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CLASH DETECTION AND AVOIDANCE FOR LARGE SCALE PROJECTS: A DELPHI SURVEY TO IDENTIFY AND PRIORITIZE CAUSES OF CLASHES

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(M. Sc. Thesis)

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ABSTRACT

Building Information Modeling (BIM) is a revolutionary advancement in the construction industry, offering numerous benefits throughout the processes from project design to construction. By utilizing three-dimensional modeling technology, BIM integrates design data from various disciplines, facilitating the easy detection of discrepancies or clashes among architectural, electrical, mechanical, structural, and other disciplines. BIM enables the early detection of such clashes and interferences before the construction processes begin, leading to time and cost savings during construction. While clash detection offers many benefits, it still requires significant time and effort as BIM managers need to individually scan and analyse each clash. Due to the time constraints of clash detection processes, a shift from clash detection to clash prevention methods has been observed in the current literature. The research objectives encompass a comprehensive exploration to uncover the underlying triggers of clashes by delving into academic literature and practical scenarios with a case study `KIA Terminal II Project`. The identified clash root causes are categorized into four main groups: process, people, product, and platform-related factors. Categorizing these reasons aims to provide a comprehensive understanding of factors contributing to clashes in different areas. The study aims to gauge the importance of these root causes through expert consensus. Therefore, 32 identified clash reasons were evaluated by 13 experts working on KIA Terminal II project using a Delphi analysis and ranked by importance. The findings of the survey have shown that `Changes during the construction` is identified as the most significant cause of clashes whereas `Software errors` ranked as the least important cause of clashes. The research proposes strategies for conflict prevention through proficient management of change, design, BIM, organization, Quality Assurance/Quality Control (QA/QC), as well as meticulous scheduling and planning. The findings of this study aim to contribute to the existing literature on BIM-based clash detection processes by identifying practical and root causes of clashes in construction projects and providing clash avoidance strategies to construction professionals.

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BÜYÜK ÖLÇEKLİ PROJELER İÇİN ÇAKIŞMA TESPİTİ VE ÇAKIŞMA ÖNLEME: ÇAKIŞMALARIN NEDENLERİNİ BELİRLEMEK VE ÖNCELİKLENDİRMEK İÇİN BİR DELPHİ ANKETİ

(Yüksek Lisans Tezi)

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GAZİ ÜNİVERSİTESİ
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ÖZET

Yapı Bilgi Modelleme (YBM), inşaat endüstrisinde devrimsel bir ilerlemedir ve proje tasarımından inşaata kadar birçok fayda sunar. Üç boyutlu modelleme teknolojisini kullanarak, YBM farklı disiplinlerden tasarım verilerini entegre eder ve mimari, elektrik, mekanik, yapısal ve diğer disiplinler arasındaki çelişkileri veya çakışmaları kolayca tespit etmeyi sağlar. YBM, bu tür çakışmaların ve müdahalelerin inşaat süreçleri başlamadan önce erken tespitini mümkün kılarak inşaat sırasında zaman ve maliyet tasarrufu sağlar. Çakışma tespiti birçok fayda sunsa da, YBM yöneticilerinin her bir çakışmayı ayrı ayrı tarayıp analiz etmesi gerektiğinden önemli zaman ve çaba gerektirir. Çakışma tespiti süreçlerinin zaman kısıtlamaları nedeniyle, mevcut literatürde çakışma tespitinden çakışma önleme yöntemlerine bir geçiş gözlemlenmektedir. Araştırma hedefleri, akademik literatür ve pratik senaryolara derinlemesine inerek çatışmaların temel tetikleyicilerini ortaya çıkarmayı amaçlar. Belirlenen çakışma kök nedenleri, süreç, insan, ürün ve platformla ilgili faktörler olmak üzere dört ana gruba ayrılmıştır. Bu nedenlerin kategorize edilmesinin amacı, farklı alanlarda çakışmalara katkı sağlayan faktörlerin kapsamlı bir anlayışını sunmaktır. Çalışma, 32 tanımlanan çatışma nedeninin KIA Terminal II projesinde çalışan 13 uzman tarafından Delphi analizi kullanılarak değerlendirilmesi ve önem sırasına göre sıralanması yoluyla bu kök nedenlerin önemini ölçmeyi amaçlar. Anket bulguları, 'İnşaat sırasında yapılan değişikliklerin' en önemli çakışma nedeni olarak tanımlandığını göstermiş olup 'yazılım hataları' en az önemli çakışma nedeni olarak sıralanmıştır. Araştırma, değişim, tasarım, YBM, organizasyon, Kalite Güvence/Kalite Kontrol (QA/QC) ve dikkatli zamanlama ve planlama yönetimi yoluyla çakışma önleme stratejileri önermektedir. Bu çalışmanın bulguları, inşaat projelerinde çakışmaların pratik ve kök nedenlerini belirleyerek inşaat profesyonellerine çakışma önleme stratejileri sunarak BIM tabanlı çakışma tespit süreçleri üzerine mevcut literatüre katkıda bulunmayı amaçlamaktadır.

Bilim Kodu : 80126
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SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations used in this thesis are presented below with their explanations.

Symbols	**Explanations**
m	Metre
m²	Metrekare
σ/ SD	Standard Deviations
α	Cronbach’s Alpha
awg	Interrater Agreement Statistic
M	Mean Value

Abbreviations	**Explanations**
2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional
5D	Five Dimensional
6D	Six Dimensional
7D	Seven Dimensional
AEC	Architectural, Engineering, Construction
BDS	Building Description System
BEP	BIM Execution Plan
BIM	Building Information Modelling
BPM	Building Production Model
CAD	Computer-Aided Design
CDE	Common Data Environment
FCC	Family Category Code
GLIDE	Graphical Language for Interactive Design
KIA	Kuwait International Airport
MEP	Mechanical, Electrical, Plumbing
NBIMS	National Building Information Modelling Standard

Abbreviations	**Explanations**
QA/QC	Quality Assurance/ Quality Control
RFI	Requests for Information

1. INTRODUCTION

Construction operations entail a form of production that relies on interdisciplinary collaboration, necessitating the preparation of various projects across all engineering domains (Ayalp and Öcal, 2016). Building Information Modelling (BIM) stands out as a significant advancement in the architecture, engineering, and construction (AEC) sector, as the use of BIM technology in buildings has many benefits for the current design and construction processes by improving coordination to enable a more efficient and well-planned process between multidisciplinary teams (Akponeware and Adamu, 2017). Effective design coordination ensures that all building components conform to functional, aesthetic, and economic requirements without clashes.

One of the key benefits of BIM is its ability to enable clash detection, a process that identifies and resolves conflicts or clashes between different building elements before construction commences (Akhmetzhanova et al., 2022; Tommelein and Gholami, 2012). A `clash` refers to conflicts identified through clash detection tests when two project elements occupy the same space and unintentionally penetrate each other (Eastman et al., 2011).

BIM modelling entails creating a three-dimensional model that incorporates design models from different parties involved in the design development process. BIM coordination processes are multidisciplinary programs that can fulfil a variety of functions. From the pre-construction phases of the construction projects, all the elements are integrated into a central model to test if those elements have positioning errors and clashes.

By analysing 3D models and detecting clashes between structural components and MEP (Mechanical, Electrical, Plumbing) systems, clash detection enhances safety performance on construction sites and contributes to better cost control. Moreover, clash detection processes streamline communication, reduce the Requests for Information (RFIs), and minimize the need for change orders during the construction phase, improving project efficiency, reducing delays, and enhancing decision-making processes. Additionally, identifying clashes in advance allows for increased opportunities for prefabrication, ensuring accurate design and seamless integration of prefabricated components, ultimately leading to faster construction timelines and cost-effective project execution.

Background of the research and research gap

In the realm of construction, Building Information Modelling (BIM) has emerged as a valuable tool, particularly notable for its application in clash detection testing. This process, integral to BIM utilization, is pivotal in pre-emptively identifying and resolving clashes, thus preventing costly rework and delays.

While BIM tools excel in automatic clash detection, the subsequent clash resolution predominantly relies on manual intervention (Hu et al., 2023). This manual process demands collaborative efforts among project stakeholders to detect clashes, propose solutions, and implement design adjustments effectively. Despite the numerous benefits of clash detection in construction projects, accurately identifying clashes requires significant time, labour, and expertise with clash detection tools. Research indicates that despite the advantages of BIM to clash detection, unresolved design coordination issues often lead to onsite rework, resulting in additional costs and delays (Mehrbod et al., 2019).

Currently, scholarly attention has shifted from conventional clash detection approaches towards strategies focused on clash avoidance. This shift emphasizes the investigation of underlying causes of clashes as a critical area of exploration. This research aims to address a significant research gap by acknowledging the known causes of clashes in large-scale projects highlighted in the existing literature and advocating for an in-depth examination of real-world scenarios to uncover additional causes with a case study. This investigation will provide a comprehensive understanding of the factors contributing to clashes in BIM implementation, which significantly contribute to the existing body of knowledge to develop strategies for clash avoidance.

Research aims and objectives

Clash avoidance involves proactive measures taken during the design and pre-construction phases to anticipate and prevent clashes from occurring in the first place. Stakeholders can collaborate to recognize clashes early on by utilizing collaborative design processes and integrating advanced tools like Building Information Modelling (BIM). This proactive approach not only lowers the chance of clashes but also improves cost savings and expedites project delivery. As a result, even though clash detection is a useful tool, concentrating on clash avoidance can result in more notable gains in project success and overall performance within the construction industry. To address these issues, this thesis aims to develop a comprehensive framework for clash avoidance in the construction sector, focusing on enhancing communication, coordination, and the utilization of technology to minimize the occurrence and impact of clashes.

Briefly, the objectives of the thesis are:

- To describe the BIM process in the preconstruction and construction stages of large-scale projects
- To identify the benefits of BIM processes and clash detection to the project
- To identify the root causes of clashes with researching both academics and in practice.
- Measuring the significance of root causes of clashes according to expert agreement with a Delphi survey
- To provide critical principles to achieve clash avoidance for all project stakeholders.

This research aims to provide a deep understanding of clash detection processes and current challenges and causes in the practice that leads to clash occurrence and methods of clash avoidance. The findings may support construction industry professionals in promoting clash avoidance by better understanding the root causes of clashes in practice.

The method of the research

The research methodology outlined in Figure 1.1, involves a four-step blend of quantitative and qualitative data collection and analysis. Firstly, the literature review provides insights from previous studies, identifies research gaps, and collects data on clash detection processes, advantages, and most importantly underlying causes of clashes.

Secondly, a case study is conducted by focusing on BIM utilization and clash detection procedures within the roof design of the KIA Terminal II project, examining architectural, structural, and MEP components of the roof. The roof of KIA Terminal II is chosen due to its intricate structure and the completion of clash tests for the roof elements. By analysing close-out reports and weekly/monthly clash detection reports, the study aims to identify additional reasons behind clashes in practise.

In the construction industry, large-scale projects often require the collaboration of multidisciplinary actors to ensure successful completion. To facilitate this collaborative effort, as the third step, a Delphi survey was conducted with a panel of thirteen experts from various disciplines, including architecture, structural, electrical, mechanical, and ICT engineering, to identify and prioritize the causes of clashes in large-scale construction projects based on the significance of each benefit and the level of agreement among the experts.

Understanding these clash causes is beneficial as it allows for developing strategies to reduce and prevent clashes effectively for all disciplines involved in the project. Therefore, at the last step of this research, clash avoidance strategies are defined for each cause of clashes identified in the data collection process. These strategies can lead to improved collaboration and coordination among multidisciplinary actors, ultimately contributing to completing large-scale construction projects.

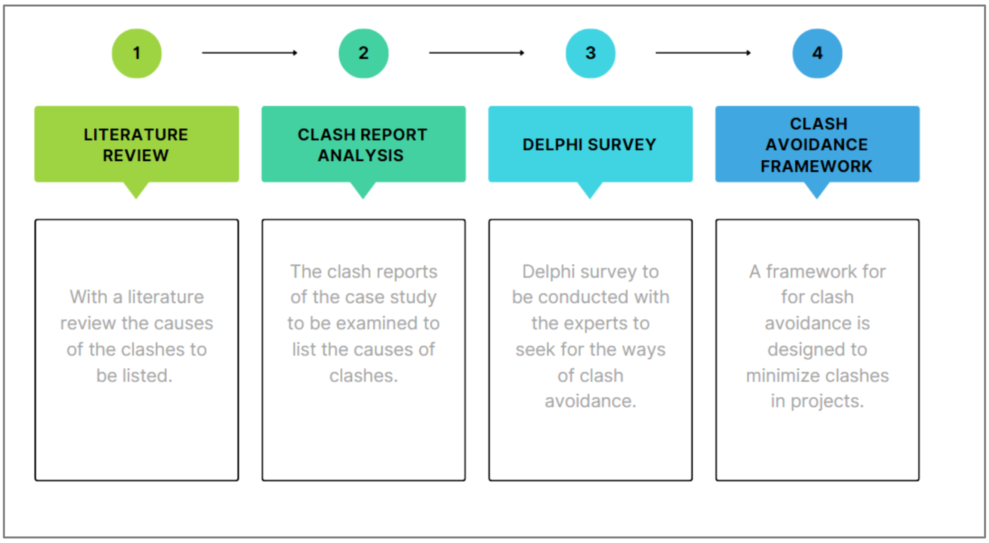


Figure 1.1. The main steps of the research methodology

2. LITERATURE REVIEW

Building Information Modelling (BIM) is an approach that represents an essential transformation in the construction industry. BIM provides a digital platform for integrating, sharing, and managing information throughout the entire life cycle of a structure. This platform aims to increase efficiency, cooperation, and quality in the processes from the design of the building to its construction, operation and maintenance. The development of BIM is supported by several theoretical frameworks and essential terms related to clash detection. The first part of this section elucidates the evolution of Building Information Modelling (BIM) technology, offering a comprehensive overview of fundamental concepts and terminologies pertinent to BIM. This exploration aims to enhance comprehension regarding the progression of computer-aided technologies within construction.

2.1. The Definition and Development of BIM

The notion of “Building Information Modelling (BIM)” was first introduced by Charles Eastman from Georgia Tech School of Architecture in the late 1970s, as illustrated in Figure 2.1 and the term “Building Information Model” was first used in the early 1990s (Latiffi et al., 2014).

In 1974, Charles Eastman drew attention to the need for more conventional information change between different parties of the construction projects. The primary source of information transfer using traditional methods is two-dimensional drawings. According to him, although drawings and specifications have strengths in designing spatial arrangements of buildings, they still need to improve when managing construction projects. The idea behind the Building Description System (BDS) is to provide a computer-based database containing elements of the buildings in space to design buildings and quickly generate sets of drawings from this database (Eastman et al., 1974).

According to Eastman (1977), a three-dimensional object can be described in three levels: image, shape, and object. The image represents the basic information of an element with disorganised sets of planar and curved faces. The shape defines the volume, the closed surface. The object, in addition to the geometrical aspects of the shape, includes functional information. The insufficiency of the computer-aided design is that it can only go up to a level at the level of shape, not the object. GLIDE (Graphical Language for Interactive Design) was developed to provide information on the physical elements by combining many principles pioneered in BDS. With GLIDE, physical elements can be represented and modelled as images, shapes, and objects.

Even though BDS and GLIDE offered many significant benefits in the design stage, at this time, there was a need for a program that would provide a collaborative environment for the construction phase. Subsequently, in 1989, a brand-new application called the Building Product Model (BPM) was developed to be utilised in design, estimating, the construction process, and interactive communication between all the construction actors (Latiffi et al., 2014).

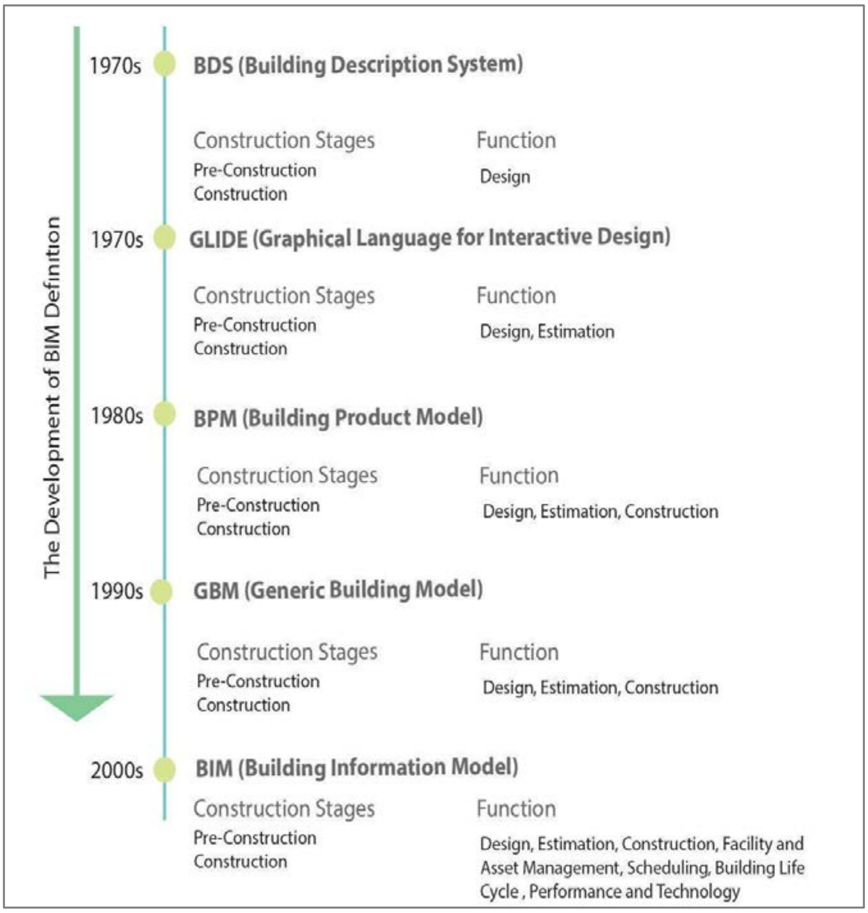


Figure 2.1. Development of BIM (Latiffi et al. 2014)

In the middle of the 2000s, the architecture, engineering, and construction (AEC) sector started integrating BIM into construction projects. Since then, it has gained popularity in the construction industry due to its advantages in planning and design in pre-construction and construction stages (Li et al., 2017). A BIM model can be defined as a 3D digital representation of a building that includes element-specific geometric and semantic data. BIM provides a successful interaction among AEC (architecture, engineering, and construction) professionals thanks to its standardised database. According to the National Building Information Modelling Standard (NBIMS), a BIM model can be categorised as a finished product, an interactive process and a requirement for lifecycle management. Therefore, the promise of BIM alters how architects, designers, consultants, and contractors control the whole construction process. This fact is the reason for the widespread adoption of BIM for large-scale projects in the AEC industry (Eastman, 2011).

2.2. Key Concepts and Terms Related to BIM

In Building Information Modelling (BIM), several key terms are crucial in facilitating clash detection processes. This section provides an overview of the critical terms of BIM that are significant for clash detection. The relationship between BIM terms like LOD (Level of Development), BIM levels, and BIM dimensions is closely intertwined with clash detection. LOD defines the level of development and accuracy of information within a BIM model. Appropriate LOD levels offer more precise and comprehensive information about the modelled objects, enabling clash detection to identify and resolve conflicts more effectively. Levels of BIM, representing different stages of a project's life cycle, help organise clash detection activities at each stage, ensuring clashes are addressed in a timely manner. Dimensions of BIM, contribute to clash detection by allowing clashes to be identified across various aspects of the project. The relationship between LOD, BIM levels, and BIM dimensions is crucial in facilitating efficient and accurate clash detection processes, ultimately leading to improved project outcomes.

Level of development

Building Information Models contain the 3D graphical and conceptual data of all the objects used in construction projects. The level of development (LOD) standard is the primary source for specifying and managing high levels of information included within the models.

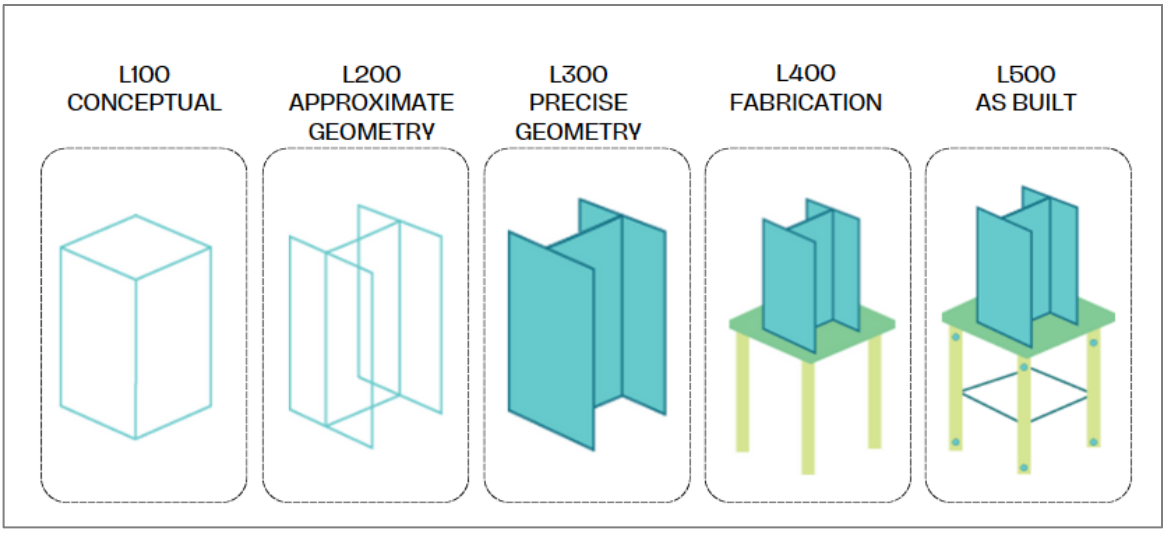


Figure 2.2. Level of development of BIM

The LOD is defined in five ranges from LOD 100 to LOD 500, as shown in Figure 2.2. As a project evolves from pre-design to construction phases, the detail levels of the model elements are developed accordingly. According to this definition of LOD, the modelling detail of an element ranges from the lowest level of representation (conceptual) to the highest level of representation (as built). In the conceptual level of detail, the model element is represented not in its actual geometry but as a volume. For the approximate geometry LOD 200, the model element is illustrated with its approximate quantities, size, shape, location, and orientation without describing its individual qualities. Compared to LOD 200, the model element is depicted with intricate geometric details at the LOD 300 level of detail. It moves closer to a detailed representation by adding more details like precise dimensions, connections, and fundamental material properties. LOD 400 offers an extensive understanding of the design and function of the element by including precise dimensions, intricate connections, material specifications, and detailed geometry. At LOD 500, every model aspect is wholly rendered, including the precise geometry, dimensions, material specifications, complex connections, and all pertinent information needed for the building or facilities management and operations and maintenance stages.

Dimensions of BIM

The dimensions of BIM refer to the different aspects or components that can be incorporated into a Building Information Model. Commonly, BIM models enhanced by a particular kind of data are referred to as “nD models,” where n refers to the amount of data utilized in the model or, more accurately, the quantity of data added to the model itself (Vycital & Jarsky, 2020). BIM began with 3D representations at first and eventually evolved to express design intent in terms of ten dimensions (Figure 2.3). Throughout a project, all dimensional aspects are identified and updated as required (Kontothanasis et al., 2019).

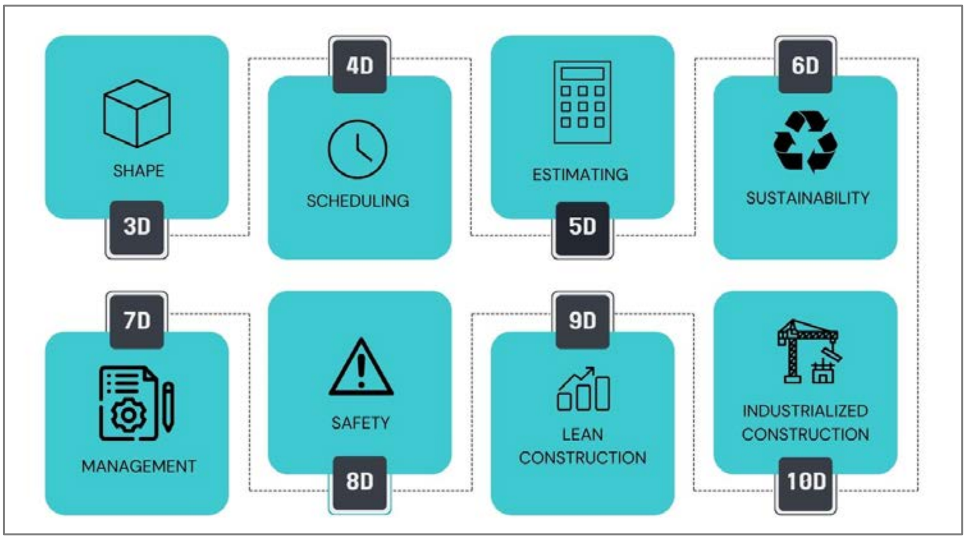


Figure 2.3. Dimensions of BIM

The 3D represents the physical geometry and spatial representation of the building. It involves creating a three-dimensional digital model that accurately represents the physical elements and their relationships within the project. The term “4D” was initially used in 1995, and it was rationally defined as three-dimensional computer-aided design (CAD) models that could display changes over the fourth dimension of time (Wildenauer, 2020). The linking of the time to the 3D model with a construction schedule or timeline allows for the visualization and simulation of the project's construction sequencing and phasing. 5D BIM, is primarily related to cost in construction projects. It facilitates cost estimation, lifecycle cost analysis, scenario exploration, quantities extraction, and real-time modelling and cost planning (Charef et al., 2018). The 6D dimension involves incorporating sustainability-related information into the BIM model. It includes the data related to energy performance, environmental impact, and lifecycle analysis. This dimension helps in designing and evaluating sustainable and energy-efficient buildings. The 7D dimension focuses on integrating facility management information into the BIM model. It involves incorporating data related to maintenance, operations, and asset management. This enables efficient facility management and maintenance throughout the building's lifecycle.

