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# Investigating the Causes of Missing Field Detected Issues from BIM-Based Construction Coordination Through Semi-Structured Interviews

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# Investigating the Causes of Missing Field Fixed Issues from BIM-Based Construction Coordination Through Semi-Structured Interviews

**by**

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# Abstract


## Investigating the Causes of Missing Field Detected Issues from BIM-Based Construction Coordination Through Semi-Structured Interviews



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Although the use of Building Information Modeling (BIM) and automatic clash detection have improved the construction coordination process in construction projects, the industry is still suffering from on-site fixes of issues, which can cause construction delays and cost overruns. In the literature, several research studies have investigated the causes of constructability issues or rework but not focused on how the issues are missed at the construction coordination stage, which is a mitigation strategy that can minimize field detected issues. This research, via expert interviews, determined underlying causes of not capturing field-detected issues during the BIM-based construction coordination process, including: missing model elements, not considering operability or maintainability, and inaccurate as-built model updates were the most mentioned causes. The research findings can benefit industry practitioners by providing the causes and preventive measures that can enhance the ability of capturing issues before they occur in the field. Moreover, this research also provides future researchers with the critical causes that need to be tackled to improve BIM-based construction coordination.

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# Chapter 1: Introduction

Rework is one of the most problematic challenges that construction projects face. On-site fixes, or field-detected issues (FDIs), lead to additional costs and delays (Assaf and Alhejji, 2006). Lee et al. (2012) found that more than half of the design errors have a direct impact on rework (Lee et al. 2012). Moreover, after investigating two case studies, Mehrbod et al. (2019) found that at the end of the design coordination stage almost a third of the design coordination issues remain unresolved, which means they are only fixed on-site (Mehrbod et al., 2019).

Design coordination is a process that assures building components are routed without spatial conflicts while meeting design and operational requirements (Barton et al. 1983). Successful managing of design coordination is essential for the delivery of cost-effective and quality projects (Mehrbod et al. 2019). In addition, 3-dimensional (3d) design coordination and automatic clash detection, which leverages building information modeling (BIM) to identify spatially conflicted building components (Sacks et al. 2015), are considered as the most frequent uses of BIM in construction projects (Bernstein et al., 2012; Hartmann et al., 2008; Mostafa & Leite, 2018)

Successful design and construction coordination should eliminate or minimize the issues that are solved in construction sites through the use of Virtual Design and Construction (VDC) tools such as automatic clash detection, and 4d simulation. However, it is widely reported that a significant number of constructability issues are solved on the spot on construction sites (Mehrbod et al., 2019). According to Love et al. (2011), although implementing BIM and 3d design coordination in construction projects may help in reducing and containing human errors through early visualization and automatic clash detection, relying solely on BIM to minimize error can result in huge responsibility and strain upon designers especially if they do not have the necessary knowledge and skills, which makes designers become complacent and not checking regularly. Previous studies have either focused on the challenges associated with the design coordination process or the rework but there is almost no study that has directly studied how rework could have been avoided at the BIM coordination stage. Therefore, an investigation on why field detected issues were not captured during that stage is needed to fill this gap.

The objective of this thesis is to determine what causes field-detected issues to be missed during the BIM coordination process, and identify preventive measures that can improve the capability of detecting the issues before they occur in the field. This study leverages semi-structured interviews with industry professionals to identify said causes and preventive measures.

# Chapter 2: Literature Review

The literature review of the thesis includes a review of the necessary background knowledge about Building Information Modeling (BIM), as well as a synthesis of previous research studies that have focused on 3-dimensional (3D) design coordination, clash detection, and rework. This chapter concludes with the gaps found in the literature.

## BUILDING INFORMATION MODELING

Building Information Modeling (BIM) is defined by the National Institute of Building Science (NIBS) (2015) as "the digital representation of the physical and functional characteristics of a facility". BIM provides a collaborative knowledge tool for the use of clients or other users throughout the life cycle of a project (NIBS 2015). In addition to accurate geometry, BIM stores relevant data required in design, procurement, fabrication, and construction processes that are needed to construct a building (Eastman et al., 2008). Moreover, the interdependency between different disciplines such as structural, architectural, mechanical, electrical, plumbing, and fire protection is made explicit with BIM by technologically coupling project organizations together (Dossick and Neft 2007). Furthermore, implementing BIM in a project enables early and more accurate visualization, automatic correction of lower-level elements when the design is changed, accurate generation of 2-dimensional (2D) drawings at any design stage, and early collaboration of the different disciplines involved (Eastman et al., 2018). BIM also improves the workflow and project delivery processes (Hardin & McCool, 2015). BIM is considered an enabler for integrated project delivery – one of the most promising delivery methods – as it enhances early collaboration between people, systems, and organizations resulting in reduced waste and increased efficiency throughout the lifecycle of the project (Glick & Guggemos, 2009).

