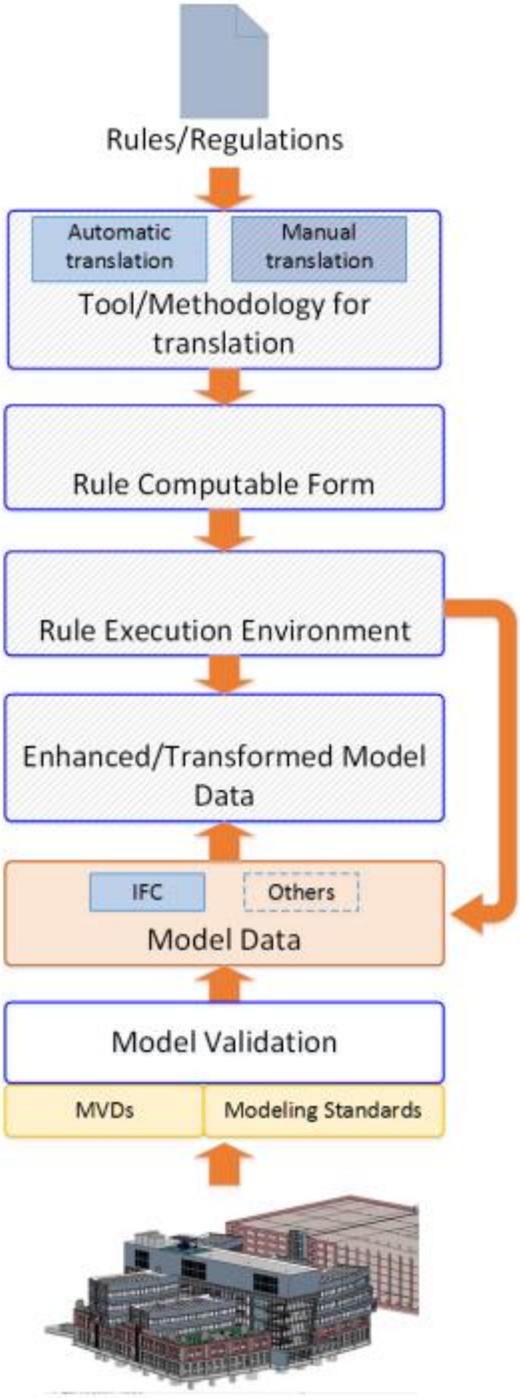

Figure 2.4 Categories of Automatic Code Compliance Checking Research (Dimyadi & Solihin, 2016)

Solihin et al. (2020) list the tools that are being used in the market for rule checking purposes. Examples of such tools that are mainly developed as an add-in or extension for a bigger platform are listed below (Solihin, Dimyadi, Lee, Eastman, & Amor, 2020).

• EDM Model Server: users can write a script using its rule schema inside the IFC express model (EPM, 2021).

• IfcDoc, which is an MVD (Model View Definition) generator, also provides a rule-checking functionality to automatically evaluate an IFC instance document for compliance with its MVD specification (Solihin et al., 2020).

• SMARTreview includes Automated Plan Review (APR) capability, which is an add-on product created for the Revit environment to provide rule checking capabilities against some provisions of the International Building Code (IBC).

• FORNAX™, one of the pioneering implementations of the code checking system that was used to develop CORENET ePlanCheck in the early 2000s, has been updated and provides a toolkit for developing rules using lua scripting language to run on its cloud hosted server (Solihin et al., 2020).

• BIM Assure, a BIM application from start-up company Invicara provides model data validation in the cloud using previously determined rule templates. Its current capability supports BIM flows back and forth with the Revit and IFC formats with rules based on properties and some object relationships (Invicara, n.d.).

One of the widely used platforms for design coordination is Autodesk Revit. It enables users not only the architectural and structural design but also MEP design and project management can be handled in the BIM platform. Regarding information quality assurance, Revit API is an Autodesk Revit feature to customize the Revit according to the user needs. It requires basic programming skills to create custom tools in the Revit environment.

Corbissniffer Tool is a Revit add-in that enables users to see the backside of the BIMs. Users can see the categorized information about the models with the help of the Corbissniffer scanning power. It basically lets users scan their models in terms of the previously defined categories, including views, sheets, families, and worksets.

Dynamo is a visual programming platform that is integrated into Autodesk Revit. It enables users to automate the iterative processes and parametric modelling. It is also very useful to export and import data while working in the Revit.

Solibri Model Checker (SMC) is another model checking tool for the BIM platforms. It is mainly used to check the quality of the BIMs by using readily available rule sets or customized rule sets. Although automated rule checking history started long time ago, the AEC industry still does not have a lot of resources to use in the market, with the exception of SMC (Solibri Model Checker, 2021). It includes not only clash detection but also different rule sets (e.g., accessibility and clearance checking). One of the most accepted advantages of SMC is that it is compatible with the Industry Foundation Class (IFC). However, users are limited with the readily available rule sets to check the BIMs.

Autodesk Model Checker for Revit (Interoperability tool) is another tool for customized rule checking in the Revit. Users can interpret their own rules to check the models.

3rd Party add-ins applications; it is also possible for the users to create their own add-ins for the BIM platforms. Of course, all such tools need a predefined rule set to perform the checks.

2.4 Existing Gap

The entire lifecycle of the built environment is governed by a variety of regulations, requirements, and standards, ranging from contractual requirements, requirements specified in the project brief, legislative regulations, and self-imposed environmental performance recommendations. The checking of compliance against these requirements is a complex task that is currently performed on a manual basis thus is highly resource intensive (CDBB, 2019). Researches, in general, focus on code compliance of BIMs. Prior to code checking, the information provided in the BIM should be assured to ensure a healthy assessment, correct information exchange. There are a limited number of studies that focus on information integrity, but with a special emphasis on architectural models, using predefined client requirements. Donato et al. (2018) focused on the architectural design process for BIM quality. Items to be checked in a BIM might be expected to vary based on the discipline. For instance, pipes or cables may need to be included in the MEP Discipline, while rooms, windows and doors need to be included in the Arch. On the other hand, steel columns or foundations need to be examined under the corresponding discipline, which is structural design. Cavka et al. (2017) looked at the quality of BIMs for the facility management scope. Zadeh et al. (2017) had the owner requirements to check the level of quality in the BIMs. In our study, the main focus arises from the structural scope, targeting 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. Identifying the quality issues for individual disciplines might give the opportunity to establish generic quality checking framework to establish a checklist for the specific discipline. In literature, there is a lack of information regarding quality issues in BIMs identified when reviewed by clients, consultants, or clients' representatives. Such issues might be different based on the domain and types of jobs a company is engaged in. Still, there is a need to explore the quality issues and develop quality assurance mechanisms to eliminate such issues. Hence, practitioners need a systematic way to identify the quality issues (e.g., inaccurate or missing information in their models) in their existing BIMs, and be able to develop in-house BIM quality assurance systems. In a future phase of the project or the design company, review comment checklists can be combined for other discipline models to see or major the level of quality in BIMs. In order to address this gap, this study aims to propose an extendable checklist from the design review comments from the client, regarding the structural domain to guide the future quality assurance processes. This study identifies the requirements for Quality Assurance in BIM to help facilitate Quality Control mechanisms to evaluate the BIM content and assess their automation potential.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the research methodology to create a quality checklist for Building Information Models from design reviews and model reviews. In Chapter 2, it was stated that there is a research gap in the quality checking of BIMs when design and modeling are combined. This study follows a case study approach. As Yin (2018) states, conducting a 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 of a project are examined in detail to generate a checklist to be used in other projects. The research methodology flowchart is shown in Figure 3.1. The first part of the research is to collect design and model review comments from the owner and the design company. The second part is to clean the review comments as they may not be in an organized and clean shape. The next phase is the analysis of the review comments. After analysis and categorization checklist development phase is carried out. The last part is to validate the developed checklist.

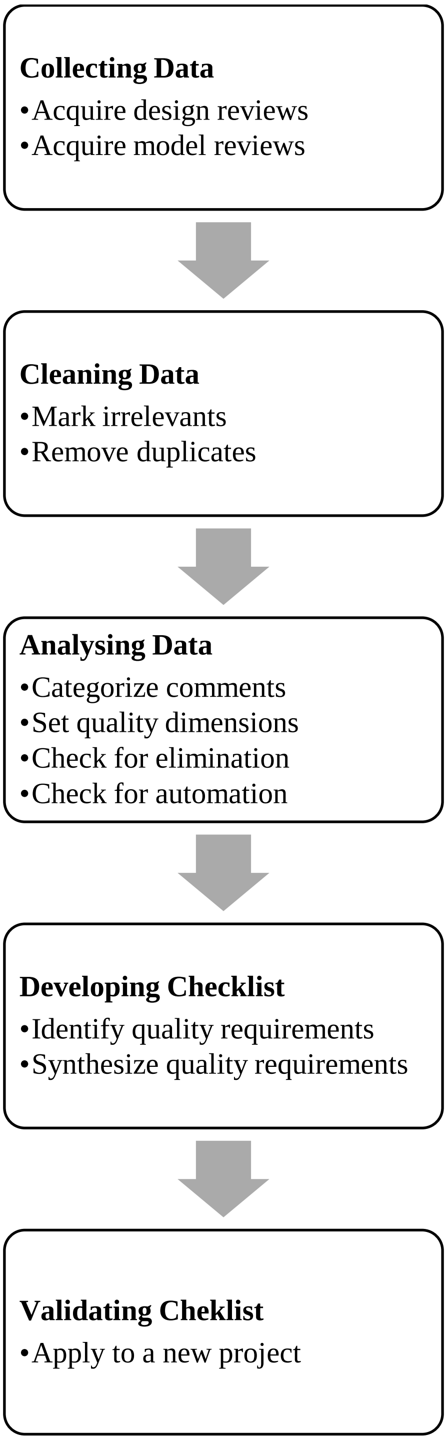

Figure 3.1 Methodology Flow Chart for Review Comments

Structural designs are mainly reviewed by state organizations or design consultants. Generally, reviewers have comments about recommendations or requests in the design for compliance or the design changes. If the review process is done in a state organization in a traditional way, it is generally done on 2D design drawings. It is also possible to have a review on a BIM with the help of the improvements on the technology in the AEC industry. Building Information Models are reviewed by the owners or BIM consultants to check the compliance of the models with the project standards or requirements if there are any defined.

In this research study, design review comments given by senior structural engineers through the design phase of the project and model review comments given by the BIM consultant are used. Since the design itself evolves on the way, it is highly expected to have new reviews and review comments about the design. Change in design leads to change in the BIM as well. For this reason, it is expected to have review comments after every project submission. Design and model review comments can be given for every project discipline since a review process can be followed for every design that is included in a project. This research methodology can be applied to other disciplines as well.

3.2 Collecting Review Comments

The first phase of this study is to collect the review comments from the reviewing party or the design company. There are two review processes expected for a project that is designed with BIM methodology. First, a design review for the design drawings, and secondly, a BIM review for the model can be caried out.

Designs prepared by an engineering company can be reviewed internally or externally. Firstly, an internal design review can be conducted within the design company to check the design and the quality. Secondly, an external entity can review the design and the BIMs that represent the design. According to the project type, the owner might review the design, or a consultancy firm assigned for the design consultancy can review the design. Internal or external, almost every review process ends with comments and questions. In order to have a design that aligns with the requirements or to meet the owner or project expectations, designers are asked to update the designs and drawings together with the BIMs.

Design and model reviews might be obligatory according to the project types. As expected, after review, comments are shared with the designer, and the design company is asked to incorporate the review comments into the drawings. These design review and model review items can be collected from the reviewing parties. Also, design reviews and updates can be completed in the digital environment with the help of BIMs.

3.3 Review Comments Phases

Design reviews generally start with the initial design meetings. Every project lifecycle composes of phases, including design, construction and operation. The design phase also has its sub-phases. They are subjected to change according to the project since every project and design is unique. Design phases are mainly composed of six stages, and designers submit drawings/BIMs to the owner or the architect almost at every stage. These design phases are:

1. Schematic Design
2. 30% Design Drawings
3. 65% Design Drawings
4. 95% Design Drawings
5. 100% Design or Construction Drawings
6. Bulletins/Revisions

In order to increase the collaboration among the project disciplines, design coordination and review meetings are held along the design stages. Besides the coordination meetings and reviews, every design discipline's work might also be reviewed by other project participants, which can be design consultants, owners' engineers, or governmental institutions.

It is possible to have design and model reviews in every design phase. Having frequent reviews and updates might be efficient in increasing the quality of the information provided in the drawings and in the BIM while also increasing the time and effort spent on the project.

3.4 Cleaning of 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 started for the review comments.

3.5 Categorization of Review Comments

Organized and categorized data would increase workability and controllability. After eliminating duplicated and unfixable comments from the list, comment categorization can be done. Comments or questions might not be in a shape that can be easily classified. Review comments can be delivered as an organized list or in bulk. One must classify the reviews to work on them. To begin with, comments should be divided according to their scope. Since there are also BIMs reviewed along with the designs, comments should be divided if it is a model review comment or a design review comment. It would be better to divide the comment categorization into two parts. These are comment location and comment content.

First of all, design review comment locations should be determined if they are in plans, details, legends, or schedules. Location is vital to make a hierarchical order for the categorization. Categorizing comment locations might give clues about the point of focus for the checking of the drawings and the BIMs.

After considering comment locations on the drawings, comment content should be checked. It is expected that a single comment addresses multiple items in the drawings. The reviewer may choose to give every point in a single comment for a design sheet. In order to handle these types of comments, contents can be divided into single addressable units to increase control and workability.

After dividing comments into single addressable units, comments should be checked if they are fixable for the design scope or the contract. All the design reviews might be on the same platform with all the design stakeholders. It is possible to assign a comment to a wrong discipline or ask a question that is not in the scope of the corresponding design team. Comments that are not going to be studied in the categorization process should be noted in this part as unfixable.

Unfixable comments cannot be predicted or eliminated. Fixable comments need further analysis to determine the causes and possible ways to eliminate them.

3.6 Analysis of the Review Comments

The next phase in the research methodology is to analyze the comments according to the comment types. In order to see the causes for the comments, the type of the comment needs to be analyzed in detail. Kim et al. (2018) divided the design review comments into five categories as given in Table 3.1. Those categories are General, Query, Suggestion, Observation, and Requirement.

Table 3.1 Comment Type Categorization (Kim et al., 2018)

Category	*Description*	*Example Comment*
General	A general comment/introduction about the document	"Overall, this drawing package is progressing nicely."
Query	A question being asked to the team	"There appears to be an existing site sign. Please confirm and label this on the site plan. Does it require piles or lighting?"
Suggestion	An idea or a recommendation put forward for consideration	"Suggest showing the electrical transformer in context with the south-east enlarged floor plan segment."
Observation	A remark or a statement made on detection	"School sign with metal letters at grade could be a target for vandalism."
Requirement	A demand made when something is needed or wanted	"Two roof drains are needed per roof area to comply with AI's Technical Design Requirements."

Those categories do not apply to this project directly since there are differences in the review comments. Instead of applying a predefined category, the categories are developed from data. Categories that arose in this study are given in Table 3.2. No comments were observed that could be categorized as General, Observation or Requirement per Table 3.1. Query, which has been named as Design Verification in this study, asks for a confirmation from the other party. Suggestion category is included list as there are comments that are categorized as a suggestion. There is no comment that can be classified as Observation category in this project. There are also additional categories to describe the comments in this project. The first category is Missing Information. It is used if there is missing information on the drawings. It can also be subcategorized as there might be missing annotations, design information, labels, and details. It is used when required information is not provided in the drawings. The other category is Errors. It is used to categorize the comments due to errors in the drawings or in the model. It can be also subcategorized as it is done for the Missing Information category. The subcategories are Modelling Error, Annotation Error and Design Error.

Table 3.2 Comment Type Categorization

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.”

After determining the comment category, they need to be re-investigated in terms of avoiding the comments in the first place. In order to see this situation in the comment list, a new check to see if the comments can be eliminated before the review process or not need to be done. If it turns out to be that a review comment can be eliminated before the reviewing process, then it needs to be added to the checklist for future use.

