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INVESTIGATING THE POTENTIAL OF BIM TO ADDRESS PROJECT DELIVERY ISSUES

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Abstract: The use of Building Information Modeling (BIM) has increased dramatically in the construction industry due to its numerous benefits for architects, engineers, contractors, owners, and subcontractors. Research efforts have consistently shown that BIM helps to reduce the number of project delivery issues, such as RFIs, change orders and conflicts. Reducing these project delivery issues has been one of the most significant benefits of BIM and has become a key metric to assess the performance of BIM. The objective of this research is to better understand the extent to which BIM implementation has the potential to address these issues. For this study, we have restricted the issues to those found in Requests for Information (RFI). We employed a case study approach and analyzed more than 1,400 construction communication documents on a large design-build project delivered with BIM for a public owner. To assist in analyzing the large amount of data, a theoretical framework was developed to characterize the issues and to relate them back to BIM. Next, we characterized the reasons or causes for each of these issues to explore the extent to which a better implemented BIM could have benefited the project. The analysis showed that the most prevalent root cause of the issues was the location, i.e., the position or orientation of the component in the model that led to design revisions due to the inadequacy of information in the BIM for coordination. Further, we analyzed the model to validate the potential enhanced use of BIM would help to reduce these issues by identifying and resolving issues proactively.

1 INTRODUCTION

Over the past few years, there has been an increase in the use of Building Information Modeling (BIM) in the construction industry due to the wide range of benefits of using BIM for design, planning, and construction. During the design phase, BIM helps to identify physical conflicts between systems and assists in design coordination and identifying errors in the design before construction starts (Leite et al. 2011; Staub-french and Khanzode 2007 and Eastman et al. 2011)). Later during the construction phase, reduction in Requests for Information (RFI), Change Orders and field coordination problems as some of the benefits of BIM (Barlish and Sullivan 2012, Bryde et al. 2014, and Staub-french and Khanzode 2007). But previous studies also show that it is difficult to leverage the complete potential of BIM, and very few industries have been able to reap all the advantages BIM has to offer (Merschbrock and Nordahl-rolfsen 2015 and Barlish and Sullivan 2012). Using BIM to its full potential depends on the information and the detail present in the model. Kiviniemi et al. (2008) found that many practitioners are doubtful as to what needs to be modeled in a BIM for construction coordination. Past studies tell us that more detail does not always require more modeling effort (Leite et al. 2011) and with such additional effort, it is more likely to identify coordination issues before construction when it is efficient and cost effective (Wang and Leite, 2013).

The objective of this paper is to investigate the potential of BIM to proactively address the issues that arise from RFI's. We employed a case study approach and analyzed more than 1,400 construction communication documents on a large design-build project delivered with BIM for a public owner. We analyzed RFI and Construction Communications (CC), along with Conflict reports, 2D drawings, and 3D models documented in the online construction management platform. We developed a framework to characterize the project delivery issues and to relate them back to BIM. Finally, with the help of examples, we explain how efficient use of BIM could have helped address these issues before construction.

2 BACKGROUND

Although there has been an increase in the use of BIM in the construction industry over the past few decades, constructability issues and other project delivery issues remain a persistent problem and projects still generate 887 RFI's on average (Shim et al. 2016). Since an RFI serves as a means of communication between project participants for clarification or additional information whenever there is an error, conflict, or uncertainty in the project (Mao et al. 2007), it is clear that there is still room for improvement in tapping into the complete potential of BIM. And it is not limited to RFI's, as a large number of other construction communications are generated in response to these RFI's and are circulated every day on a project for coordination and collaboration among project stakeholders every time an issue arises over the course of a project. It is, therefore, necessary to analyze these RFI's and construction communications to better understand the extent to which BIM has the potential to address these types of project delivery issues.