## BIM-BASED MEP DESIGN COORDINATION

Previous research on BIM-based Mechanical, Electrical, Plumbing, and Fire Protection (MEP) design coordination has focused on the process, benefits, challenges, and limitations of implementing BIM in the MEP design coordination process. For example, Staub-French and Khanzode (2007) have proposed different approaches for assembling project teams to leverage the latest technologies at the time and discussed modeling requirements to implement 3D and 4D in projects. The authors also elaborated on the benefits, shortcomings, and lessons learned associated with implementing 3D and 4D coordination in projects (French and Khanzode, 2007). Another example, Mehrbod et al. (2020), developed a characterization of the BIM-enabled design coordination process and discussed the challenges that might hinder the efficiency of the process, and proposed design considerations that can help to alleviate those challenges. Other studies have focused on knowledge management and knowledge capture strategies in MEP design coordination (e.g,. Korman et al., 2003; Tabesh & Staub-French, 2005; Wang & Leite, 2016). These studies have mainly focused on reducing the overreliance of project teams on tacit knowledge during the MEP design coordination stage and improving the ability to reuse information captured from previous events.

## CLASH DETECTION

Clash detection is the process of detecting if building elements are physically or functionally interfering with one another and, prior to the inception of BIM, had been traditionally done by overlapping 2D drawings on a light table (Porwal & Hewage, 2013). Nowadays, BIM has enabled this process to be done automatically by combining

3D models from different disciplines into federated models, or consolidated models, and then running an automatic clash detection tool on the federated model. Clashes can be categorized as soft, hard, and time clashes. A hard clash is when two or more building components physically interface. When the minimum clearance for a building component is occupied by other components, it is a soft clash. Time clashes are clashes that impose spatial challenges when considering the constructability and operability of the facility (Leite, 2019; Tommelein & Gholami, 2012).

Several studies have focused on improving or investigating BIM's automatic clash detection process. For example, Leite et al. (2011) found that the use of automatic clash detection increases the recall rate, which is the number of actual clashes that have been detected during the MEP design coordination process, compared to the traditional method. However, the clashes found in the automatic clash detection process include many false positives, which are not actual clashes but were flagged as clashes (Leite et al., 2011), imposing a challenge on BIM coordinators related to filtering a number of irrelevant clashes. Therefore, studies such as (Hu et al., 2019) have tried to address this laborious process by proposing solutions to filter out irrelevant clashes. Moreover, Akponeware and Adamu (2017) proposed the use of Open Work In Progress (OWIP) by the stakeholders to achieve clash avoidance rather than delaying the process until the clash detection stage. Also, Akponeware and Adamu (2017) have summarized the causes of clashes that are found in literature in Table 1:

| Causes | Source |
|---|---|
| Use of wrong or low level of detail | Leite et al, 2011 |
| Design uncertainty/use of Placeholders | Tommelein and Gholami, 2012 |
| Failing of design rules | Tommelein and Gholami, 2012 |
| Accuracy versus deadline | Tommelein and Gholami, 2012 |
| 3D model objects exceeding allowable clearance | Tommelein and Gholami, 2012 |
| Designers working in isolation from each other | Craig & Zimring, 2002 |
| Design complexity | Tommelein and Gholami, 2012; Korman et al., 2003; Ashcraft, 2008 |
| Insufficient time | Benning et al, 2010; Ashcraft, 2008 |
| Use of 2D instead of 3D models | Leite et al, 2011; Hartmann, 2010 |
| Design errors | Love et al., 2009; Tommelein and Gholami, 2012 |
| Use of different file formats | Kensek, 2014 |
| Lack of experts | Leite et al, 2011; Ashcraft, 2008;Kensek, 2014; Wang & Leite, 2014 |

Table 1: Summary of the causes of clashes found in the literature (adapted from Akponeware and Adamu, 2017)

## REWORK STUDIES

Previous rework studies have no agreement on the definition of rework. According to Love (2002), rework is "the unnecessary re-doing of a process or activity that was implemented incorrectly the first time". This definition includes omissions, errors, and changes that arise from designers or owners. On the other hand, Robinson-Fayal et al. (2003) defined rework as the direct cost of redoing activity in the site no matter what the cause is. However, Robinson-Fayal et al. (2003) explicitly excluded change orders and errors that arise from off-site manufacturers from their rework definition. It is worth noting that this lack of consistency on the definition of rework had implications on rework studies and their results (Love and Smith, 2003) especially those related to the cost and causes of rework because the causes and cost of rework would change depending on whether the activity is considered rework or not. As cited in Love et al. (2016), previous case study research showed that the cost of rework during the construction stage ranged from 2-5% of the contract value (e.g., Love and Li, 2000; Kakitahi et al., 2014; Taggart et al., 2014). This range increases to 16-23% if indirect costs are taken into account (Barber et al., 2000).

Studies have focused on the causes of rework through investigating case studies, conducting surveys, and experts' interviews. Some causes that have been identified include ineffective contract documentation, poor quality management application, inadequate briefing, poor pre-contract planning, and the use of inexperienced design personnel (Love et al., 2004). Also, owner changes, design error, and other managerial aspects such as unclear management processes are found in previous studies as major causes for rework in construction (Love et al., 2010; Ye et al., 2014).

## GAPS IN THE LITERATURE

The underlying causes of rework and field detected issues found in previous studies lack explicit descriptions. For example, causes of rework in previous studies will almost always include design error, omissions, poor communication. These are most likely valid causes for rework or field detected problems, but they cannot provide practitioners with direct countermeasures to minimize the issues that are found on-site in the future. Moreover, these causes also do not provide software developers with what can be improved to avoid rework.

Furthermore, most previous studies which identified the causes of rework started with collecting factors that were found in the literature. In principle, this is good practice.