Respectively, there will be comments that cannot be eliminated before the review process. There might be two reasons for those types of comments. The first one is that a comment cannot be eliminated before the review process since the comment gives a new suggestion about the project. It is not possible to predict the new suggestions in the design before submitting the design. The second one is design confirmation. As it is the case for new suggestion, design confirmation comment is hard to eliminate since it was not expected before the submission. Other than those two types of comments, comments can have the possibility of being eliminated before the review process.

In addition to elimination, comments should also be checked for being eliminated manually or automatically with the help of BIM tools or Add-In's. This study is trying to understand the possibility of automation in the list of check items. By doing this check, a partially or fully automated quality check is being targeted at the end of the study. The automation can be examined in three categories;

- Manual check
- Semi-automated check
- Automated check

A check item may not be automatically done at the beginning, but some part of the checking can be done automatically after a certain level of the project. This partial automation can be defined as semi-automated process.

Possibility of elimination should rely on the project or owner requirements if there are any requirements provided at the beginning of the project. The owner may expect the designers to comply with the design and modeling requirements of the project, which may have previously been defined. Also, it is possible that requirements are determined together with the design stage. In this case, elimination may not be applicable for most of the review comments since there is not any standard or requirement to reference.

Model review comments should also be analyzed in order to see the level of quality in terms of the model quality perspective. Just like design review comments, model review comments are gathered after each design package submission. Although there are basic initial requirements for the models, most of the 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.

Clash detection analysis is done by the owner or the BIM consultants of the project for every design package submission. Clash reports are shared with related disciplines and they are required to solve the corresponding clashes until the next design issuance. Clash analysis is also considered a quality item for BIMs.

Almost all of the model review items can be checked via Revit tools or Add-ins. Currently, it is obvious that one tool is not enough to check all the BIM items in a project. For this reason, a combination of tools, add-ins and manual checks are used. There are examples of the items that need to be checked manually for the quality of a BIM. These items can be listed as:

- Levels and Grids are copy-monitored from the Arch file
- All the linked files are pinned
- BIM360 publish settings set up according to the project requirements
- Phase mapping is done along the discipline models
- Title block uses project standards
- View Browser organization set up according to the project requirements
- Sheet Browser organization set up according to the project requirements

The most common information quality dimensions used for BIM-related studies include accuracy, completeness, and consistency. This study considers inconsistency as a subset of incorrect information; hence accuracy and completeness of the BIMs are used as two main quality dimensions.

3.7 Developing the Checklist

After the categorization of the comments, every comment needs to be checked if there is a possibility to eliminate these comments in the beginning. The possibility of elimination means that items can be added to a checklist for a future check to increase the quality of the BIM. It is certain that missing information while it needs to be provided on the design drawings can be checked before the submission if it is included in the checklist. It is almost the same for an error in the design drawings. If the points labeled as error in the design reviews are gathered and grouped for a future check, then checklist items are generated one by one for that specific type of project.

On the other hand, there are items that cannot be eliminated in the future design package submission as well. A new suggestion from the reviewer or the owner cannot be predicted. Similarly, a design verification request cannot be eliminated as it is not possible to guess a future design verification request. By grouping and categorizing the comments, possible missing items and errors in the design or in the model can be eliminated by generating a generic checklist. Moreover, if there were no requirements or expectations in terms of the design drawings, then it is not very likely to eliminate the review comment before the submission. Owner requirements or project standards that have been set up before the design submissions would be the best source to establish the checklists.

The other point for the overall quality checking of the BIM is the model review comments. There are items that need to be checked manually and items checked via tools or add-ins. All of the comments gathered from the model reviews need to be examined for the possibility of automated checking.

3.8 Validating the Checklist

Validation of the checklist can be done in several ways. In this study, the validation is performed using the review comments of other projects. Once the model review and design review comments were assessed for the initial project, a checklist is developed that can be used in future projects to eliminate such issues. The checklist generated from this project is used for other projects to see if the check items cover all the items generated from a single case study project.

CHAPTER 4

CASE STUDY

4.1 Introduction

The research flow explained in Chapter 3 is demonstrated in this chapter. It is important to examine a project, which consists of multiple structural items to be designed like steel, concrete, and composite elements. Having different structural items to be designed increases the probability of having more review comments to establish a generic and extendable checklist.

A structural design project that has model review and design review comments is selected for a case study analysis. The project is planned to be constructed in the US as a warehouse. The footprint for the building is about 175000 sq. ft. The design scope includes the structural analysis and design of the main gravity and lateral load-carrying systems. The design company is also responsible for the structural Building Information Model and drawings of the project. The design phase is totally on the cloud environment on BIM360 platform in order to increase the collaboration. The structural design group has its own discipline-specific BIM on the cloud that is updated simultaneously together with the other disciplines.

The design company is a United States based structural engineering company, which has an office in Ankara-Turkey as well. Design of the project handled during the design process of the project, design reviews and model reviews are collected.

A Nondisclosure Agreement (NDA) document is signed with the design company for the project so that detailed information about the projects and the documents cannot be shared or published without the written permission of the design company and the owner. The contents shared in this document have been approved by the company management team.

Disciplines that were gathered to design and coordinate the project are briefly explained below, and the interaction diagram is given in Figure 4.1.

- ARCH – architectural design and coordination
- STR – structural design and coordination
- CIVIL – exterior/landscape design and coordination
- ELEC – electrical design and coordination
- MECH – mechanical design and coordination
- PLUMB – plumbing design and coordination
- FP – fire protection of the project
- FA – fire alarm system design and coordination
- INTERIOR – interior design and layout
- SECURITY – security infrastructure and coordination
- TELECOM - telecommunication design and coordination of the project
- PRODUCT – specially designed and used products design and coordination

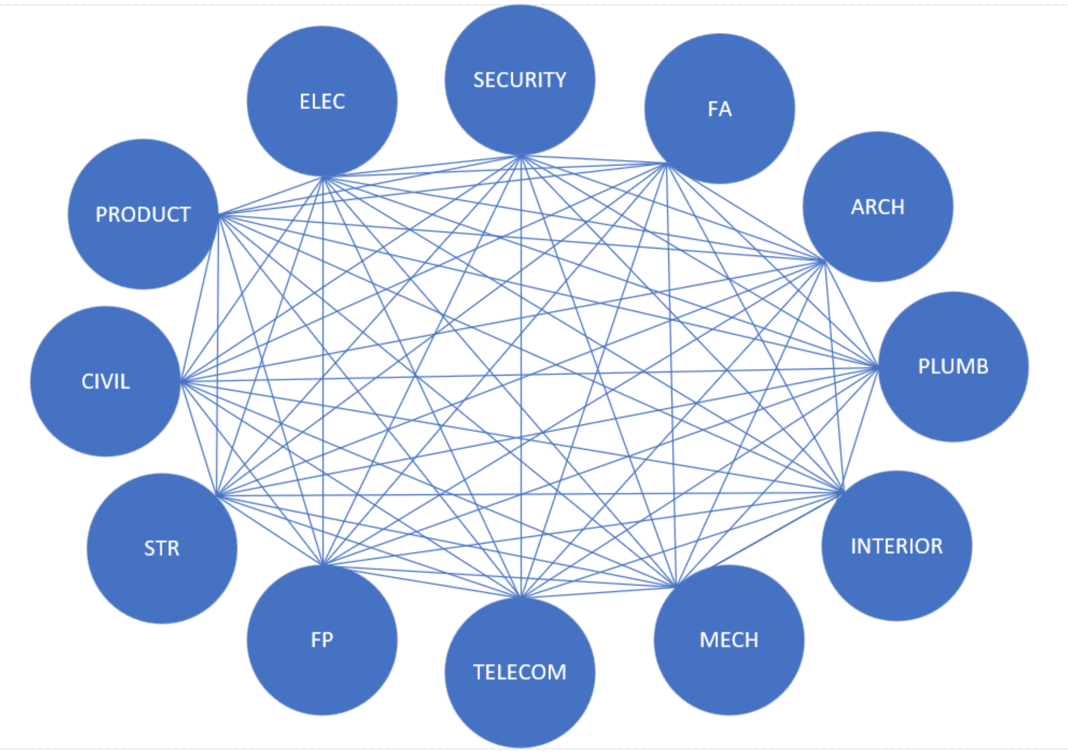

Figure 4.1. Disciplines Included in the Design Process

4.2 Project Determination

Review comments were taken from a warehouse project. It is a two-story steel building with a composite slab and a steel roof. Every discipline needs to add its discipline-specific elements to models in an organized way. It includes more disciplines than a default construction project has. Structural, architectural, mechanical, electrical, plumbing, telecom, security, interior architecture, civil, fire alarm, and fire protection disciplines are the main disciplines included in the design phase in a cloud environment for collaboration. There are also subdisciplines for specific requirements by the owner.

It is not very common that all the disciplines mentioned above are gathered in a single project. It becomes very important to organize not only the construction but also the design phase. All the disciplines work in a cloud environment (BIM360) by using the Autodesk Revit tool. Moreover, all of the drawings and models are reviewed by the owner engineers or consultants to increase the quality of the design and modeling. It is not only reviewers who give comments on the drawings. Designers also can give comments about their discipline-specific coordination items. Every discipline provided comments in terms of design issues, coordination items, and model quality. BIM360 is extensively used for coordination in this project. Almost all of the comments are given on the cloud platform in order to have a more organized and easier to follow comment structure.

This project is selected for the research by consensus between the company and the researchers since it includes review comments for both drawings and the Structural BIM. The aim was to determine a checklist that addresses all of the design review and model review comments. With the help of the proposed checklist, the overall quality of the projects can be checked and improved.

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 at the beginning of the project. For example, every discipline needs to have a Revit model that is clean of warnings. It is a very basic requirement since warnings are generally due to an error in the modelling. The subjects explained in the BEP can be listed as:

- Project Information
- Project Milestones
- BIM Uses
- Organization Roles
- Responsibility Matrix
- BIM Project Deliverables
- Project Technology
- Architect/Engineers Collaboration Information
- Modelling Information
- Clash Coordination
- Quality Assurance/Quality Control

Although above mentioned categories are provided in the BEP, there is not an organized and detailed Quality Requirements for the project. Project quality requirements are mainly determined parallel to the project development.

Table 4.1 shows the BIM Uses for the selected project according to the BEP. As can be seen, BIM is used for design authoring, design reviews and 3D coordination together with the cost estimation.

Table 4.1 BIM Uses for the Project according to BEP

	PLAN		DESIGN		CONSTRUCT*		OPERATE*
	PROGRAMMING	X	DESIGN AUTHORING		SITE UTILIZATION PLANNING		BUILDING SYSTEM ANALYSIS
	SITE ANALYSIS	X	DESIGN REVIEWS		CONSTRUCTION SYSTEM DESIGN	X	ASSET MANAGEMENT
		X	3D COORDINATION		3D COORDINATION		SPACE MANAGEMENT / TRACKING
	COST ESTIMATION (5D)	X	COST ESTIMATION (5D)		COST ESTIMATION (5D)		COST ESTIMATION (5D)

4.3 Review Comment Collection

Different ways are used for the project reviews. The first one is reviewing the 2D design drawings. Review comments are combined on a list and sent to the structural design team from here. The second one is reviewing the 2D drawings on BIM360 platform with the 3D model available. Review comments are given to the 3D model in this case. This option is mainly used for the clash resolution between the design parties. After the drawings and BIM submission, the structural model is also reviewed by the owner's BIM Team. This review includes the model only. There is nothing about the design drawings in this part. It is mainly about the model structure on the Revit. Model review comments are also combined on a list to be delivered to the design teams, and every design party has their discipline models reviewed by the BIM team. Design drawings are reviewed by experienced engineers mainly, and there are different reviewers for different disciplines. However, discipline models are reviewed by the same team to satisfy the consistency and the quality in the models. The review comments are transmitted to the designers after every submission for the selected project after a reviewing process. The commenter expects a response for each item on the comment list, whether it is resolved or waiting for further coordination. Every comment is also a coordination item for the project collaboration. It first starts with the Schematic Design. It is not expected to have many comments about the modeling at this phase, mainly design comments. The number of design and model review comments starts to increase after the first Design Drawing submission. As expected, the number of comments decreases in the Bulletins/Revisions after Construction Drawings are submitted as the project is close to finalization.

As stated in Chapter 3, projects might have different milestones for the design submissions. It is expected to have more review comments when the design process becomes detailed. Review comment distribution is explained in detail in Chapter 5 for this case study project.

4.4 Cleaning and Categorization of Review Comments

Review comments were cleaned as specified in Chapter 3. Cleaning includes removing the unrelated or misassigned comments from the categorization process. Duplicated comments were also eliminated as they may lead to double counting of the data. The ones that include more than one comment were divided into single addressable units for this study.

Table 4.2 shows the list of worksets that need to be used by the Structural Design Team. This list represents the condition used in the case study project. The workset structure for a structural BIM is generally in this shape with minor adjustments.

Table 4.2 Proposed Workset Structure

Workset Name	*Description*
Levels & Grids	Levels, Structural Grids
Reference Planes, Lines & Scope Boxes	Reference Planes
	Reference Lines
	Scope Boxes, Match Lines
LINKS	Every link file to have its own workset
STRUC_COLUMNS	Structural Columns
STRUC_FRAMING	Structural Beam Systems, Structural Framing, Structural Stiffeners
	Structural Trusses
STRUC_FOUNDATION	Floors, Structural Foundations
STRUC_WALL	Structural Interior Walls
	Structural Exterior Walls
	Retaining Walls
STRUC_REIN	Structural Area Reinforcement
	Structural Fabric Areas
	Structural Fabric Reinforcement
	Structural Path Reinforcement
	Structural Rebar
	Structural Rebar Couplers
Workset1	As needed for working

Comment categorization results of the case study are shown in the Chapter 5 Findings and Discussion.

4.5 Analysis of the Review Comment for the Case Study

Comments analysis is an iterative study. After cleaning and categorizing the comments according to their contents, an analysis needs to be performed. This analysis includes the assessment of elimination and the assessment of automation.

An elimination assessment was carried out to determine if it was possible to eliminate the comment before the reviewing process or not. If a comment can be eliminated, then it needs to be added to the checklist for future use. There are also comments that cannot be eliminated even before the reviewing process. For example, design verification cannot be eliminated prior to review since a design verification comment cannot be forecasted. The other example might be giving a new suggestion to the design team since a new suggestion cannot be predicted earlier than the review process. Hence, a new suggestion comment is hard to predict and thus to be eliminated.

The other analysis is automation assessment. This analysis is carried out to determine the possibility of automation of the check items, which were determined as "can be eliminated" items from the elimination assessment. Automation assessment is considered as three separate parts. The first one is "can be automated." Review comments that can be eliminated before the submission with an automated checking or an automated editing process. The second part is "can be semi-automated." A semi-automated tag means that an action item to eliminate a comment is neither automated nor completely manual. For this type of comments, semi-automated category is introduced. Either the check or the edition can be automated in this part while it is also required to make some adjustments or checks manually. The third one is a "cannot be automated or manual." In this case, a manual check or editing is required, and it cannot be automated.

A second analysis is performed for the semi-automated category in order to see if an item in this category can be tagged as “can be automated” after the manual process is achieved through the project.

Assessment of elimination and assessment of automation are also carried out for the model review comments. Comments were first analyzed if they could be eliminated before the review process or not as it is done for the design review comments. The second analysis was to see whether the checking process can be automated or not. Model review comments were analyzed for each phase individually as there are new categories checked for the project phases. Review comments were structured mainly from a Revit add-in Corbis Sniffer. It is important to emphasize that Corbis Sniffer does not provide any comment based on the BIM. It provides all the information in the model in a pre-structured way. Reviewers take the exported file and review the output file together with the actual model used in the design. There were also other comments that are not covered in the add-in but need to be addressed in the model for the quality of the BIMs. The comments were divided into two different sets manually checked items and comments from the Corbis Sniffer output file.

Analysis results can be seen in the Findings Chapter. New items can be added to the checklist after the first analysis. Every comment and opinion is important for the overall improvement of the study. While trying to check the level of BIM quality, it is also important to develop the accuracy and usability of the proposed checklist.

4.6 Development of the Checklist

After analysis of the design review comments, a checklist that can be applied to the projects to eliminate the future review comments is developed. While creating the checklist, it is important to address all of the comments given through the review process. For this reason, every comment is considered individually for the elimination assessment part. If a review comment can be eliminated, then it needs to be included in the checklist.