In contrast to the more widely used dimensions, such as 3D to 7D, the ideas of 8D, 9D, and 10D in the context of Building Information Modelling (BIM) need to be standardized and acknowledged. Nonetheless, some sources might depict additional improvements and integrations to the BIM process using these higher dimensions.

BIM maturity levels

BIM maturity levels can be identified as the stages of adoption and implementation of Building Information Modelling (BIM) within an organization or on a project. BIM maturity levels are not linear, as indicated in Figure 2.4, and organizations or projects can operate simultaneously at different levels. The levels provide a framework for understanding the extent of BIM implementation and collaboration within a specific context.

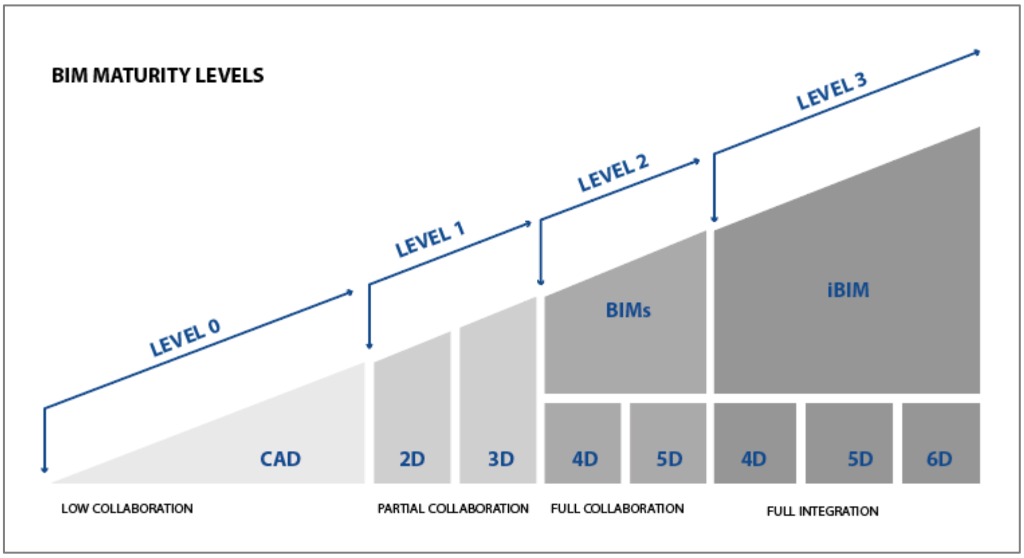


Figure 2.4. BIM maturity levels (Adapted from Barlish and Sullivan, 2012)

In the progression of Building Information Modelling (BIM) adoption, Level 0 represents the baseline where there is no digital collaboration, and the design and construction processes are based on conventional 2D drawings. Advancing to Level 1, there is an introduction of 2D CAD for drafting and documentation, with occasional, isolated uses of 3D modelling. At Level 2, BIM integration becomes more pronounced, with various disciplines developing their own 3D models that are shared and coordinated through a common data environment. Level 3, which denotes the highest point of BIM implementation, is distinguished by a completely integrated and cooperative setting in which all stakeholders collaborate together.

2.3. Clash Detection

This part of this section will concentrate on the classification of clashes, clash detection, and clash avoidance. Of utmost importance, it will delve into the root causes that lead to the occurrence of clashes in the construction industry.

2.3.1. Classification of the clashes

In the literature, clashes are classified into different kinds. These classifications help identify the nature and severity of clashes to determine which clashes need to be resolved. According to Tommelein and Gholami (2012), one classification of clashes includes “hard clashes” and “clearance clashes.” (Figure 2.5). A hard clash occurs when two or more building components occupy the same physical space and pass through each other. These clashes are relatively easy to detect. On the other hand, a clearance clash arises from insufficient geometric tolerances given to an object, resulting in components being too close to each other without physically intersecting.

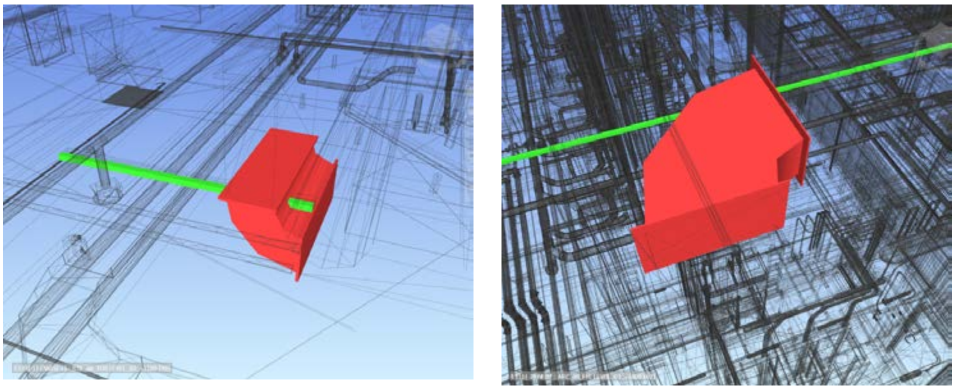

(a) (b)

Figure 2.5. (a) Hard clash, (b) Clearance clash

Pärn et al., 2018 proposed a different classification of clashes, which includes four categories. The first category is “error clashes,” considered as faults that must be found and resolved. These clashes can lead to significant issues if not addressed. The second category is “pseudo clashes,” which are acceptable and do not require resolution. These clashes may occur due to overlapping components that do not affect the functionality or safety of the structure. The third category is “deliberate clashes,” which are intentionally created clashes. These clashes may be used for specific design purposes or to represent elements that will be modified later. The fourth category is “duplicate clashes,” repeated throughout the model. These clashes may occur due to errors in the modelling process or duplication of components.

Chahrour et al., 2020 proposed another classification of clashes based on their significance and the parties involved. They categorize clashes as major, medium, and minor. Major clashes require the participation and approval of the client team, designer, and contractor. These clashes have been considered to impact the project and require significant careful resolution. Medium clashes involve the contractor and require the approval of the designer. These clashes may have a moderate impact on the project and must be addressed promptly. Minor clashes involve the contractor and do not require approval from the designer or client. These clashes have a minimal impact on the project and can be resolved without significant disruption.

2.3.2. Clash detection versus clash avoidance

While clash detection refers to identifying the clashes in the pre-construction and construction stages, clash avoidance can be defined as an intention to avoid the spatial intersection of the element by providing strong spatial coordination of different components of the projects. Both procedures have similarities in their main objectives since a clash-free model and better design quality are aimed at preventing cost and time overruns.

Regarding differences, clash avoidance is a proactive procedure that guarantees collaboratively established design decisions. In contrast, clash detection is a reactive procedure that can only be applied after design decisions. Clash detection typically occurs during the later stages of the design or construction process when the design decisions have been made, and 3D models are developed. It helps to identify clashes that may have been overlooked during the initial design stages. Clash avoidance occurs during the early stages of the projects, even before the 3D models are created. It involves thorough coordination and communication among the project team to anticipate and address potential clashes before they occur. Software tools are used in clash detection to examine 3D models and find collisions based on preset guidelines and algorithms. Clashes are represented visually, enabling stakeholders to examine and settle them. Clash avoidance emphasises proactive preparation and collaboration amongst project stakeholders. It entails routine meetings, talks, and collaboration to avoid conflicts, settle disputes, and maintain effective coordination between various building parts. Therefore, clash avoidance requires a successful process of design coordination and management skills, and its focus is the collaboration between different disciplines. In contrast, the focus of clash detection is the rules and tools for identifying clashes, which requires basic management skills (Akponeware & Adamu, 2017).

2.3.3. Causes of clashes

The main purpose of this literature review is to investigate and identify the primary causes of clashes in construction projects. The review encompasses a wide range of scholarly articles and research papers that comprehensively analyse the driving factors of clashes identified in the literature. By synthesising and analysing the findings from these sources, this review aims to shed light on the key causes of clashes, including issues related to design coordination, communication breakdowns, inadequate project planning, and technological limitations. Understanding these causes is crucial for developing effective strategies and implementing preventive measures to mitigate clashes and improve project coordination in the construction industry.

The thesis explores the causes of clashes, as obtained through literature (Table 2.1), which are categorised into four main categories: process, people, product, and platform-related factors. By categorising these causes, the thesis aims to provide a comprehensive understanding of the factors contributing to clashes in various domains, enabling better conflict resolution and prevention strategies.

1. Process related: This category focuses on the processes and workflows involved in clash detection and resolution. It includes the methods, procedures, and tools used to identify and resolve clashes.
2. People related: This category emphasises individuals' role and collaboration in clash detection and resolution. It involves the skills, knowledge, and expertise of team members.
3. Product-related: This category relates to the design and construction elements that can lead to clashes.

4. Platform related: This category refers to the technological platforms and software used in clash detection and resolution. It encompasses the common data environments (CDEs), file formats, and software tools that facilitate the sharing and analysis of BIM models.

Table 2.1. Root causes of clashes

Category	Cause of Clash	Reference
Process Related	Isolated working	Craig and Zimring, 2002 Froese, 2010
	Lack of experience in BIM	Akhmetzhanova et. al, 2021
	Time limitations	Akhmetzhanova et. al, 2021 Tommelein and Gholami, 2012 Benning et al., 2010 Pärn et al.
	Changes during construction	Lee et al., 2005
	Deceptive planning and timing	Arayici et al., 2012
	Poor coordination and management	Arayici et al., 2012
People Related	Lack of qualified specialists	Akhmetzhanova et al., 2021 Leite et al., 2011 Wang and Leite, 2014 Ahmed, 2018
	Modelling errors	Akhmetzhanova et. al, 2021 Craig and Zimring, 2002
Product Related	Design complexity	Korman and Simonian, 2010 Ashcraft, 2008
	Design uncertainty	Tommelein and Gholami, 2012
	Design error	Love et al.. 2009 Han et al., 2013 Tommelein and Gholami, 2012
	Failing of design rules	Tommelein and Gholami, 2012
	Inadequate level of development (LOD)	Akhmetzhanova et. al, 2021 Leite et al., 2011
	Complexity of modelled object	Tommelein and Gholami, 2012 Akhmetzhanova et. al, 2021
Platform Related	The current structure of common data environments	Akponeware and Adamu, 2017
	Use of 2D instead of 3D models	Hartmann, 2010 Leite et al., 2011 Porwal and Hewage, 2013
	Use of different file formats	Akhmetzhanova et. al, 2021 Kensek and Noble, 2014 Pärn et al. Shafiq et al., 2012
	Software errors	Merschbrock and Munkvold, 2015

Process-related causes can be defined as causes of clashes driven by workflows and coordination processes that are not planned correctly. Therefore, the reasons related to the process highlight the significance of effective coordination, knowledge accumulation, time management, and effective communication in reducing clashes during the project process. By utilizing BIM in the workflows, different teams and subcontractors can work on the same project database. This ensures that each component, building element, and system is coordinated. When a team makes a change, other teams can immediately see these changes and adjust their work accordingly. Coordinated work allows for early detection and resolution of clashes in a project. For instance, if electrical and mechanical teams plan to install an electrical installation and a ventilation system in the same area, this overlap is noticed in advance thanks to BIM, and necessary arrangements can be made in the design, which prevents unnecessary time and cost losses at the site (Akponeware & Adamu, 2017). *Isolated working* is one of the causes of clashes in the literature that arise from team members or disciplines working separately without efficient collaboration and coordination (Craig and Zimming, 2022; Froese, 2010). It is highlighted as the root reason for the conflicts between the MEP elements (Akponeware and Adamu, 2017).

The adoption of BIM has taken place at different speeds in many countries and companies. In some countries, especially pioneer countries such as the UK, USA and Singapore, the use of BIM has been encouraged and made mandatory at the government level. Other countries, on the other hand, have developed various policies to promote the use of BIM in their construction sectors. Another factor that leads to clashes is *a lack of experience in Building Information Modelling (BIM)*. When team members do not have adequate knowledge about BIM tools and processes, errors and clashes may occur in models. It is stated in the literature that BIM users in the construction industry are frequently young and do not have sufficient field experience to integrate BIM processes into the project workflow (Chelson, 2010). Due to inadequate knowledge, there may be difficulties in accurately representing the elements in the projects and ensuring coordination (Akhmetzhanova et al., 2017).

Time limitation is also an influential factor in the causes of clashes. Insufficient time is dedicated to clash detection and coordination, resulting in undetected issues that emerge during the construction phase, potentially causing delays and the need for rework. Due to time limitations and deadlines in construction projects, designers may intentionally keep unresolved clashes to balance deadlines and model accuracy (Akhmetzhanova et al., 2017; Tommelein and Gholami, 2012).

Deceptive planning and timing can lead to conflicts in construction projects, leading to mismatches and delays between different project teams (Arayici et al., 2012). When the sequence of work of different teams is planned incorrectly, a team may make revisions that may cause conflicts because it has not mastered the details that a previous team will apply. As a result of the inability to determine the hierarchy between the structural elements, conflicts may arise between different disciplines or elements in the same discipline. For example, if mechanical and electrical teams design mechanical and electrical teams in a project without coordinating architectural elements, conflicts may arise during architectural coordination.

Failure to properly coordinate the *changes made during construction* may lead to conflicts between existing and newly proposed elements (Lee et al., 2005). For example, cables will be passed in a construction project in a particular area for electrical installation. However, during the construction, because of a meeting with the mechanical installation team, the project team decides to add a new sewer line to that area for the ventilation system. This change coincides with the predetermined cable paths for electrical installation. However, if this change is not coordinated correctly, the electrical team may continue laying cables without being informed. As a result, clashes arise between the ventilation ducting and the electrical cables in the later stages of construction.

Clashes in the BIM model are more likely to occur when *poor management and coordination* prevent the seamless integration of various design aspects (Arayici et al., 2012). Conflicts can arise from inadequate management techniques, such as unclear roles and tasks or insufficient supervision. Poor management could result in a lack of accountability and coordination, which could cause mistakes or omissions throughout the design phase.

Another category for classifying the clashes is *people-related* causes, which refer to clashes derived from human error or inadequate knowledge about the BIM and clash detection processes. Providing adequate information, proper understanding, and using BIM technologies and processes are essential in preventing clashes. Therefore, in the literature, *the lack of qualified specialists* is considered one of the critical causes of people-related causes of clashes (Ahmed, 2018).

Modelling errors were identified as another people-related cause of clashes in the literature. Modelling errors refer to wrong-modelled BIM components of building systems in the BIM model (Figure 2.6). These errors might be derived from missing guidelines, project requirements, installation sequences, processes, or required clearances between particular objects.

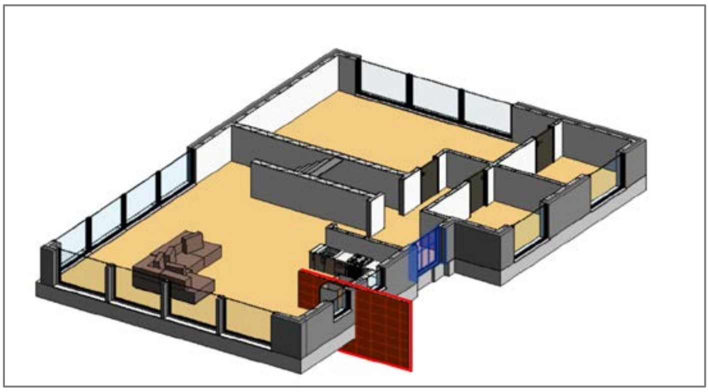


Figure 2.6. Modelling errors

Design uncertainty is one of the significant *product-related* causes of clashes highlighted in the literature. This type of clashes are likely to occur when the latest design is unclear for an object, but it is put on the models for coordination reasons by leaving insufficient room for the specific component to fit.

Construction projects are frequently characterised by being large and becoming more complex. These are characteristics of complex structures with many different components and many different entities or elements. These components are interconnected in a complex web of causal relationships between the components. In the literature, it is reported that to solve complex designs, designers sometimes intentionally leave some clashes to explain only the design intent in the early stages. However, it may continue until the design development and construction stages. Therefore, *design complexity* is counted as one of the major causes of the clashes.

In such projects with high complexity in terms of design, designers continue to improve their designs while still determining the exact space that their systems can or will fill. When a model element's positioning or dimensions deviate from the initial design intent, it is considered a *design error* in the literature (Tommelein & Gholami, 2012). Since this situation indicates that the placement of the object differs from the planned layout, it would affect the overall quality and accuracy of the design and the identification of the clashes in clash detection processes.

This failing of the design rules is considered one of the significant causes of the hard clashes. This refers to a lack of standards, agreements, or designs before and during the process that would indicate how specialized systems should be integrated with other elements.

Many projects require high coordination between disciplines to provide information workflow between the parties. Every project has different requirements and levels of detail for different stages and purposes. LOD 350 specifies an element's relationship to and connection with other components and precisely describes an element's information. Coordination between many disciplines, such as clash detection, is developed using LOD 350. (Latifi et al. 2015) In the literature, research has been conducted to compare the effects of different levels of details of model elements on the precision of clash detections. It is found that a BIM model with a higher LoD level can lead to more precise identification of clashes, which can better support design and construction processes. Therefore, *using wrong or low detail can* be counted as a primary cause of process-related reasons.

The complexity of the modelled objects is considered another significant cause of clashes. Complex objects are more likely to have elements in the model that overlap or clash. Because of these complexities, it may be harder for engineers and designers to identify and resolve conflicts (Akhmetzhanova et al., 2017).

Platform-related reasons are the problems arising from the hardware problems of BIM models and the inability of the methods used for clash detection testing not to follow the current technology. A common data environment is a cloud-based platform where different stakeholders involved in a project can share and collaborate on data. This environment facilitates the exchange of information between different disciplines and allows employees to access the same data at different project stages. The common data environment is used in BIM (Building Information Modelling) projects to prevent conflicts, increase coordination, and facilitate data sharing. Studies show that the *current structure of the cloud-based* *common data environments* (CDEs) (Figure 2.7) is one of the causes of clashes since they are unsuitable for conflict prevention and encourage isolated work (Akponeware & Adamu, 2017).

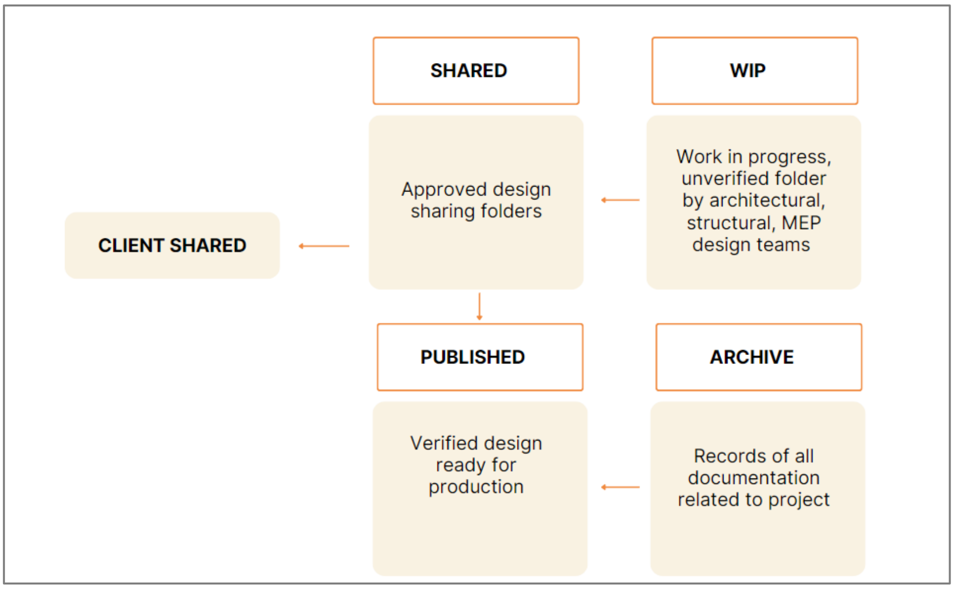


Figure 2.7. General structure of a common data environment as per PAS 1192-2

Using 2D manual clash detection is reported in the literature as one of the reasons for clashes. The use of 2D plans for 3D construction projects can make it difficult to fully detect clashes because the project's actual volume and details are not fully considered. Using an organized Building Information Model (BIM) with automatic clash detection procedures offers benefits for the early detection and resolution of clashes (Hartmann, 2010).

A typical file exchange workflow for BIM requires the use of different file formats as indicated in Figure 2.8. *Using different file formats* can cause conflicts in BIM tools because incompatibility and inconsistency of files in different formats can lead to conflicts. For example, the dimensions or position of an object in one model may be represented differently in another file. BIM tools may have difficulty detecting clashes or giving incorrect results. (Akhmetzhanova et al., 2017).

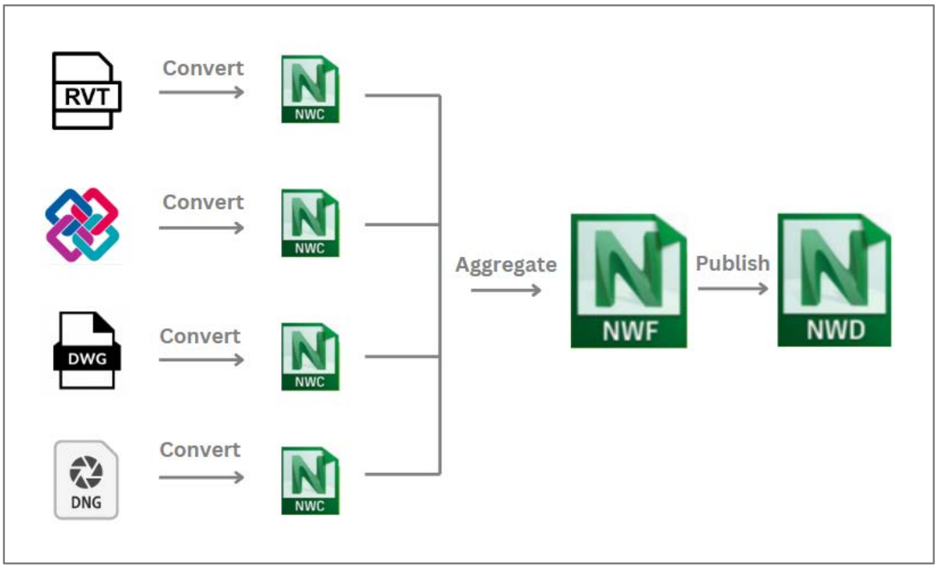


Figure 2.8. The typical workflow for the different file formats

Another platform-related cause of clashes is *software errors*. A computer program for clash detection tests may not indicate a hard clash when an incorrectly sized or placed component is not obstructed. Similar to how there is no space contention when a component is physically, but incorrectly, surrounded by another component, no physical penetration may be computed. Therefore, having a clash-free BIM model does not always count as clash-free construction work.

3. MATERIAL AND METHOD

Quantitative and qualitative analysis are employed in the data collection process, as the causes of clashes cannot be fully explored through quantitative analysis alone (Figure 3.1). This process involves a literature review and an analysis of clash test reports from the case study, KIA Terminal II, to identify the causes of clash detection. The roof design of the terminal involves numerous subcontractors from architectural, structural, and MEP disciplines. During the quantitative phase, clash test close-out reports and periodic (monthly or weekly) clash detection reports are analysed to examine the clash detection processes for this large-scale project while also investigating the root causes of clashes.

In the final stage, a two-round Delphi survey is conducted to reach a consensus among experts regarding the root causes of clashes to create a framework for minimizing and preventing clashes.