However, this might have led to three main issues. First, previous studies on rework often mix up the causes of rework with the causes of the delay (Ye et al., 2015). Second, previous studies include case studies of construction projects that are scattered all around the globe and a wide variety of project types, the causes may vary depending on the location and the type of the project. Finally, the causes that are found in recent studies have been repeatedly found since decades ago (Love et al., 2016).

Another gap in the literature is that previous studies have either focused solely on causes of issues and challenges in 3D design coordination such as Staub-French & Khanzode (2007) or rework causation such as Ye et al. (2015). Therefore, a practical investigation on the underlying causes of missing field detected issues from state-of-the-art Virtual Design and Construction (VDC) tools is needed.

# Chapter 3: Research Approach

Since the causes that lead to missing field issues from MEP design coordination have not been explicitly investigated in previous studies, this study is considered exploratory research. Exploratory research studies can be conducted through different methods such as case studies, secondary literature reviews, and in-depth interviews (Creswell, 2017). As depicted in Figure 1, this research relies mainly on literature review, and experts' interviews in order to find the causes of FDIs, and the preventive measures that can be taken to increase the efficiency of the BIM coordination. The interview process which is the main approach for data collection in this research is further elaborated in this chapter.

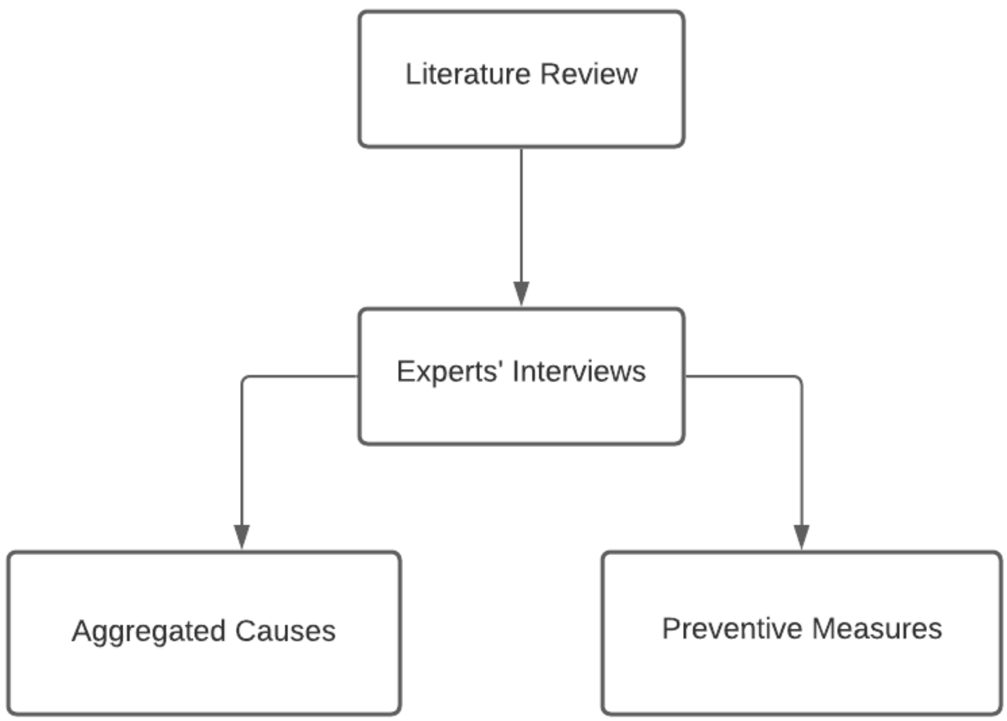


Figure 1: Research Approach

## EXPERTS' INTERVIEW:

Data in qualitative research are collected in an environment where participants experience the issue or the problem. And, the data can be gathered by direct communication with people considering their behaviors and acts within a particular context (Creswell 2017). Therefore, the second method of data collection in this study is done through interviewing experts who most likely have experienced FDIs. Target participants include professionals who have MEP design coordination experiences, such as VDC engineers and BIM coordinators, and professionals with field experience like superintendents, and field engineers. Professionals with experience in both VDC and the field, such as project managers, will also be sought.

According to Creswell 2017, the interview sample size, for qualitative research purposes, is six to eight professionals per group (Creswell, 2017). Since two groups are targeted in this study, the MEP design coordination and the field, a total number of 12-16 professionals shall be sufficient for this exploratory research.

| No. | Position | Years of Experience |
|---|---|---|
| 1 | VDC Manager | 5 |
| 2 | BIM Engineer | 5 |
| 3 | Quality Manager | 5 |
| 4 | VDC Speciallist | 4 |
| 5 | VDC Manager | 8 |
| 6 | Project Manager | 6 |
| 7 | Project Engineer | 7 |
| 8 | VDC Manager | 12 |
| 9 | Project Engineer | 6 |
| 10 | Project Manager | 11 |
| 11 | BIM Coordinator | 5 |
| 12 | Senior BIM Manager | 11 |

Table 2: Profiles of the interviewees

Table 2 above shows the interviewees' roles and years of experience. The interviews were semi-structured which means the researcher has prepared a set of open-ended questions beforehand but were not strictly following a certain structure. A sample of the interview questions can be found in Appendix A. The questions are focused on the field issues, in which the participants are first asked about the significance of the issue and the current state of the industry. Then, the interview dives into discussing the causes and the preventive measures that could help in avoiding the field issues based on the participants' experience. The interviews were conducted through video calls or teleconferences and their duration ranged from 40 to 80 minutes.