There are also model review comments from the BIM team, as specified previously. Model review comments are also analyzed according to their content. With the help of the review comments from the manual process and Revit Add-in output file, a model review checklist is created to be used in the future to eliminate model review comments. The results of the application of the checklist are given in Chapter 5.

CHAPTER 5

FINDINGS AND DISCUSSION

5.1 Introduction

The findings of the study are presented in this section. Design review comments are sorted and analyzed according to their contents and types. Several categories were used in the analysis procedure. A framework to analyze review comments is presented. Not only structural design but also other disciplines will be able to use this framework to classify the review comments. It is a contribution to the AEC industry that BIMs can be checked prior to review processes so that quality expectations are satisfied at every stage of the design and modeling.

5.2 Characterization and Formalization of the Analysis

As stated earlier, comment categorization is an iterative process. After several iterations, a framework to analyze the review comments is established. Review comment structure examined to determine the categories in this framework. Figure 5.1 shows the comment classification process that is applied to the design review comments of the case study project.

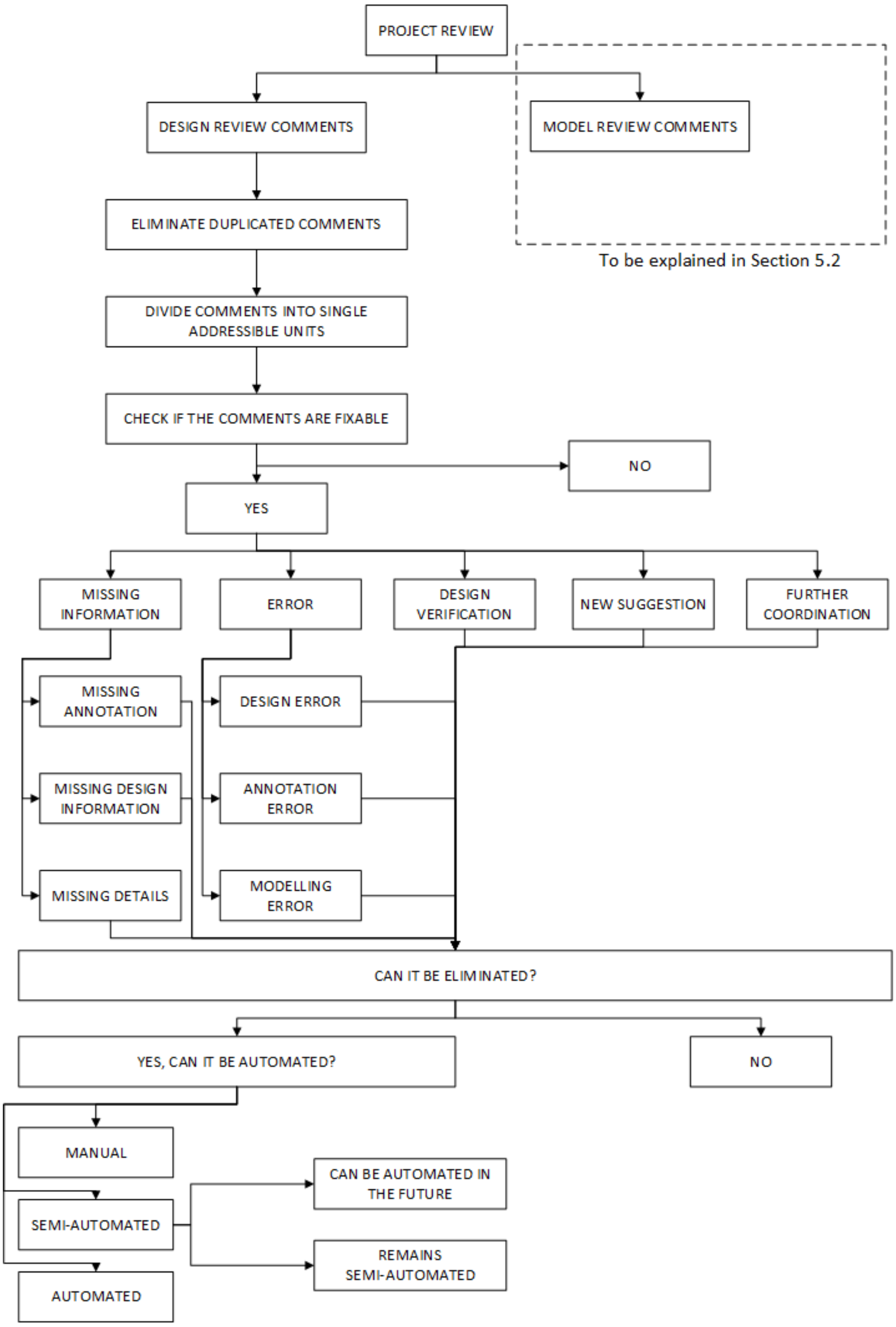

Figure 5.1 Design Review Comment Classification Process

There are also model review comments to be categorized for the case study. As it is stated, model review comments are from the BIM Team of the project. Most of the comments are collected in a structure that is directly exported from the Revit add-in Corbis Sniffer. The model review comment classification procedure is shown in Figure 5.2 below.

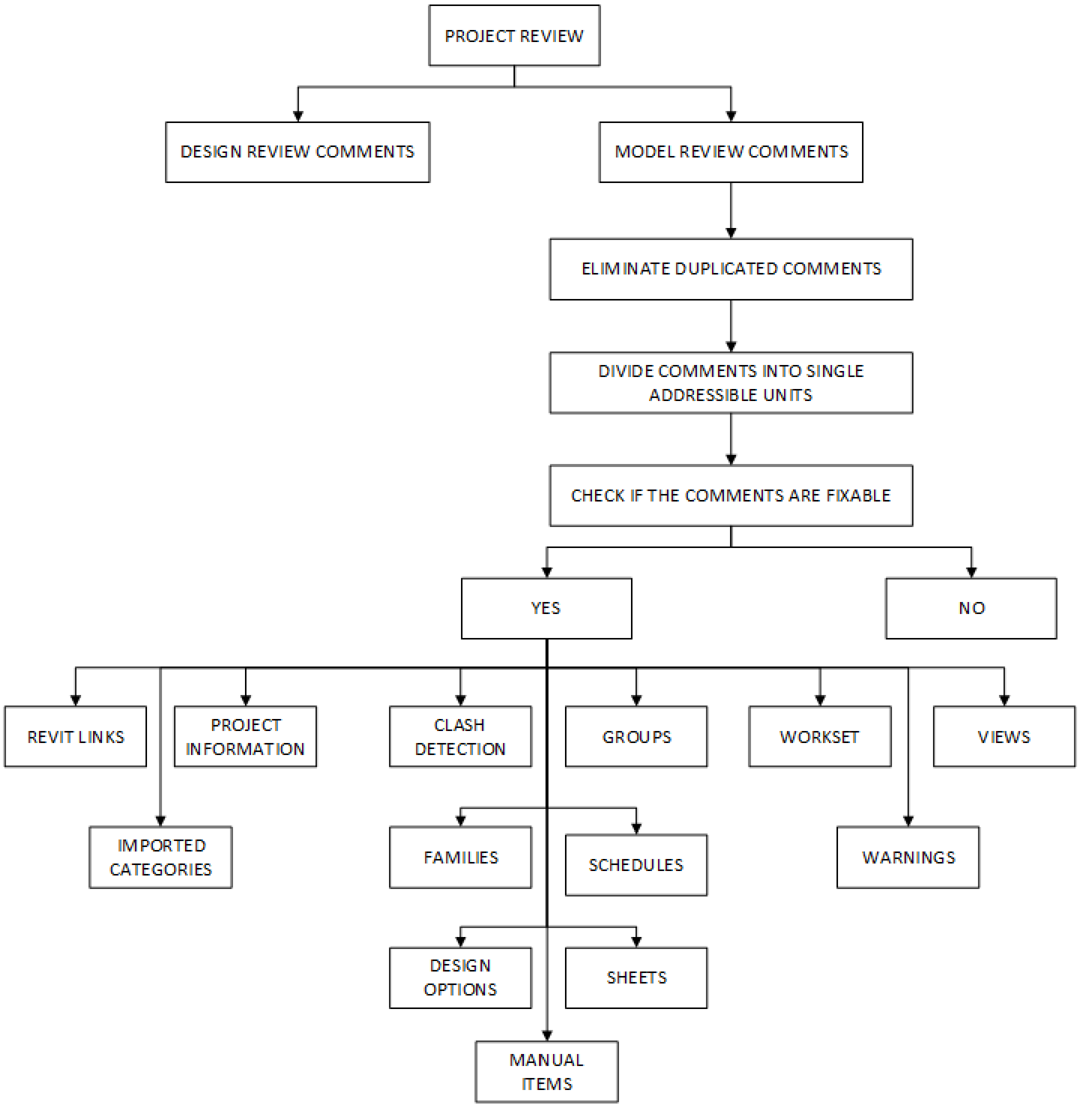

Figure 5.2 Model Review Comment Classification Procedure

Design review comments were collected after every project review during the design stage. There was a total of 143 comments collected after 100% design package submission. All of the comments are organized in a single document to ease the categorization process. The first action was to eliminate the duplicated comments. There are also cases that one comment addresses multiple issues in a single sheet or view. 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 duplicated comments and dividing multiple issues containing comments, there are 220 comments to organize and classify. Table 5.1 shows the comment distribution along with the design submissions.

Table 5.1 Comments Based on the Submission Packages

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

It can be seen that the initial design phases do not include a lot of comments. 63% of the review comments are given for the 65% design drawings, as it is shown in Figure 5.3. As the design approaches to the final stage, the number of comments decreases. 95% design drawings include 35% of the total review comments from this case study.

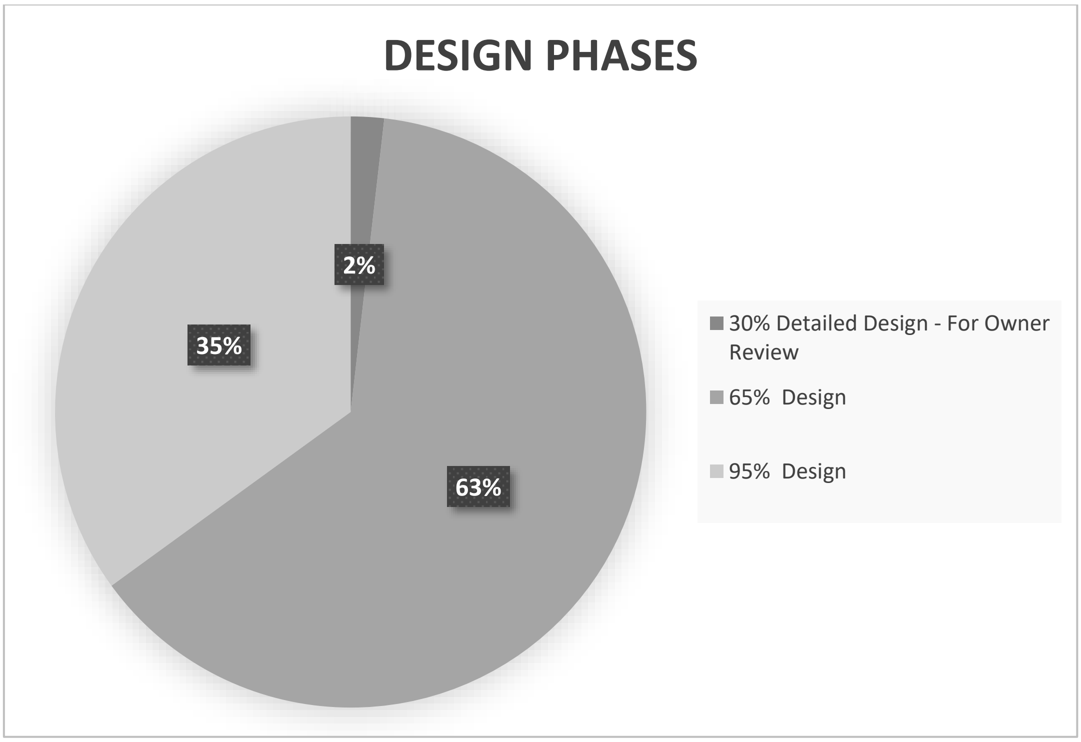

Figure 5.3 Comment Distribution Through Design Phases

Initial categorization was to determine the comment locations on the drawings to see the points that need more attention during the design stage. In order to determine comment distribution along the project drawings, every comment was categorized according to the location on the design drawings. Table 5.2 represents the list of locations on the structural drawings where design review comments were originated from.

Table 5.2 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

It can be seen that most of the comments given for the Drafting Views, Foundation Plans and Live Sections. In general, the majority of the comments come from the plan views and plan notes in the drawings.

The following categorization was to determine if the comments were fixable or not. There are several reasons for a comment to be considered as an unfixable comment in the project and structural profession scope. The first example for the unfixable comment would be the duplicated comments since they require double work. Although each discipline's drawings are reviewed by an experienced discipline engineer, there are items that are miss-assigned to the structural profession. These types of misassigned comments were considered as unfixable comments. Another example for the unfixable comments is that the reviewer asks for verification or a missing item, although it has already been provided in the drawings, but the reviewer could not see the information. Table 5.3 shows the number of comments which were considered fixable or unfixable during the analysis.

Table 5.3 Comment Fixable Distribution

Fixable	*# of Comments*
Yes	208
No	12

After classifying and eliminating unfixable comments, reasons for a comment origination need to be investigated. The first reason for a comment can be missing information. There are obviously multiple cases of comments due to missing information. This missing information might be an annotation, a piece of design information, a label, or a code reference. Table 5.4 shows the distribution of the comments according to whether a comment was originated from a missing item or not. It can be seen that 46% of the comments were categorized under the category of the missing item.

Table 5.4 Comment due to Missing

Missing	*# of Comments*
Yes	101
No	107
N/A	12

The other reason for a comment origination can be an error in the drawings. There might be several types of an error during the design stage. Modeling error, design error, or an annotation error can be given as an example. Table 5.5 shows the distribution of comments according to whether it is an error or not. This distribution says that 28% of the comments are due to an error in the structural design drawings.

Table 5.5 Comment due to Errors

Error	*# of Comments*
Yes	61
No	147
N/A	12

If a fair comment is not due to an error or missing information, then there might be other reasons for the comment. All the remaining comments were categorized, and other reasons for the reviewer to give a comment on the issues were identified. Firstly, the commenter might give a suggestion about a specific point in the design or in the drawings. It might be given to have a better understanding of the design drawings. Secondly, the reviewer may ask for a design verification according to the information given in the drawings. A structural framing or a structural element may seem to be under-designed or overdesigned to the reviewer. Also, the reviewer may want the design to be double-checked in certain cases. The other reason might be a coordination item to be resolved with the other design disciplines in the next issuance of the design drawings. All the comment distribution from gathering the comments in different design stages to the first classification can be seen in Figure 5.4 below.

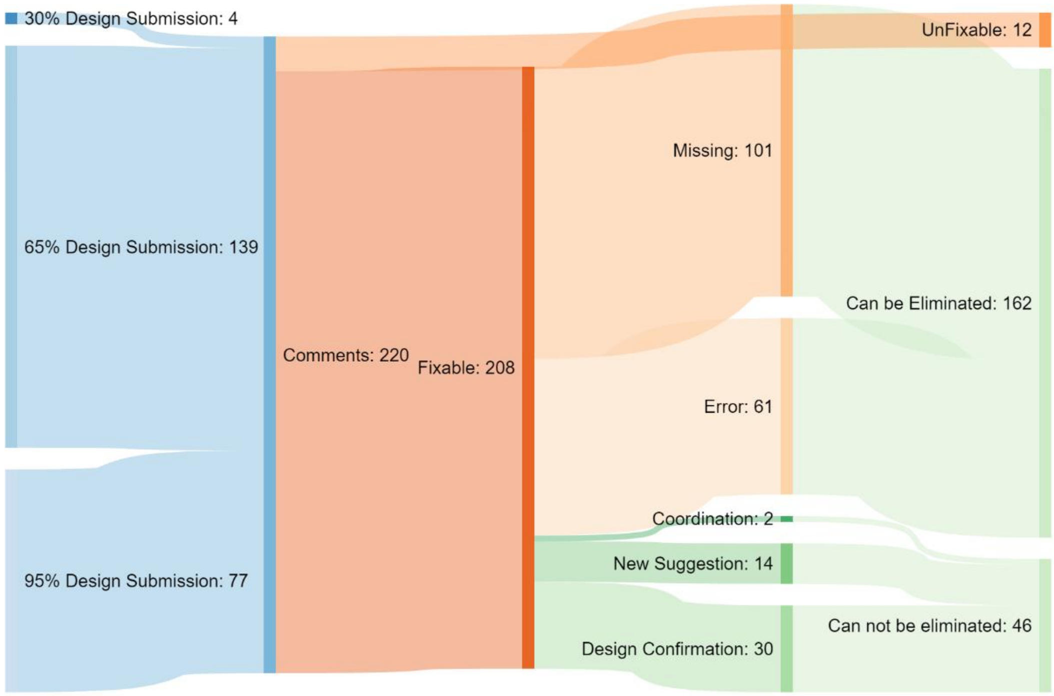

Figure 5.4 Comment Distribution

5.3 Assessment of Elimination

It is obvious that examining the comments on whether there is missing information or an error in the drawings is not enough for a quality check. It must also be checked that if such comments could be eliminated even before the review process. In order to see if the comments could be eliminated in an earlier stage or not, each comment was re-evaluated. Table 5.6 shows that comments that were grouped under missing information were divided into subcategories, and each subcategory investigated if they could be eliminated or not.