From previous studies, we know that construction documents like RFI's are not well structured (Mao et al. 2007, Songer et al. 2004, Rojas and Lee, 2007). Hence, to analyze the issues in these RFI's, we had to first develop a framework to categorize and structure the data in these RFI's to information that can be related back to BIM to see how the issue could have been identified earlier with the use of BIM. To develop this classification framework, we have mainly focused on past literature on RFI's as the structure of construction communications is similar to that of an RFI document. After doing a thorough study of previous literature on RFI's, we saw that previous researchers largely classified RFI's based on the type and reason of the issue, as shown in Table 1. For example, Shim et al. 2016 and Brazee 2014 classification of RFI's was limited to RFI categories whereas Chin and Russell. 2008, Hanna et al. 2012 and Tilley 1997 tried to analyze the cause or the reason for the issue and categorized them further accordingly.

Table 1: RFI Classification from Past Literatures

Author	Shim et al. 2016	Brazee 2014	Hanna et al. 2012	Chin and Russell, 2008	Tilley 1997
RFI Classification	Confirmation Only	Design Clarification	Added Scope	Omissions or errors in contract documents	Alternative Design Solution
		Request for Design Change	Construction Communication	Hidden/Unexpected Field Condition	Approvals
	Drawing Clarification	Request for Substitutions	Constructability Issues	Inconsistency	
			Utility Conflict		Information Clarifications
	Plan/Spec Discrepancies	Constructability Issue	Change of Staging/Phasing	Changes Requested by the contractor	
			Value Engineering		Information Confirmations
	Specs Clarification	Differing Site Condition	Design Change	Just Confirmed	Other
	Others		Design Clarification		
			Design Method		
			Design Coordination		
			Deleted Scope		
			Incomplete Plans/Specs		
			Material Change		
			Differing Site Conditions		

3 RESEARCH FRAMEWORK AND ANALYSIS

A qualitative case study methodology was employed for this study. The case studied is that of the construction of a public owner BIM initiated institutional building in Edmonton, Alberta, Canada which was procured under a design-build contract with the government of Alberta. The project team was made up of 29 different stakeholder organizations. For this study, employing content analysis method, we analyzed 1400 RFI and Construction Communication (CC), along with Conflict reports, 2D drawings and 3D models documented on the online construction management platform manually as the content of the construction communication documents which are filled by project participants manually is highly dependent on their personal experiences and writing styles, which is impossible for computers to understand and characterize without additional data.

3.1 Development of Framework

Before explaining the process of how we analyzed the RFI documents, we will briefly explain the structure format of the RFI's we analyzed. A typical RFI document has very little information in the structured format at the top of the document which includes title, important dates and the participants involved. This is followed by an unstructured main body which includes Question and Answer (Q&A) which is the topic of focus for our study here. The participant who initiates the RFI asks the question according to the situation which is than answered by the responsible project participant by filling the response in the RFI document below the question in the main body or by sending a separate CC. In this project, out of the 1400 documents analyzed, 167 were RFI, and the rest were CC's generated by the consultant as a response to RFI's. But for the development of the framework, we first analyzed the 167 RFI documents. As mentioned before, for this study, we were interested mainly in the Q&A body part of the documents. An iterative process was used to code these RFI's into categories using content analysis. In the first round of coding, the author identified the type of the issues being raised based on the wording and nature of the question. For example, one of the RFI question content says*, "requests to revise the electrical drawings, and as a result, move the power source"*. After carefully reading and reflecting on the question content, the author summarized and categorized this RFI type as a Design Revision. In the next round, we delved in a little deeper to understand why the issue was being raised as we envisioned that asking the question why the issue originated would help us understand how the issue could have been addressed with a better use of BIM. We will use the same example quoted above to explain the development of reason category. The content of the question in the same RFI also says*, "Drawing E.2.02- Level P1, Part 1 Power Plan shows P-26, DCW Booster Pump in the Boiler Room. However, drawing M3.02- Mechanical Fan Room 2 indicates the same P-26 pump to be in Fan Room 2."* And *"location discrepancy"* was mentioned in the RFI body. Hence, we summarized this RFI cause as design discrepancy. But, many other RFI's also mentioned inconsistency between designs. Finally, while developing the RFI reason category, we grouped discrepancy and inconsistency under Design Inconsistency category.