Furthermore, in order to achieve consistency among practitioners who were interviewed in this study, the FDI was clearly defined to the participants as any issue that is detected on the site leading to an increase in cost or schedule and could have been avoided in a previous stage. So, this excludes cost increase or delays that occurred due to changes from the owner because avoiding them at an earlier stage is not currently possible. Moreover, as mentioned in the literature review, the factors found in previous studies are repeatedly found and not directly relevant to the FDI; therefore, they have not been the basis for the experts' interviews, and the findings of this research mostly rely on the causes found through the experts' interviews.

# Chapter 4: Results and Discussions

The results of this study include the causes that lead to missing FDIs from the BIM coordination stage and the preventive measures that can be taken by the BIM coordination teams to enhance their ability to capture most of the issues before they occur in the field. This chapter starts with a discussion regarding the categorization of the causes found, then the causes and relevant examples are presented. And, it ends with presenting the preventive measures.

## CATEGORIZATION OF THE CAUSES

The causes that were found through expert interviews were aggregated into three main categories including modeling related causes, BIM coordination related causes, field related causes depending on when the FDI could have been avoided or captured, and the overall category which include causes that can happen in more than one of the categories. It could be argued that this study is focusing on causes of FDIs that are missed from the BIM coordination stage, and why modeling and field-related causes are included. However, as depicted in Figure 2 what is meant by the BIM coordination in this study is the whole process starting from the models being created and submitted by the different trades till the coordinated models are deployed in the field, and as-built models are captured and updated for subsequent BIM coordination. For instance, if the issue is caused by not providing the field personnel with the latest drawing, then it is a field-related cause because it was found and could have been avoided at the field stage of the process. It was found important to categorize the causes to know the teams that will benefit the most from preventing those causes.

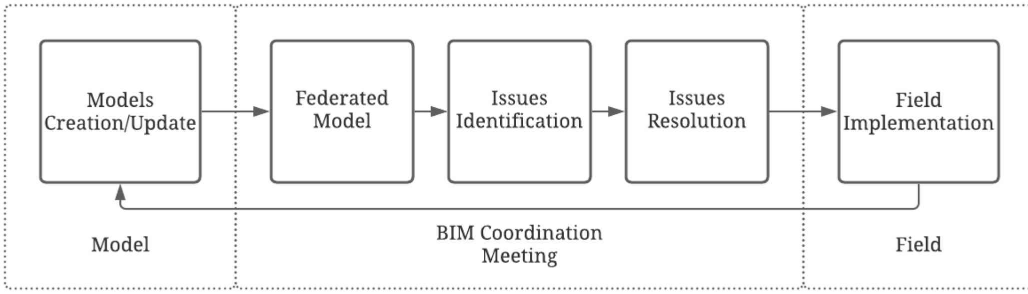


Figure 2: The flow of the BIM coordination process

## CAUSES AND EXAMPLES

The causes found through expert interviews are summarized in Table 3. The causes are sorted by their main categories and the number of times that experts mentioned them. Although this is considered as exploratory qualitative research that does not aim to provide quantitative analysis, the consensus on some of the causes among the interviewees shows some significance and importance of those causes. The causes found through expert interviews are further discussed with examples in this section. However, the details of the examples vary depending on how they were mentioned or presented by the experts, for example, some include screenshots from the model some do not. All examples shown in this chapter were discussion in the expert interviews and the figures were extracted from real-world coordination models for illustration purposes.

| Category | Causes of missing FDI issues from BIM coordination | Frequency |
|---|---|---|
| Modeling | Missing model elements | 4 |
| | Low LOD or model accuracy | 4 |
| | The use of wrong references or origin points | 3 |
| | Missing required clearances | 1 |
| BIM | Not considering operability | 4 |
| | Not considering maintainability | 4 |
| | Not considering functionality | 2 |
| | Not considering constructability | 2 |
| | Ignoring what seems to be minor clashes | 1 |
| Field | Inaccurate as-built models' updates | 3 |
| | Using outdated drawings | 2 |
| Overall | Lack of experience in codes and regulatory requirements | 3 |
| | Time constraint | 3 |

Table 3: Causes of missing FDIs from BIM coordination

**Missing model elements**

In the BIM execution plan, the general contractor typically agrees with the subcontractors on what to include in their models the elements that are most critical for the BIM coordination process. However, since constructions projects are one-off projects, and there cannot be a general rule on what to model, it was frequently mentioned by the experts that many of the FDIs are because elements were not modeled, and they in some cases are intentionally left out because they seem insignificant and can be easily adjusted.

However, they might end up causing issues in the field that cause an impact on cost or schedule.

Example 1: Overhead conduits electrical conduits in the ceiling are modeled by the electrical subcontractor, but not the dropdowns to the switch box, nor the switch boxes, and in the field, a plumbing pipe that was coordinated was found to be running through that switch box, as results they had to reroute the pipe and fix the issue in the field.

Example 2: Due to congestion in the space, the BIM coordination team decided to run electrical conduits inside a plumbing chase as can be seen in Figure 3, the dark blue pipes are electrical conduits, and the brown pipes are the plumbing pipes. The coordinated model, as can be noticed in Figure 3, was clash-free the conduit ran smoothly with no issue between the plumbing pipes. But, the toilet carriers, which were not modeled, had a spatial conflict with the electrical conduits that were already installed. The conduits, which were clashing with the carrier had to move, and new cores needed to be drilled on the concrete slab because the sleeves were placed in the original location.