Table 5.6 Missing Sub-Categorization

Missing	*Numbers*
Design Related	8
Annotation Related	81
Modelling Related	3
View Related	9

After examining Missing Information in detail, comments classified as Error were also sub-categorized, as shown in Table 5.7. Comments tagged as Error were grouped as design-related, annotation-related, modeling related or naming-related. In general, if there is an error in the design or in the model, most probably, it can be eliminated before the review process. This case is also exemplified in the table below.

Table 5.7 Error Sub-Categorization

Error	*Numbers*
Design Related	40
Annotation	16
Modeling	3
Naming	2

An example elimination assessment for the review comments can be seen in Table 5.8 below. There are example comments from the review process of the project. These examples are carefully selected to represent the comment categories and corresponding comments for each category. It is also shown if the comments can be eliminated before the review process or not. There are also figures for each comment category listed in the table to show the points where review comments were originated. Moreover, updated or changed conditions for the comment locations are shown in a separate figure in order to have a better understanding of how the review comments affect the design process.

Table 5.8 Comment Elimination Assessment

Category	*Example Comment*	*Can it be eliminated?*
Missing Information	(#193) “Footing tag missing at Q line continuous footing.”	Yes, check that all structural elements have tags
Errors	(#60) "Structural Steel - use latest ASTM designation for bolts.”	Yes, check that up-to-date standards are required
New Suggestion	(#134) “Consider supporting precast panel directly on footing in lieu of the additional cost to form and place short grade wall.”	No, it is a new suggestion
Design Verification	(#122) “Check effectiveness of bracing between column lines J and K.”	No, it is a design confirmation
Further Coordination	(#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.”	No, it is a new suggestion

Figure 5.5 represents a partial view from the foundation plan of the project from 65% Design Drawings submission. As can be seen from the figure, singular footings have footing tags and elevations right next to them. However, continuous footing along the perimeter of the building does not have any footing tag to represent the size of the footing, and also it does not have an elevation tag to represent the top of footing elevation as the adjacent singular footings have. After getting the review comment for the missing information item, structural drawings are updated before the 95% Design Drawings submission, and Figure 5.6 represents the updated view from the foundation plan; the continuous footing has footing and elevation tag.

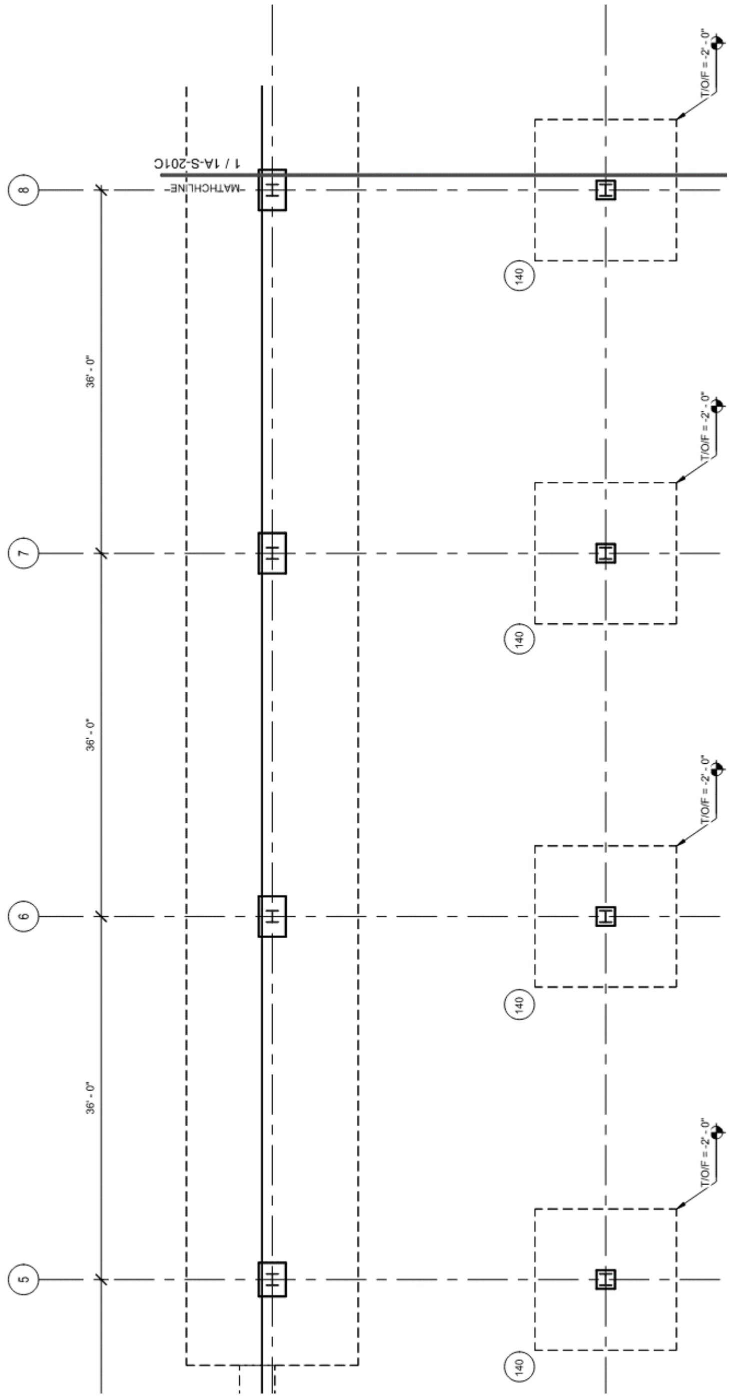

Figure 5.5 Footing Tag Missing for Continuous Footing – 65% Design Drawings

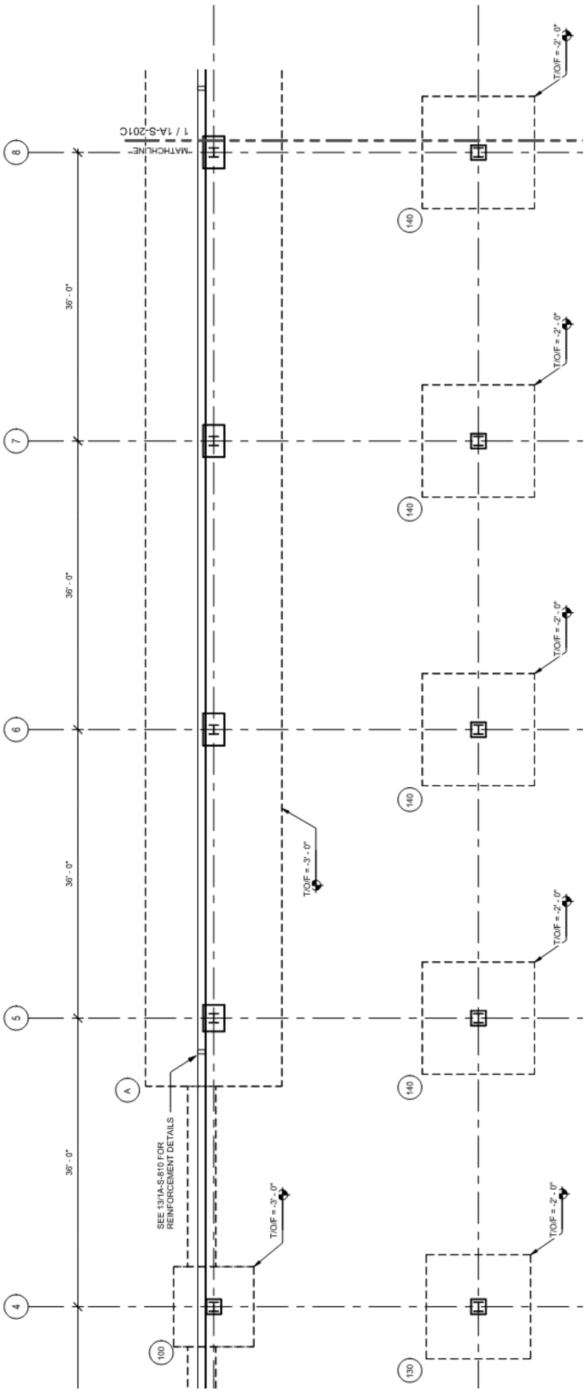

Figure 5.6 Footing Tag Missing for Continuous Footing – 95% Design Drawings

Figure 5.7 shows the location of the error example in the structural drawings before the 65% Design Drawings submission. The review comment is listed in Table 5.8 above. The bolt designation for the high-strength bolts is updated according to the latest ASTM specifications. It is an error to reference the old ASTM designation, and structural drawings have a review comment for this issue. Figure 5.8 below represents the latest ASTM bolt designation as updated in the 95% Design Drawings submission.

STRUCTURAL STEEL

1. PROVIDE STRUCTURAL STEEL FRAMING SECTIONS FOLLOW:
   a. WIDE FLANGE SHAPES: ASTM A992, GRADE 50
   b. CHANNELS: ASTM A36
   c. ANGLES: ASTM A36
   d. RECTANGULAR AND SQUARE HSS: ASTM A500, GRADE B
   e. MISCELLANEOUS STEEL PLATE: ASTM A36 OR ASTM A572 GR 50
   f. ANCHOR RODS: ASTM F1554, GRADE 36, UNO

2. BOLTS SHALL BE MINIMUM 3/4" DIAMETER AND SHALL CONFORM TO THE FOLLOWING DESIGNATIONS, UNLESS NOTED OTHERWISE:
   HIGH STRENGTH BOLTS ASTM A325 OR A490

Figure 5.7 ASTM Bolt Designation – 65% Design Drawings

STRUCTURAL STEEL

1. PROVIDE STRUCTURAL STEEL FRAMING SECTIONS FOLLOW:
   a. WIDE FLANGE SHAPES: ASTM A992, GRADE 50
   b. CHANNELS: ASTM A36
   c. ANGLES: ASTM A36
   d. RECTANGULAR AND SQUARE HSS: ASTM A500, GRADE B
   e. MISCELLANEOUS STEEL PLATE: ASTM A36 OR ASTM A572 GR 50
   f. ANCHOR RODS: ASTM F1554, GRADE 36, UNO

2. BOLTS SHALL BE MINIMUM 3/4" DIAMETER AND SHALL CONFORM TO THE FOLLOWING DESIGNATIONS, UNLESS NOTED OTHERWISE:
   HIGH STRENGTH BOLTS ASTM F1852 (A325 GROUP A) OR F2280 (A490 GROUP B)

Figure 5.8 ASTM Bolt Designation – 95% Design Drawings

As stated in Table 5.8, another comment category is New Suggestion. As can be seen in Figure 5.9 below, the precast wall is supported by a short grade wall. The reviewer states that eliminating the grade wall would decrease the cost of the construction. There is an elevation difference between the top of wall footing and the bottom of precast panel elevations. In order to bear the precast panel on the footing, footing elevation is increased by adding a short grade wall. However, as the reviewer suggested decreasing the bottom of precast wall elevation might be another option instead of adding a short grade wall.

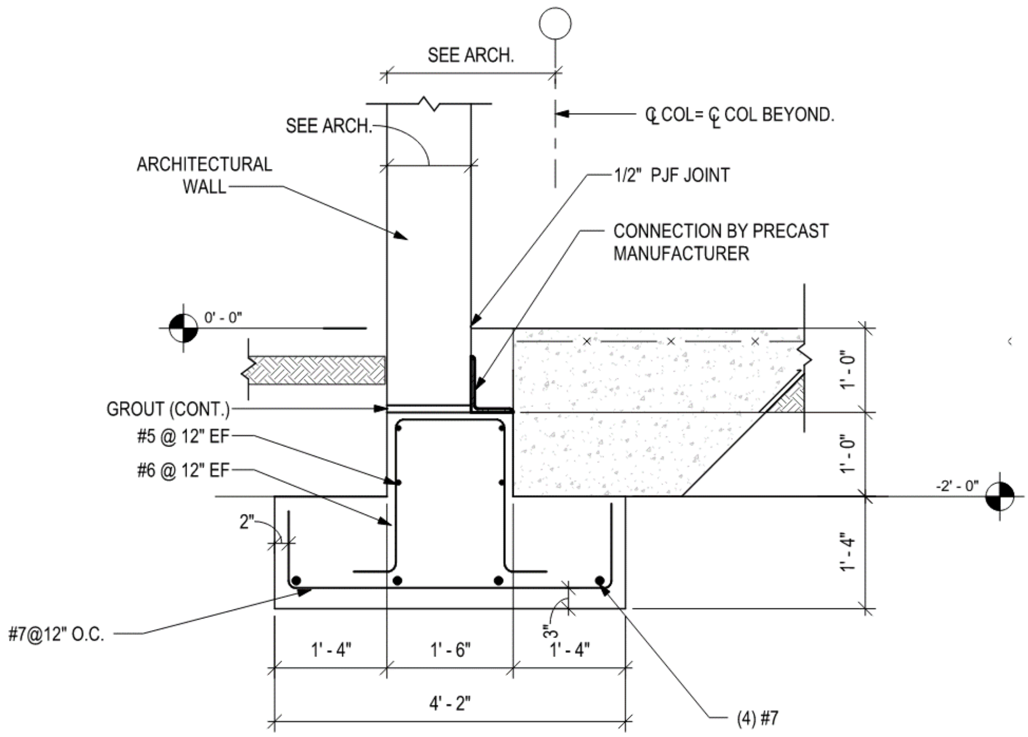

Figure 5.9 Precast Wall Support Detail – 65% Design Drawings

As stated in Figure 5.10, a new suggestion from the reviewer was taken into consideration, and typical detail at the precast wall to footing connection is updated. This update might decrease the construction cost for the connection of precast panels to the footings.

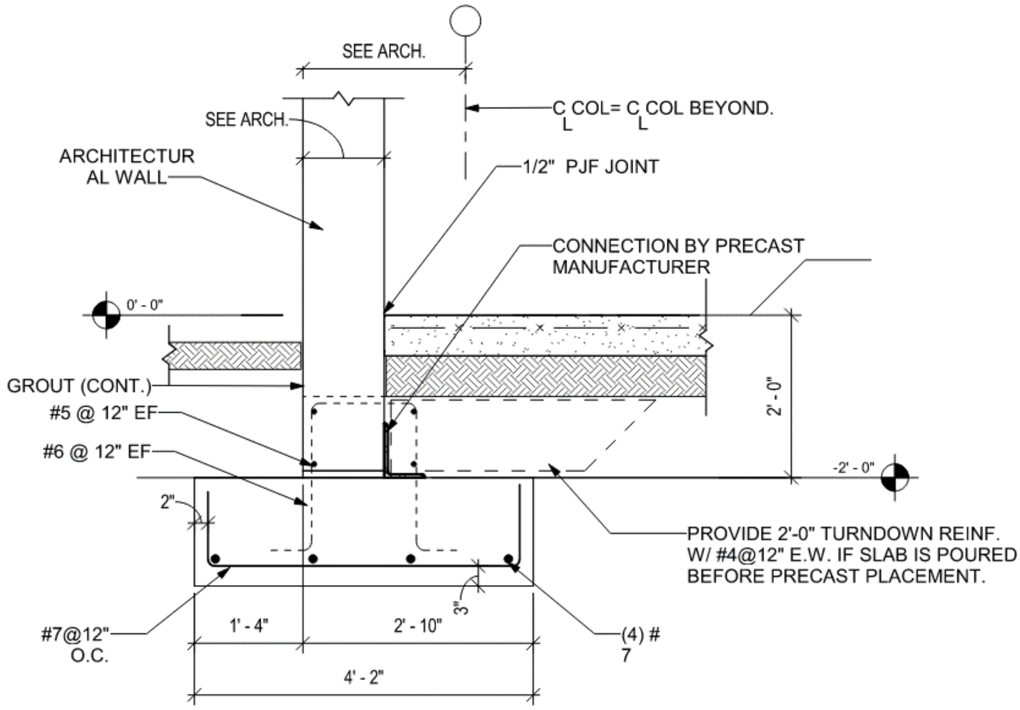

Figure 5.10 Precast Wall Support Detail – 95% Design Drawings

Another comment category listed in Table 5.8 is Design Verification. The reviewer asks the design engineer to check or verify the design represented in the structural design drawings. An example comment for this case is given in the table above. The reviewer asks the designer to check the effectiveness of the brace frames between column lines J and K. A section view of the brace frames from 65% Design Drawings is given in Figure 5.11 below.