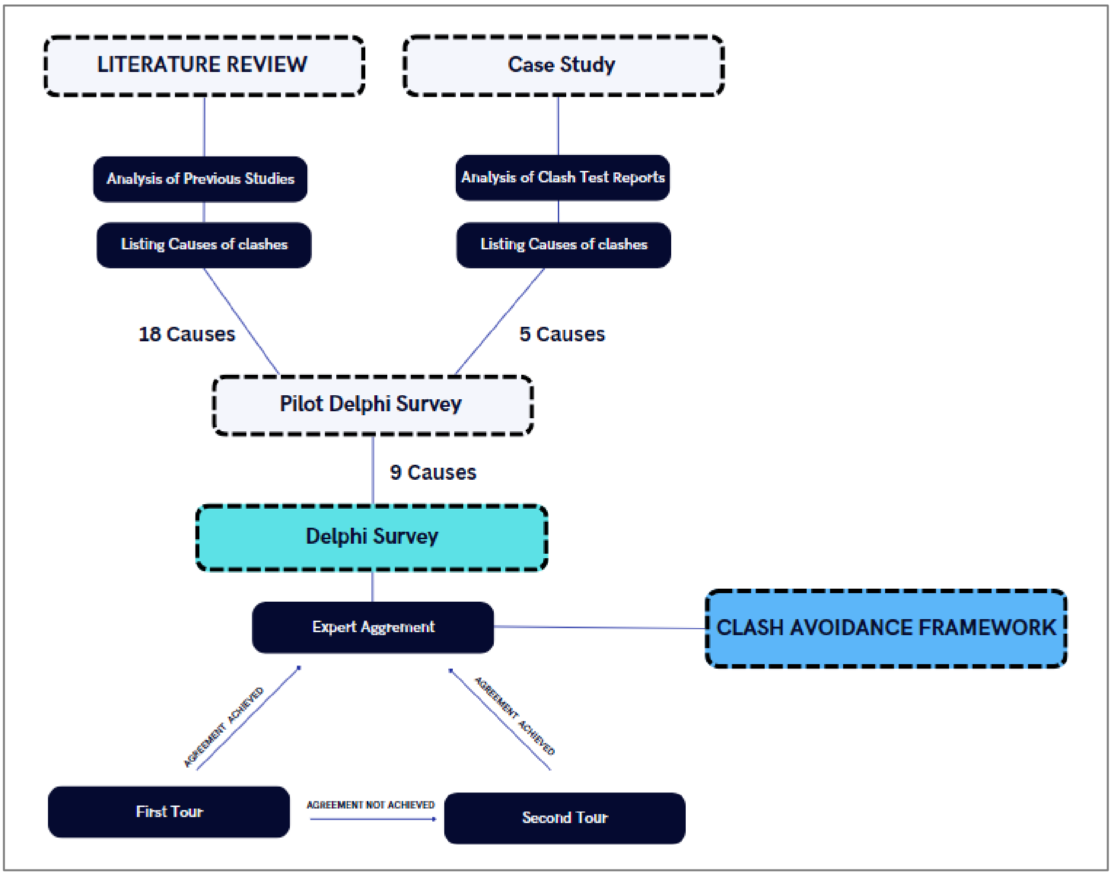


Figure 3.1. Method of the research

3.1. Literature Review

A literature study was conducted to gain insight into earlier research, determine any gaps in the field, and gather information on clash detection processes, benefits, and root causes of clashes. Before the literature review, a theoretical framework is given to understand the background of the research with the development of BIM usage, terms and related topics to BIM usage, and so clash detection. This literature review was conducted to determine the root causes of conflicts in construction projects and contribute to the current knowledge on this issue. The research method used for the literature review is a comprehensive literature review to understand the main factors contributing to conflicts in different project environments. In this screening process, the main reasons for the conflicts have been tried to be revealed. Elements such as problems in design coordination, communication deficiencies, inadequate project planning, and technological limitations will be examined and clarified within the framework of this analysis. The 18 main causes identified in the research are divided into four categories: process, people, product, and platform-related factors. This classification aims to provide a comprehensive understanding of the factors affecting conflicts with different sources and to produce specific solutions.

The literature review has classified the root causes of conflicts into four main categories: process, people, product, and platform-based factors. This classification aims to provide a comprehensive understanding of the factors that contribute to conflicts in different areas. This study carried out through research methods, synthesis, and analysis of literature sources, aims to reveal the main causes of the conflicts that arise during the screening process. In light of this information, the materials and methods department should explain in detail how the literature review was conducted, which sources were used, and how these sources were analysed. The research conducted a comprehensive literature review to understand the main factors contributing to conflicts in different project environments and aimed to determine the root causes of conflicts resulting from this review. This study aims to contribute to the current knowledge to prevent conflicts in construction projects.

3.2 Case Study

This section of the thesis emphasises the clash detection procedures concerning the roof of the KIA Terminal II project to identify the root causes of clashes in practice after the literature review. As mentioned before the roof is chosen to analyse due to its complex structure and the completion of clash tests.

The initial phase of the case study involves a comprehensive examination of the project, specifically focusing on elucidating its implementation through Building Information Modelling (BIM). Subsequently, the second part of the case study offers an intricate emphasis on the roof design, encompassing its architectural, structural, and M.E.P components. This detailed analysis aims to define the constituents of the roof thoroughly, facilitating a more refined analysis of the clash detection processes among these elements and the roof clash detection procedures within the context of the KIA Terminal II project. The main objective of this case study is to discern and highlight the fundamental causes of clashes in practical scenarios, particularly within the scope of intricate and large-scale construction projects.

3.2.1. Project description

The Kuwait International Airport project was designed as an architectural landmark and a new gateway for the State of Kuwait (Figure 3.2). Once completed, it is planned to serve 13 million passengers per annum.

Figure 3.2. Location of Kuwait International Airport Terminal II project

The terminal building at Kuwait International Airport Terminal II features a unique triangular footprint (Figure 3.3) and reflects traditional architecture with the use of local materials. The terminal is built on 708,111 m^2 area, and each façade extends for 1.2 kilometres. The total roof area is 320.000 m^2, and the clear height is 25 meters in the central area of the project called the "hexagon".

Figure 3.3. Kuwait International Airport Terminal II project

The terminal building at Kuwait International Airport has three levels above ground, two mezzanine levels, and two underground levels, as indicated in Figure 3.4. Basement floors house technical support functions. The ground level houses technical support, and eight dedicated check-in desks are in the west section on the ground level for the crew's convenience. This ensures a smooth and separate process for crew members. The mezzanine floor, located above the ground floor, is also a technical support area. The first floor, or arrivals level, includes the gate lounge for arriving passengers. The second floor, or departures level, is where departing passengers can access the car park and transfer passenger facilities. The inner structure of the Kuwait International Airport Terminal II is designed to handle passenger check-in and baggage handling processes efficiently. The check-in area consists of 160 economy check-in desks in the central zones on Level +12.00, providing ample space for passengers to complete their check-in procedures. Additionally, 60 premium check-in desks are situated in the east and west sections on the same level, catering to passengers with premium services.

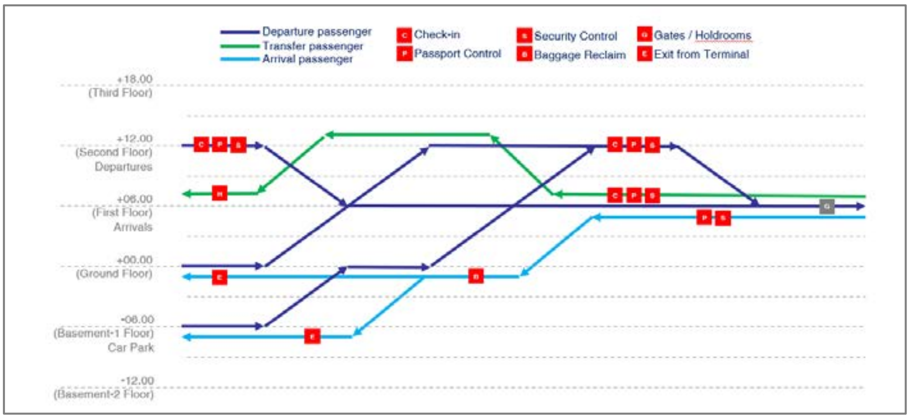


Figure 3.4. Levels and passenger flow diagram

The main construction elements of the terminal include a reinforced concrete raft foundation and superstructure, utilizing in-situ, precast pre-stressed, and post-tensioned techniques. The external facades are made of glass and consist of 75 bays, with sizes ranging from 45 meters wide by 38 meters high to 45 meters by 10 meters. The total glazed facade area is approximately 62,000 square meters.

The roof profile is derived from a sphere and extends to 60 meters beyond the facade line, providing shading to the facade, fixed links, and landside drop-off areas. A 45-meter-high roof covers the central portion of the terminal. The terminal's composite roof incorporates photovoltaic roof panels. The facility has approximately 116 elevators, 28 travelators, and 85 escalators to facilitate passenger movement. The MEP (Mechanical, Electrical, and Plumbing), baggage handling, and special systems are also integral to the terminal's functionality.

The tender package for the terminal includes construction, completion, furnishing, and maintenance work. The scope of the project includes the Terminal Building (TEB) and Ancillary Buildings, which are the Central Plant Building (CPB), Guard House (GH), Water Tank Building (WTB), Utility Tunnels (UTT), Switching Substation-1 (SSS-1), Switching Substation-2 (SSS-2) (Figure 3.5).

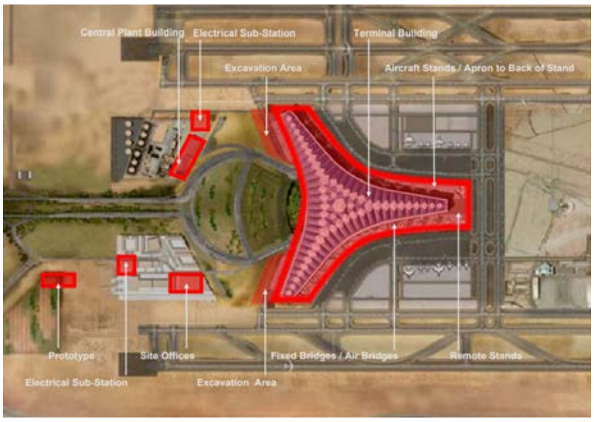


Figure 3.5. Tender package scope of works

3.2.2. Use of BIM and BIM execution plan of KIA terminal II

Considering the project size consisting of 760.000 m^2 with axillary buildings, the BIM model of the Kuwait International Airport II project is one of the largest BIM projects in the world. To create such a big BIM model for the Terminal Building and auxiliary buildings of the new Kuwait International Airport, more than 35 companies and 40 design teams collaborated to create 3 million model elements and 293 Revit models.

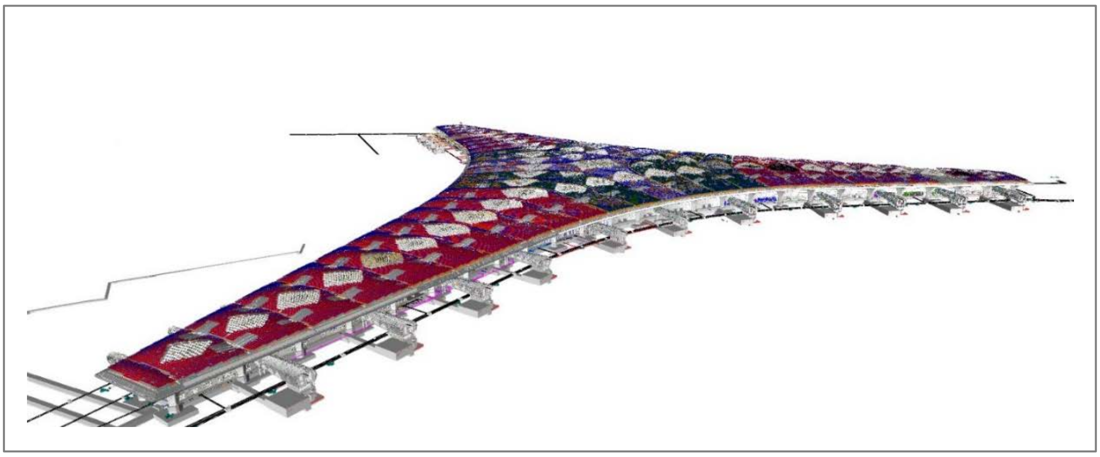


Figure 3.6. BIM model of KIA Terminal II Project

The BIM model for the Kuwait International Airport Terminal II Project (Figure 3.6) is planned to be utilized for several purposes, including design, coordination, documentation processes in the design, planning construction sequence and scheduling, detecting clashes to provide coordination between trades and disciplines, providing a 3D illustration of the building to the client and stakeholders, providing an as-built model to be used for facility management and maintenance.

Clash detection is a key component of the Building Information Modelling (BIM) process utilized in constructing the New Passenger Terminal II at Kuwait International Airport (Figure 3.7). Clash detection is accurately locating, examining, and notifying interferences in a 3D project model. In KIA, clash detection is used in the preconstruction and construction phases. It entails efficiently examining and documenting interferences in a three-dimensional project model comprising two or more shop models. In this project, a Clash matrix supports clash detection, enabling the identification of any interferences before construction.

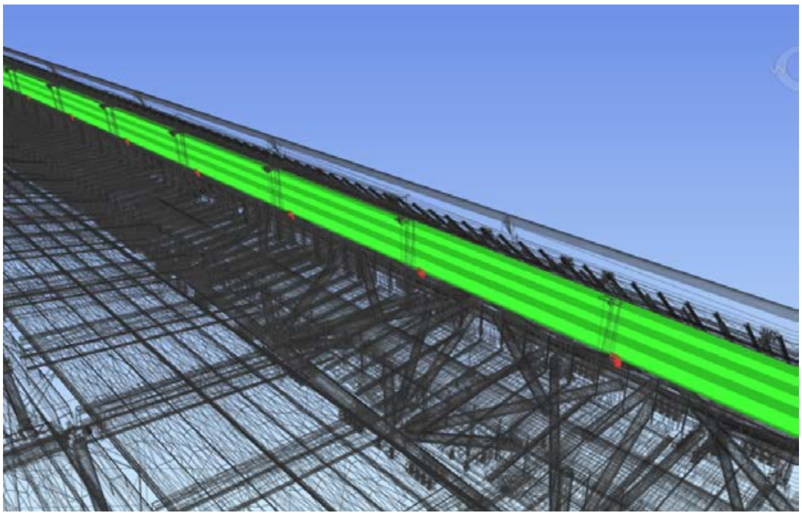


Figure 3.7. Clash detection example in Navisworks for KIA Terminal II Project

By adding a time parameter to the existing 3D BIM model, a 4D construction simulation is prepared by the BIM team (Figure 3.8). For the terminal, + 760000 sqm construction simulated. Project participants create their content according to the determined schedule. Special planning units are being created for the project, especially for the construction site teams for the work follow-up. In a business model where timing is so critical, being able to transfer this information to project models contributes to overall project management by ensuring that the ranking is determined during the project and construction process.

Figure 3.8. 4D construction simulation of KIA Terminal II

During the as-built stage, the BIM team has actively participated in the management, QAQC check, document control, and coordination of LIDAR files, ensuring the fulfilment of the standards outlined in the BIM Execution Plan (BEP). They have also directed design teams to incorporate the point clouds into their design models (Figure 3.9) and helped the survey team verify the quality of the point clouds.

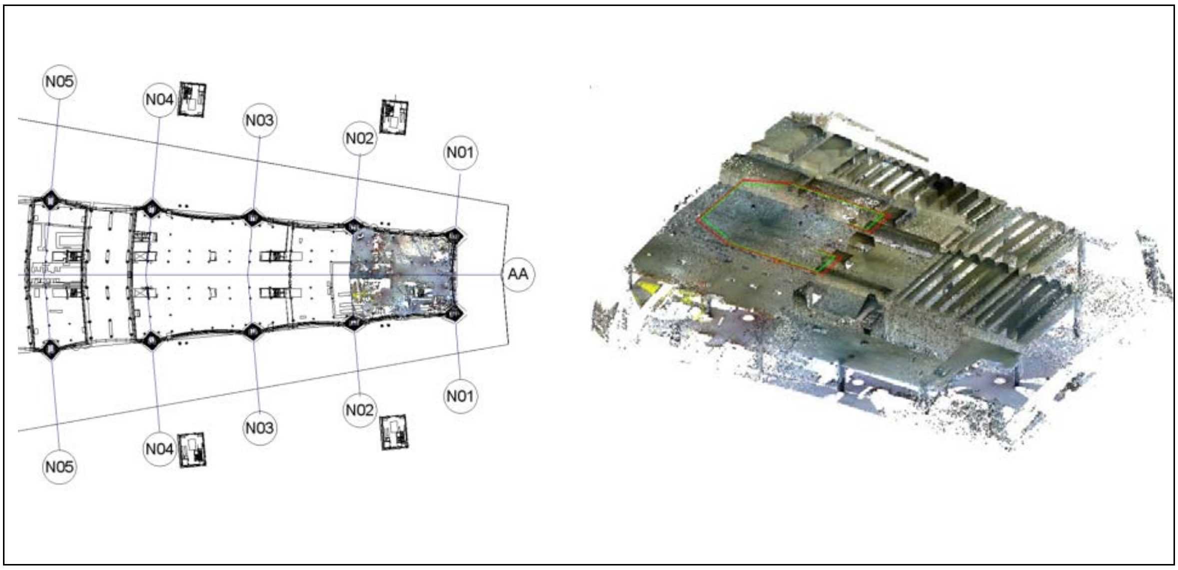


Figure 3.9. An example of LIDAR use in KIA Terminal II

Quantity extraction based on data management and specifications is part of applying 5D BIM in the context of the New Passenger Terminal II project at the Kuwait International Airport. This makes it possible to forecast station costs and compare building costs at different stages. A thorough understanding of the project's costs is provided by the 5D BIM process, which also aids in allocating resources and budget. The use of 7D BIM is related to asset maintenance and facility management. The data that different teams have added to the model allows for the best possible asset maintenance over its life, enhancing maintenance, conservation, and prevention.

The BIM management team has provided a BIM Execution Plan for Kuwait International Airport Terminal II. The main objective of the BIM Execution Plan is to give the project team precise direction regarding the roles of the team members, equipment, methods, and systems that will be employed in the Building Information Modelling (BIM) design, procurement, and construction of Kuwait International Airport's New Passenger Terminal II. The plan describes the precise scope of work, which includes producing a BIM/3D computer model of the terminal building and using data management systems and BIM tools. The plan also describes the project's information delivery strategy, standards, collaboration tools, and BIM approach. The overall goal of the BIM Execution Plan is to guarantee that BIM is implemented effectively and efficiently throughout the project.

A schematic workflow is presented in the BIM Execution Plan for the Kuwait International Terminal II Project, illustrating the main actions taken by all the parties involved to conclude with a coordinated and clash-free final BIM model (Figure 3.10).

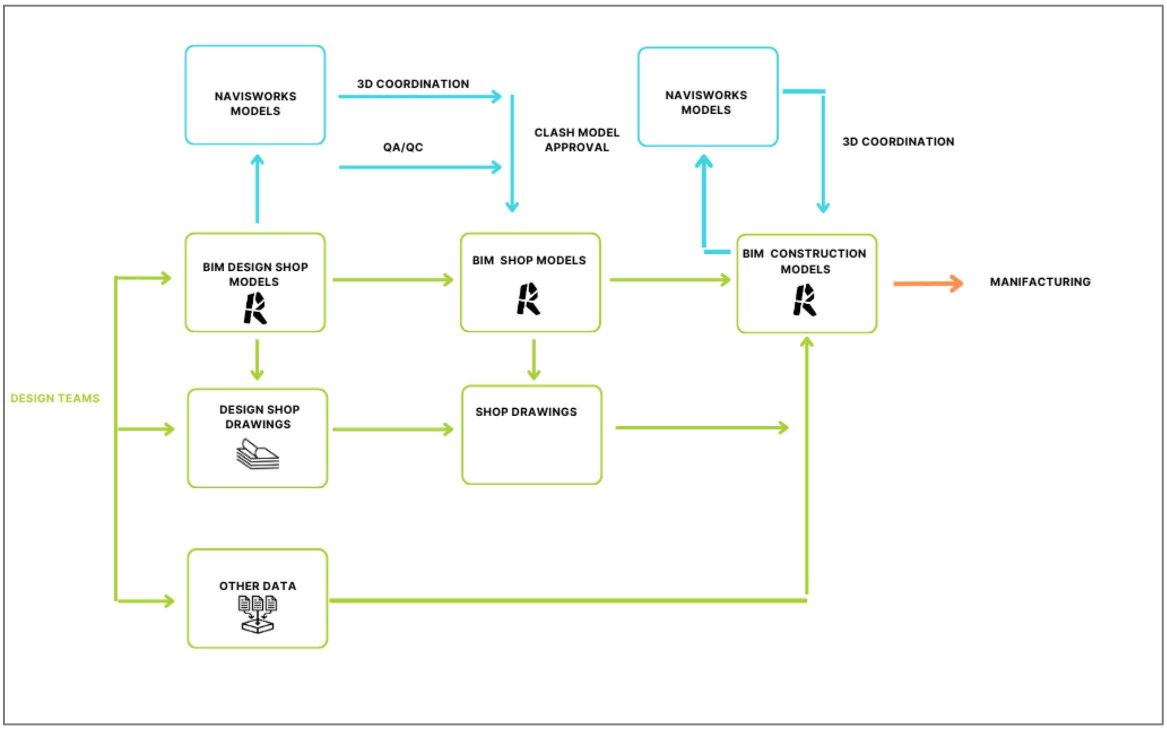


Figure 3.10. A schematic workflow for BIM execution plan

The project workflow of the Kuwait International Airport project includes multiple phases and procedures. In the scope of this thesis, the design shop stage and shop stage for models between the design and BIM teams of the KIA Terminal II Project are examined. The design shop stage can be defined as the phase starting with the coordination of the design stage. It is carried out by the design team for the coordination purposes of the design as per the tender requirements. The shop stage requires a more detailed model and serves to generate shop drawings for construction purposes. Shop models also contain the construction models per BEP requirements, which can be described as the fragmented models for a specific area containing very detailed geometry. Each stage is defined by the level of development required for modelled elements.

The first step in the workflow is to create the design information in a 3D model format utilizing discipline-based tools that facilitate data exchange, design collaboration, and analysis. At every project level, teamwork is prioritized, and the BIM model serves as the foundation for review, assessment, and feedback. The BIM model manages the work and facilitates commissioning, scheduling, costing, and logistics.

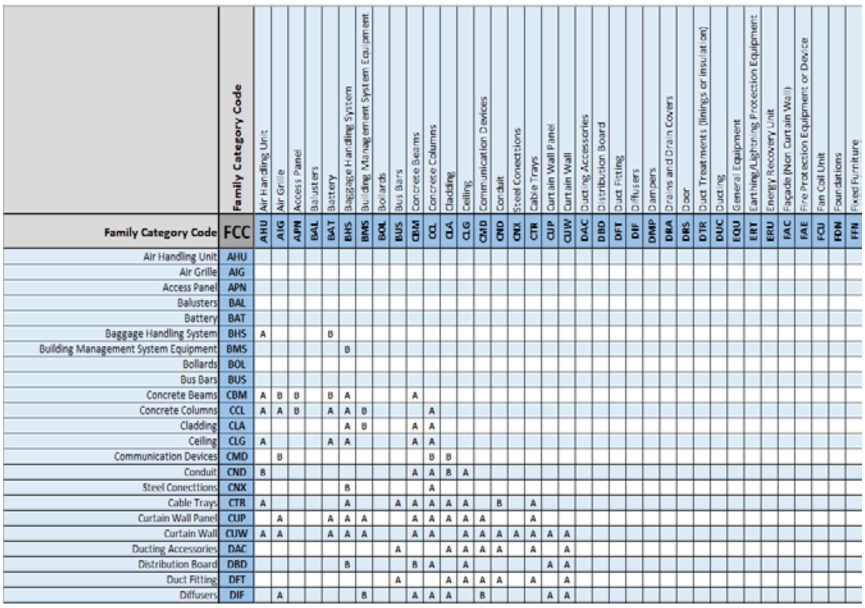
All functions and disciplines utilize the BIM model, and related work information is distributed to all parties from a common data environment (CDE). All teams add more data to the model at different stages to create a comprehensive project information resource for efficient handover.

Using BIM models and related data, the project workflow aims to guarantee effective coordination, collaboration, and control throughout the project's design, procurement, and construction phases. Autodesk Revit platform is used to develop the project BIM model, and Autodesk Navisworks is used for the 3D design review, clash detection, and intra and inter-disciplinary coordination. “Aconex” is selected as internet-based software for project Information management to store, process, and follow project information and submittals.

3.2.3. Clash detection and approval procedure of the KIA terminal II

A clash detection matrix finds clashes between various project elements, like architectural features, mechanical systems, and structural components in engineering and construction projects. It lessens mistakes, delays, and cost overruns by assisting project teams in identifying and resolving possible conflicts before construction.