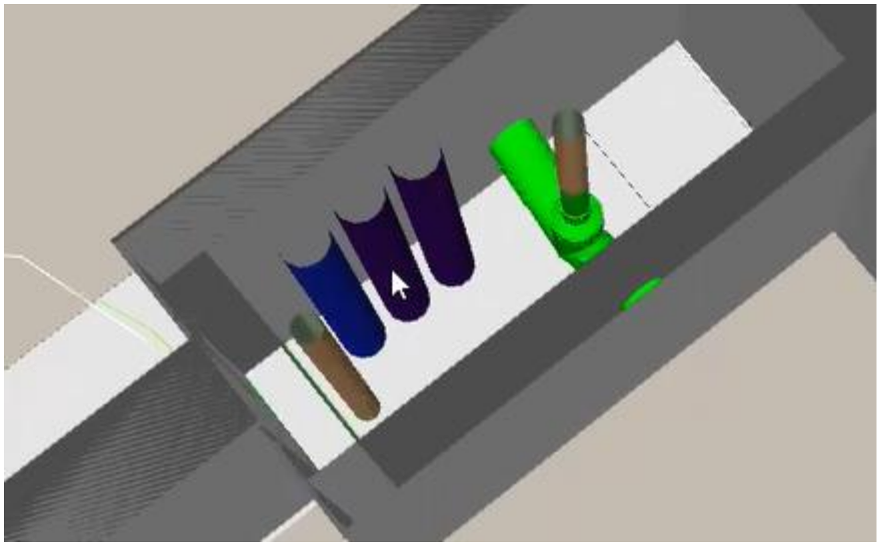

Figure 3: Plumbing pipes (green) and electrical conduit pipes (Dark blue) inside a plumbing chase.

**Low Level of Detail (LOD) or Model Accuracy**

BIM project execution plans, which are typically used for each project that utilizes BIM for construction coordination, should include what LOD required from each subcontractor. However, in some cases, BIM coordination is run based on models that lack accuracy or are not created to an appropriate LOD. This might result in some issues or clashes due to changes in the elements' actual dimensions or certain details that are only captured and fixed in the field. It is worth mentioning that Leite et al. (2011) have also found that low LOD causes a low recall rate in the BIM automatic clash detection.

Example 1: The BIM coordination was conducted based on models that are provided by the steel subcontractor without connection details as shown in Figure 4. So, the initial consolidated model used for BIM coordination did not have any clashes and was signed off by all trades. However, in the field, a gusset plate was found to be clashing with a plumbing pipe as Figure 5 shows after the structural model was updated to an appropriate LOD which included the gusset plate that is clashing with a plumbing pipe.

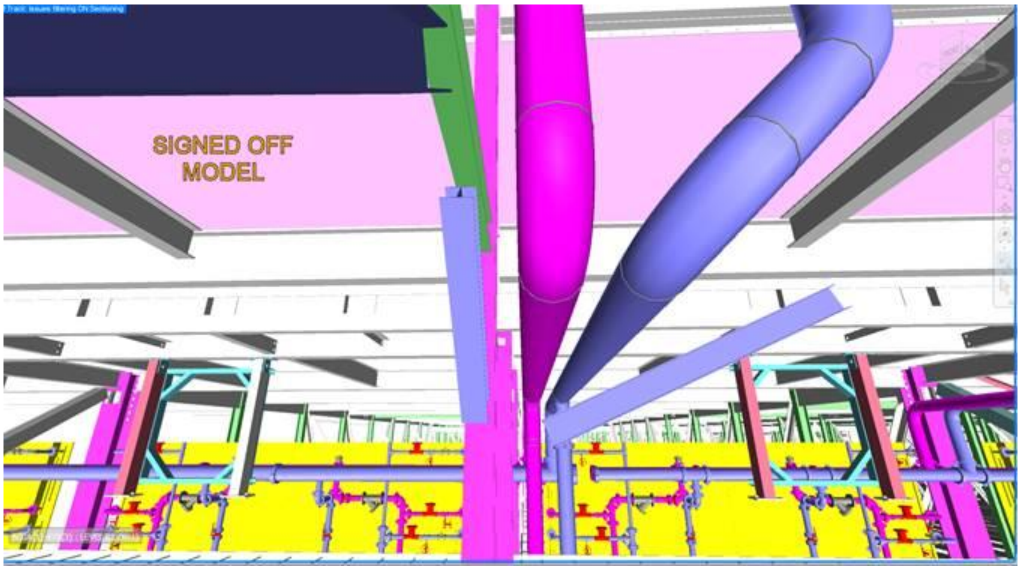


Figure 4: A structural model without connection details and not clashing with the plumbing pipe.