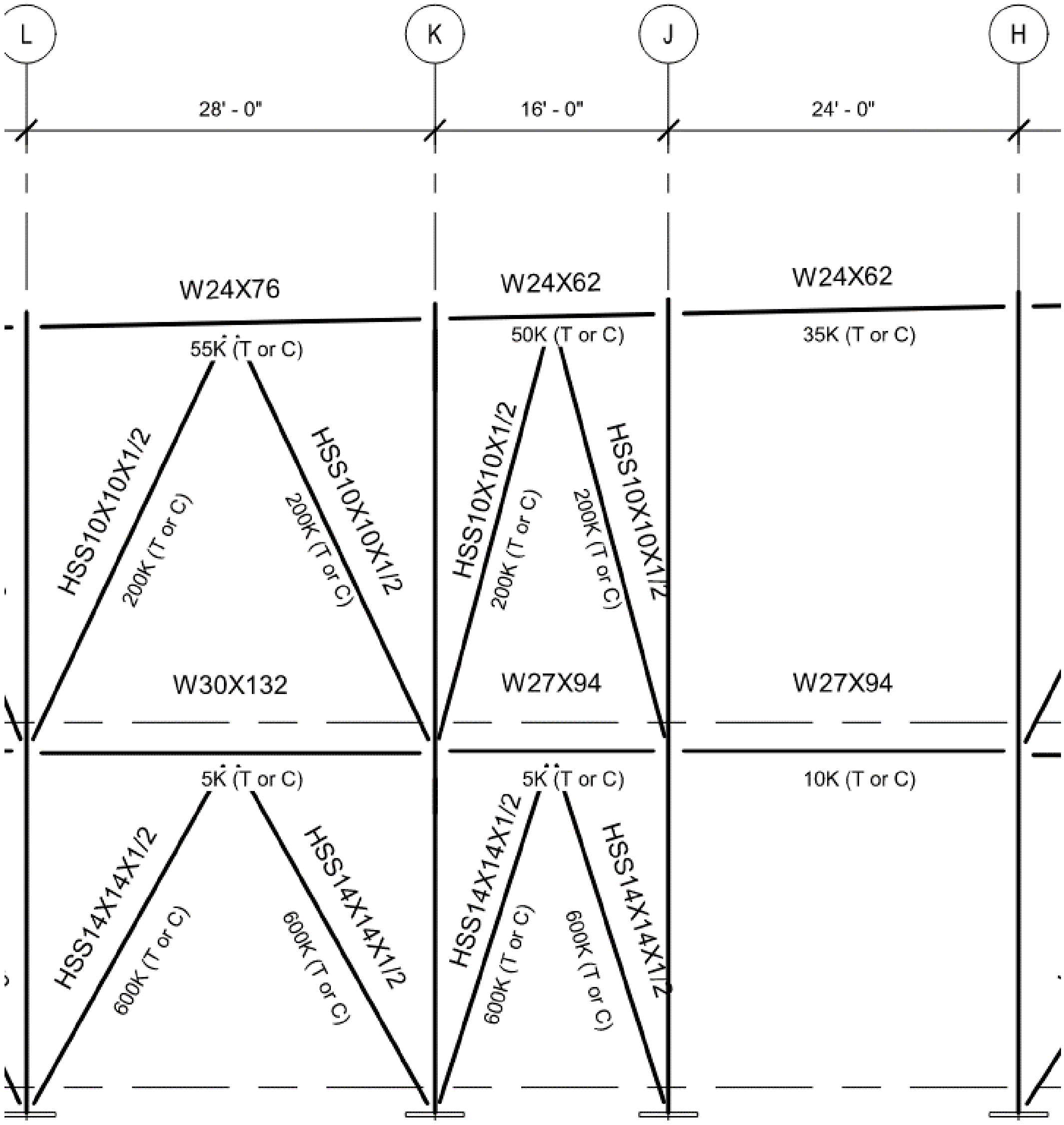

Figure 5.11 Brace Effectiveness Check – 65% Design Drawings

Isometric view of the brace frame for the same location is also shown in Figure 5.12. Figure is taken from 65% Design submission model. As compared to the adjacent brace frame, one may think that it might not be effective for such a short span.

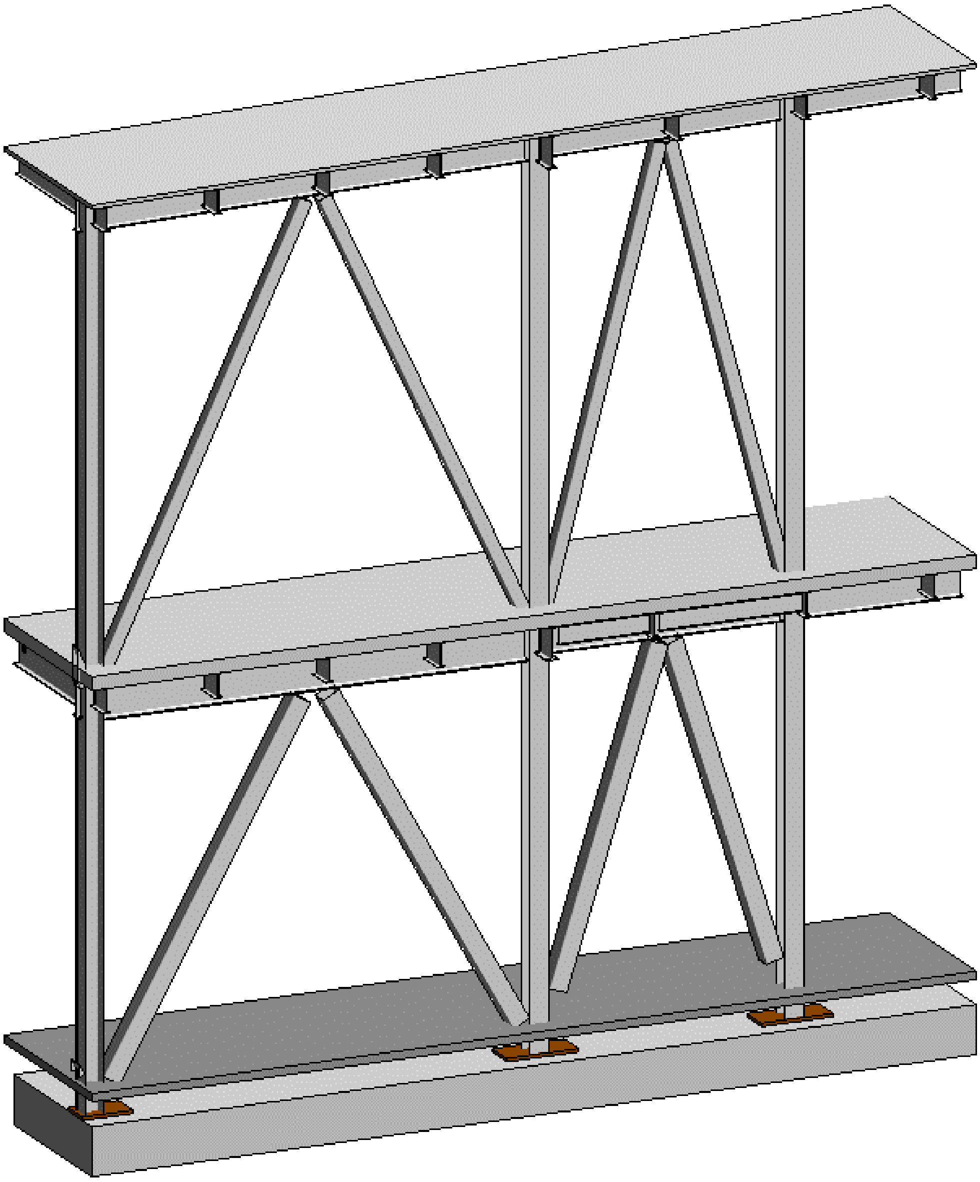

Figure 5.12 Isometric View of Brace Line

After checking the effectiveness of the brace frames between column lines J and K, it is realized that adding brace frames does not provide any significant effect on the overall stiffness of the building. The main reason for that is the short span of the bay.

Braces have to be connected with an angle of 75° due to 16ft span, and this will significantly decrease the effectiveness of the brace frame. After analysis of the effectiveness of the braces, members between column lines J and K were removed as shown in Figure 5.13 below.

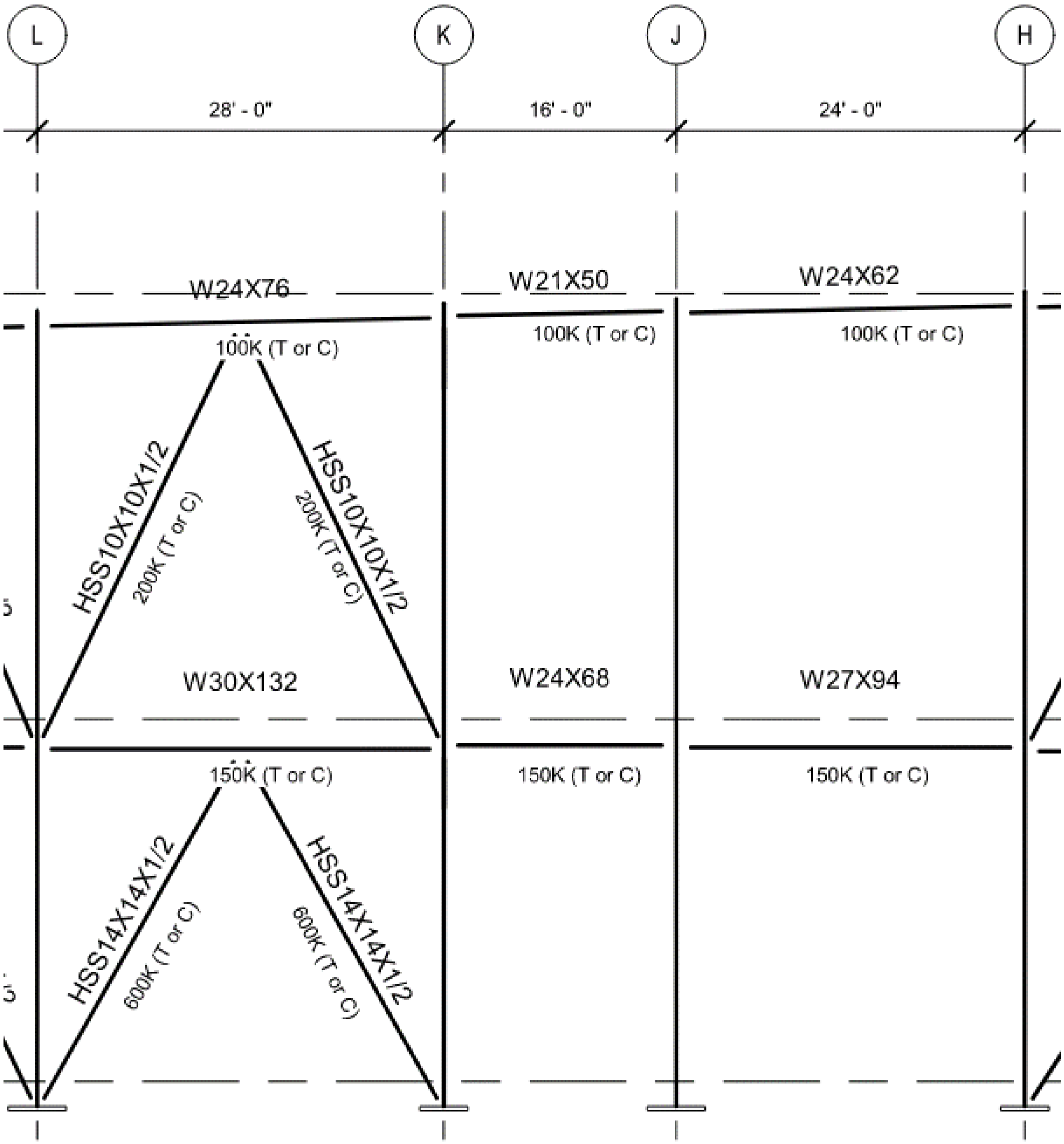

Figure 5.13 Brace Effectiveness Check – 95% Design Drawings

Some of the reviewer comments can be eliminated with initial checks before the submission. When the comments from the case study were examined, it was seen that there were mainly three basic checks for the design drawings. Those comments can be grouped under Design Checks, Constructability Checks, and Value Engineering Checks.

Figure 5.14 is a snapshot of the second-floor structural framing plan. There was a review comment about this portion of the framing plan. The reason for the comment is a heavier steel beam is connected to a less heavy beam. It is also shown in the isometric view of the framing portion in Figure 5.15. It is an error since it is not sensible to connect a heavier beam to a less heavy beam. This is a fixable comment. This issue was corrected in the next design drawing submission, which is 95% Design Drawing, as shown in Figure 5.16. It can also be seen that isometric view is also updated to represent the latest member sizes chosen in Figure 5.17.