Two Clash Detection matrices are developed for the detection clashes in the KIA Terminal II project: FCC vs. FCC and Item Group vs. FCC by the BIM team. A Family category code (FCC) can be explained as an object specification specifically defined for KIA Terminal II Project. The FCC represents the clash tests between sets of components categorized by FCC value vs FCC matrix (Figure 3.11). Clash tests between a set of components with the same FCC and a group of elements chosen based on predetermined criteria are made possible by the Item Group vs. FCC matrix.



	Family Category Code	Air Handling Unit	Air Grille	Access Panel	Balusters	Battery	Baggage Handling System	Building Management System Equipment	Bollards	Bus Bars	Concrete Beams	Concrete Columns	Cladding	Ceiling	Communication Devices	Conduit	Steel Conecttions	Cable Trays	Curtain Wall Panel	Curtain Wall	Ducting Accessories	Distribution Board	Duct Fitting	Diffusers	Dampers	Drains and Drain Covers	Door	Duct Treatments (linings or insulation)	Ducting	General Equipment	Earthing/Lightning Protection Equipment	Energy Recovery Unit	Façade (Non Curtain Wall)	Fire Protection Equipment or Device	Fan Coil Unit	Foundations	Fixed Furniture
Family Category Code	**FCC**	**AHU**	**AIG**	**APN**	**BAL**	**BAT**	**BHS**	**BMS**	**BOL**	**BUS**	**CBM**	**CCL**	**CLA**	**CLG**	**CMD**	**CND**	**CNX**	**CTR**	**CUP**	**CUW**	**DAC**	**DBD**	**DFT**	**DIF**	**DMP**	**DRA**	**DRS**	**DTR**	**DUC**	**EQU**	**ERT**	**ERU**	**FAC**	**FAE**	**FCU**	**FDN**	**FFN**
Air Handling Unit	AHU																																				
Air Grille	AIG																																				
Access Panel	APN																																				
Balusters	BAL																																				
Battery	BAT																																				
Baggage Handling System	BHS	A				B																															
Building Management System Equipment	BMS						B																														
Bollards	BOL																																				
Bus Bars	BUS																																				
Concrete Beams	CBM	A	B	B		B	A				A																										
Concrete Columns	CCL	A	A	B		A	A	B				A																									
Cladding	CLA						A	B			A	A																									
Ceiling	CLG	A				A	A				A	A																									
Communication Devices	CMD		B									B	B																								
Conduit	CND	B									A	A	B	A																							
Steel Conecttions	CNX						B					A																									
Cable Trays	CTR	A					A			A	A	A	A	A		B		A																			
Curtain Wall Panel	CUP		A			A	A	A			A	A	A	A	A			A																			
Curtain Wall	CUW	A	A			A	A	A			A	A		A	A	A	A	A	A	A																	
Ducting Accessories	DAC									A			A	A	A	A		A		A																	
Distribution Board	DBD						B				B	A		A					A	A																	
Duct Fitting	DFT									A			A	A	A	A		A		A																	
Diffusers	DIF		A					B			A	A	A		B				A	A																	

Figure 3.11. Clash matrix created for KIA Terminal II project (source; KIA BIM team)

Clashes are classified into two as per their degree of collision: ‘hard’ or ‘clearance’. For each clash type, clash tests are performed with different tolerance values. Indicating priority values as A or B enables the project team (as well as the BIM Coordinator) to quickly decide which components of one system should be modified to work with another system in a clash case.

Before the building process really begins, clash detection enables project teams to spot, stop, and resolve problems in the virtual model, which lowers costs, lowers the risk to the schedule, and lowers the likelihood of suggested change orders and RFIs. For a clash-free federated model, the clash approval process involves several steps shown in Figure 3.12.

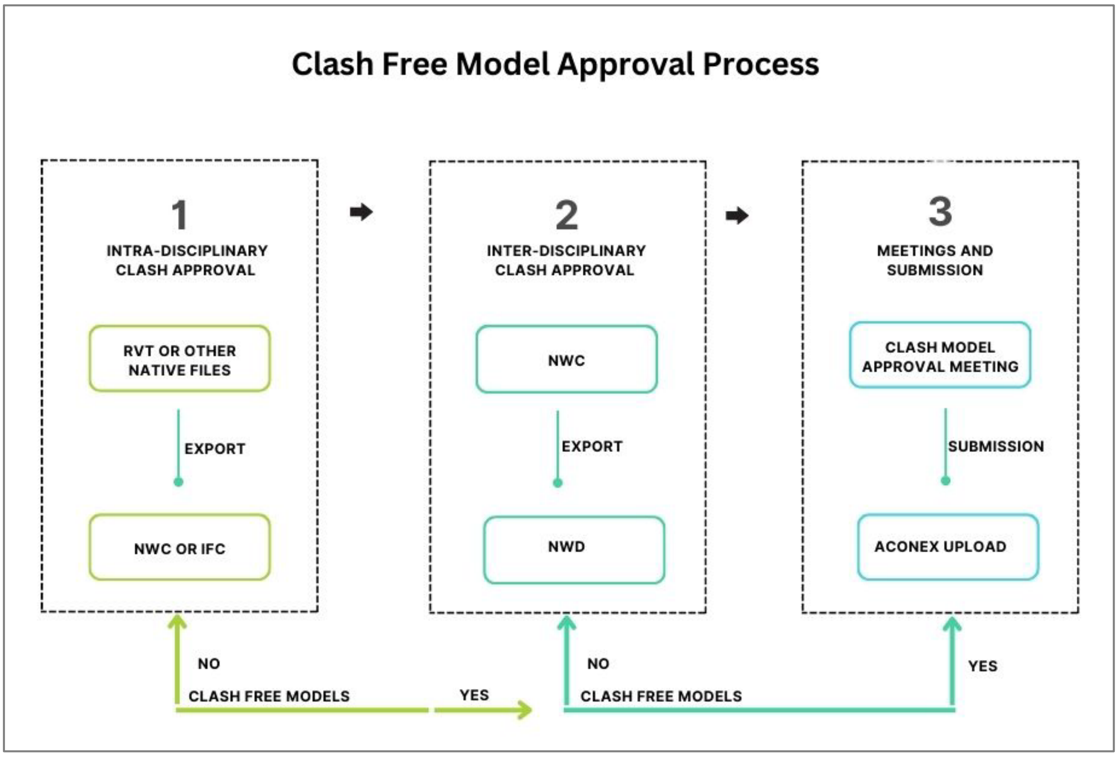
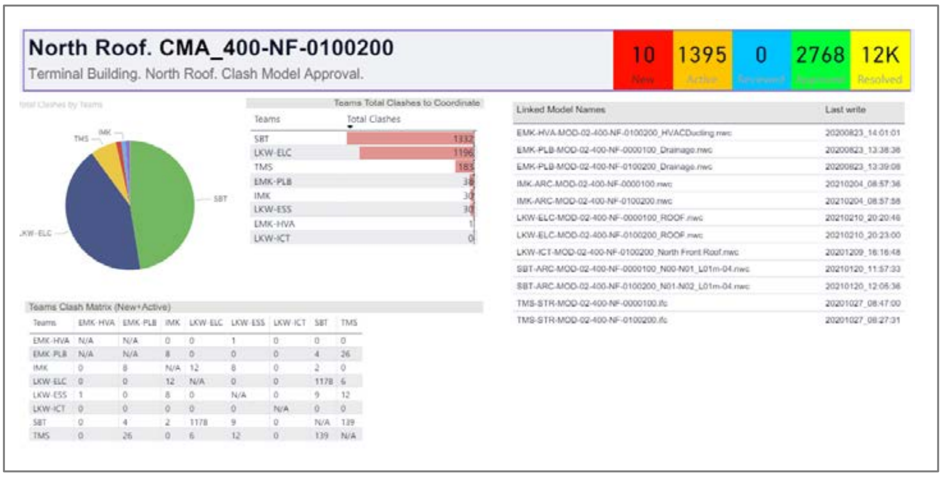


Figure 3.12. Clash model approval process

First, for an intra-disciplinary clash test process, subcontractors must ensure that their models contain no clash elements. To demonstrate this, they must complete their Intra-disciplinary clash matrix, which Navisworks then converts into clash tests. The matrix is used to configure the clash tests, indicating the type (hard or clearance) and tolerance. These clash tests are carried out inside their models to find conflicts within each subcontractor's discipline. After that, the inter-disciplinary clash test begins by combining the NWC files by contractors into a federated model in Navisworks. Clash tests are conducted to identify clashes between various models and are communicated to the contractor's design subcontractors to address and resolve clashes. A Clash Free Approval meeting is held after all clashes from the Intra-disciplinary and Inter-disciplinary Clash Tests are settled or accepted. The Navisworks (NWD) files are uploaded via transmittals with the appropriate revision markings, and the clash-free report(s) and model(s) are uploaded to Aconex if an agreement is reached.

When reporting on design clashes, the BIM team creates periodic clash detection reports (Figure 3.13.) and coordination meetings that include information such as.

- Classification of the clashes within each discipline. (For example, “Plumbing (MEP) vs. building frame (ARC)”)
- Location of the clashes as per zone and level
- Status of the clashes (active and unresolved or resolved).
- Priority of the clash (Normal, critical)
- the date that the clash was found.
- The subcontractor that the clash resolved was assigned to



North Roof. CMA_400-NF-0100200
Terminal Building. North Roof. Clash Model Approval.

10	1395	0	2768	12K
New	Active	Reviewed	Approved	Resolved

Teams Total Clashes to Coordinate

Teams	Total Clashes
SBT	1332
LKW-ELC	1196
TMS	183
EMK-PLB	38
IMK	30
LKW-ESS	30
EMK-HVA	1
LKW-ICT	0

Linked Model Names	Last write
EMK-HVA-MOD-02-400-NF-0100200_HVACDucting.nwc	20200823_14:01:01
EMK-PLB-MOD-02-400-NF-0000100_Drainage.nwc	20200823_13:38:36
EMK-PLB-MOD-02-400-NF-0100200_Drainage.nwc	20200823_13:39:08
IMK-ARC-MOD-02-400-NF-0000100.nwc	20210204_08:57:36
IMK-ARC-MOD-02-400-NF-0100200.nwc	20210204_08:57:58
LKW-ELC-MOD-02-400-NF-0000100_ROOF.nwc	20210210_20:20:46
LKW-ELC-MOD-02-400-NF-0100200_ROOF.nwc	20210210_20:23:00
LKW-ICT-MOD-02-400-NF-0100200_North Front Roof.nwc	20201209_16:16:48
SBT-ARC-MOD-02-400-NF-0000100_N00-N01_L01m-04.nwc	20210120_11:57:33
SBT-ARC-MOD-02-400-NF-0100200_N01-N02_L01m-04.nwc	20210120_12:05:36
TMS-STR-MOD-02-400-NF-0000100.ifc	20201027_08:47:00
TMS-STR-MOD-02-400-NF-0100200.ifc	20201027_08:27:31

Teams Clash Matrix (New+Active)

Teams	EMK-HVA	EMK-PLB	IMK	LKW-ELC	LKW-ESS	LKW-ICT	SBT	TMS
EMK-HVA	N/A	N/A	0	0	1	0	0	0
EMK-PLB	N/A	N/A	8	0	0	0	4	26
IMK	0	8	N/A	12	8	0	2	0
LKW-ELC	0	0	12	N/A	0	0	1178	6
LKW-ESS	1	0	8	0	N/A	0	9	12
LKW-ICT	0	0	0	0	0	N/A	0	0
SBT	0	4	2	1178	9	0	N/A	139
TMS	0	26	0	6	12	0	139	N/A

Figure 3.13. Clash model approval coordination reports

3.2.4. Roof clash detection and clash report analysis of KIA terminal II

Efficient detection and solving of clashes are related to successful coordination processes between all the disciplines involved in a project. The complexity and number of building systems in a facility impact how challenging the design coordination process is. Mechanical, electrical, and plumbing (MEP) coordination is considered one of the most difficult tasks encountered in the delivery of construction projects, according to construction industry professionals (Korman et al., 2003)

In practice, the roof of the KIA Terminal II is selected to identify the main causes of the clashes since it acts like a canopy where architectural, structural, and MEP equipment comes together within a complex roof design.

Roof design

One of the characteristic features of the Kuwait International Airport II project is its roof since it sits under a single large roof canopy. While the roof covers 320.000 square meters of area, the complexity of the design of the roof is not derived only from its size but from the composition of the many architectural elements: skylights, cladding, facade elements, etc.

The Y-shaped roof structure of the terminal has dimensions of about 1130 m by 977 m with a height of 25–55m (Figure 3.14). The primary supporting structure of the roof is constructed from up of post-tensioned cable stays and in-situ and precast concrete parts with internal tendons. A grid shell of a hybrid system of steel members and concrete components is put between the concrete elements. Several truss systems that support the grid shell also provide the lateral stiffening of the primary concrete structure.

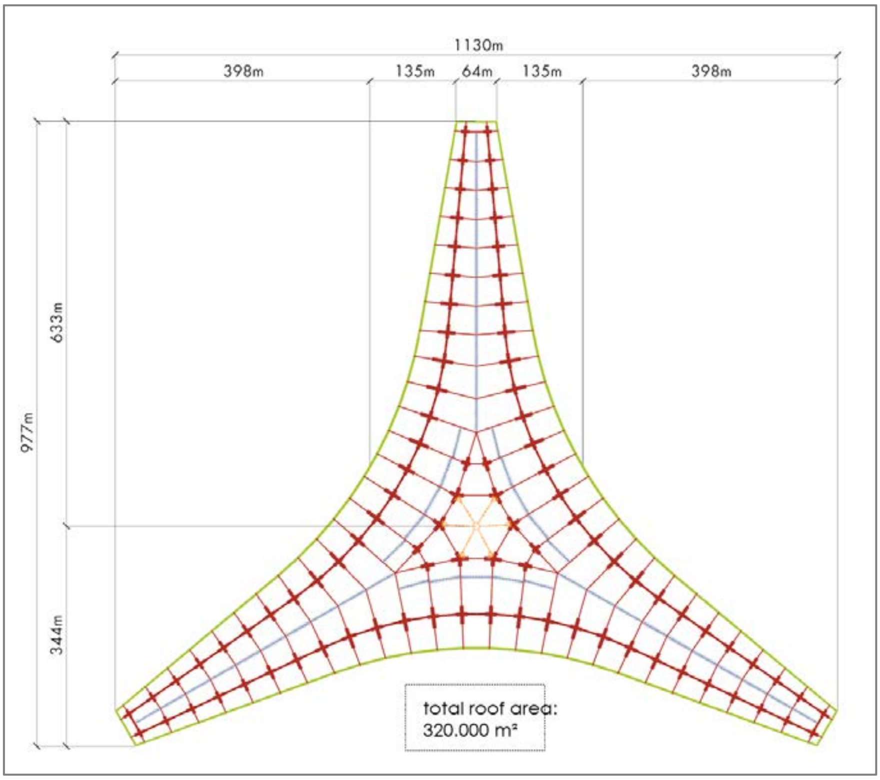
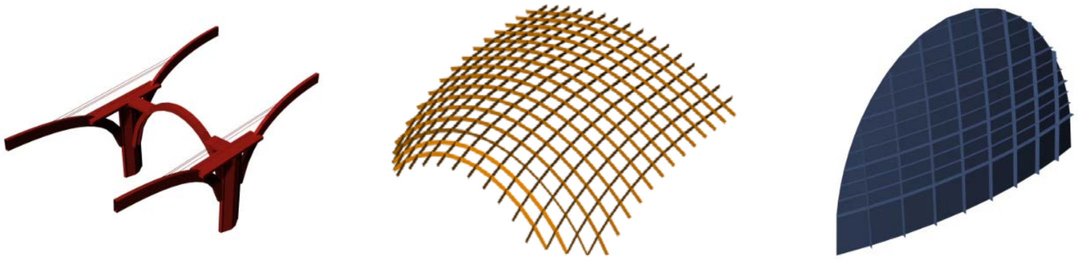


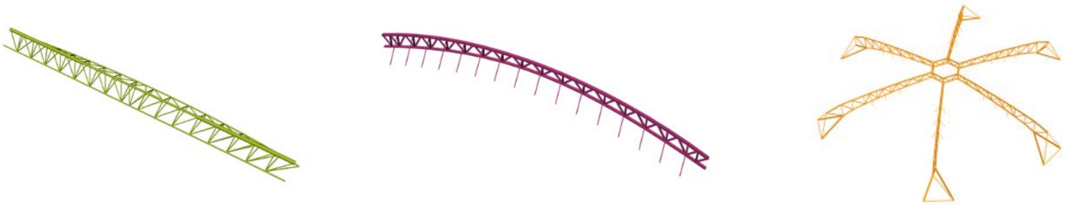
Figure 3.14. General layout and dimensions of the roof

With a free span of up to 120 meters, the primary roof structure is constructed from 90 in-situ roof columns and an intricate structure of prefabricated and pre-stressed arches. The 823 single prefabricated mega-elements that comprise the arch system have a maximum weight of 340 tonnes a piece. Due to the detailed placement of longitudinal rebars in numerous rows, stirrups, local reinforcements, tendons ducts, and many embedding plates, each prefabricated piece is a unique, complex assembly. These are the primary points of contact between all other structural components and reinforced concrete. They were put through a unique design process, which included customised design tools and parametric models.

The structure and facade system of the terminal roof is mainly divided into the components: the roof columns, the composite shell structure, shell cassettes, the trusses, the secondary roof structure, and the glass façade and roof cladding (Figure 3.15).



(a) Roof Columns (b) Grid Shell (c) Facade



(d) Edge Truss (e) Center Truss (f) Dome Truss

(g) Secondary Roof Structure (h) Shell Cassettes (i) Roof Cladding

Figure 3.15. Main components of the roof

The edge trusses are situated near the edge of the roof structure. Their primary role is to provide the roof structure with more rigidity in vertical and horizontal directions. The center trusses provide extra vertical support for the shell cassettes and lateral stiffness for the entire roof structure. They are situated at the centrelines of the roof structure.

The dome truss, situated in the middle of the roof structure, creates lateral rigidity for the entire roof structure and extra vertical support for the shell cassettes. The six single trusses that jointly make up the arched-shaped dome truss are connected virtually in a circle in the center.

The ribs and spines are connected by a composite steel/concrete shell, which is also supported by several truss systems. One of the great ways to build intricately shaped, wide-span buildings is by using reinforced concrete shells. Wide expanses may be created with the least amount of material by triggering their membrane-like behaviour through the definition of a form (Blandini & Nieri). To comply with the organic characteristics of the design intent, the shell structure follows the double-curved geometry. To form the grid cell, various steel boxes encapsulating the concrete, called 'shell cassettes, ' are brought together.

The roof cladding includes insulated metal standing seam roofs, non-insulated roofs, roof nose cladding, gutter system, and skylight funnel system. Pressure-resistant and soft insulation are combined to insulate the roof's standing seam cladding system. The roof nose cladding comprises precast concrete elements with hidden back-fixing stainless-steel brackets. It includes a stainless-steel ladder to access the lower gutter. The gutter system is composed of the main gutters and the nose gutters, both of which are designed to be walkable. The primary gutter is an insulated gutter supported by a secondary steel structure. Another non-insulated gutter, the nose gutter, is attached to a trapezoidal sheet fastened to the secondary steel structure. On top of the roof, 8.000 skylights are placed to combine artificial light fixtures with daylight. The gold tone claddings of the funnels reflect sunlight inside the terminal.

Close-out analysis

This section examines close-out reports for the KIA terminal II roof to identify causes of clashes. The main objective of the close-out report is to document the current state of the effectiveness of the project teams concerning the Coordination Model Approval (CMA) procedure of the roof and to point out clashes and problems in the coordinating models and emphasize their necessity for solutions.

By using Navisworks, the BIM team performed the automatic clash detection. For the clash detection tests, the roof is examined using 40 NWC models and 503 files for clash model approvals. The clash detection system of the terminal building is divided into sections for planning and construction-related purposes. NWD models developed for clash detection must be generated following these divisions. The roof of the project is broken down into four major sections: the east and west wings and the central dome. These parts are divided into zones between grids, such as 01-02, 02-03, etc. Each wing has been broken into 12 different models for detection tests, and the central dome is divided into four models (Figure 3.16).

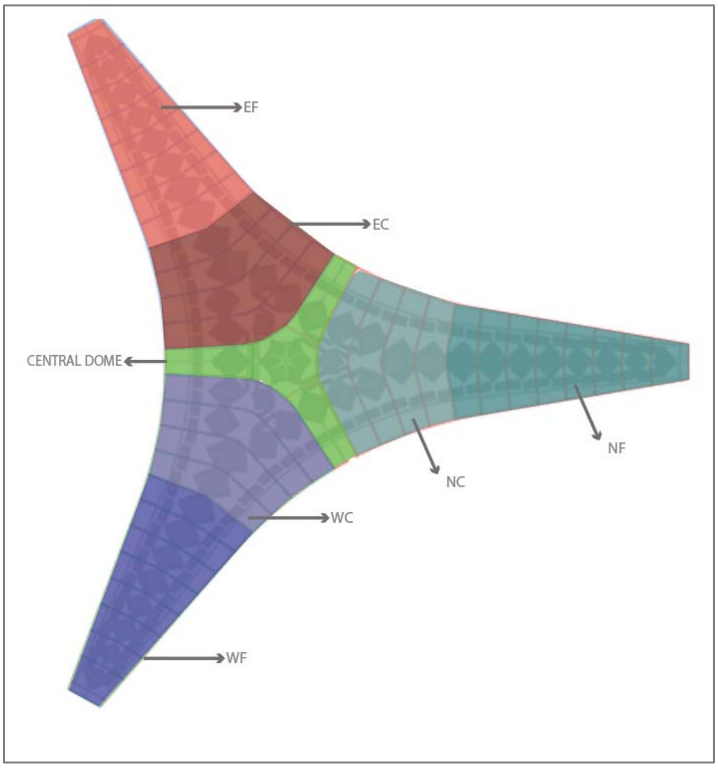
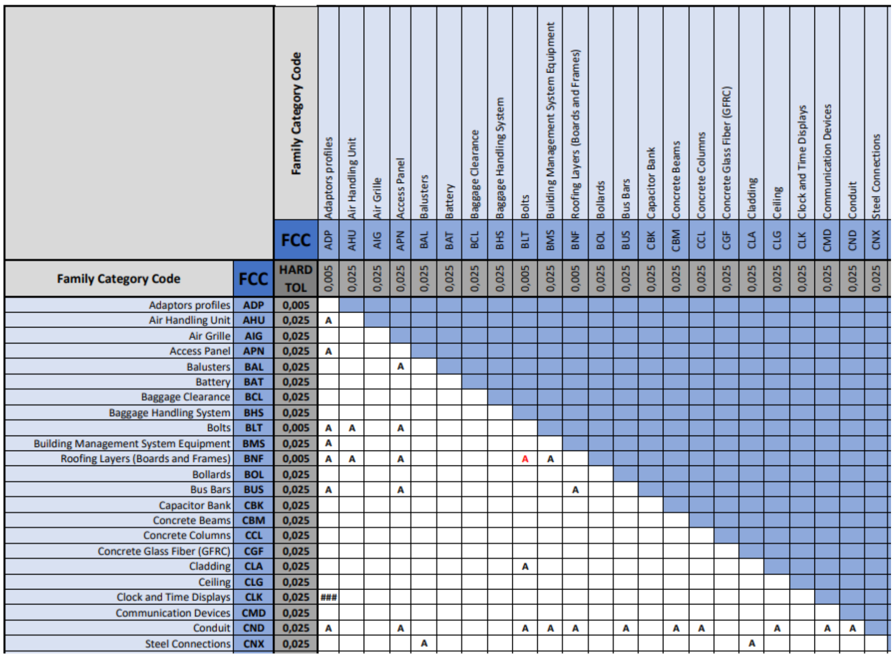


Figure 3.16. Model breakdown structure of the roof of KIA

As previously explained in section 3.2.3, the clash matrix for the roof is created based on FCC (Family Category Code) vs. FCC. As illustrated in Figure 3.17, this matrix includes a comprehensive overview of the various categories and equipment provided by the broad Family Category Code list, which covers a wide range of components like architectural columns, air handling units, cladding, ceilings, lighting fixtures, sanitary fixtures, steel beams, and much more. In addition to offering a comprehensive list of Family Category

Codes essential for efficiently managing the wide range of construction and equipment elements within the terminal, it offers an organized method for detecting and coordinating clashes.