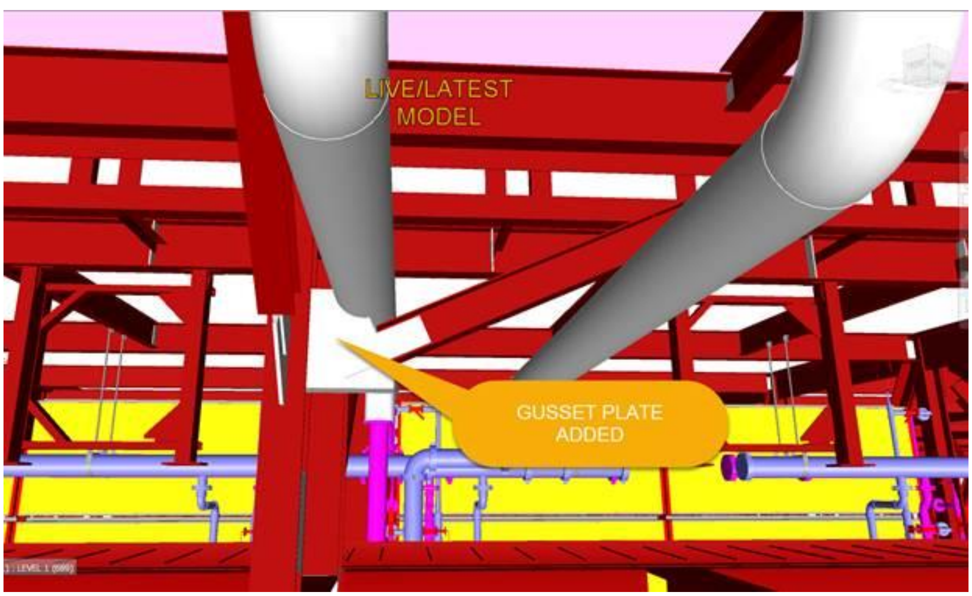


Figure 5: A structural model including the connection details (gusset plate) and it is clashing with the plumbing pipe.

Example 2: A piece of equipment in a mechanical room that was included in the consolidated model using a box as a placeholder without any details, and when the suppliers provided the manufacturer details it was found that the piece of equipment is clashing with other elements in the room.

**The use of wrong references or origin points**

If the origin points or references are not followed accurately when creating the 3d models used for BIM coordination, this can result in issues and rework in the field especially when the elements in those models are buried underground or fixed in structural elements such as a sleeve in a concrete slab or bolt holes in structural steel.

Example 1: Plumbing pipes that were intended to be used as drains in the kitchen were not placed in the right position where the kitchen equipment outlets are.

Example 2: Civil utility models had wrong coordinates resulted in having an equipment pad located in the wrong place. As a result, concrete was poured in the wrong location. Also, some parts of the concrete pad had to be chipped out to adjust the location of the electrical stub-ups to the new corrected location.

**Missing required clearances**

Subcontractors when creating their 3d models usually include in the model the required clearances represented by boxes in front of where the element should be reached or accessed mostly for operation or maintenance purposes. But, in some cases, this is missed particularly when the needed accesses should be provided by other trade.

Example: An access door in a ceiling that is supposed to be used to access pieces of equipment above the ceiling was not able to open because it was clashing with other elements when opening it this did not show in the model because clearance for that access panel was not modeled.

**Not considering operability**

What is constructed needs to be operatable, and if operability is not considered in the BIM coordination, this can lead to fixing that issue assuring operability in the field and these types of issues might not be found until commissioning.

Example 1: a control panel in a mechanical room was placed in a location that is impossible to be reached because the area is too congested, so pieces of equipment had to be rearranged in order to provide access to the control panel.

**Not considering maintainability**

In any facility, maintenance is an essential part that occurs frequently in the lifecycle of the facility. Assuring that required maintenance could be conducted is important. And, the BIM Coordination provides a good opportunity to visualize the building and making sure it is maintainable. But, sometimes this is overlooked and only found in the field or a later stage.

Example: The AC unit, which is the element in light blue in Figure 6, requires maintenance accessibility, so the red box is supposed to provide the clearance required for the air handling unit; however, because of the electrical lines below that clearance a technician can't access that AC unit. Figure 7 shows an actual photo of that after construction and figuring out it is an issue. Hence, the project team had to fix this by lowering the air handling unit below the level of electrical conduits.

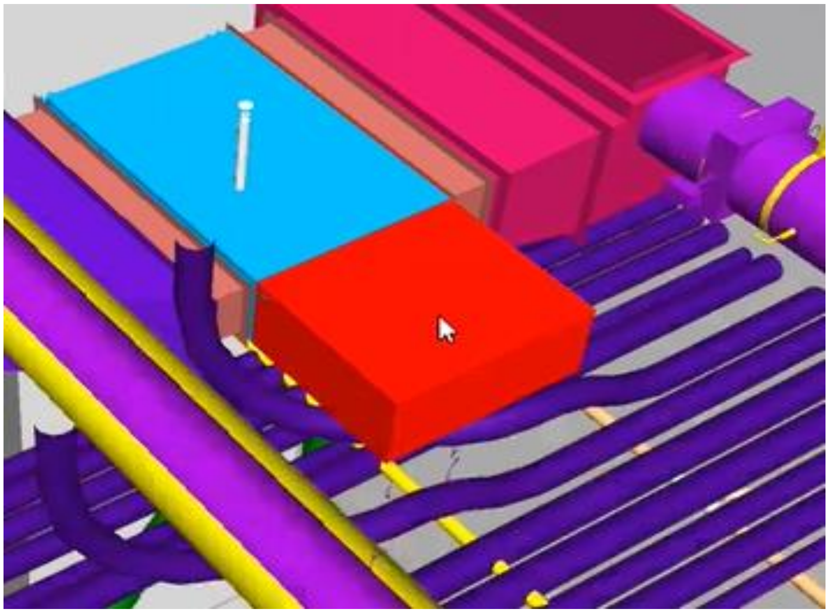

Figure 6: An air handling unit (light blue) with the clearance (red).