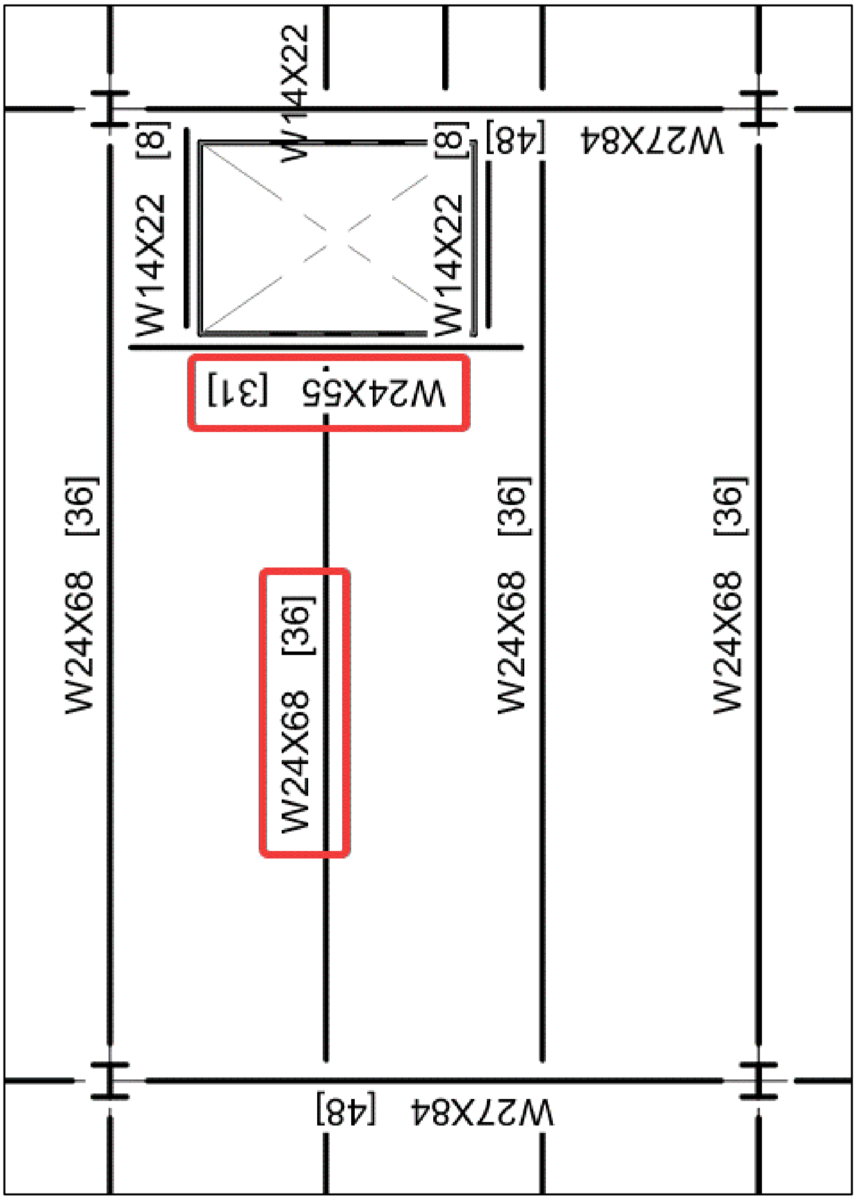

Figure 5.14 Error in Framing Configuration in 65% Design Drawings

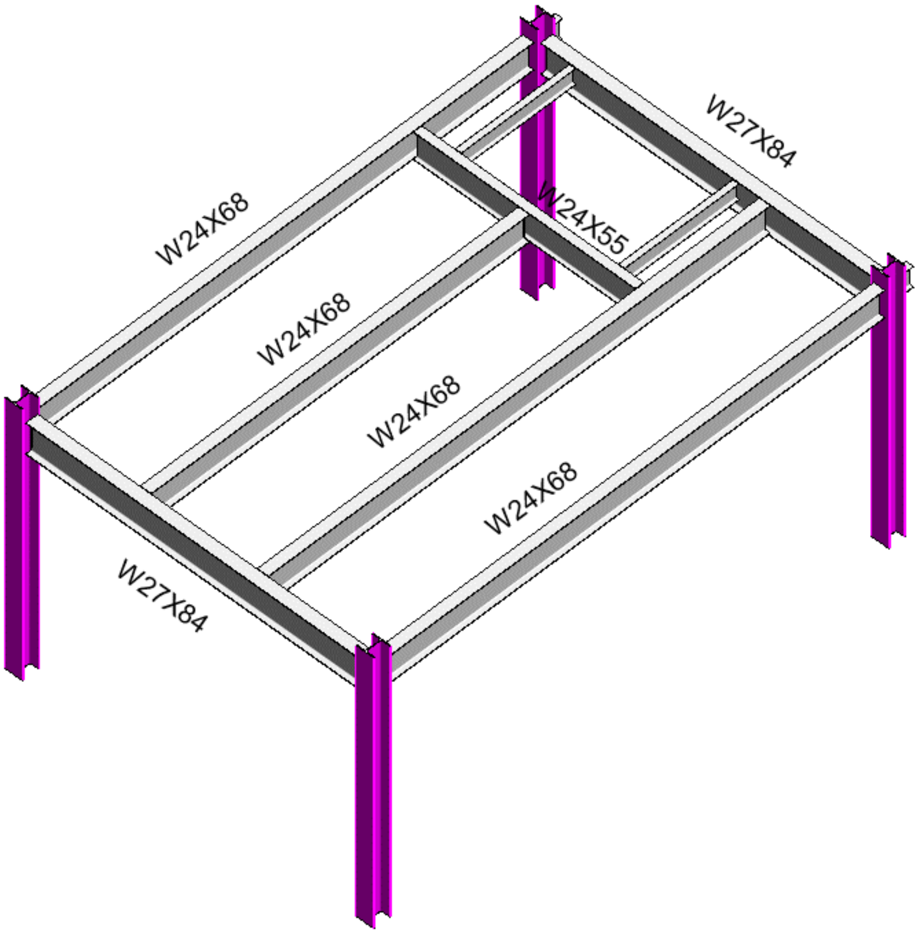

Figure 5.15 Framing Configuration Isometric View – 65% Design Drawings

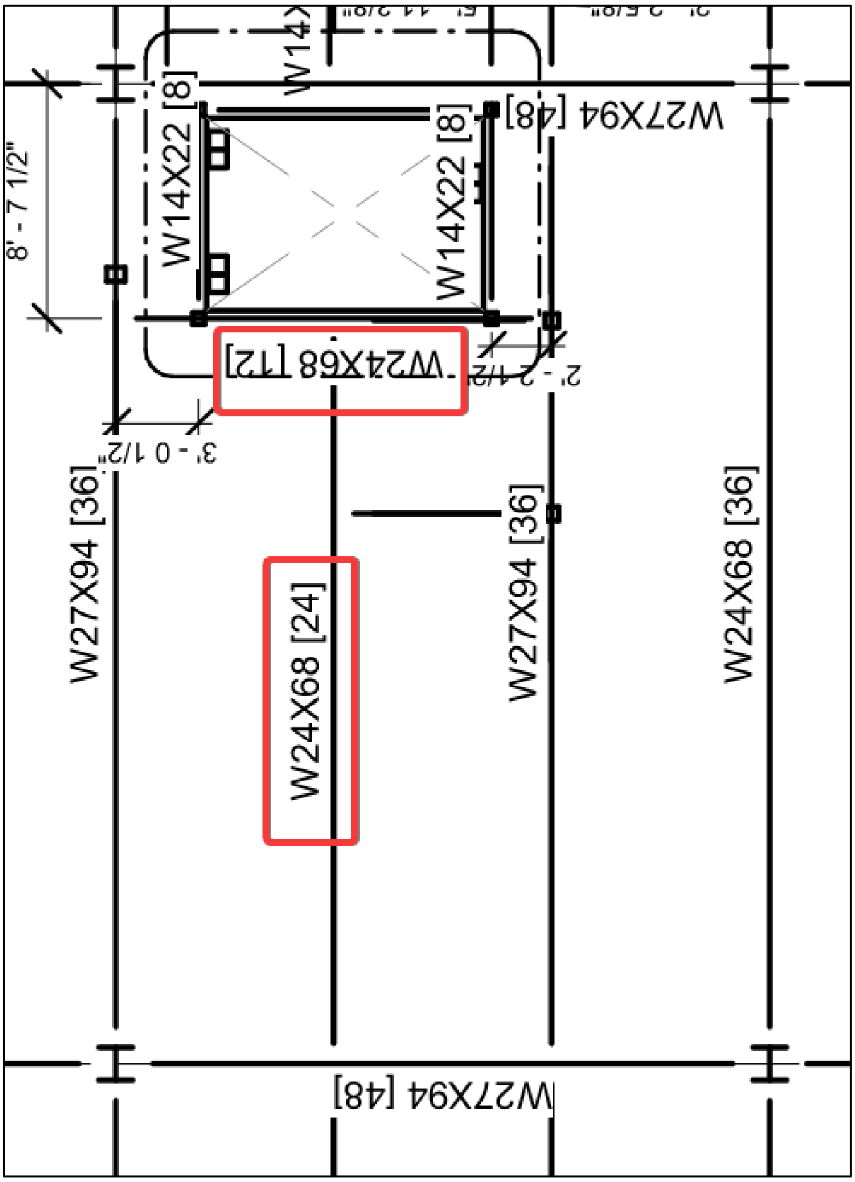

Figure 5.16 Framing Configuration in 95% Design Drawings

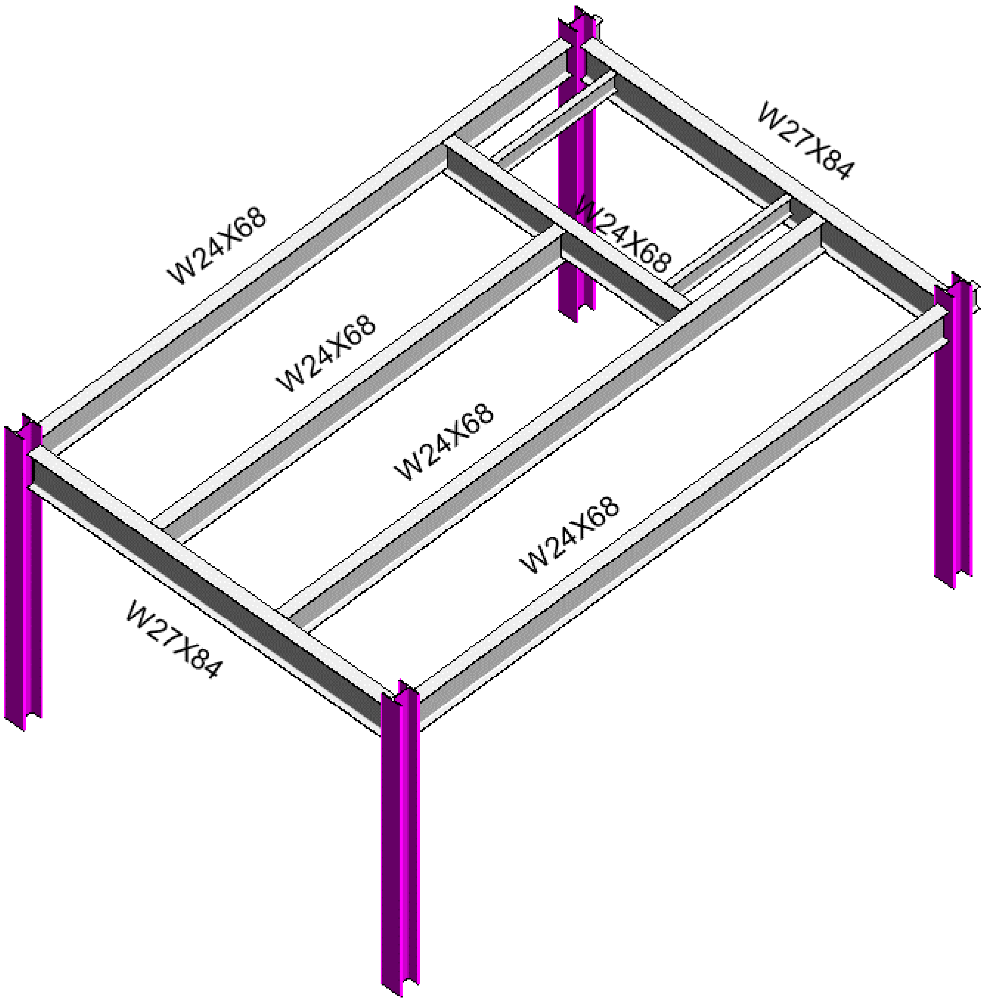

Figure 5.17 Framing Configuration Isometric View – 95% Design Drawings

WIND LOADS*

ANALYSIS PROCEDURE: ANALYTICAL METHOD - ASCE 7-16 DIRECTIONAL METHOD

ULTIMATE WIND SPEED (3-SECOND GUST)		120 mph (FIG. 1609A - IBC 2018)
NOMINAL WIND SPEED		93 MPH (T.1609.3.1 - IBC 2018)
RISK CATEGORY	II	(TABLE 1604.5 - IBC 2018)
WIND EXPOSURE	C	(SECT. 1609.4.3 - IBC 2018)

$V_{asd} = V_{ult} \times \sqrt{0.6}$

<u>COEFFICIENTS AND PRESSURES:</u>

WIND IMPORTANCE FACTOR, Iw	1.00
INTERNAL PRESSURE COEFFICENT	+0.18/-0.18
GUST FACTOR, G	0.85
TOPOGRAPHIC FACTOR, Kzt	1.00
WIND DIRECTIONALITY FACTOR, Kd	0.85
ENCLOSURE CLASSIFICATION	ENCLOSED
VELOCITY PRESSURE @ HEIGHT z=h, Qh	31.99 psf
VELOCITY PRESSURE @ HEIGHT z, Qz	31.99 psf
V. PRESSURE EXPOSURE COEF. @ HEIGHT z=h, Kh	1.09
V. PRESSURE EXPOSURE COEF. @ HEIGHT z, Kz	1.09
WALL (MWRS - WINDWARD)	34.15 psf
WALL (MWRS - LEEWARD)	-23.60 psf
WALL (MWRS - SIDE)	-30.80 psf
ROOF (MWRS - ZONE1*)	-37.51/8.0 psf
ROOF (MWRS - ZONE2*)	-37.51/8.0 psf
ROOF (MWRS - ZONE3*)	-24.02/8.0 psf
ROOF (MWRS - ZONE4*)	-17.27/8 psf

Figure 5.18 Missing Ke Factor for ASCE 7-16 Wind Loading

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 that needs to be stated in the drawings, was missing, as represented in Figure 5.18. Although the governing code ASCE 7-16 and wind loading references are correct, loading parameter Ke was missing in the wind loading sheet. This comment is labeled as missing information.

WIND LOADS*

ANALYSIS PROCEDURE:	ANALYTICAL METHOD - ASCE 7-16 DIRECTIONAL METHOD	
ULTIMATE WIND SPEED (3-SECOND GUST)		120 mph (FIG. 1609A - IBC 2018)
NOMINAL WIND SPEED		93 MPH (T.1609.3.1 - IBC 2018)
RISK CATEGORY	II	(TABLE 1604.5 - IBC 2018)
WIND EXPOSURE	C	(SECT. 1609.4.3 - IBC 2018)
Vasd = Vult x $\sqrt{0.6}$		

COEFFICIENTS AND PRESSURES:

WIND IMPORTANCE FACTOR, Iw	1.00
INTERNAL PRESSURE COEFFICENT	+0.18/-0.18
GUST FACTOR, G	0.85
TOPOGRAPHIC FACTOR, Kzt	1.00
WIND DIRECTIONALITY FACTOR, Kd	0.85
ENCLOSURE CLASSIFICATION	ENCLOSED
VELOCITY PRESSURE @ HEIGHT z=h, Qh	34.42 psf
VELOCITY PRESSURE @ HEIGHT z, Qz	34.42 psf
V. PRESSURE EXPOSURE COEF. @ HEIGHT z=h, Kh	1.09
V. PRESSURE EXPOSURE COEF. @ HEIGHT z, Kz	1.09
GROUND ELEVATION FACTOR, Ke	1.00
WALL (MWRS - WINDWARD)	29.60 psf
WALL (MWRS - LEEWARD)	-20.82 psf
WALL (MWRS - SIDE)	-26.67 psf
ROOF (MWRS - ZONE1*)	-32.52/8.0 psf
ROOF (MWRS - ZONE2*)	-32.52/8.0 psf
ROOF (MWRS - ZONE3*)	-20.82/8.0 psf
ROOF (MWRS - ZONE4*)	-14.97/8 psf

Figure 5.19 Ke Factor Added in 95% Design Drawings

Missing information is updated in the next design drawings issuance as can be seen in Figure 5.19.

Figure 5.20 represents the distribution of review comments through the analysis procedure. First, comments were divided according to their origination design phase without any evaluation of the comment content. The majority of the comments were given in the 65% Design Drawing phase. The reason for this might be that main design decisions may be finalized in this stage, and there is a lot of design information updated or added in the drawings to be reviewed. Then all of the comments are categorized according to their point of origination. The main locations for the comments are Plan Notes and Plans, as can be seen from the distribution diagram. Since the subject to be reviewed is a structural design drawing set, it might be expected to have more comments on the structural plans and details.

Next, review comments were filtered through a cleaning process according to their content. Duplicated and unrelated comments were tagged as unfixable comments. Fixable comments were categorized according to their type, as stated in the Chapter 3. It can be seen that the main comment type for this project is Missing Information. New suggestions and design confirmation requests are minor items when they are compared with the missing information and error categories.

After doing an elimination assessment, it was obvious that missing and error type comments could be eliminated if they were checked prior to the design submission.