		Family Category Code	Adaptors profiles	Air Handling Unit	Air Grille	Access Panel	Balusters	Battery	Baggage Clearance	Baggage Handling System	Bolts	Building Management System Equipment	Roofing Layers (Boards and Frames)	Bollards	Bus Bars	Capacitor Bank	Concrete Beams	Concrete Columns	Concrete Glass Fiber (GFRC)	Cladding	Ceiling	Clock and Time Displays	Communication Devices	Conduit	Steel Connections
		FCC	ADP	AHU	AIG	APN	BAL	BAT	BCL	BHS	BLT	BMS	BNF	BOL	BUS	CBK	CBM	CCL	CGF	CLA	CLG	CLK	CMD	CND	CNX
Family Category Code	**FCC**	**HARD TOL**	0,005	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,005	0,025	0,005	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025
Adaptors profiles	**ADP**	**0,005**																							
Air Handling Unit	**AHU**	**0,025**	A																						
Air Grille	**AIG**	**0,025**																							
Access Panel	**APN**	**0,025**	A																						
Balusters	**BAL**	**0,025**				A																			
Battery	**BAT**	**0,025**																							
Baggage Clearance	**BCL**	**0,025**																							
Baggage Handling System	**BHS**	**0,025**																							
Bolts	**BLT**	**0,005**	A	A		A																			
Building Management System Equipment	**BMS**	**0,025**	A																						
Roofing Layers (Boards and Frames)	**BNF**	**0,005**	A	A		A					A	A													
Bollards	**BOL**	**0,025**																							
Bus Bars	**BUS**	**0,025**	A			A							A												
Capacitor Bank	**CBK**	**0,025**																							
Concrete Beams	**CBM**	**0,025**																							
Concrete Columns	**CCL**	**0,025**																							
Concrete Glass Fiber (GFRC)	**CGF**	**0,025**																							
Cladding	**CLA**	**0,025**									A														
Ceiling	**CLG**	**0,025**																							
Clock and Time Displays	**CLK**	**0,025**	###																						
Communication Devices	**CMD**	**0,025**																							
Conduit	**CND**	**0,025**	A			A					A	A	A		A		A	A			A		A	A	
Steel Connections	**CNX**	**0,025**					A													A					

Figure 3.17. Clash detection matrix roof of KIA (source; KIA BIM team)

The clash detection reports classify detected clashes into five categories: new, active, reviewed, approved, and resolved, according to their clash resolution status. `New clashes` refer to identified clashes with the last updates on the models. `Active clashes` represent the clashes the subcontractors have not reviewed yet. Reviewed clashes represent clashes investigated by a responsible party and awaiting arrangement by other responsible parties. Approved clashes refer to false positives or clashes that are not real, while resolved clashes refer to coordination between teams and resolution. In the close-out reports, a total of 40 models are analysed, a total of 1128757 clashes were identified, and 1020149 of the clashes were resolved. Clash data obtained from the models is shown in Table 3.1. A clash-free model was identified by analysing total active and resolved clashes. The summary of new, active and reviewed clashes is considered as `total active` clashes. The sum of approved and resolved clashes is defined as resolved clashes. As per the last version of the clash test (v290), the roof coordination models were recorded as not clash-free, whereas %91.78 of the clashes were resolved.

Table 3.1. Total identified clashes for the roof

MODEL NAME		New	Active	Reviewed	Approved	Resolved
East Center	EC-09-10	0	7651	0	1038	10983
	EC-10-11	7	4023	4435	1239	11588
	EC-11-12	10	6329	7061	1351	13045
	EC-12-13	3	7577	7091	1367	14307
East Front	EF-01-02	0	2003	2792	90	8800
	EF-02-03	0	2290	2292	720	8626
	EF-03-04	0	1751	3168	770	7119
	EF-04-05	0	1813	3238	813	7453
	EF-05-06	0	1179	1836	4269	8409
	EF-06-07	0	900	1263	4625	6236
	EF-07-08	0	1988	1238	3837	9640
	EF-08-09	0	2253	479	5520	10951
North Center	NC-09-10	1	22	247	7614	27435
	NC-10-11	7	4023	4435	1239	115888
	NC-11-12	10	6329	7061	1351	13045
	NC-12-13	11	660	457	12875	48252
North Front	NF-01-02	0	7	14	4929	20249
	NF-02-03	0	252	38	5290	20283
	NF-03-04	0	0	10	5423	24356
	NF-04-05	0	42	18	6069	17040
	NF-05-06	0	88	71	6242	28554
	NF-06-07	0	31	74	6058	26352
	NF-07-08	0	1410	44	6198	28263
	NF-08-09	0	1137	45	6910	20629
West Center	WC-09-10	0	55	57	8379	18620
	WC-10-11	5	233	65	8374	18683
	WC-11-12	5	355	80	12145	35653
	WC-12-13	1	380	192	14708	37358
West Front	WF-01-02	0	129	98	4223	9451
	WF-02-03	0	30	37	5541	10353
	WF-03-04	0	2	24	5891	11835
	WF-04-05	1	6	0	5906	11749
	WF-05-06	6	37	12	7590	13480
	WF-06-07	15	23	45	6471	19945
	WF-07-08	4	71	8	5817	14433
	WF-08-09	2	31	2	7407	14505
Central Dome	XX-13-13-0	7	212	1223	4308	35934
	XX-13-13-1	13	41	867	4654	19273
	XX-13-13-2	4	38	1883	5483	20615
	XX-13-13-3	17	326	752	5509	12516

Figure 3.18 shows the total active and resolved clash quantities according to zones. The analysis shows that each zone has varying clashes and progress in resolving them. The data provided indicates that the West Front zone of the project has achieved a near-perfect resolution rate for clashes, with almost 100% of the identified clashes being resolved. This is a significant achievement and suggests that the teams working on this zone have been highly effective in their clash detection and resolution processes. Following closely behind, the West Center and North Front zones have a clash resolution percentage of 99%, indicating a high level of coordination and attention to detail in this area. The Central Dome has a resolution percentage of 95%. This may suggest that the complexity of the dome has presented some challenges in clash resolution, but overall, the teams have managed to address most issues. The North Center zone has a resolution rate of 91%. The East Front zone has a resolution percentage of%74 and East Center has of 55%, which is the lowest among the zones listed.

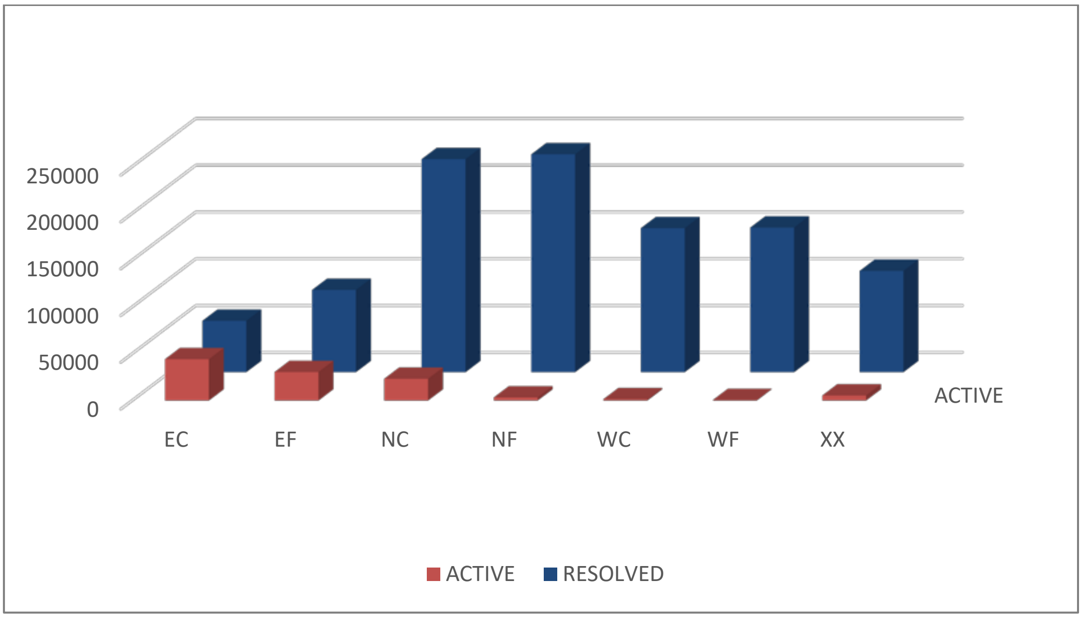


Figure 3.18. Total active and resolved clashes as per zones

For a detailed analysis to deeply understand the differences in the total active and resolved clashes, two CMA models are selected as EC-12-13 and WC-12-13 (Figure 3.19.). In terms of architectural and structural design, these two zones are almost mirrored. Architectural, structural, and mechanical works in these two areas are contracted by the same subcontractors.

Although these similarities in terms of design and subcontractors, these two areas illustrate a big difference in terms of total active and total resolved clashes, as shown below. For the EC area between the 12th and 13th axis, a total of 30345 clashes are detected, and only 52% of them are resolved by the stakeholders. In the WC area on the same axis, 99% of the clashes are resolved out of the 52.639 total identified clashes.

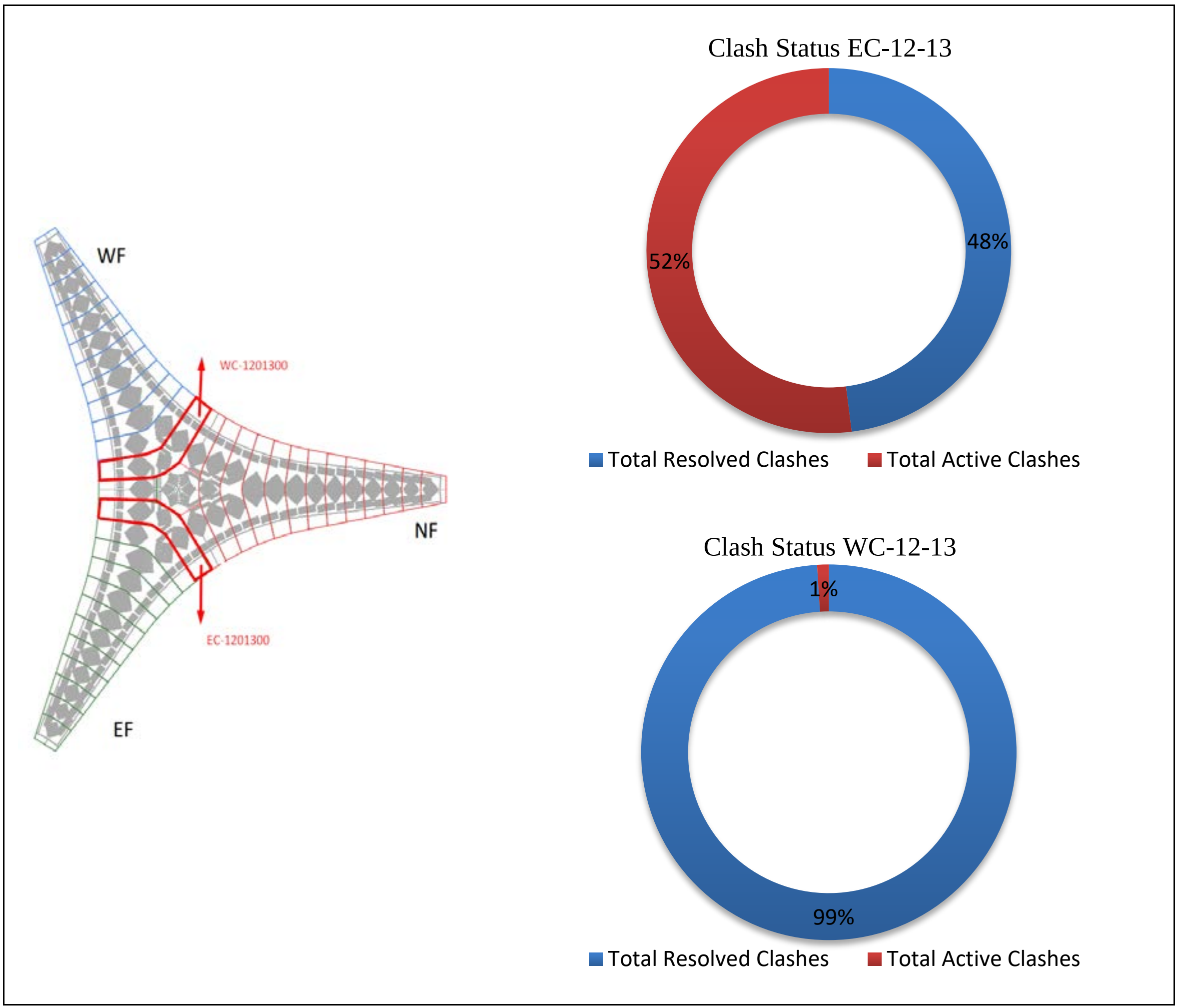


Figure 3.19. Comparison of resolved clash between EC-12-13 and WC-12-13

As indicated earlier, the clash tests for the KIA project were divided into two distinct clash detection matrices: FCC (Family Category Code) vs FCC and Item Group vs FCC. According to the FCC vs FCC matrix of roof clashes, each stakeholder is expected to declare their FCCs correctly for each element in their models. *The QA/QC (Quality Assurance/ Quality Control) status of the models* is an important factor for clash detection because low QA/QC status may result in clashes are not being identified. For the clash tests, the elements with incorrect FCC are defined as unofficial, those with correct FCC but missing from the stakeholder sheet are undeclared, and elements without any representation in the clash matrix are considered missing. Total missing, ok, undeclared, unofficial and unpresented FCCs for EC-12-13 and WC-12-13 are shown in Table 3.2.

Table 3.2. Comparison of FCC quality for EC-12-13 and WC-12-13

	EC-1201300	Missing	Ok	Undeclared	Unofficial		Unpresented
EC-12-13	ARC	212	9125	21164	213	0	212
	SUB-ARC	0	4790	0	0	0	0
	SUB-ARC 2	9	25641	74	0	0	9
	SUB-STR	81	139966	134	0	0	81
	SUB -STR 2	0	27869	0	0	0	0
	SUB-HVA	8	13446	0	0	0	8
	SUB-PLB	0	18004	0	0	0	0
	ELC	0	33222	0	0	0	0
	ICT	522	4552	395	0	444	522
	SUB-BMU	0	1	0	0	0	0
WC-12-13	ARC	2	8979	20542	259	0	2
	SUB-ARC	0	4976	0	0	0	0
	SUB-ARC 2	4	20154	72	0	0	4
	SUB-STR	73	139992	134	0	0	73
	SUB -STR 2	0	27957	0	0	0	0
	SUB-HVA	0	19152	0	0	0	0
	SUB-PLB	0	14207	0	0	0	0
	ELC	0	28890	0	0	0	0
	ICT	38	3574	558	0	773	38
	SUB-BMU	0	1	0	0	0	0

Note: To ensure the confidentiality of the companies involved, each firm has been assigned a unique code that corresponds to related discipline

Based on the data presented in Table 3.2, teams such as SUB-ARC, SUB-STR 2, SUB-HVA, ELC, and SUB-PLB have submitted XML files containing models where the majority of elements are marked with a status of "OK," signifying the correct application of Family Category Codes (FCCs). This likely leads to a more accurate and efficient clash detection process, as elements can be correctly identified and coordinated. The quality of the models provided by these teams is low, with many elements missing FCCs or having unofficial FCCs. This lack of proper FCC usage can lead to inaccuracies in the clash detection process, as elements may not be correctly identified or coordinated.

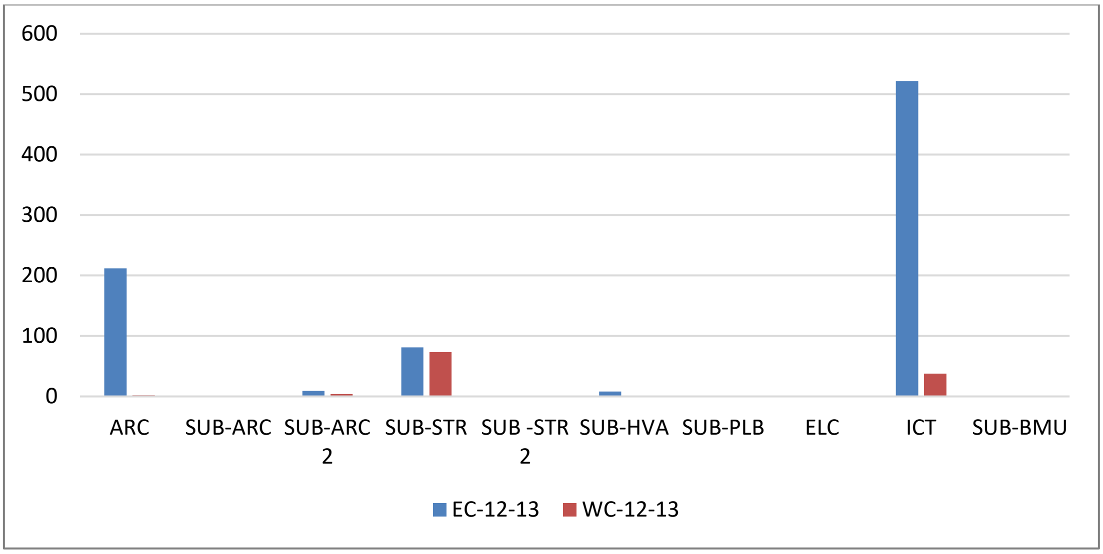


Figure 3.20. Comparison of missing FCCs between EC-12-13 and WC-12-13

Figure 3.20 shows the missing FCCs in the models for EC-12-13 and WC-12-13 to indicate the effect of correct FCC declaration for the clash tests. When elements lack the appropriate FCC, they are not considered during clash tests. This omission can result in elements being overlooked in the clash coordination process, which may lead to inaccuracies and inefficiencies. The figure indicates that the ARC and ICT teams have a higher number of elements without the correct FCCs in the EC-12-13 model, contributing to unresolved clashes.

This situation shows the importance of ensuring that all elements within a model are assigned the correct FCCs. Without this level of detail, the clash detection process is compromised, and the potential for errors increases, which can have significant implications for the construction process and project outcomes. Therefore, teams must review and correct FCC assignments to facilitate a more accurate and efficient clash detection process.

Incomplete or outdated NWC/IFC Files can result in clashes when outdated information is used for coordination. Lack of coordination among teams working in isolation can lead to clashes if one team makes substantial changes without informing others to update their models accordingly. This disconnected approach can result in conflicts due to teams not updating their models with the modifications made by other parties.

As it is shown in below Figure 3.21 only 4 teams updated their models for the close-out clash test. This lack of model updates negatively impacts the clash detection process and delays the resolution of clashes. It indicates a lack of coordination and progress between the teams involved.

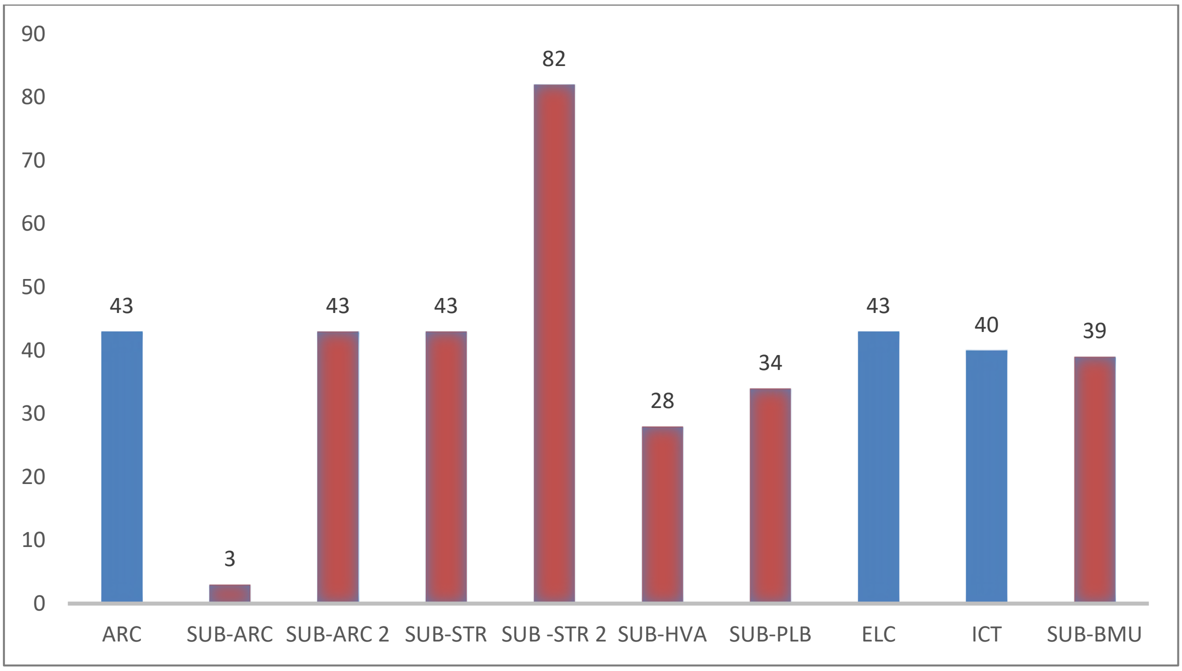


Figure 3.21. Comparison of updated and not updated models by subcontractor

As it is mentioned in the clash detection processes when clashes are identified they are assigned to various project trades._*Progress of total active clashes* is shown in Figure 3.22 and 3.23 for each stakeholder for EC-12-13 and WC-12-13. From the comparison, it can be observed that some teams have made significant progress in resolving clashes and reaching a clash-free status. For example, ARC and SUB-ARC teams have resolved all clashes and achieved a clash-free status for both zones and all teams contributed to the clash resolution process in the WC-12-13. On the other hand, teams like SUB-ARC 2, SUB-STR, SUB-

HVA, ICT, SUB-BMU, and ELC have a high number of new and active clashes, indicating a lack of progress in resolving these clashes in the EC-12-13.

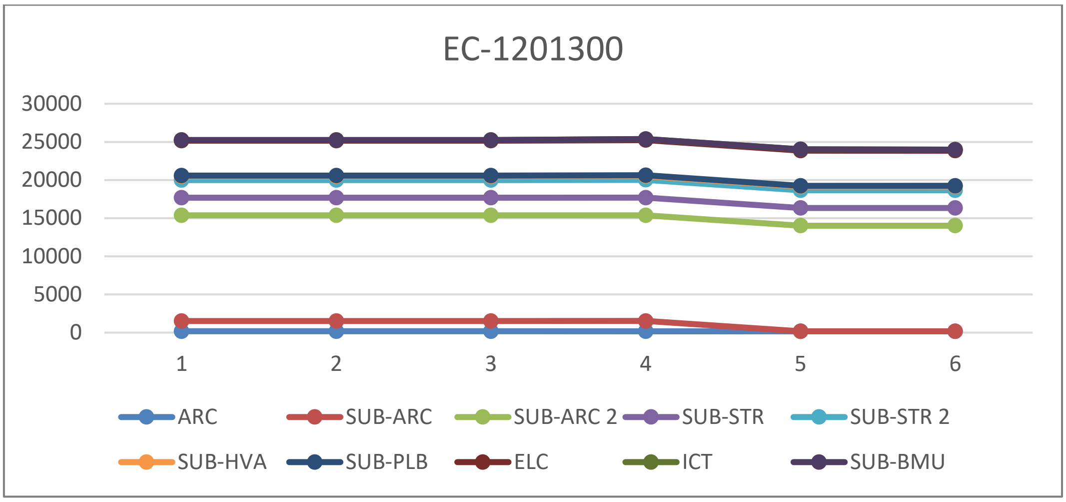


Figure 3.22. Progress of total active clashes for EC-12-13

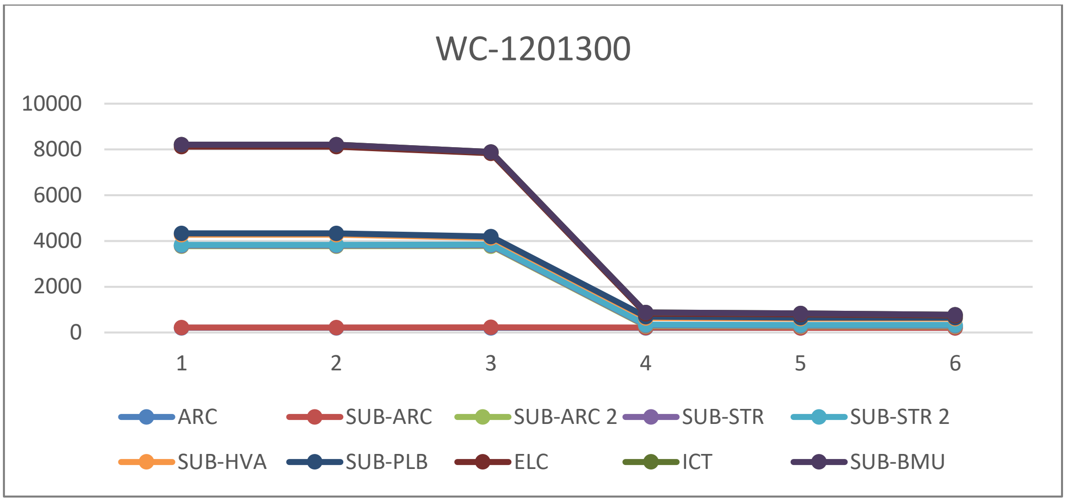


Figure 3.23. Progress of total active clashes for WC-12-13

Uploading XML files is essential for effective clash detection. These files store critical data on reviewed clashes, enabling design teams to resolve identified issues during coordination. The Clash Matrix utilizes XML files to pinpoint clashes between model elements, with settings and tests based on FCCs selected by teams. Therefore, *lack of XML file submission* could result in coordination problems and clashes in the final design. The quantity of uploaded XML files varies among design teams, tailored to their specific needs in below Figure 3.24. It is indicated that only SUB-ARC, SUB-ARC 2 and ELC teams provided XML files for clash resolution

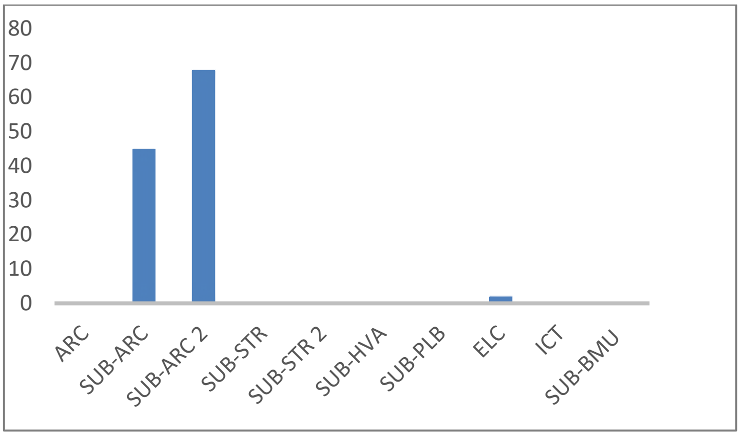


Figure 3.24. XML file submission by subcontractors

Conflicts that have been examined by one responsible party and are awaiting resolution by additional responsible parties are referred to as reviewed conflicts. These conflicts show that one of the opposing teams has made some progress.