Figure 7: Electrical conduits that preventing the accessibility to the air handling unit.

**Not considering functionality**

When building elements do not meet their design intent, this might result in rework in the field before handing over the project. Although catching such issues might be challenging for BIM coordination teams, avoiding them before finding out in the field can result in saving a great deal of cost and effort.

Example 1: Mechanical ductwork was found blocking the lighting from the light fixtures above it, as shown in Figure 8. This was not an issue that can be found in the automatic clash detection process, it was caught only when the duct was installed. To resolve this, they had to change the location and the type of light fixtures so they can be hanged in pendants to bring them below the ductwork, and since the lights were planted in the concrete floor they had to chip and expose the wires to move the lights to the new location.

Figure 8: The lighting from light fixtures is blocked by an HVAC duct.

**Ignoring what seems to be a minor clash**

In the BIM coordination, some minor clashes are intentionally left for the field to resolve because they are thought to be easily fixed in the field. However, what looks minor in the BIM coordination can result in significant rework and impact on cost and schedule.

Example: Duct hangers were clashing with ceiling fabric, as can be seen in figure 9, which was neglected because typically hangers clash with the ceiling. But because the ceiling material was fabric, this clash was not easily fixed in the field. The subcontractors ended up moving the fabric to allow the hangers through, as depicted in figure 10, by cutting the plywood used for the fabric

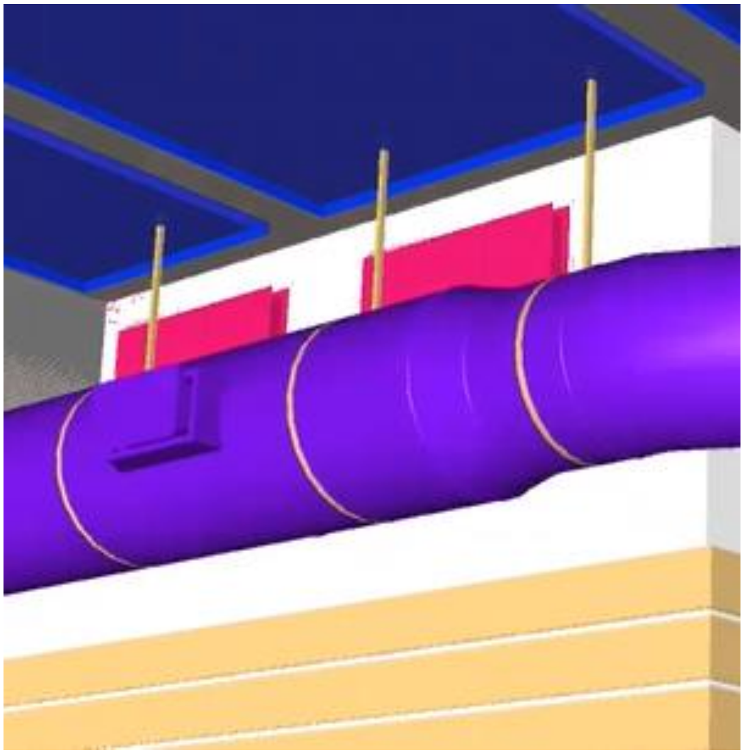

Figure 9: Hangers holding the HVAC ducts clashing with ceiling fabric.

Figure 10: Ceiling fabric system moved away from the hangers.

**Inaccurate as-builts updates**

If the models that are used in BIM coordination are not updated accurately and in a timely manner for the subsequent coordination events, the BIM coordination process can be inefficient because what is being coordinated does not exactly reflect what is the field. This becomes more significant in phased contracts when the same or a new GC takes the project at a certain phase such as MEP and interior contracts after the core and shell.

**Using outdated drawings**

When the BIM coordination teams agrees on the coordinated models and signs it off, the updates and changes made in the coordination process should be delivered to the site team through updating the shop drawings and the other issue for construction (IFC) drawings that are used for construction.

Example: Although the issue was addressed in BIM coordination and resolved, the plumbing subcontractor installed a plumbing pipe below the ceiling according to the original shop drawing, which was not updated according to the coordinated model, resulting in rework in the field to move the plumbing pipe to its original location.

**Lack of experience in design codes and regulatory requirements**

If the design team missed some design code or regulatory requirements, the BIM coordination can be a good opportunity to capture that. However, it is challenging since VDC specialists are typically not experts in design codes or regulatory requirements. Therefore, those issues can be missed from both the design teams, and BIM coordination, and only detected in the field during auditing or inspections

Example 1: In a parking garage, some concrete columns and beams above a ramp were constructed in a height that violates the minimum required height, which was not incorporated in the BIM coordination, this resulted in adjustments made in the field, which is decreasing the slope of the ramp to meet the minimum required height.

Example 2: Light fixtures were placed close to fire sprinklers violating the minimum radius required to avoid the heat from the light fixture to reach the fire sprinklers. That made the fire sprinkler go off during commissioning which resulted in fixing the issue and mess caused by that on the field.