But identifying what is the issue and why the issue arose is not sufficient here to fulfill our objective as we also need to understand what information should be detailed in the model for which we further classified the issues depending on the parameter that was the subject of the body of the construction document in order to identify the root concern of the issues. Based on codes adapted from Cavka et al., (2016), we used an initial Property codes like size, location, function, type, quantity, etc. to analyze the RFI's. The categories were then revised whenever needed based on the patterns observed during the content analysis of the RFI's.

Figure 1 shows how we analyzed and developed RFI type and reason categories shown in Table 1 and Table 2 along with their description. After developing the framework, we analyzed the 1200 CC's similarly to check whether the framework is sufficient to analyze the information in the CC's. The CC's were analyzed by two coders which helped to identify loosely described and ambiguous codes.

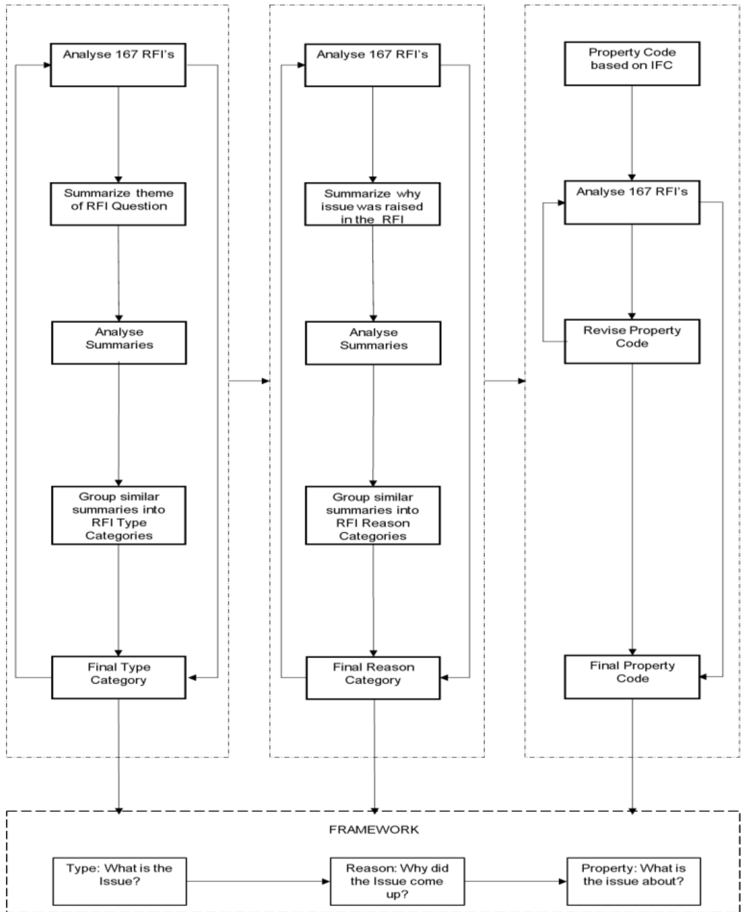

Figure 1: Coding Process Map

Table 2: Description of RFI Type Categories

Type	Description
Design Revision	A change in design or request for change in plan/ drawings made
Design Clarification	Clarification about the content of plan/drawings or intent of the design
Construction Coordination	A request to change the sequence of process or clarification regarding installation, process or schedule of construction
Design Communication	Communicating decisions made prior in a meeting for example, to the team
Scope Clarification	Clarification about who is responsible for the work or the extent of work/scope
Design Alternative	Suggesting an alternative/substitution for the design which is more feasible or for better coordination
Design Review	Communication of document for review from other disciplines or request to review updated design
Information Request	Requesting more details about a component or requesting for a plan/section/elevation/drawing