Because they indicate unresolved disputes between components in the coordination models, *reviewed clashes* might lead to clashes. Conflicts that are examined but not resolved indicate a difference of opinion or disagreement between the design teams on how to handle the conflict. The comparison of the total reviewed clashes for EC-12-13 and WC-12-13 is shown in Figure 3.25.

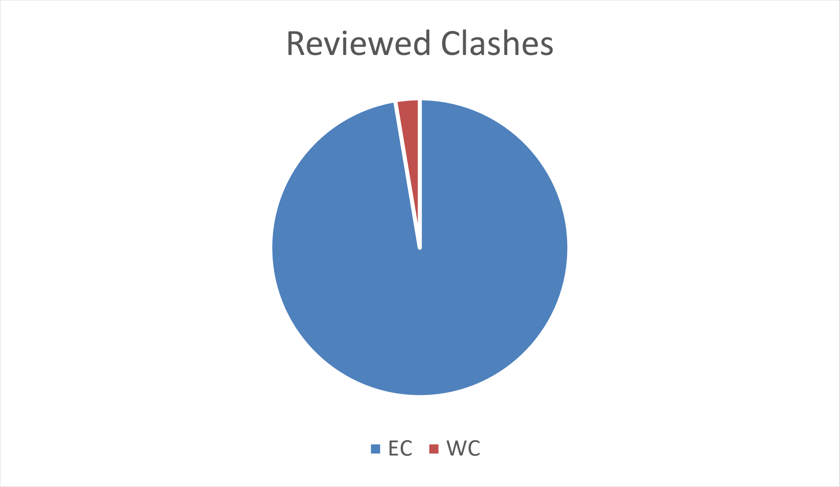


Figure 3.25. Comparison of total reviewed clashes in EC-12-13 and WC-12-13

With the analysis of the clash test reports and close out report analysis total five more cause of clashes are detected as illustrated in Table 3.3. Most of the identified clashes (for out of five) is categorized as process related causes while one of them is categorized as people related.

Table 3.3. Causes of clashes identified through case study

Category	Cause of Clash
Process Related	QA/QC status of the models
People Related	Incomplete or outdated NWC/IFC files
Process Related	Progress of total active clashes
Process Related	Lack of XML file submission
Process Related	Reviewed clashes

3.3. Delphi Survey

The Delphi survey technique was characterised as an interactive research approach to achieve a common assessment of a group of experts. The difference between the Delphi method and other structured survey techniques is that it offers feedback in multiple rounds (Figure 3.26) to gather a consensus (Olawumi & Chan, 2018).

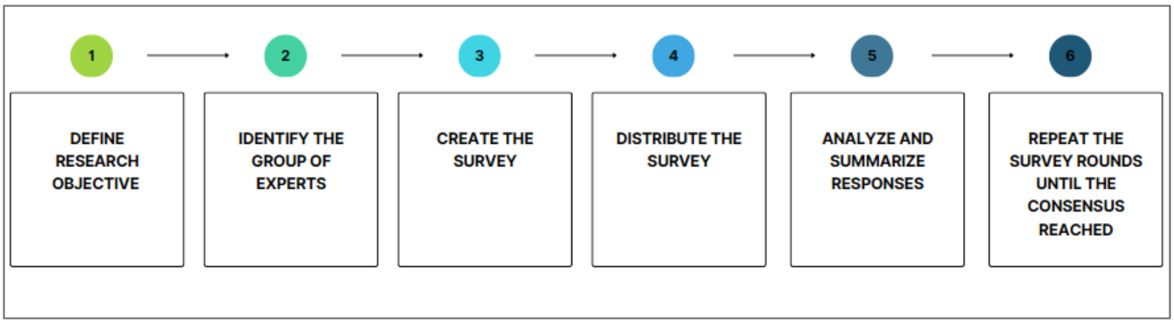


Figure 3.26. Steps of the Delphi survey

In this research, this technique is chosen to rank and prioritise the causes of clashes to avoid and minimise the clash occurrence before the construction process, and the ethics committee's permission is taken with E-77-082166-302.08.01-912489. The causes were obtained through a comprehensive literature review, and a case study by analysing the clash detection reports for the project roof. The literature review identified various reasons for clash occurrence, and the case study provided additional insights into the main reasons for clashes based on the analysis of the clash detection reports. To examine the real causes of the clashes in the process of clash detection, 32 causes were analysed by experts by benefiting from the Delphi technique. Then, the experts were invited to a two-round Delphi survey to rank the causes of clashes. The Delphi survey design employed participatory action research where the experts were embedded within the KIA Terminal II project in the BIM or clash detection processes.

The causes obtained from both literature, case studies, and pilot surveys are collected and categorised for ease of data collection and analysis in the Delphi survey, allowing for a more structured and comprehensive understanding of clash occurrences. These four pillars provide a framework for understanding and addressing clashes in the BIM environment, considering the processes, people, products, and platforms involved.

The expertise of the experts participating in the Delphi survey is crucial in obtaining trustworthy and accurate results. The selection criteria should be carefully set to guarantee that they have expertise and understanding in the field (Özkan, 2021). In this study, participants of the survey chosen from the KIA project, as shown in Table 3.4, have different responsibilities from the different disciplines to achieve a consensus between the different perspectives.

Table 3.4. Profile of the Delphi survey participants

	Profession	Title	Education Level	Experience Profession	Experience in KIA
P1	Architect	BIM Manager	Master`s Degree	19	5
P2	Architect	Arch Design Manager	Master`s Degree	16	7
P3	Architect	Arch Design Manager	Bachelor`s Degree	20	7
P4	Architect/ Façade Specialist	Façade and Roof Design Manager	Master`s Degree	20	4
P5	Architect	Roof Arch BIM responsible	Bachelor`s Degree	8	3
P6	Structural Engineer	Structural Design Manager	Master`s Degree	22	6
P7	Structural Engineer	Senior Structural Engineer	Bachelor`s Degree	20	5
P8	Structural Engineer	Senior Structural Engineer	Bachelor`s Degree	10	5
P9	Mechanical Engineer	Mechanical Design manager	Bachelor`s Degree	17	7
P10	Mechanical Engineer	Mechanical BIM responsible	Bachelor`s Degree	3	3
P11	Elv& Bms Manager	Electrical Engineer	Bachelor`s Degree	12	5
P12	Electrical Engineer	Electrical BIM Responsible	Bachelor`s Degree	12	5
P13	ICT Engineer	ICT BIM Responsible	Bachelor`s Degree	11	6

3.3.1. Pilot survey

A pilot survey was sent to three experts working on the KIA project to validate the structure of the Delphi survey and gather their opinions on the causes of clashes according to their experiences. Table 3.5 indicates the profile of the pilot survey participants.

Table 3.5. Participants of the pilot survey

	Title	Profession	Experience in Profession	Experience in KIA
P1	BIM Manager	Architect	19	5
P2	Design Manager	Architect	16	7
P5	BIM Responsible for Roof Design	Architect	8	3

According to the result of the pilot survey nine causes of clashes are identified as shown in Table 3.6. *Late involvement of the subcontractors* is defined as one of the crucial process-related causes of the clashes during the design phase of the roof by P2 and P5. Subcontractors may need to add new details or elements to the already clash-free models when they join a project after the initial round of clash tests. Clashes may arise when the models are modified or combined with preexisting components. Furthermore, since the disciplines that join the project later and add their models may be absent during the first control phase, pertinent disciplines may neglect them during clash control. When models from other disciplines are included, this can cause serious clashes because they are rushing to adopt their models.

Different stages in the same project are considered one of the significant causes of clashes, as P1 pointed out. While some subcontractors are in the production stage, some are still in the design stage. Since this situation may lead to design changes, this might affect already clash-free designed and produced elements.

Incompatible planning and objectives between site and design are mentioned as other causes of the KIA Terminal II project clashes by P1. Design teams should adhere to the construction schedule and be compliant with it. However, the advancement of construction occasionally overtook the design, as highlighted in the literature (Chang et al., 2010). To ensure the construction at the site, the design team must conduct proper clash detection tests to avoid clashes later at the site.

To achieve a clash-free model, each subcontractor must work to resolve the clashes at the same time and in the same area. However, *divergent goals among stakeholders*, as highlighted by P2, may lead to specialized teams or disciplines working separately, each concentrating on their own unique set of goals. When these disparate efforts are combined, there may be spatial conflicts, interferences, or inconsistencies between the activities of various stakeholders due to this lack of coordination.

Not including as-built updates to the model is highlighted by P1 as one of the significant causes of the clashes because incorporating as-built information is necessary for the models to accurately reflect the actual placement of components and systems, leading to clashes with existing structures or systems. Suppose the site data needs to be provided to the BIM models and design teams. In that case, the design model may not align with the actual site conditions, leading to clashes when the design is later integrated with the site information.

Disparities between LOD levels from each subcontractor in the models might cause conflicts when LOD (Level of Development) levels diverge in the same model as P1 stated. Using multiple LOD levels by different subcontractors or project stakeholders may lead to inconsistent model element representation. One subcontractor may, for example, supply a model with a high LOD that includes precise geometry and component information. In contrast, another subcontractor may supply a model with a lower LOD that needs to be more accurate. When attempting to combine the models, these differences may cause conflicts since the components may need to line up appropriately, causing interference or spatial conflicts.

Missing elements can lead to clashes owing to incomplete representations of the project's components and systems, as explained by P2 and P5. The situation occur when some elements' spatial requirements or interferences are not considered throughout the design and coordination phases arises when certain elements are missing from the BIM (Building et al.) models. Conflicts may arise if certain components are subsequently added during implementation or building. For instance, the absence of relatively minor components from one party's BIM model can result in conflicts when these pieces are put in crowded places where many disciplines have model elements. Furthermore, the lack of essential plumbing, mechanical, electrical, or structural parts may cause interference or conflicts in space with other systems during construction.

As P5 pointed conflicts and functional problems during building and implementation might result from modelling that *neglecting production, assembly, and movement tolerances.* Failure to consider these tolerances may lead to components that do not fit together properly, causing interferences or conflicts in space. For instance, failure to include the exact measurements and tolerances needed for assembly and manufacture in the models may result in installation issues or misalignments, which may result in clashes with neighbouring components or systems. Moreover, movement tolerances for dynamic components, such as those impacted by thermal expansion, should be considered to avoid operational problems and conflicts in the field.

As P5 pointed out within a design, *incomplete modelling moving objects* can lead to clashes due to the failure to account for spatial requirements and clearances during operation. For example, in the case of the KIA Terminal II project, sufficient space is needed to safely operate moving parts like building maintenance units, roller blinds, and revolving door systems. Clashes may arise during operation or implementation if the design needs to include these items' movement pathways, clearances, or dynamic spatial needs. When these objects cannot be moved around in the specified environment, it might cause physical interferences and inefficiencies in operations.

Table 3.6. Causes of clashes identified through pilot survey

Category	Cause of Clash
Process Related	Late involvement of the subcontractors
People Related	Different stages in the same project
Process Related	Incompatible planning and objectives between site and design
Process Related	Divergent goals among stakeholders
Process Related	Not including as-built updates to the model
Product Related	Different Lod levels from each subcontractor
People Related	Missing elements
People Related	Neglecting production, assembly, and movement tolerances while modelling
Product Related	Incomplete modelling of the moving objects

3.3.2. Development of the final Delphi survey

A mixed-method approach, incorporating a literature review, case study analysis, and semi-structured pilot surveys, was used to identify causes of clashes in large-scale projects. Total 32 causes were identified: 18 from the literature review, 5 from clash test analysis, and 9 from pilot Delphi survey. The final Delphi questionnaire was divided into three sections in its organization as shown in Figure 3.27.

First, an introductory explanation about the research was provided to the panel experts. This explanation outlined the purpose of the study, the significance of understanding the causes of clashes by ensuring that the panel experts had a clear understanding of the research objectives. Second, a personal information section was included in the survey to gather relevant details about the panel experts. Last, the panel experts were asked to evaluate the significance of each cause within four categories. This step allowed for a systematic assessment of the causes, enabling the identification of the most influential factors contributing to clashes in construction projects.

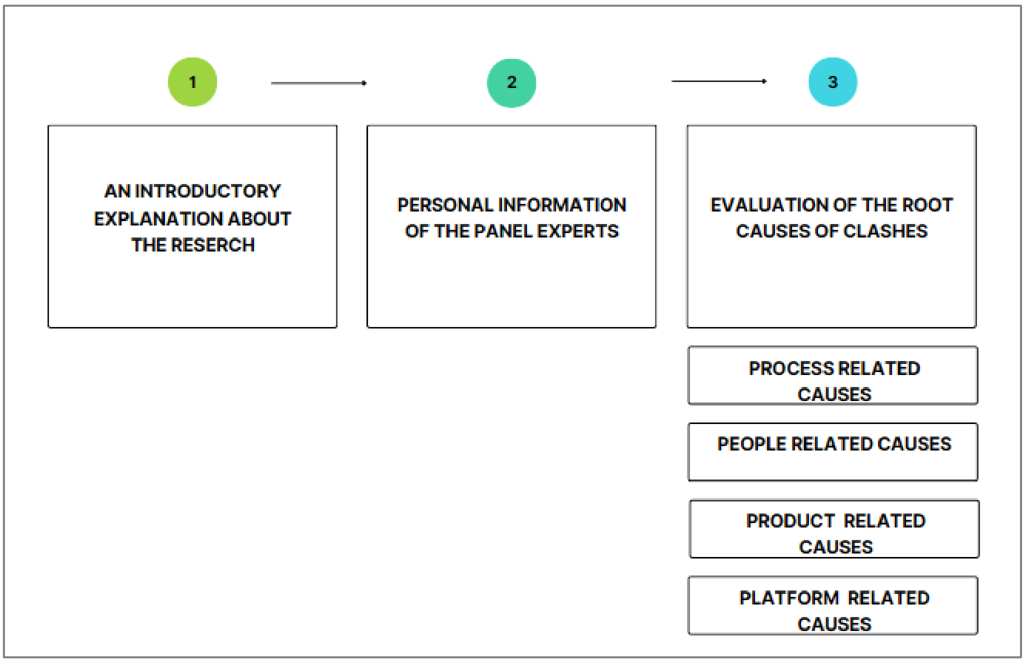


Figure 3.27. Organization of the Delphi survey

A Likert scale is utilized to assess the significance of process, people, product, and platform related causes contributing to clashes in construction projects. The Likert scale used ranges from 1 to 5, with 1 representing “Not a reason” and 5 representing “Extremely Significant.”

Participants are requested to rate each cause on this scale, indicating the extent to which they believe each factor influences clash occurrences. (Table 3.7) By gathering ratings from participants, valuable insights can be gained regarding the importance of root causes of clashes and their impact on coordination in construction projects.

Table 3.7. The five-point Likert scale

1	2	3	4	5
Not a Reason	Limited Reason	Moderate Reason	Significant Reason	Extremely Significant Reason

The final Delphi survey consists of 32 identified causes of clashes, as presented in Table 3.8. Each cause is evaluated based on its associated driving factors. According to these factors, the causes are categorized as follows: fourteen are classified under process-related causes, six are attributed to people-related causes, eight are considered product-related causes, and four are identified as platform-related causes.

Table 3.8. The causes of clashes listed for the delphi survey

			LITERATURE	CLASH REPORTS	SURVEY
Process Related	C1	Changes during construction	✓		
	C2	Deceptive Planning and Timing	✓		
	C3	Different stages in the same project			✓
	C4	Divergent goals among stakeholders			✓
	C5	Incompatible planning and objectives between site and design			✓
	C6	Isolated working	✓		
	C7	Lack of experience in BIM	✓		
	C8	Lack of XML file submission		✓	
	C9	Late Involvement of the subcontractors			✓
	C10	Poor Coordination and Management	✓		
	C11	Not including as built updates to the model			✓
	C12	Progress of total active clashes		✓	
	C13	Reviewed clashes		✓	
	C14	Time Limitations	✓		

Table 3.9. (continued) The causes of clashes listed for the Delphi survey

People-related	C15	Incomplete or Outdated NWC/IFC Files		✓	
	C16	Lack of Qualified Specialists	✓		
	C17	Missing elements			✓
	C18	Modelling Errors	✓		
	C19	Neglecting Production, assembly, and movement tolerances while modelling			✓
	C20	QA/QC Status of the Models		✓	
Product-related	C21	Complexity of modelled object	✓		
	C22	Design complexity	✓		
	C23	Design Error	✓		
	C24	Design uncertainty	✓		
	C25	Disparities between Lod levels from each subcontractor			✓
	C26	Inadequate Level of Development	✓		
	C27	Failing of design rules	✓		
	C28	Incomplete modelling of the Moving Objects			✓
Platform-related	C29	The current structure of common data environments	✓		
	C30	Use of 2D instead of 3D models	✓		
	C31	Use of different file formats	✓		
	C32	Software errors	✓		

3.3.3. Data analysis of the Delphi survey

The data analysis methods used to analyse the Delphi survey include Cronbach's alpha reliability test to assess the internal consistency of responses, mean and median calculations to determine central tendency, and standard deviation and awg (interrater agreement statistic) to evaluate the consensus level among Delphi survey participants.

Cronbach's alpha coefficient is a statistical measure used to evaluate the internal consistency of a measurement tool. It is often used to determine the reliability of questionnaires, tests, or scales and measures the consistency between different questions or items of the measurement tool. In the Delphi analysis, Cronbach's alpha coefficient was used to evaluate the extent to which the answers given by experts are compatible with each other so an idea of the consistency of expert opinions can be obtained.

A high alpha value suggests the items are correlated, implying a trustworthy scale. This will help with subsequent analysis and interpretation. According to Table 3.9, Cronbach's alpha index of 0.7 or greater is considered to be reliable for further examination (Ozkan, 2022)

Table 3.9. Range of Cronbach’s alpha index and reliability level (Adopted from Arof et al., 2018)

Cronbach's alpha index	Reliability Level
$0.90 \le \alpha$	Excellent
$0.80 \le \alpha < 0.90$	Good
$0.70 \le \alpha < 0.80$	Acceptable
$0.60 \le \alpha < 0.70$	Questionable
$0.50 \le \alpha \le 0.60$	Poor
$\alpha < 0.60$	Unacceptable

Mean values and standard deviation values are calculated to measure significance and agreement level for each of 32 factors in 4 groups. To interpret the significance levels, mean values are utilized by evaluating them according to a range provided by Li et al., (2013) shown in below Table 3.10.

Table 3.10. Ranges of significance levels

Mean Value	Significance Level
$M \le 1.50$	Not Important
$1.51 \le \alpha \le 2.5$	Somewhat Important
$2.51 \le \alpha \le 3.5$	Important
$3.51 \le \alpha \le 4.5$	Very Important
$4.51 \le M$	Extremely Important

After mean and standard deviation values are obtained from the results, the expert agreements between the respondent groups were analysed and validated using the interrater agreement statistics provided by Brown and Haunstein in 2005.

$$awg = 1 - \frac{2 * \mathrm{SD}^2}{\{(\mathrm{A} + \mathrm{B})\mathrm{M} - (\mathrm{M2}) - (\mathrm{A} * \mathrm{B})\} * (\mathrm{n}/\mathrm{n} - 1)} \tag{3.1}$$

The variables awg (interrater agreement statistic) formula can be explained as follows: n represents the number of respondents which is 13 in this survey. SD is the standard deviation, A is the maximum scoring value (5), B is the minimum scoring value (1). The IRA analysis have been deducted according to the ranges illustrated in Table 3.11 (Lebreton and Senter, 2008).

Table 3.11. Ranges of agreement levels

awg	Agreement level
$0.00 \leq \alpha \leq 0.30$	Lack of Agreement
$0.31 \leq \alpha \leq 0.50$	Weak Agreement
$0.51 \leq \alpha \leq 0.70$	Moderate Agreement
$0.71 \leq \alpha \leq 0.90$	Strong Agreement

4. RESULTS AND DISCUSSIONS

This research investigated the root causes of clashes through a literature review and case study. Using qualitative and quantitative data collection techniques, the research obtained perspectives from professionals in practice and academics to determine the causes of clashes for large-scale construction projects.

The results for Cronbach`s alpha for the first round (Table 4.1) indicate that the survey is reliable for testing and illustrate that the survey questions in each category measure the corresponding constructs reliably.

Table 4.1. First round Cronbach’s alpha index

	Cronbach's alpha index
Process Related	0.75
People Related	0.91
Product Related	0.84
Platform Related	0.82

Although the survey is reliable for testing, when the agreement levels are evaluated, it is observed that most of the causes have a lack of or weak agreement levels in the first round. Since the agreement between panel experts in the first round could not be achieved, the second round was conducted.

For the second round of the Delphi Survey, mean values obtained from the first round were shared with the participants to take their feedback and request to reconsider their responses according to mean values. As required by the Delphi method, the survey participants' anonymity was maintained while providing feedback and requesting the second round of the survey.

According to the results of the second tour, Cronbach alpha values for each subcategory are analysed. For the second round, Cronbach's alpha values were also obtained at more than 0.70, which shows the internal reliability of the survey (Table 4.2).

Table 4.2. Second round Cronbach’s alpha index

	Cronbach's alpha index
Process Related	0.72
People Related	0.91
Product Related	0.83
Platform Related	0.77

Overall, the second round of the Delphi survey demonstrated improved agreement and consensus levels for the identified causes of clashes in the research Table 4.3. This increase in agreement levels indicates a higher consensus among the expert panel regarding these causes of clashes. In total, for 27 out of 32 causes of clashes, an increase in the agreement levels is observed.

In the second round of the Delphi survey, five causes of clashes indicated strong agreement among the expert panel. Causes “(C2) Deceptive Planning and Timing”, “(C3) Different stages within the same project,” “(C21) Complexity of modelled object,” “(C30) Use of 2D instead of 3D models,” “(C23) Design Error,” “(C25) Disparities between LOD levels from each subcontractor,” “(C27) Failing of design rules,” and “(C29) The current structure of common data environments” demonstrated high levels of agreement in the second round.

Regarding significance levels, the causes range from important to very important except the “(C32) Software Errors”, which is somewhat important. The significance levels for the causes in the first and second rounds of the Delphi survey were compared to detect any increase or decrease in Table 4.3. For two causes, a decrease in the significance level is observed. “(C23) Design Error” significance level is decreased from very important to important, and “(C32) Software Errors” from important to somewhat important. For one cause “(C24) Design uncertainty,” an improvement in the significance level from important to very important is observed.