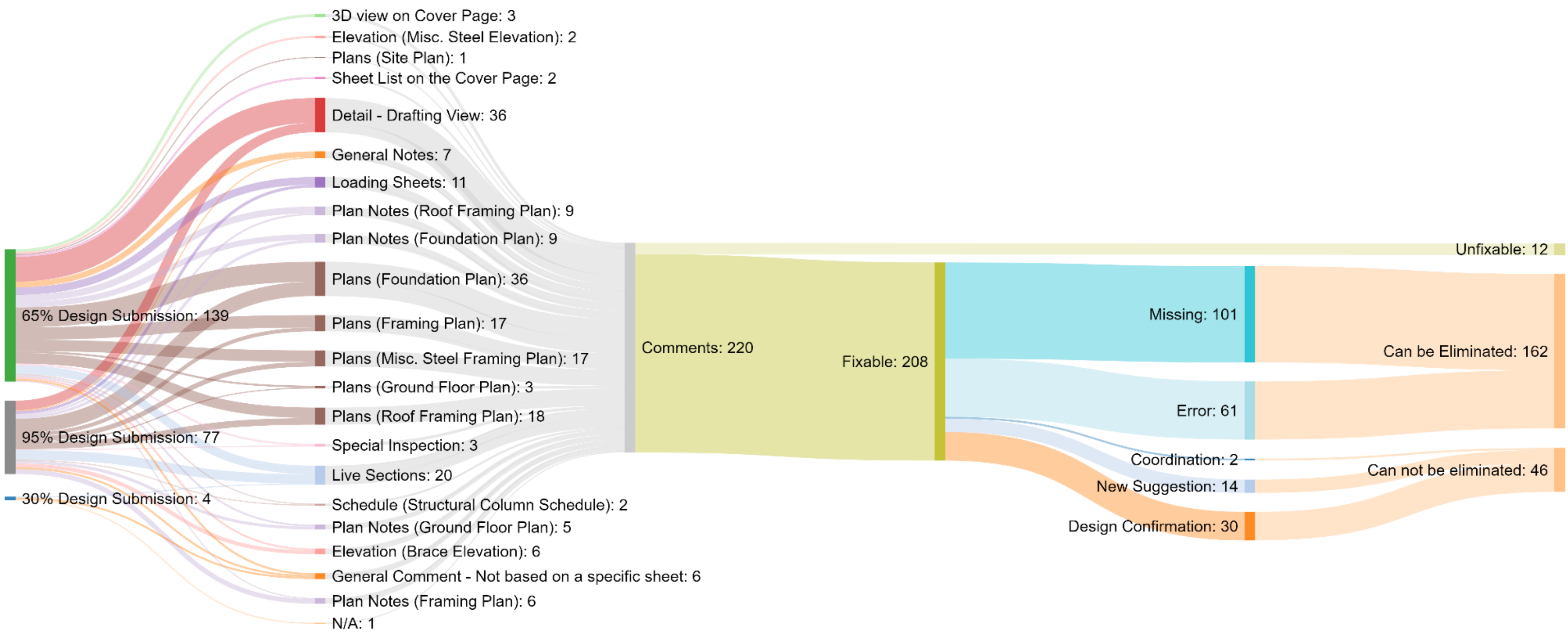

Figure 5.20 Review Comment Distribution Diagram

5.4 Assessment of Automation

After examining the comments in terms of the possibility of elimination, a new classification is done to see if the check or the editing can be automated in the elimination process. Respectively, there need to be categories to describe the automation in the checking process. Obviously, there are items that cannot be automatically checked or edited. They are labeled as manual check items. For example, a design check requirement by the reviewer needs to be done manually. Also, an annotation checking on the drawings may need a manual check to eliminate a possible future comment or an issue. Figure 5.21 shows the distribution of the comments that can be checked or edited manually or automatically.

In this study, the automated check criterion is assumed as an action that can be automatically checked with the help of the readily available BIM tools. These tools can be extended via Autodesk Dynamo, Revit API, or external Revit Add-Ins. Almost every day, a new tool or a capability of a software is introduced to minimize human intervention and maximize the quality and consistency in the AEC industry.

It can be expected that there is also another classification item which is called semi-automated. Semi-automated means part of the check or editing can be done automatically, but the remaining part of the action needs to be done manually or vice versa.

There is also another level of classification for semi-automated items. Since some part of the action is described as manual, it is also possible to check these items automatically after a design submission package. If the manual involvement of the action is at the beginning, for example, defining the project parameters, then the remaining part of the action becomes fully automated for future checks.

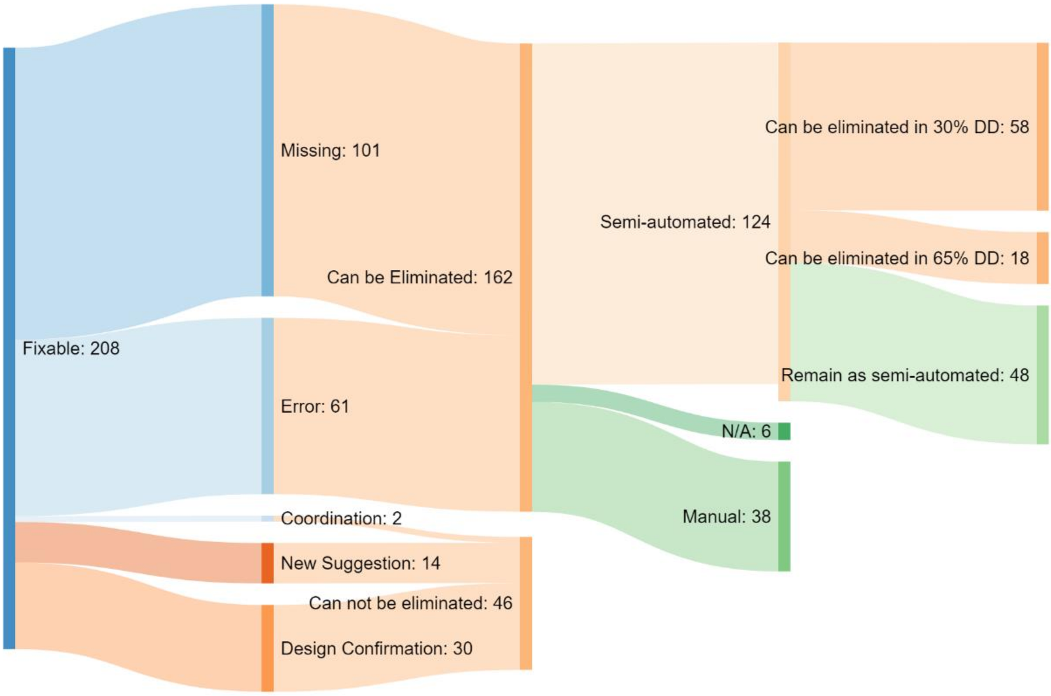

Figure 5.21 Possibility of Automation

An example automation assessment for the comments is given in Table 5.9. Using some comments from the project, automation or future automation cases are examined. As expected, new suggestions and design verifications cannot be eliminated and cannot be automatically checked before the submission.

Table 5.9 Automation Assessment Example

Category	*Example Comment*	*Can it be Automated?*	*When can it be automated?*
Missing Information	(#193) "Footing tag missing at Q line continuous footing."	Semi-automated, check footings have tags	N/A
Errors	(#60) "Structural Steel - use latest ASTM designation for bolts."	Semi-automated, check code references	30% DD
New Suggestion	(#134) "Consider supporting precast panel directly on footing."	N/A	N/A
Design Verification	(#122) "Check effectiveness of bracing between column lines J and K."	N/A	N/A
Further Coordination	(#6) "Alternate sheet names for Steel Plans S-202E, S-202F and S-220E that are not in series with main 1/8th scale part plans A-D is recommended."	Automated, extract sheet names and numbers and compare via Dynamo	30%DD

5.5 Structural Design Review Checklist

By combining all the comment analyses, our study ended up with a list of items to be checked in order to eliminate the review comments in the structural drawings prepared in a BIM tool. This checklist is prepared from the comments that can be eliminated according to our analysis. If a comment can be eliminated, then it has to be on the checklist. The checklist is created from the case study project, but it is an extendable list that can be improved based on the project types and needs.

Part of the checklist is represented in Figure 5.22. Check items are grouped according to their categories. These categories are;

- Abbreviations
- Codes
- Design
- General Notes
- Reporting
- Schedule
- Sheet & View
- General

Each check item may need to be checked in the different design phases. For this reason, design phases are included in the checklist as 30%, 65%, 95% Design Drawings, and Construction Drawings. Check items are also checked if they are complete and correct according to the scope of the check.

CHECKLIST ITEMS									
#	CATEGORY	ITEM	N/A	30%	65%	95%	CD	COMPLETE	CORRECT
1	Abbreviations	Abbreviation List is provided							
2	Abbreviations	Check that correct form of abbreviations are used in the drawings. Add to abbreviation list if there are new ones.							
3	Codes	Up-to-date standards & codes are used							
4	Codes	Design codes used in the project are consistent with the project requirements							

Figure 5.22 Design Review Checklist Preview

The full list of the Design Review Checklist can be found in Appendix A. This checklist is proposed based on the review comments gathered from the project that is examined in this study. It can be extended and updated according to the specific project needs for potential future users.

5.6 Structural Building Information Model Review Checklist

Our study on the model review comments ended up with a checklist to inspect the Building Information Models in order to determine the quality of the BIMs. There are items that can be automated and items that need to be checked manually on this checklist. All the items were grouped according to their categories. These categories were determined based on the review comments from the reviewers. A full list of items to be checked can be found in Appendix B.

Figure 5.23 represents the structure of the model review checklist prepared from the review comments gathered in the case study project.

MODEL QA/QC CHECK								
CATEGORY	ITEM	N/A	30%	65%	95%	CD	COMPLETE	CORRECT
GENERAL ITEMS	Link Files are pinned							
	Levels and Grids copy-monitored							
	Phase mapping is done for all of the linked models							
	Arch links room-bounded							
	Grids and Levels are Pinned							
	View Browser organisation set							
	Sheet Browser Organisation Set							
	Annotation size and type is consistent and matches with owner requirements							
	Title block is up-to-date and matches with the requirements							
	Model to be purged before submission							
	Line Styles and Thicknesses coordinated							
	BIM360 Publish settings set up correctly							

Figure 5.23 Model Review Checklist Preview

As a summary of the findings, the automation possibility of the checklist items examined and shown here. It is also shown that how much of the semi-automated check items can be automated after a certain design phase.

After classification and analysis of comments according to if the comment could have been eliminated or not before the review process, a generic checklist is created. It is composed of two main parts:

- General Checks: Generic items to be checked in every review process
- Project Specific Checks: Project-specific items listed in this section

CHAPTER 6

VALIDATION OF CHECKLIST

6.1 Introduction

The validation of the checklist is presented in this chapter. There are three different parts of the validation process for the proposed checklist. The first one is to examine the review comments from another project to see if they can be eliminated before the design submission if the proposed checklist is used. The second part of the validation is to review a structural design drawing and give comments to see if the review comments match with the actual review comments provided by professional reviewers. The third and the last part is to have a workshop with the experienced engineers working in the structural design profession and ask for their opinions if there are points that need to be included in the checklist, or the points that need further improvement according to their perspective.

6.2 Project Information

The project is a single-story warehouse project. It is composed of precast panels and a steel roof. The project includes multiple disciplines, as the case study project examined through this study.

Review comments started after 65% Design Drawings for this project. There are 95% Design Drawings and For Construction drawings available as well.

6.3 Application of the Checklist

65% Design Drawings review comments are examined if they could have been eliminated with the help of the checklist. There were a total of 62 review comments for this phase of the structural design drawings. Two of the comments were divided into smaller comments since there are multiple items included in the same comment. Sixty-four review comments are categorized according to their content. Thirty-nine of the review comments can be eliminated before the submission since there are check items in the checklist to eliminate those comments before the submission. Figure 6.1 represents the comment distribution according to the categories determined through the case study project.

As expected, some of the categories cannot be eliminated before the submission as a matter of course. Coordination, Design Verification, and New Suggestion are the categories that cannot be eliminated even before the submission. These categories are subject to occur almost in every project, but the elimination of those comments is not an easy task.

There is also a new category is added for the comment classification. For example, there are direct questions to the Structural Engineer working on the project. These questions could not be categorized under previously determined groups. For this reason, a new category is added for the new items that cannot be addressed through the checklist. A total of 4 review comments are grouped under the Questions category.

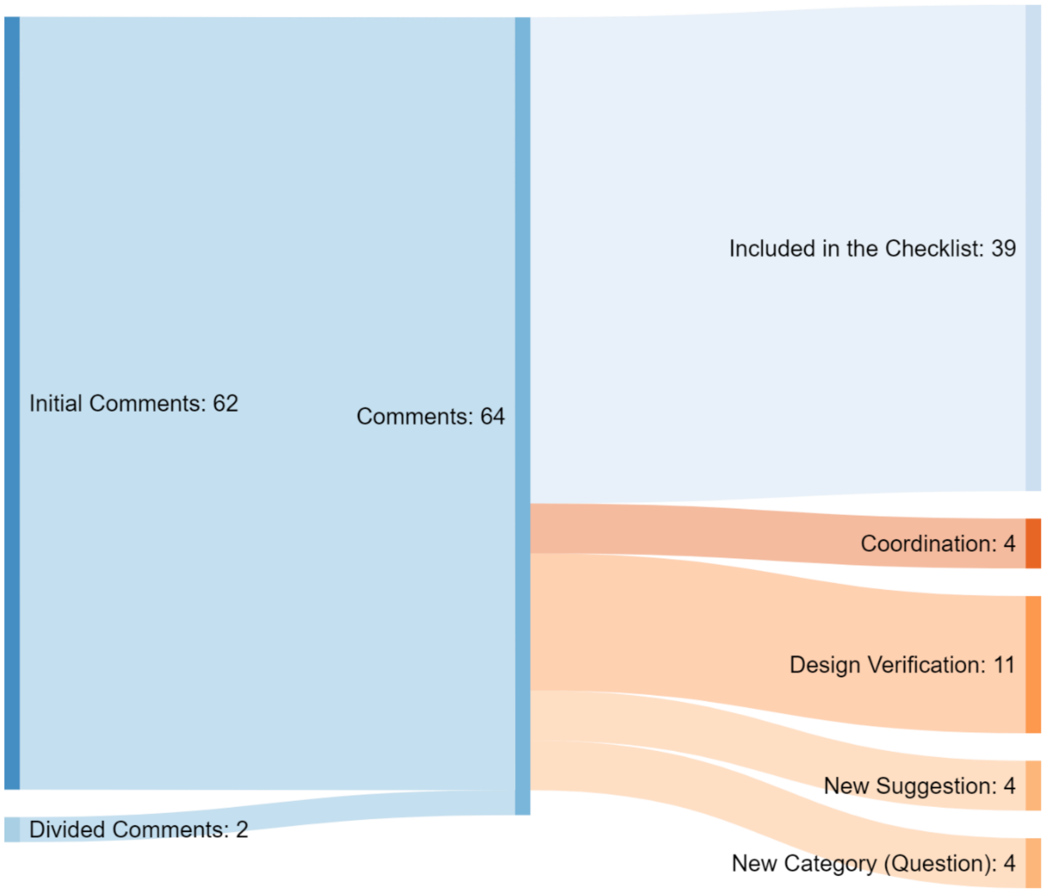

Figure 6.1 Review Comment Distribution

6.4 Workshop

A workshop is done with experienced structural engineers about the applicability of the checklist to the design projects in the company. Engineers reviewed the checklists and provided comments about the points that need developments and items that may need to be added to the checklist. Their comments and suggestions are taken into consideration for the development of the checklist. Those comments are mainly for different design topics. The reason for that is the initiation of the checklist is from a warehouse project which is a 2-story composite building.

However, since the checklist is aimed to be applied to other structural design projects, other design topics should also be included in the checking process. According to the workshop conducted in the design company, one-story distribution centers, high-rise buildings, residential buildings are also considered in the design checking process, and there are check items in terms of the design of these types of buildings. The check items are extended to contain more design methodologies, i.e., post-tensioned design, moment-frame design.

6.5 Updated Review Categories and Checklist

Review categories are updated according to the first application of the checklist to the 65% Design Review Comments. As stated earlier, a new category is added to the comment categories to group the questions asked to the designer. Table 6.1 shows the example comment from the review comments labeled as a question. Like the other categories, New Suggestion, Design Verification, and Coordination, this category cannot be eliminated before the review process. A designer cannot eliminate a question from the reviewer.

Table 6.1 New Category from Design Review

Category	*Example Comment*	*Can it be eliminated?*
Question	(#160) “Generator Pad Elevations here are set at 3" above grade, rather than 6" as in reference model. Does this change require any coordination with other disciplines?”	No, it is a question

There were also comments from the design engineers for the checklist for the designs. The checklist is added to the Appendix C with its final version after making necessary updates based on the feedbacks from the design engineers.

CHAPTER 7

CONCLUSION

7.1 Introduction

Although there are numerous studies about code compliance, information quality did not get enough attention in the literature. There are limited studies about the information quality of BIMs. Existing research studies 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 a QA/QC from their mistakes on the projects for 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. A brief summary of this research, limitations, and possible future studies are explained in this chapter.