**Time and schedule constraints**

Construction projects usually have a very tight schedule which can impose time challenges on the BIM coordination teams. This can lead to rushing on issue resolutions and not thoroughly investigating the feasibility of resolving the issues. In some cases, the resolution of some issues found in BIM coordination is deliberately delayed to the field especially when field teams reached the level or area that being coordinated in the BIM coordination process. Previous studies have also found that insufficient time can impose challenges on the BIM coordination team and increase the number clashes (Benning et al, 2010; Ashcraft, 2008).

### PREVENTIVE MEASURES

In addition to the causes of missing FDI from BIM coordination, the experts were asked about preventive measures that could have taken to avoid the field issues, and enhance the ability to resolve them earlier during the BIM coordination, which can result in saving in cost and schedule. The preventive measures that were suggested by experts are summarized below:

- **As-built updates:** Timely and accurately updating of as-built assures that the BIM coordination is conducted based on the latest models that incorporated any site changes.
- **The right knowledge in the BIM coordination meeting:** The more experts with the different phases of the lifecycle of a facility such as experts in constructability, operability, and maintainability involved in the BIM coordination, the more efficient the BIM coordination would be by allowing experts to visualize the facility and foresee issues before execution.
- **Enhancing field personnel access to the coordinated models:** Assuring that the latest coordinated models are efficiently communicated to the field is important to avoid rework activities that are resulted from following outdated drawings.
- **Rework log and VDC team lessons learned**: The VDC team should be aware of the issues that occurred in the field especially what could have been avoided during the BIM coordination in order to avoid similar issues from occurring in future events.
- **Modeling to the right accuracy and LOD:** The models submitted by subcontractors should be created to an LOD that is sufficient enough to meet the purpose of the BIM coordination process which is avoiding field detected issues. So, the model should accurately represent the actual dimensions and details this becomes significantly important in congested mechanical rooms or tight ceiling spaces.
- **Subcontractors modeling capabilities:** General contractors should assure that the subcontractors involved in the project have 3d modeling capabilities. This is an essential part of successful BIM coordination implementation that should be addressed as early as the agreement stage.
- **Include in the model whatever is not flexible:** Elements that cannot be smoothly moved, or adjusted in the field should be included in the 3d models used for BIM coordination.

# Chapter 5: Conclusion

Although the use of BIM for MEP design coordination has enhanced the ability to capture issues before they occur in the field, the industry is still suffering from field fixed issues which results in project delays and cost overruns (Assaf and Alhejji, 2006). Previous studies have investigated the causes of rework (e.g. Love et al., 2010; Ye et al., 2014) and the causes of challenges associated with BIM-based coordination (Tommelein and Gholami, 2012). However, those studies have not directly investigated what caused the FDIs to be missed from the BIM coordination process. Therefore, in order to improve the efficiency of the BIM coordination or the issue identification rate, the possible causes of not capturing the FDIs and some preventive measures were explored in this study through interviewing 12 industry professionals, including experts who work in the field and are exposed to field issues such as project engineers, and experts who have experience with BIM coordination (e.g., VDC engineers), as well as experts that have experience on both (e.g., project managers).

The causes found were categorized into three groups based on when the issue could have been identified or avoided, include modeling, BIM coordination meetings, field, and the overall process. The causes were summarized in Table 3 and sorted in each category by the number of times they were mentioned by experts. Among the causes found, missing model elements, not considering operability or maintainability, and inaccurate as-built model updates were the most mentioned causes. All the causes found were discussed and further elaborated with examples in the results chapter. Moreover, the professionals were asked about what preventive measures can be taken in order to enhance the ability to avoid FDIs and having the right knowledge in the BIM coordination meetings was frequently mentioned by experts, in addition to other preventive measures which were presented in the results chapter.

## CONTRIBUTION

The findings of this study are beneficial for professionals and researchers in myriad ways. Industry professionals can utilize the causes and preventive measures to further enhance the BIM coordination capability of capturing issues before they occur in the field. Furthermore, researchers can use the findings of this study as a point of departure for various research topics related to BIM-based MEP coordination such as quantifying the cost and schedule impact of the field issues that are categorized by the causes found.

## LIMITATIONS

Although the number of interviews conducted falls within the recommended range for exploratory research (Creswell, 2017), the results found cannot be generalized without validation through conducting a case study or quantitative analysis on the causes found. Moreover, most of the professionals interviewed are working on commercial projects, but the type of the project was not considered when discussing each specific cause or example with experts.

## FUTURE WORK

Future work should focus on investigating the significance of the causes found, and validating this study through utilizing a quantitative research approach. Moreover, once the most critical and significant causes are identified, the focus should be on proposing a solution that can address those critical causes allowing industry practitioners to make the most out of the BIM-enabled MEP coordination.

# Appendices

Appendix A: The interview questions

- How significant is the impact of fixing constructability issues onsite on the cost and schedule of a project?
- Do you think most of the field-detected issues in construction projects could have been avoided in the BIM/construction coordination stage?
- Why even after having a clash-free model, some issues remain undetected and are only solved onsite? Can you provide examples?
- What could have been done to capture these issues during the design and construction coordination stages?
- What is a good metric that tells us the amount of field-detected constructability issues in construction projects?
- Can rework activities that are triggered by owner change be excluded from that metric?
- Would different settings and methods that are used at the design coordination stage impact the amount of field-detected issues?

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