Table 4.3. Comparison of the first and second rounds of the Delphi survey

		FIRST ROUND		SECOND ROUND	
		Significance Level	Agreement Level	Agreement Level	Significance Level
C1	Changes during construction	V.Important	Lack of agreement	V.Important	↑Weak agreement
C2	Deceptive planning and timing	Important	Moderate agreement	Important	↑Strong aggrement
C3	Different stages in the same project	Important	Moderate agreement	Important	↑Strong aggrement
C4	Divergent goals among stakeholders	V.Important	Lack of agreement	V.Important	↑Moderate aggrement
C5	Incompatible planning and objectives between site and design	V.Important	Lack of agreement	V.Important	↑Weak agreement
C6	Isolated working	V.Important	Lack of agreement	V.Important	↑Moderate aggrement
C7	Lack of experience in BIM	Important	Lack of agreement	Important	↑Moderate aggrement
C8	Lack of XML file submission	Important	Lack of agreement	Important	↑Moderate aggrement
C9	Late involvement of the subcontractors	V.Important	Weak agreement	V.Important	Weak agreement
C10	Poor coordination and management	V.Important	Lack of agreement	V.Important	↑Moderate aggrement
C11	Not including as-built updates to the model	Important	Weak agreement	Important	↑Moderate aggrement
C12	Progress of total active clashes	V.Important	Weak agreement	V.Important	↑Moderate agreement
C13	Reviewed clashes	Important	Lack of agreement	Important	↑Strong aggrement
C14	Time limitations	V.Important	Moderate agreement	V.Important	Moderate aggrement
C15	Incomplete or outdated NWC/IFC files	V.Important	Moderate agreement	V.Important	Moderate aggrement
C16	Lack of qualified specialists	Important	Lack of agreement	Important	↑Moderate aggrement
C17	Missing elements	V.Important	Lack of agreement	V.Important	↑Weak agreement
C18	Modelling errors	Important	Lack of agreement	Important	↑Moderate aggrement
C19	Neglecting production, assembly, and movement tolerances while modelling	Important	Lack of agreement	Important	↑Weak agreement
C20	QA/QC status of the models	Important	Moderate agreement	Important	↑Strong aggrement

Table 4.3. (continued) Comparison of the first and second rounds of Delphi survey

C21	Complexity of modelled object	V.Important	Moderate agreement	V.Important	Moderate aggrement
C22	Design complexity	V.Important	Lack of agreement	V.Important	↑Weak agreement
C23	Design Error	V.Important	Lack of agreement	↓Important	↑Moderate aggrement
C24	Design uncertainty	Important	Weak agreement	↑V.Important	Weak agreement
C25	Disparities between Lod levels from each subcontractor	Important	Lack of agreement	Important	↑Weak agreement
C26	Inadequate level of development	Important	Weak agreement	Important	↑Moderate agreement
C27	Failing of design rules	Important	Weak agreement	Important	↑Moderate agreement
C28	Incomplete modelling of the moving Objects	Important	Lack of agreement	Important	↑Moderate agreement
C29	The current structure of common data environments	Important	Lack of agreement	Important	↑Strong agreement
C30	Use of 2D instead of 3D models	V.Important	Lack of agreement	V.Important	↑Moderate agreement
C31	Use of different file formats	Important	Lack of agreement	Important	↑Moderate agreement
C32	Software errors	Important	Weak agreement	S.Important	↑Strong agreement

Note: ↓- decrease & ↑- increase. ent; V. important = Very Important

4.1. Analysing and Prioritization of Causes of Clashes

The findings of the Delphi survey indicated that in the second round, the expert panel was reasonably in agreement and consensus regarding the causes of clashes. As demonstrated by an increase in Cronbach's alpha and awg values and a decrease in standard deviations, the Delphi survey concluded following the second round.

Table 4.4 provides the results and prioritization of causes of the clashes according to the results of the second tour of the Delphi survey accompanied by mean, median, standard deviation values (σ), significance levels, and agreement levels. The mean values of causes of clashes range from 4.23 to 2.23, with significance levels spanning from very important to somewhat important.

According to the results, the most prominent causes of clashes are identified as process-related causes, with an average mean value of 3.49. After the process-related causes, people-related causes followed with the total mean value of 3.31, product-related causes at 3.28, and last, product-related causes at 3.08.

“(C1) Changes during construction” and “(C5) Incompatible planning between site and design teams” were identified as the most significant causes of clashes in the case of the KIA Terminal II project. The causes C1 and C5 were considered very important according to the Delphi survey participants, with mean values of 4.23 and 4.08. It has been noted that concurrent design and construction improves project timing. However, this approach can be vaguer and more complex than the traditional sequential design and construction process since it might cause unexpected errors and clashes that negatively affect project performance (Lee et al., 2005).

The third most significant cause of the clashes was “(C22) Design complexity”, with an average rating of 4.08. As highlighted in the Delphi survey by P4, *“KIA Terminal II Roof Project stood out as a unique case because of its large scale, intricate design, and the diverse range of parties involved. Almost every product used in the roof project was bespoke elements that the related specialist subcontractors created. All factors above had impacts on the clash resolution process”.*

After Design Complexity “(C9), Late Involvement of the subcontractors” ranked as the fourth cause of the clashes. Building projects consist of a wide range of operations, most of which can easily be subcontracted work items. As a result, subcontractor coordination can significantly impact project success, and companies that hire more subcontractors may find it more difficult to maintain control over the coordination process (Ulubeyli et al., 2010). Potential clashes resulting from inadequate coordination between various work packages can be minimized by involving subcontractors early on. Early involvement enables subcontractors to offer feedback during the design stage, anticipating possible clashes and suggesting ways to coordinate building elements. This proactive strategy reduces rework, expedites the construction process, and improves project efficiency overall.

“(C14) Time Limitations” is the fifth root reason for clashes. To balance deadlines and model accuracy, designers purposefully leave conflicts unresolved in construction projects due to time constraints and deadlines, as mentioned in the literature (Akhmetzhanova et al., 2017; Tommelein & Gholami, 2012). In practice, time constraints and deadlines are crucial factors that greatly affect how effectively project stakeholders coordinate with each other. Setting rigid deadlines can lead to rushed decision-making, poor coordination, and a higher risk of mistakes and conflicts. Realistic scheduling and efficient time management techniques are crucial to overcome this difficulty.

“(C12) Progress of the total clashes” and “ (C17) missing elements” are ranked after C14 with the same mean of 3.77. P5 explained in the survey how missing elements in the model affected the coordination of the roof of the Kuwait International Airport II project: *`Especially in crowded spaces, relatively small elements of one of the parties involved that are not included in the BIM models can cause significant clashes during implementation in the field, which has become one of the problems faced in the KIA project. `*

“Divergent goals among stakeholders” and “Poor Coordination and Management” were also identified as significant causes of clashes, with a mean value of 3.69. Conflicting priorities and misaligned goals among stakeholders can cause breakdowns in communication and coordination, leading to clashes when a project is being executed. As highlighted in the survey, the *management level of focus has to be more coordination-oriented and differs from subcontractor internal workflows or site progress. Contractors' engineering teams can manage those two aspects, which management shall follow up.*

“(C6) Isolated working” isolated working or “over-the-wall” collaboration is considered an acceptable reason for the lack of design information between the different teams. According to the research, the “work in progress” (WIP) section of the common data environments unintentionally promotes isolated working at a critical early stage of design since this is a major contributing factor to clashes occurring (Akponeware & Adamu, 2017).

“(C24) Design uncertainty”, with a mean of 3.62, ranked as the eleventh cause of clashes. Design uncertainty can arise from the complexity and unpredictability of the design process, particularly when dealing with novel or unstructured problems that need a clear solution path (Daalhuizen et al., 2009).

BIM methodologies are particularly effective for spatial analysis and visualization, leveraging 3D models to detect potential clashes or conflicts. Therefore, the utility of these methods has contributed to their increasing popularity in the field (Hu & Castro-Lacouture, 2019). “(C30) Using 2D models instead of 3D models” listed after design uncertainty with the same mean value is another cause of clashes. Using 2D drawings for clash detection is inherently limited because it fails to capture the full spatial complexity of a building. Two components appear compatible on a flat drawing but could intersect in three-dimensional space. On the other hand, 3D models provide a comprehensive view of the building's structure and systems. They allow for a more accurate and thorough analysis of potential clashes because they represent the three-dimensional relationships between building components.

“(C15) Incomplete or Outdated NWC/IFC Files” and “(C21) Complexity of modelled object” listed after C30 with the same mean value of 3.54. For BIM to succeed, cooperation between all relevant parties is required to add, remove, update, or change data in the BIM model at various phases of the facility's life cycle (Lindblad, 2013). Therefore, all stakeholders need to update their models accordingly. Complex objects are more difficult to model accurately, resulting in errors such as incorrect dimensions or overlaps where there should be clearances. (Akhmetzhanova et al., 2017) These errors can manifest as clashes when different systems or elements within the BIM model are found to occupy the same space.

“(C2) Deceptive Planning and Timing” is listed as the fifteenth most significant cause of cash, with a mean value of 3.38. Like C14 and C5 this time management factor is also important since good time management also facilitates better communication between team members to avoid clashes.

In addition to these reasons and other reasons which have a mean value of more than three ranked as follows; “(C3) Different stages in the same project” (with mean of 3.31), “(C16) Lack of Qualified Specialists” (with mean of 3.31), “(C23) Design Error” (with mean of 3.31), “(C31) Use of different file formats” (with mean of 3.31), “(C20) QA/QC Status of the Models ” (with mean of 3.15), “(C29) The current structure of common data environments” (with mean of 3.15), “(C11) Not including as-built updates to the model” (with mean of 3.08), “(C19) Neglecting Production, assembly, and movement tolerances while modelling" (with mean of 3.08), "(C18) Modelling Errors" (with mean of 3), "(C25) Disparities between Lod levels from each subcontractor" (with mean of 3), "(C27) Failing of design rules" (with mean of 3). Following to mentioned causes, "(C28) Incomplete modelling of the Moving Objects" (with mean of 2.92), "(C13) Reviewed clashes" (with mean of 2.85), "(C26) Inadequate Level of Development" (with mean of 2.77), "(C7) Lack of experience in BIM" (with mean of 2.69), "(C8) Lack of XML file submission" (with mean of 2.54), and least important cause is determined as "(C32) Software errors" (with mean of 2.23).

Table 4.4. Mean, median, standard deviation, and awg for the second tour of Delphi survey

			Mean	Median	SD	IRA
Process R.	C1	Changes during construction	4.23	5	0.93	0.36
Process R.	C5	Incompatible planning and objectives between site and design	4.08	4	0.95	0.41
Product R.	C22	Design complexity	4.08	4	0.95	0.44
Process R.	C9	Late involvement of the subcontractors	3.92	4	0.95	0.47
Process R.	C14	Time Limitations	3.85	4	0.8	0.6
Process R.	C12	Progress of total active clashes	3.77	4	0.93	0.53
People R.	C17	Missing elements	3.77	4	1.17	0.34
Process R.	C4	Divergent goals among stakeholders	3.69	4	0.95	0.53
Process R.	C10	Poor coordination and management	3.69	4	0.95	0.53
Process R.	C6	Isolated working	3.62	3	0.96	0.53
Product R.	C24	Design uncertainty	3.62	4	1.04	0.47
Platform R.	C30	Use of 2D instead of 3D models	3.62	3	0.96	0.62
People R.	C15	Incomplete or outdated NWC/IFC files	3.54	4	0.97	0.64
Product R.	C21	Complexity of modelled object	3.54	4	0.88	0.64
Process R.	C2	Deceptive planning and timing	3.38	3	0.65	0.8
Process R.	C3	Different stages in the same project	3.31	3	0.75	0.73
People R.	C16	Lack of qualified specialists	3.31	3	0.95	0.62
Product R.	C23	Design error	3.31	3	1.03	0.52
Platform R.	C31	Use of different file formats	3.31	3	0.95	0.66
People R.	C20	QA/QC status of the models	3.15	3	0.69	0.8
Platform R.	C29	The current structure of common data environments	3.15	3	0.9	0.7
Process R.	C11	Not including as built updates to the model	3.08	3	1.04	0.5
People R.	C19	Neglecting production, assembly, and movement tolerances while modelling	3.08	3	1.12	0.48
People R.	C18	Modelling errors	3	3	1.08	0.51

Table 4.4. (continued) Mean, median, standard deviation, and awg values for the second tour of Delphi survey

Product R.	C25	Disparities between Lod levels from each subcontractor	3	3	1.08	0.49
Product R.	C27	Failing of design rules	3	3	1	0.56
Product R.	C28	Incomplete modelling of the Moving Objects	2.92	3	0.95	0.6
Process R.	C13	Reviewed clashes	2.85	3	0.69	0.78
Product R.	C26	Inadequate level of development	2.77	3	0.93	0.62
Process R.	C7	Lack of experience in BIM	2.69	3	0.85	0.65
Process R.	C8	Lack of XML file submission	2.54	3	0.97	0.54
Platform R.	C32	Software errors	2.23	2	0.73	0.77

4.2. Clash Avoidance Strategies

The next section of this thesis will discuss effective clash avoidance strategies that are tailored to address the causes of clashes within the research scope after identifying the causes of clashes. Table 4.5 provides strategies for each cause of clashes in each category.

Table 4.5. Strategies for clash avoidance for the identified causes of clashes

Process-related	Causes of Clashes	Strategies to Promote Clash Avoidance	Solution
	C1) Changes during construction	C1; Create a change management process to review, approve, and thoroughly inspect all modifications made during construction.	Change Management
	C2) Deceptive planning and timing C3) Different stages in the same project C5) Incompatible planning and objectives between site and design C9) Late involvement of the subcontractors C14) Time limitations	C2; Do regular progress checks and make the required schedule modifications. C3; Ensure that there is efficient communication and coordination between the various project stages. C5; Improve planning and scheduling to ensure that project teams are appropriately cooperating. C9; Include subcontractors as early in the design process as possible to gain their input, and foresee potential conflicts. C14; Find a balance between meeting deadlines and maintaining model correctness by using effective time management strategies and realistic scheduling.	Scheduling and Planning

Table 4.5. (continued) Strategies for clash avoidance for the identified causes of clashes

	C4) Divergent goals among stakeholders C6) Isolated working C10) Poor coordination and management	C4; Distinguish site progress or internal workflows of subcontractors in Favor of a more coordination-oriented management approach. C6; Encourage open communication and information sharing among design teams to address the problem of isolated working and to help with the early identification and successful resolution of conflicts. C10; Enhance stakeholder involvement, training, risk assessment, change impact analysis, and communication.	Organization Management
	C7) Lack of experience in BIM C8) Lack of XML file submission C11) Not including as-built updates to the models C12) Progress of total active clashes	C7; Provide proper training and support to employees to adjust to using BIM effectively. C8; Ensure that all required files are submitted in the appropriate format. C11; Ensure that site information is added to the models regularly. C12; Ensure all stakeholders resolve their assigned clashes regularly	BIM Management
People-related	C15) Incomplete or outdated NWC/IFC files	C15; Ensure that all files and models are regularly updated and reviewed.	Change Management
	C17) Missing elements C18) Modeling errors	C17; To prevent major clashes during field implementation, ensure all elements are included in the BIM models. C18; Ensure thorough requirement analysis to understand what is to be modelled, peer review to check models	BIM Management
	C19) Neglecting production, assembly, and movement tolerances while modelling	C19; Ensure that clearance tolerances for the production and assembly tolerances are included in the models	Design Management
	C16) Lack of qualified Specialists C20) QA/QC status of the models	C16; Provide training to educate employees about BIM and project requirements. C20; Ensure the quality requirements of BIM models and model elements are provided	QA/QC Management
Product-related	C22) Design complexity C23) Design error C24) Design uncertainty	C22, C23; Encourage multidisciplinary cooperation and cooperative planning meetings with BIM software for 3D visualization to spot disputes early in the design process. C24; Create a clear context concerning design choices and the collaborative process of establishing agreement with clients.	Design Management

Table 4.5. (continued) Strategies for clash avoidance for the identified causes of clashes

	C25) Disparities between Lod levels from each subcontractor C26) Inadequate Level of Development C28) Incomplete modeling of the moving objects	C25; Make sure that each subcontractor maintains the same LoD levels. C26; Ensure that proper level of development in the models provided for each model element. C28; Ensure that every moving object is appropriately represented.	BIM Management
Platform-related	C29) The current structure of common data environments	C29; Ensure that CDE includes document management, emailing, application sharing, collaborative platforms, task and workflow management, and the ability for project participants to freely exchange project data.	Organization Management
	C30) Use of 2D instead of 3D models C32) Software errors	C30; Encourage the use of BIM software for 3D visualization to identify conflicts between different building systems and components. C32; Choose reliable BIM software that is regularly updated and maintained by the vendor. Ensure that the software is compatible with the project's requirements and can handle the complexity of the models.	BIM Management
	C31) Use of different file formats	C31; Ensure that all files are in compatible formats and check after file exchange to avoid conflicts.	QA/QC Management

When the causes of clashes are examined, it can be stated that clash avoidance can be achieved with the implementation of proper change, design, BIM, organization and QA/QC management, and effective scheduling & planning as shown in Figure 4.1;

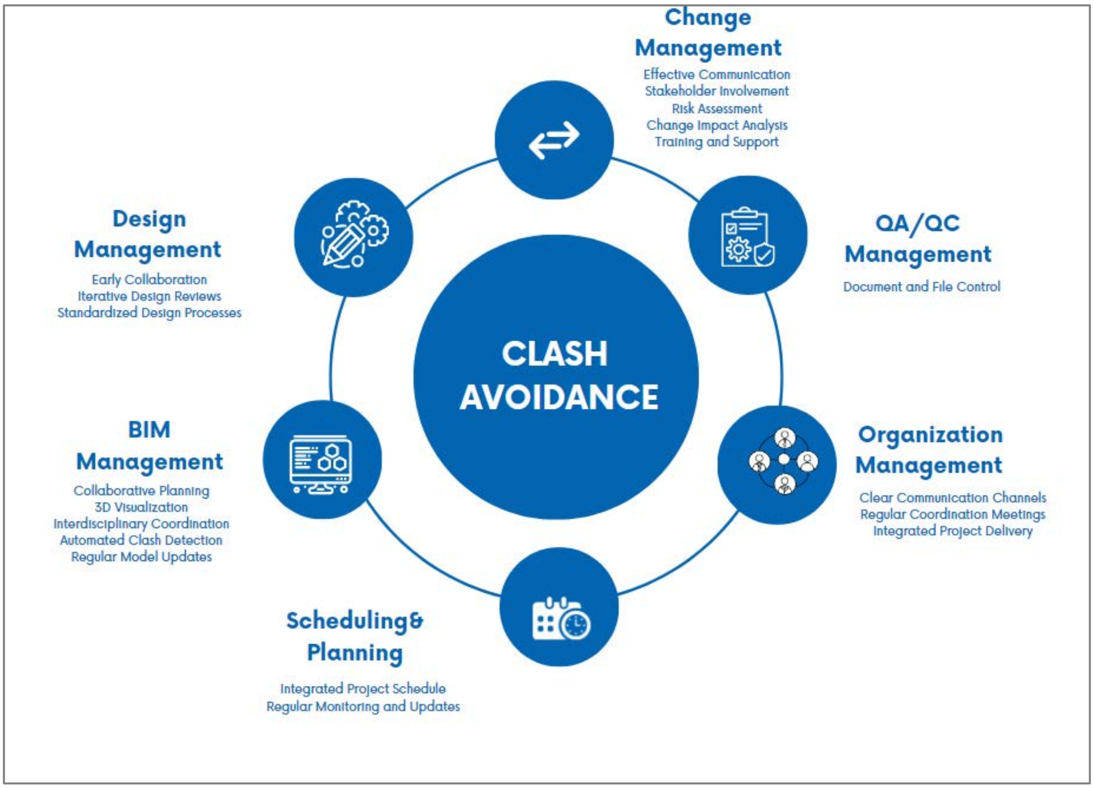


Figure 4.1. Clash avoidance framework

- Change Management: Changes and/or alterations in the construction project are unavoidable and they occur during every stage of the design and construction process (Hao et al., 2008). Change management involves setting out precisely how changes are to be managed by receiving approval from any relevant parties, and making sure that all project team members are informed of and have access to the updated documentation for effective construction change management. To achieve effective change management in construction the focus is to improve communication, stakeholder involvement, risk assessment, change impact analysis, and training and support. ensuring that all parties involved are aware of the reasoning behind any changes, clear and continuous communication helps to minimize or avoid possible clashes. Performing comprehensive risk assessments facilitates the early detection of possible clashes and the development of proactive prevention plans. Potential clashes can be identified and resolved by analysing how changes will affect different parts of the organization. Employees who receive proper training and support are more likely to be able to adjust to changes without difficulty, which lowers the possibility of conflicts arising from resistance or misunderstanding.

- QA/QC Management: By placing a strong emphasis on strict adherence to standards, thorough inspections, employee training, document control, and root cause analysis, quality assurance and quality control (QAQC) management plays a critical role in clash avoidance. Preventing clashes requires establishing standard operating procedures that specify quality standards and clash detection procedures. Frequent quality inspections guarantee that project components adhere to specifications, lowering the possibility of quality-related conflicts. It is ensured that clash detection and resolution are given priority as part of quality management by training personnel on QAQC procedures. Good document control procedures support accurate project documentation, making it easier to identify and resolve conflicts.

- Organization Management: Project clash avoidance depends on organization management, which can be accomplished through efficient channels of communication, frequent coordination meetings, integrated project delivery, technology use, and thorough design review procedures. Having open lines of communication between all teams of the project guarantees that information is shared efficiently. Frequent coordination meetings offer an open forum to discuss about the status of the project, seeing possible clashes, and working together to find solutions. By putting an integrated project delivery approach into practice, various disciplines can collaborate and identify conflicts early on. Using technology, like coordination management software, makes it easier to identify and effectively resolve conflicts. Strong design review procedures aid in the methodical examination of project plans and models for conflicts, guaranteeing the early detection and settlement of issues.

- Design management: By encouraging early collaboration among design disciplines, iterative design reviews, the use of Building Information Modelling (BIM), standardized design processes, and cross-functional communication, design management plays a crucial role in clash avoidance. Encouragement of early collaboration enables design teams to proactively resolve possible conflicts before they become more serious. Clashes between different design elements and disciplines can be found through iterative design reviews at different stages of a project. Encouraging open dialogue and information exchange among design teams facilitates the early detection and effective resolution of conflicts. Through the application of these design management principles, organizations can successfully avert conflicts and guarantee more seamless project implementation.

- BIM Management: Robust BIM management techniques can help construction projects avoid clashes efficiently. Project teams can prevent potential clashes from escalating by encouraging collaborative planning sessions where all parties collaborate to identify conflicts early in the design phase. By using BIM software for 3D visualization, teams can see the project as a whole and identify clashes between different building systems and components. To detect and effectively resolve conflicts, interdisciplinary coordination—which integrates models from various disciplines, including architecture, structure, and MEP systems—is essential to clash avoidance. BIM software has automated clash detection features that further automate the process by automatically highlighting clashes between various elements. BIM models should be updated and reviewed frequently to make sure that any new design conflicts are detected.

- Scheduling& Planning: Possible clashes can be predicted and avoided before they occur by creating a thorough project schedule that allows enough time for each phase. The likelihood of clashes is reduced when project elements are logically sequenced, which is ensured by careful planning. Through the implementation of routine progress reviews and necessary schedule updates, project teams can anticipate and resolve potential conflicts that may arise from modifications to project timelines or scope. To further minimize the likelihood of conflicts, team members and teams must communicate effectively to guarantee that everyone agrees on project milestones and dependencies.

5. CONCLUSION

This thesis provides a comprehensive list of causes of clashes in large scale construction projects, along with strategic approaches to avoid clashes. Listing the causes of clashes is essential for achieving clash avoidance in the construction sector because it allows for the identification and understanding of potential issues, enabling the development of targeted strategies and solutions. Avoiding between building elements and systems before they occur, construction projects can help in minimizing rework, delays, and accidents, ultimately ensuring the success and sustainability of the industry. Research indicates that approximately 57% of design coordination errors directly impact construction costs, with specific errors costing as much as USD 26,000 per instance (Lee et al., 2012). Therefore, proficient management of the design coordination process is crucial for successfully delivering cost-effective, high-quality projects and avoid clashes.

Through a literature review, case study and the Delphi method, this study investigated and listed the root causes of clashes and prioritization of them in the scope of roof design of the Kuwait International Airport Terminal II project. By combining the analysis of the literature review and case study, a total of 32 causes have listed and were divided into four categorizations as process-related, people related, product-related and process-related causes.

Thirteen qualified experts who were or are working in the KIA Terminal II project participated to the survey in two rounds of the Delphi method to rank the causes of clashes regarding the roof design. The standard deviation, interrater agreement, and Cronbach's alpha statistics were used to validate the results. The results show that there is a sufficient degree of consensus and agreement among the expert panel on the indicated reasons of the clashes in the second tour of the Delphi survey. According to the result of Delphi survey 14 causes identified as “very important” cause while 16 of them as “important”. Only one of the causes determined to be “somewhat important which is software errors.

The primary causes of clashes identified as process-related, people-related, product-related, and lastly, platform-related causes. The results ranked each cause and most significant three causes are “Changes during construction” (C1), “Incompatible planning between site and design teams” (C5) and “Design Complexity”. With the analysis of the root causes of the clashes this thesis provided strategies for clash avoidance with the effective management of change, design, BIM, coordination, QA/QC and though scheduling and planning.