7.2 Summary of Findings

Design review and model review comments are analyzed and categorized through an iterative process. A categorization pattern for the review comments is proposed. Other disciplines that have review comments can use and classify their own review comments to use in their quality improvement strategy.

Review comments are grouped if there are any errors or missing information. Besides that, there are comments that ask for design verification. There are also comments about new design suggestions for the project. There was a total of 143 review comments collected for the project. After dividing multiple issues containing comments into single comments, the review comment number increased to 220. Out of all the comments, 95% were tagged as fixable according to their content. According to the categorization pattern that is developed by multiple iterations;

- 46% Missing
- 28% Error
- 14% Design Confirmation
- 6% New Suggestion
- 1% Coordination

Kim et al. (2018) specified BIM review-related comment types and grouped them into five categories. In this study, a data-driven categorization is proposed, and a different set of categories are acquired. The most significant different from Kim et al. (2018), is the existence of error and missing information categories. Analysis revealed that almost 50% of the comments are due to missing information. Moreover, about 30% of the review comments are due to an error in the drawings.

Checklists were created at the end of the review comment analysis procedure. The checklists are extendable, and they are targeted to increase organizational learning since this procedure supports learning from previous experiences.

The validation of the QA/QC process was performed using a new project. While the use and applicability of the checklist are validated, the checklist is extended with a new comment category (Query), and the language of the checklist is improved.

This study contributed to the understanding of the quality-related issues in BIMs via review comment categorization and analysis procedure. With the help of the checklists created through the review comment analysis procedure, information quality checking was formulated.

The checklist preparation process and the checklist itself can be taken as a guide for the potential users on how they can apply these procedures to their projects. This will increase the managerial contribution of the study to the design companies.

It is important to state that this study does not imply that BIMs should be created in a way that this study directs in order to have a quality BIM. In fact, this study aims to check the quality of already-created BIMs before the submission in order to assess the quality.

7.3 Limitations of the Study

The checklist is derived from a structural project mainly composed of steel and composite frames. 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 can be added for a more detailed analysis.

Structural BIM review comments are Revit-oriented comments since the overall project is created in Revit and BIM360 platform. Revit is just a BIM tool, but there are other BIM tools as well. In order to make the checklist applicable to the other BIM projects that are not using Revit, an IFC-based checklist is required. This study did not consider the IFC for the checklist creation.

The proposed checklist created throughout this study is for the design teams, not for the owners. Owners may develop their own quality checking procedures for specific purposes. Design teams may use the output and the analysis procedure of this study as a starting point for their own quality checking process.

This study does not state a standard for a quality checking of BIMs. In fact, this study proposes a company-wide quality checking procedure via learning from previously designed and submitted projects.

7.4 Recommendations and Future Studies

The following research directions are recommended to be researched for future studies:

- As a future research recommendation, semi-automated items in this study can be automated. This study is done by reviewing structural design review comments, but it is also possible to do a similar study for other disciplines to compare the results.
- There might be quality-review scores during the checks in every design phase. And also, a quality certificate can be issued for the design team at the end of the project. By doing this, the quality level of the BIMs is evaluated and certified through the organizations.
- Level of Detail, consistency, and well-formedness of the information is not considered in this study. There was not any feedback about the LOD. However, it can be added for the projects and design teams that have a detailed definition of LODs. Consistency is taken as a sub-category of correctness. Well-formedness can also be included as an information quality dimension for future studies if there is an issue with this dimension. They may need to be studied in future research.
- This study focuses on the design team perspective for the quality checking of BIMs. Checking the models in terms of the code compliance perspective and preparing guidance can be future work for this study.

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APPENDICES

A. Design Review Checklist

General Items

#	CATEGORY	ITEM
1	Abbreviations	Generic Abbreviation List is provided
2	Abbreviations	The correct form of abbreviations is used in the drawings. Add to abbreviation list if there are new ones
3	Codes	Up-to-date standards & codes are used
4	Codes	Design codes used in the project are consistent with the project requirements
5	Codes	Stud details are given according to the code in practice for the composite floor
6	Cover Page	The sheet List on the cover sheet lists all the submission sheets
7	Cover Page	Titleblock provides correct family, project name, project address, sign & seal, issuance & revision info
8	Design	Design loads are provided in the drawings. Loading sheets (Gravity and Lateral Loading) are complete and up-to-date
9	Existence Check	Drawings/sheet list to be submitted in each submission package is presented
10	General Notes	General Notes section are referenced by location
11	Graphical	The visibility of lines is on all printed views are as seen on the model
12	Loading Plan	Loading information used in the design is presented in the drawings (Slab, Roof, Equipment)
13	Reporting	Incomplete (Design Pending) design/details in the submission cycle is clearly reported
14	Reporting	Geotechnical design parameters are specified if there is a Geotech report. Point out the assumptions if there is not a Geotech report
15	Sheet/View	View (Plan/Elevation/Section/Detail) names are explanatory
16	Sheet/View	All the views to be submitted are complete and aligned in the sheets
17	Sheet/View	There are no duplicated details/views/sheets

18	Sheet/View	Sheets include all the views/details required (No typical detail missing)
19	Sheet/View	Design information for typical structural framing, slab type is consistent throughout the drawings
20	Sheet/View	The sheets and their nomenclature are aligned with the views included in the sheet
21	Sheet/View	All corresponding plans have the same type of consistent plan notes/legends/schedules
22	Sheet/View	A legend is provided for the symbols used in the drawings
23	Sheet/View	Matchline is labeled in all of the plans
24	Sheet/View	Section references and plan notes are mapped and located correctly
25	Sheet/View	All plans and elevations have grid-to-grid and overall dimensions
26	Sheet/View	Plan notes are consistent with the design intent (Foundation & SOG Plan, Framing Plan, Roof Plan)
27	Sheet/View	Edge of structural slab dimensions are provided & Section references for the details are given
28	Sheet/View	CJ (control joint) locations are given in the slab on grade plan
29	Sheet/View	Top of footing and bottom of encasement elevations are given in the foundation plan
30	Sheet/View	Stepped footing locations and elevations provided in the foundation plans
31	Sheet/View	Every steel beam is connected to the same or a bigger size
32	Sheet/View	All beams on the plans are located and tagged in the framing plans
33	Sheet/View	All elements that need support has structural support/framing (Miscellaneous equipment supports, exterior/interior)
34	Sheet/View	Typical section cuts are provided along the perimeter of the building
35	Sheet/View	All structural elements (Columns/walls) have footings/foundation
36	Sheet/View	Steel typical details have reference callouts/section cuts
37	Sheet/View	Concrete typical details have reference callouts/section cuts
38	Sheet/View	Framing above and below the roof level is given in different sheets and this is stated in plan note or detail

39	Sheet/View	CMU (Concrete masonry unit) typical details have reference callouts/section cuts
40	Sheet/View	Weld designations for steel connections are correct
41	Sheet/View	Typical details for RTU support are provided if there is any RTU on the roof or on the ground
42	Sheet/View	Foundation typical details have reference callouts/section cuts
43	Sheet/View	Slab and deck details are consistent throughout the drawings
44	Sheet/View	Structural footing schedule is correct/consistent with the design
45	Sheet/View	Wall details are coordinated with the design before submission, Walls CMU or Cast-in, Tilt-up or precast
46	Sheet/View	Beam or column splice details are provided if there is a beam or column splice
47	Sheet/View	Perimeter isolation joint reinforcements are shown if there are any
48	Sheet/View	If there are elements attached to the steel frame exposed to open air, a detail to prevent thermal bridges is needed
49	Sheet/View	Project layout regions are labeled on a site plan if there is any
50	Sheet/View	The structural column schedule is correct/consistent with the design
51	Sheet/View	Top of steel elevation is provided on the steel framing and roof plans
52	Sheet/View	Sufficient information is provided for the base plate details (size, thickness, grade, bolts, etc.)
53	Sheet/View	Top of footing and bottom of encasement elevations are given
54	General	Spellcheck is done for all the project
55	General	For the components that are still in the coordination process, design alternatives are clearly stated and a single alternative is consistently used in this submission cycle. Proper note is provided for the items that are still in coordination process. Make sure that either option is used consistently in the drawings
56	Sheet/View	View numbers are sequential

Project Specific Items

#	CATEGORY	ITEM
57	Design	Check if piers are required for the dropped footings of the braced frames or the steel columns will be exposed to the soil
58	Design	Check that if there are braced frames at corners and extremes of building as single frame. If yes, then thermal and self-stressing loads on the structure need to be examined
59	Sheet/View	The interaction and constructability of the closely placed single footings should be checked
60	Design	If moment frames are used - Moment frame collects less force compared to stiffer elements like walls. It is better to use 3D Finite Element Model to find the tributary - Design the connections accordingly
61	Design	If the braces do not go to the ground, it is expected to have higher drifts. Check the drift ratios and it may be needed to fix the column bases
62	Design	If column reinforcement ratio is less than 1%, need to decrease the concrete strength by the decrease in the reinforcement ratio stating from 1%

B. BIM Review Checklist

GROUP	ITEM
GENERAL ITEMS	Link Files are pinned
	Levels and Grids are copy-monitored
	Phase mapping is done for all of the linked models
	Arch links are room-bounded
	Grids and Levels are Pinned
	View Browser organization set
	Sheet Browser Organization Set
	Annotation size and type is consistent and matches with owner requirements
	Title block is up-to-date and matches the requirements
	Purge the model before submission
	Line Styles and Thicknesses are coordinated
	BIM360 Publish settings set up correctly
PROJECT INFORMATION	Project Name
	Project Address
	Project Status
	Project Coordinates
REVIT LINKS	Models shall be linked to each other via 'Origin To Origin' or with Shared Coordinates
	Each Revit link is on its own workset
	Links remain loaded to the model
	All linked fromBIM360
VIEWS	Views grouped according to their use (Coordination, On Sheet)
	Unused views are removed before 100% submission
	Views names comply with the requirements (No generic naming, Section 1, Elevation 1)
SHEETS	Sheets grouped according to their use (Coordination, Submission)
	Sheet numbers and names are consistent
	Coordination sheets are removed before 100% submission
WARNINGS	Review and reduce the warnings
WORKSETS	Worksets are consistent for all disciplines

	Easy to understand and useful
	Individual worksets are not allowed
	Each element is assigned to the corresponding workset
FAMILIES	Family naming is consistent with the owner requirements
	Family size does not exceed 1MB max
	Model-in-place families are not allowed
	Nested images and imported .dwg are not allowed
	Max nesting depth is 2
GROUPS	Generic group names are not allowed (Group1, Group2)
	Group names are simple, easy to understand
	Remove groups with a single instance
DESIGN OPTIONS	Only approved design options are allowed
	Design options are consistent for all disciplines
HATCH STYLES	Hatch styles are Revit based.
	.dwg based hatch types are not allowed
	Hatch type name is simple, descriptive and easy to understand
LEGENDS	Tables with line and text are not allowed
	Legend names are simple, descriptive and easy to understand
SCHEDULES	Tables with line and text are not allowed
	Revit based schedules or AutoCAD based live schedules are allowed
	Schedule names are simple, descriptive and easy to understand
CLASH DETECTION AND RESOLUTION	Clash detection and clash resolution need to be performed for the coordination with the other disciplines.

C. Updated Design Review Checklist

#	CATEGORY	ITEM
1	Abbreviations	Generic Abbreviation List is provided
2	Abbreviations	The correct form of abbreviations is used in the drawings. Add to abbreviation list if there are new ones
3	Codes	Up-to-date standards & codes are used
4	Codes	Design codes used in the project are consistent with the project requirements
5	Codes	Stud details are given according to the code in practice for the composite floor
6	Cover Page	The sheet List on the cover sheet lists all the submission sheets
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11	Graphical	The visibility of lines is on all printed views are as seen on the model
12	Loading Plan	Loading information used in the design is presented in the drawings (Slab, Roof, Equipment)
13	Reporting	Incomplete (Design Pending) design/details in the submission cycle is clearly reported
14	Reporting	Geotechnical design parameters are specified if there is a Geotech report. Point out the assumptions if there is not a Geotech report
15	Sheet/View	View (Plan/Elevation/Section/Detail) names are explanatory
16	Sheet/View	All the views to be submitted are complete and aligned in the sheets
17	Sheet/View	There are no duplicated details/views/sheets
18	Sheet/View	Sheets include all the views/details required (No typical detail missing)
19	Sheet/View	Design information for typical structural framing, slab type is consistent throughout the drawings

20	Sheet/View	The sheets and their nomenclature are aligned with the views included in the sheet
21	Sheet/View	All corresponding plans have the same type of consistent plan notes/legends/schedules
22	Sheet/View	A legend is provided for the symbols used in the drawings
23	Sheet/View	Matchline is labeled in all of the plans
24	Sheet/View	Section references and plan notes are mapped and located correctly
25	Sheet/View	All plans and elevations have grid-to-grid and overall dimensions
26	Sheet/View	Plan notes are consistent with the design intent (Foundation & SOG Plan, Framing Plan, Roof Plan)
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36	Sheet/View	Steel typical details have reference callouts/section cuts
37	Sheet/View	Concrete typical details have reference callouts/section cuts
38	Sheet/View	Framing above and below the roof level is given in different sheets and this is stated in plan note or detail
39	Sheet/View	CMU (Concrete masonry unit) typical details have reference callouts/section cuts
40	Sheet/View	Weld designations for steel connections are correct
41	Sheet/View	Typical details for RTU support are provided if there is any RTU on the roof or on the ground

42	Sheet/View	Foundation typical details have reference callouts/section cuts
43	Sheet/View	Slab and deck details are consistent throughout the drawings
44	Sheet/View	Structural footing schedule is correct/consistent with the design
45	Sheet/View	Wall details are coordinated with the design before submission, Walls CMU or Cast-in, Tilt-up or precast
46	Sheet/View	Beam or column splice details are provided if there is a beam or column splice
47	Sheet/View	Perimeter isolation joint reinforcements are shown if there are any
48	Sheet/View	If there are elements attached to the steel frame exposed to open air, a detail to prevent thermal bridges is needed
49	Sheet/View	Project layout regions are labeled on a site plan if there is any
50	Sheet/View	The structural column schedule is correct/consistent with the design
51	Sheet/View	Top of steel elevation is provided on the steel framing and roof plans
52	Sheet/View	Sufficient information is provided for the base plate details (size, thickness, grade, bolts, etc.)
53	Sheet/View	Top of footing and bottom of encasement elevations are given
54	General	Spellcheck is done for all the project
55	General	For the components that are still in the coordination process, design alternatives are clearly stated and a single alternative is consistently used in this submission cycle. Proper note is provided for the items that are still in coordination process. Make sure that either option is used consistently in the drawings
56	Design	Check if piers are required for the dropped footings of the braced frames or the steel columns will be exposed to the soil
57	Design	Check that if there are braced frames at corners and extremes of building as single frame. If yes, then thermal and self-stressing loads on the structure need to be examined
58	Sheet/View	The interaction and constructability of the closely placed single footings should be checked

59	Design	If moment frames are used - Moment frame collects less force compared to stiffer elements like walls. It is better to use 3D Finite Element Model to find the tributary - Design the connections accordingly
60	Sheet/View	View numbers are sequential
61	Design	If the braces do not go to the ground, it is expected to have higher drifts. Check the drift ratios and it may be needed to fix the column bases
62	Design	If column reinforcement ratio is less than 1%, need to decrease the concrete strength by the decrease in the reinforcement ratio stating from 1%
63	Design	Design approach is consistent with the project realities. Check that retaining wall design cases are consistent with the project
64	Design	Special equipment loads are provided or a meaningful explanation is given about the unprovided loading information
65	Design	Check that snow drift calculations consider the equipment on top of the roof
66	Design	Geotechnical Report and site parameters are up-to-date
67	Design	Seismic parameters and loadings are correct
68	Design	Wind Loading parameters and loadings are correct
69	General Notes	Project related sections of the General Notes provided (composite, wood, post-tensioned, etc.)
70	Design	Snow Loading parameters and loadings are correct
71	Design	Canopy design and details are given, if there is any
72	Design	Ladder support design and details, if there is any
73	General	Steel connection details correct (Base plate, beam-column, beam-beam)
74	General	Steel-to-concrete connection details (panel embeds)