To summarize, the outcomes of this research offer significant perspectives on the root reasons behind clashes in construction projects. With the help of the data-driven approach, which includes both qualitative and quantitative assessments, construction stakeholders can effectively prioritize and address issues by gaining a comprehensive understanding of the factors that contribute to clashes. The Delphi survey enhances industry understanding of clashes in construction projects by determining the significance and agreement levels of various factors. It also lays the groundwork for developing focused solutions to reduce the impact and frequency of clashes. The outcomes of this study have added to the body of knowledge presently available on clash detection and clash avoidance by listing and ranking the causes of clashes by analysing both industry experts and academics. The results are expected to assist the project team follow suggested strategies to promote clash avoidance.

6. LIMITATIONS AND FUTURE WORKS

This research analyses the causes of clashes for BIM-based projects from contractors’ point of view. This approach is valuable as it provides insights into the challenges faced on the construction site, which are critical for successfully implementing Building Information Modelling (BIM) technologies. However, the causes and impacts of clashes can vary significantly among different project stakeholders, including clients, consultants, architects, and engineers.

Future research could investigate the significance level of causes of clashes from the perspective of each stakeholder group to expand upon this research. Understanding the varying perspectives would enable a more comprehensive strategy for clash avoidance, as different stakeholders may prioritize certain factors over others.

Such an inclusive approach to clash detection and avoidance would improve communication and coordination and lead to better-integrated designs and more efficient construction processes. Early in the project lifecycle, it would motivate stakeholders to proactively resolve potential conflicts, lowering the risk of costly errors and guarantee a more seamless project delivery.

REFERENCES

Ahmed, S. (2018). Barriers to implementation of building in-formation modeling (BIM) to the construction industry: areview. *Journal of Civil Engineering and Construction,* 7(2), 107–113.

Akhmetzhanova, B., Nadeem, A., Hossain, M., and Kim, J. (2022). Clash detection using building information modeling (BIM) technology in the republic of Kazakhstan. *Buildings,* 12(2), 102.

Akponeware, A., and Adamu, Z. (2017). Clash detection or clash avoidance? An investigation into coordination problems in 3D BIM. *Buildings,* 7, 75.

Arayici, Y., Egbu, C. O., and Coates, S. P. (2012). Building Information Modelling (BIM) implementation and remote construction projects: Issues, challenges, and critiques. *Journal of Information Technology in Construction*, 17, 75.

Ashcraft, H., (2008). *Implementing BIM: A Report from the Field on Issues and Strategies.* In The 47th Annual Meeting of Invited Attorneys, Seattle, WA, USA, 53–84.

Barlish, K., and Sullivan, K. (2012). How to measure the benefits of BIM—A case study approach. *Automation in Construction,* 24, 149-159.

Benning, P., Dumoulin, C., Dehlin, S., Tulke, J., Åberg, P., Fristedt, S., and Holopainen, R. (2010). Report-Collaboration Processes. *Framework for Collaboration, InPro Consortium: Brussels, Belgium*, 1-125.

Blandini, L., and Nieri, G. (2020). Kuwait international airport terminal 2: Engineering and fabrication of a complex parametric megastructure. *Fabricate 2020,* 84-91.

British Standards Institute (2013). *Specification for information management for the capital/delivery phase of construction projects using building information modelling; PAS 1192–2:2013.* London, UK: BSI, 25-26.

Brown, R. D., and Hauenstein, N. M. (2005). Interrater agreement reconsidered: An alternative to the rwg indices. *Organizational Research Methods,* 8(2), 165-184.

Chahrour, R., Hafeez, M. A., Ahmad, A. M., Sulieman, H. I., Dawood, H., Rodriguez-Trejo, S., Kassem, M., Naji,K. K., and Dawood, N. (2021). Cost-benefit analysis of BIM-enabled design clash detection and resolution. *Construction Management and Economics,* 39(1), 55-72.

Chang, A. S., Shen, F. Y., and Ibbs, W. (2010). Design and construction coordination problems and planning for design–build project new users. *Canadian Journal of Civil Engineering,* 37(12), 1525-1534.

Charef, R., Alaka, H., and Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. *Journal of Building Engineering,* 19, 242-257.

Chelson, D. E. (2010). *The effects of building information modeling on construction site productivity.* Ph.D. Thesis, University of Maryland, College Park, MD, 37-55

Craig, D. L., and Zimring, C. (2002). Support for collaborative design reasoning in shared virtual spaces. *Automation in Construction,* 11(2), 249–259.

Daalhuizen, J., Badke-Schaub, P., and Batill, S. (2009). *Dealing with uncertainty in design practice: Issues for designer-centered methodology.* In 17th International Conference on Engineering Design, Stanford, 147-158.

Daalhuizen, J., Badke-Schaub, P., and Batill, S.M. (2009). Dealing with Uncertainty in Design Practice: Issues for Designer-Centered Methodology.

Eastman, C., and Henrion, M. (1977). Glide: A language for design information systems. *Proceedings of the 4th Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH 1977, January,* 24–33. https://doi.org/10.1145/563858.563863

Eastman, C., and Henrion, M. (1977). Glide: A language for design information systems. *Annual Conference on Computer Graphics and Interactive Techniques,* 11(2), 24-33.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K., (2011). *BIM handbook,* (Second Edition). New Jersey: Wiley and Sons, 216-218.

Eastman, C.M. (1974). An outline of the building description system. *Research Report No. 50.* Carnegie-Melleon University, Pittsburgh, 4-23.

Froese, T. M. (2010). The impact of emerging information technology on project management for construction. *Automation in Construction,* 19(5), 531-538.

Gliem, J. A., and Gliem, R. R. (2003). Calculating, interpreting, and reporting Cronbach’s alpha reliability coefficient for Likert-type scales. *Midwest Research-To-Practice Conference In Adult, Continuing, And Community Education*, 1, 82-87.

Gümüşburun Ayalp, G., and Öcal, M. E. (2016). Türk inşaat sektöründe mimari tasarım süreci hataları ve nedenleri. *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi,* 32(1), 1-8.

Han, S., Love, P., and Peña-Mora, F. (2013). A system dynamics model for assessing the impacts of design errors in construction projects. *Mathematical and Computer Modelling,* 57(9-10), 2044-2053.

Hao, Q., Shen, W., Neelamkavil, J., and Thomas, R. (2008, July). *Change management in construction projects.* In the Proceedings of International Conference on Information Technology in Construction CIBW78, Santiago, 15-17.

Hartmann, T. (2010). Detecting Design Conflicts Using Building Information Models: a Comparative Lab Experiment. Proceedings of the CIB W78 2010: 27th International Conference –Cairo, Egypt, 16-18 November.

Hartmann, T. (2010). Detecting design conflicts using building information models: a comparative lab experiment. In the Proceedings of International Conference on Information Technology in Construction CIBW78, Cairo, 1-9.

Hu, Y., and Castro-Lacouture, D. (2019). Clash relevance prediction based on machine learning. *Journal of Computing in Civil Engineering,* 33(2), 04018060

Hu, Y., Xia, C., Chen, J., and Gao, X. (2023). Clash context representation and change component prediction based on graph convolutional network in MEP disciplines. *Advanced Engineering Informatics,* 55, 101896.

Kensek, K., and Noble, D. (2014). *Building information modelling.* Hoboken: John Wiley and Sons Inc., 59-65.

Kontothanasis, Panayotis and Krommyda, Vicky and Roussos, Nikolaos. (2019). BIM and Advanced Computer-Based Tools for the Design and Construction of Underground Structures and Tunnels. 10.5772/intechopen.88315.

Korman, T., and Simonian, L. (2010, June). *Using building information modeling to teach mechanical, electrical, and plumbing coordination.* In 2010 Annual Conference and Exposition, Louisville, 15-1320.

Korman, T., Fischer, M., and Tatum, C. B. (2003). Coordinating building systems: Process and knowledge. *Journal of Architectural Engineering,* 6(4), 116–121.

Latiffi, A. A., Brahim, J., Mohd, S., and Fathi, M. S. (2015). Building information modeling (BIM): exploring level of development (LOD) in construction projects. *Applied Mechanics and Materials,* 773, 933-937.

Lebreton, J. M., and Senter, J. L. (2008). Answers to 20 questions about interrater reliability and interrater agreement. *Organizational Research Methods,* 11(4), 815–852.

Lee, G., Park, H. K., and Won, J. (2012). D3 City project - Economic impact of BIM-assisted design validation. *Automation in Construction,* 22, 577–586.

Lee, G., Park, M., and Won, J. (2012). A study on the classification of design errors in building construction. *Automation in Construction,* 22, 468–477.

Lee, S., Peña-Mora, F., and Park, M. (2005). Quality and change management model for large scale concurrent design and construction projects. *Journal of Construction Engineering and Management,* 131(8), 890-902.

Leite, F., Akcamete, A., Akinci, B., Atasoy, G., and Kiziltas, S. (2011). Analysis of modeling effort and impact of different levels of detail in building information models. *Automation in Construction,* 20(5), 601–609.

Li, X., Wu, P., Shen, G. Q., Wang, X., and Teng, Y. (2017). Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. A*utomation in Construction,* 84, 195-206.

Lindblad, H. (2013). *Study of the implementation process of BIM in construction projects analysis of the barriers limiting BIM adoption in the AEC-industry*. Master of Science Thesis, School of Architecture and Built Environment, Department of Real Estate and Construction Management, Stockholm, 15-18.

Love, P. E., Edwards, D. J., Smith, J., and Walker, D. H. (2009). Divergence or congruence? A path model of rework for building and civil engineering projects. *Journal of Performance of Constructed Facilities*, 23(6), 480-488.

Mehrbod, S., Staub-French, S., Mahyar, N., and Tory, M. (2019). Beyond the clash: investigating BIM-based building design coordination issue representation and resolution. *Journal of Information Technology in Construction*, 24, 33-57.

Merschbrock, C., and Munkvold, B. E. (2015). Effective digital collaboration in the construction industry–A case study of BIM deployment in a hospital construction project. *Computers in Industry,* 73, 1-7.

Mohd Arof, K. Z., Ismail, S., and Saleh, A. L. (2018). Contractor’s performance appraisal system in the malaysian construction industry: Current practice, perception and understanding. *International Journal of Engineering and Technology,* 7, 46.

Olawumi, T. O., and Chan, D. W. (2018). Identifying and prioritizing the benefits of integrating BIM and sustainability practices in construction projects: A Delphi survey of international experts. *Sustainable Cities and Society*, 40, 16-27.

Özkan, S. (2022). *Analyzing the benefits and challenges of common data environment implementation in BIM-based projects: Impacts on project performance.* Yüksek Lisans Tezi, Özyeğin Üniversitesi Fen Bilimleri Enstitüsü, İstanbul, 76-77.

Pärn, E. A., Edwards, D. J., and Sing, M. C. (2018). Origins and probabilities of MEP and structural design clashes within a federated BIM model. *Automation in Construction,* 85, 209-219.

Porwal, A., and Hewage, K. N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction*, 31, 204-214.

Shafiq, M. T., Matthews, J., and Lockley, S. R. (2012). Requirements for model server enabled collaborating on building information models. *International Journal of 3-D Information Modeling,* 1(4), 8-17.

Tommelein, I. D., and Gholami, S. (2012, July). *Root causes of clashes in building information models.* In 20th Annual Conference of the International Group for Lean Construction, San Diego, LA., 10.

Ulubeyli, S., Manisali, E., and Kazaz, A. (2010). Subcontractor selection practices in international construction projects. *Journal of Civil Engineering and Management,* 16(1), 47-56.

Vycital, M., and Jarský, C. (2020). An automated nD model creation on BIM models. *Organization, Technology and Management in Construction: An International Journal*, 12(1), 2218-2231.

Wang, L., and Leite, F. (2014, May). *Comparison of experienced and novice BIM coordinators in performing mechanical, electrical, and plumbing (MEP) coordination tasks.* In Construction Research Congress 2014, Construction in a Global Network, Atlanta, GA, 21-30.

Wildenauer, A. A. (2020). Critical assessment of the existing definitions of BIM dimensions on the example of Switzerland. *International Journal of Civil Engineering and Technology,* 11, 134-151

APPENDICES

APPENDIX 1. Delphi survey

Causes of Clashes in KIA Terminal II Project: Delphi Survey

In this Delphi survey, participants will be asked to rank the causes of clashes in the Kuwait International Airport II project according to the four categories: process-related factors, people-related factors, product- related factors, and platform-related factors. This survey aims to gather expert opinions and insights to identify the most significant factors causing to clashes in construction. Participants will be provided with a list of causes, and they will be asked to rank these causes based on their perceived importance and impact on clash occurrences. The results of this survey will help develop strategies and interventions to mitigate clashes and improve coordination in construction projects. Your valuable input will contribute to a better understanding of the causes of clashes and ultimately enhance the efficiency and effectiveness of construction processes.

General Information of the Participant

First Name   Last Name

Company

Education Level

Profession

Experience in Profession (Year)

Experience in KIA (Year)

Title

APPENDIX 1. (continued) Delphi survey

In this section, we kindly request your input on process-related factors that contribute to clashes. Please rate the following causes on a Likert scale, indicating the extent to which you believe each factor influences clash occurrences. The Likert scale ranges from 1 to 5, with 1 representing “Not a reason “ and 5 representing “Extremely Significant.” Your ratings will help us gain valuable insights into the significance of process-related causes and guide efforts to improve coordination in construction projects. Your expertise and input are greatly appreciated, and we thank you for your time and contribution.

Changes during construction refers to modifications, alterations, or adjustments made to the design, plans, or specifications of a project after the construction phase has commenced. These changes can occur due to various reasons, such as design revisions, unforeseen site conditions, client requests, or evolving project requirements.

Deceptive planning and timing refer to the process of incorrectly or insufficiently arranging and planning the order of tasks in building projects. Because it causes mismatches, delays, and a lack of coordination between various project teams, this might result in conflicts.

Different stages in the same project can result in causes such as misalignment in timelines, conflicting requirements, changes in scope, and potential rework. Additionally, communication gaps among project stakeholders can also contribute to challenges when transitioning between project stages.

Divergent goals among stakeholders can lead to clashes due to specialized teams or disciplines working separately, each focusing on their unique set of objectives. When these efforts are combined, spatial conflicts, interferences, or inconsistencies between the activities of various stakeholders may arise due to a lack of coordination.

Incompatible planning between site and design may cause clashes because the design teams may work without conducting proper clash detection tests, leading to clashes later at the site.

Isolated working: refers to a situation where team members or different disciplines within a project work separately and independently, without effective collaboration and coordination.

Lack of experience in BIM refers to a situation where team members or individuals involved in a project have insufficient knowledge and proficiency in the tools, processes, and methodologies associated with BIM.

Lack of XML file submission identified as one of the cause of clashes in the KIA project. Since the XML files contain reviewed and approved clash information from design teams, they are essential for clash detection because they allow identified clashes to be resolved and approved during the coordination process, guaranteeing proper coordination and preventing potential clashes in the final design.

Late involvement of subcontractors after initial clash tests have been conducted may lead to clashes as new elements or details are added to already clash-free models.

Not including as-built updates to the model may cause clashes because without incorporating this information, the models may not accurately reflect the actual placement of components and systems, leading to clashes with existing structures or systems.

Poor coordination and management may lead to inconsistencies, errors, or omissions in the design that cause clashes. For instance, a lack of accountability and coordination might result from unclear responsibilities and tasks allocated to team members or from inadequate supervision, which raises the possibility of conflicts in the BIM model.

Progress of total active clashes refers to the progress of the total resolved clashes by different subcontractors. It is identified that some subcontractors did not actively address to the clash resolution process and it is identified as one of the causes of clashes in the KIA project.

Reviewed clashes are defined as the clashes that have been examined by one responsible party and are awaiting resolution by additional responsible parties are referred to as reviewed conflicts. These conflicts show that one of the opposing teams has made some progress. Because they indicate unresolved disputes between components in the coordination models, reviewed clashes might lead to clashes

Time limitations can have various impacts on a project. They can lead to rushed work, inadequate planning, and increased stress for team members. When time is limited, there may be a lack of thoroughness in tasks, which can result in errors, omissions, or overlooked details.

APPENDIX 1. (continued) Delphi survey

	PROCESS RELATED	1	2	3	4	5
C1	Changes during construction	○	○	○	○	○
C2	Deceptive Planning and Timing	○	○	○	○	○
C3	Different stages in the same project	○	○	○	○	○
C4	Divergent goals among stakeholders	○	○	○	○	○
C5	Incompatible planning and objectives between site and design	○	○	○	○	○
C6	Isolated working	○	○	○	○	○
C7	Lack of experience in BIM	○	○	○	○	○
C8	Lack of XML file submission	○	○	○	○	○
C9	Late Involvement of the subcontractors	○	○	○	○	○
C10	Poor Coordination and Management	○	○	○	○	○
C11	Not including as built updates to the model	○	○	○	○	○
C12	Progress of total active clashes	○	○	○	○	○
C13	Reviewed clashes	○	○	○	○	○
C14	Time Limitations	○	○	○	○	○

What are your experiences or comments regarding the process-related causes of clashes in KIA Terminal II Project?

APPENDIX 1. (continued) Delphi survey

In this section, we kindly request your input on people-related factors that contribute to clashes. Please rate the following causes on a Likert scale, indicating the extent to which you believe each factor influences clash occurrences. The Likert scale ranges from 1 to 5, with 1 representing “Not a reason “ and 5 representing “Extremely Significant.” Your ratings will help us gain valuable insights into the significance of process-related causes and guide efforts to improve coordination in construction projects. Your expertise and input are greatly appreciated, and we thank you for your time and contribution.

Incomplete or outdated NWX/IFC files can cause clashes because they lead to lack of synchronization between the models by the other subcontractors, missed design changes and delay of clash resolution. Providing an accurate and up-to-date representation of the project elements may help effective clash detection and resolution.

Lack of qualified specialist is considered as another people related cause of the clashes since insufficient understanding of the BIM and collision detection procedures lead to clash occurrence. Preventing clashes requires having enough knowledge, understanding, and application of BIM technology and procedures.

Missing elements in the model can cause clashes because the absence of certain components from the Building Information Modelling (BIM) models may result in conflicts when these pieces are implemented in crowded areas where many disciplines have model elements. Furthermore, the lack of essential plumbing, mechanical, electrical, or structural parts may cause interference or conflicts in space with other systems during construction.

Modelling errors refer to incorrectly represented BIM elements or omitted building system components. Missing project specifications and guidelines, installation procedures, processes, or necessary clearances between certain objects can all lead to modelling errors.

Neglecting production, assembly, and movement tolerances while modelling may cause clashes due to components not fitting together properly, resulting in interferences or clashes in space.

APPENDIX 1. (continued) Delphi survey

QA/QC status of the models confirms that each element on the models has the appropriate Family Category Code (FCC) allocated to it. This entails determining if the FCCs are consistently and appropriately assigned and each of the elements with correct FCC code counted in the clash tests. Through proper FCC compliance, QA/QC contributes to increased clash detection accuracy.

	PEOPLE RELATED	1	2	3	4	5
C15	Incomplete or Outdated NWC/IFC Files	○	○	○	○	○
C16	Lack of Qualified Specialists	○	○	○	○	○
C17	Missing elements	○	○	○	○	○
C18	Modelling Errors	○	○	○	○	○
C19	Neglecting Production, assembly, and movement tolerances while modelling	○	○	○	○	○
C20	QA/QC Status of the Models	○	○	○	○	○

What are your experiences or comments regarding the people-related causes of clashes in KIA Terminal II Project?

APPENDIX 1. (continued) Delphi survey

In this section, we kindly request your input on product-related factors that contribute to clashes. Please rate the following causes on a Likert scale, indicating the extent to which you believe each factor influences clash occurrences. The Likert scale ranges from 1 to 5, with 1 representing “Not a reason “ and 5 representing “Extremely Significant.” Your ratings will help us gain valuable insights into the significance of process-related causes and guide efforts to improve coordination in construction projects. Your expertise and input are greatly appreciated, and we thank you for your time and contribution.

Design complexity is considered as one of the causes of clashes. Complex constructions are a combination of numerous elements and different entities or components. To resolve complex designs, designers have occasionally purposefully left some conflicts unresolved in order to merely clarify the design objective at the outset. However, this may persist all the way through the design development and construction phases and causes clashes.

Design uncertainty refers to conflicts that arise when most recent design of an element is unclear but is nonetheless included in the models for coordinating reasons. This may occur when a certain component cannot fit properly due to a lack of room. Designers occasionally purposefully leave conflicts in the early phases to clarify their intentions.

Design errors in design occur when the dimensions or placement of model pieces deviate from the original plan, which can impact the precision of clash detection.

Failing of the design rules refer to lack of standards, agreement, or prior to and during design, on how specialty systems are to be related to others by avoiding clashes by occupying each other’s space.

Inadequate level of development of BIM is one of the significant reasons for clashes. Higher LoD levels in BIM models, according to research, result in more accurate conflict identification, assisting the design and construction processes. Therefore, the accuracy of clash detection may be compromised if an inappropriate level of development is used.

Complexity of the modelled object is considered to be a major contributing factor in conflicts. Model elements that overlap or conflict with one another are more common in complex items. It might be more difficult for engineers and designers to accurately recognize and resolve disputes as a result of these complexities.

APPENDIX 1. (continued) Delphi survey

Disparities of LoD levels between subcontractors may lead to clashes because the usage of multiple LOD levels by different subcontractors or project stakeholders may result in inconsistent model element representation. When attempting to combine these models, differences in LOD levels can cause conflicts as the components may not line up appropriately, leading to interference or spatial conflicts.

Ignoring movements of moving objects within a design can led to clashes due to the failure to account for spatial requirements and clearances during operation. For instance, insufficient space for the safe operation of moving parts like building maintenance units or revolving doors can result in clashes during operation or implementation, causing physical interferences and operational inefficiencies.

	PRODUCT RELATED	1	2	3	4	5
C21	Complexity of modelled object	○	○	○	○	○
C22	Design complexity	○	○	○	○	○
C23	Design Error	○	○	○	○	○
C24	Design uncertainty	○	○	○	○	○
C25	Disparities between Lod levels from each subcontractor	○	○	○	○	○
C26	Inadequate Level of Development	○	○	○	○	○
C27	Failing of design rules	○	○	○	○	○
C28	Incomplete modelling of the Moving Objects	○	○	○	○	○

What are your experiences or comments regarding the Product-related causes of clashes in KIA Terminal II Project?

APPENDIX 1. (continued) Delphi survey

In this section, we kindly request your input on platform-related factors that contribute to clashes. Please rate the following causes on a Likert scale, indicating the extent to which you believe each factor influences clash occurrences. The Likert scale ranges from 1 to 5, with 1 representing “Not a reason “and 5 representing “Extremely Significant.” Your ratings will help us gain valuable insights into the significance of process-related causes and guide efforts to improve coordination in construction projects. Your expertise and input are greatly appreciated, and we thank you for your time and contribution.

The current structure of the common data environments failing to effectively prevent conflicts by promoting isolated work among stakeholders. Clashes within the project may result from this, which can impede coordination and cooperation.

Use of 2D instead of 3D refers to depending solely on manual clash detection techniques can be error- prone and lead to inaccurate findings. It can make it more difficult to detect conflicts in an efficient manner, particularly when dealing with disorganized BIM models.

Use of different file formats may lead to variances in representation of the modelled objects, such as dimensions or positioning. This may make it difficult for clash detection software to identify clashes correctly, leading to potential clashes being missed or false clashes being reported.

Software errors occurs when the software used for clash detection tests cannot indicate a clash when an incorrectly sized or placed component is not obstructed. Similar to how there is no space contention when a component is physically, but incorrectly, surrounded by another component, no physical penetration may be computed.

	PLATFORM RELATED	1	2	3	4	5
C29	The current structure of common data environments	○	○	○	○	○
C30	Use of 2D instead of 3D models	○	○	○	○	○
C31	Use of different file formats	○	○	○	○	○
C32	Software errors	○	○	○	○	○

What are your experiences or comments regarding the Platform-related causes of clashes in KIA Terminal II Project?

APPENDIX 2. The institution / Organization permission

REGARDING THE INSTITUTION/ORGANIZATION PERMISSION TO THE THESIS ABOUT KUWAIT INTERNATIONAL AIRPORT II PROJECT

The document states that permission has been granted for the use of drawings, reports, visuals, and other documents provided by Limak Construction Company in thesis titled “Clash Detection and Avoidance for Large Scale Projects: A Framework for Roof Design of Kuwait International Airport II”. Sharing this information with third parties or using it for commercial purposes is prohibited.

Research Title: Clash Detection and Avoidance for Large Scale Projects: A Framework for Roof Design of Kuwait International Airport II

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APPENDIX 3. The Ethical Permission

ETHICAL PERMISSION OF THE RESEARCH

In this study, all the rules specified within the scope of the “Higher Education Institutions Scientific Research and Publication Ethics Directive” were followed.

Name of the committee that conducted the ethical evaluation: T.C. Gazi University Rectorate Ethics Commission

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