Table 3: Description of RFI Reason Categories

Reason	Description
Design Inconsistency	Discrepancies in design or inconsistency between plans/sheets/section/elevation or interdisciplinary drawings.
Design Coordination	Coordination of design between different discipline
Conflict	Physical/ Spatial conflict between components in the design
Design Error	Error in the design or Mistake in calculation
Constructability Issue	Difficulty in constructing as per the design on site
Requirement	Mostly change in design required to suit the product or owner's requirement
Code Requirement	Requirement to meet code specifications
Owner's Request	Request/Clarification made by owner
Contractor's Request	Request made by Contractor
Value Engineering	Cost reduction
Missing Information	Information not available regarding a particular component in the plan/drawing or Section/Elevation detail is missing
Design Modification	Updates/ modification made in the design as the project proceeds
Confirmation	To verify/approve or confirm the information assumed by the sub
Material Unavailability	Material specified not available

3.2 Content Analysis

After developing the final categorization, all the 1400 RFI's and CC's were analyzed and categorized. The result of the analysis is summarized in Figure 2 and Figure 3. From Figure 2, we can observe that almost 60% of the construction communications was about design revision, out of which 28% originated because of design coordination issues while another 20% were initiated to meet the project requirements like owner's specifications or the procured product requirements.

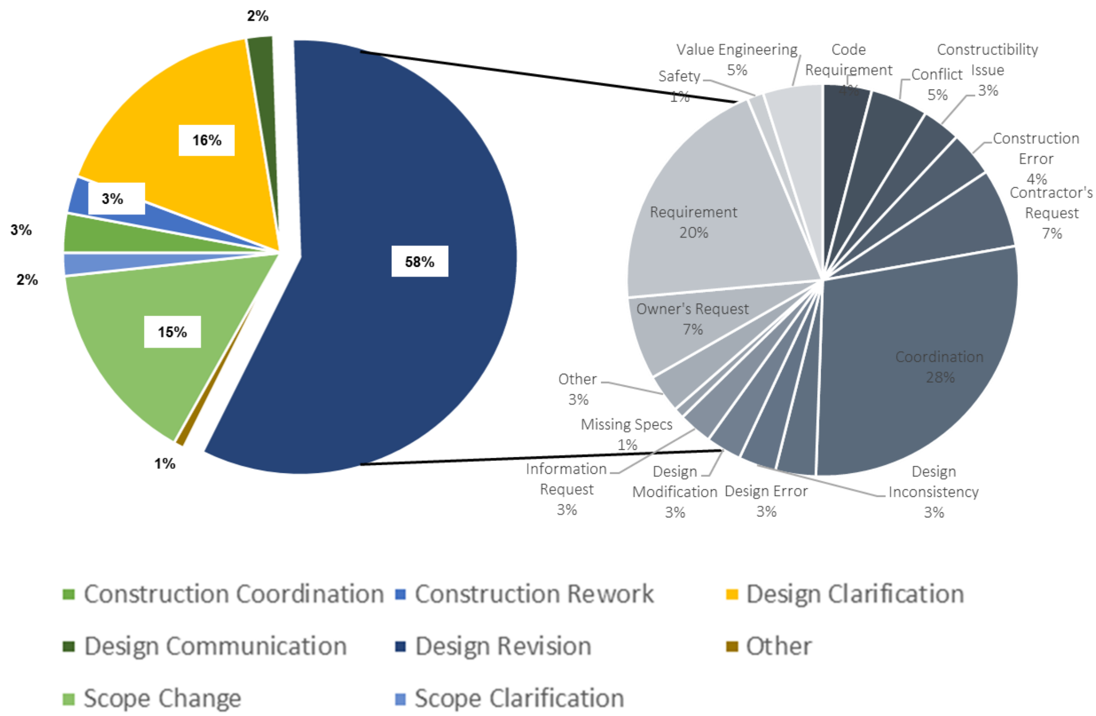

Figure 2: Distribution of RFI's across Different Type and Reason Categories

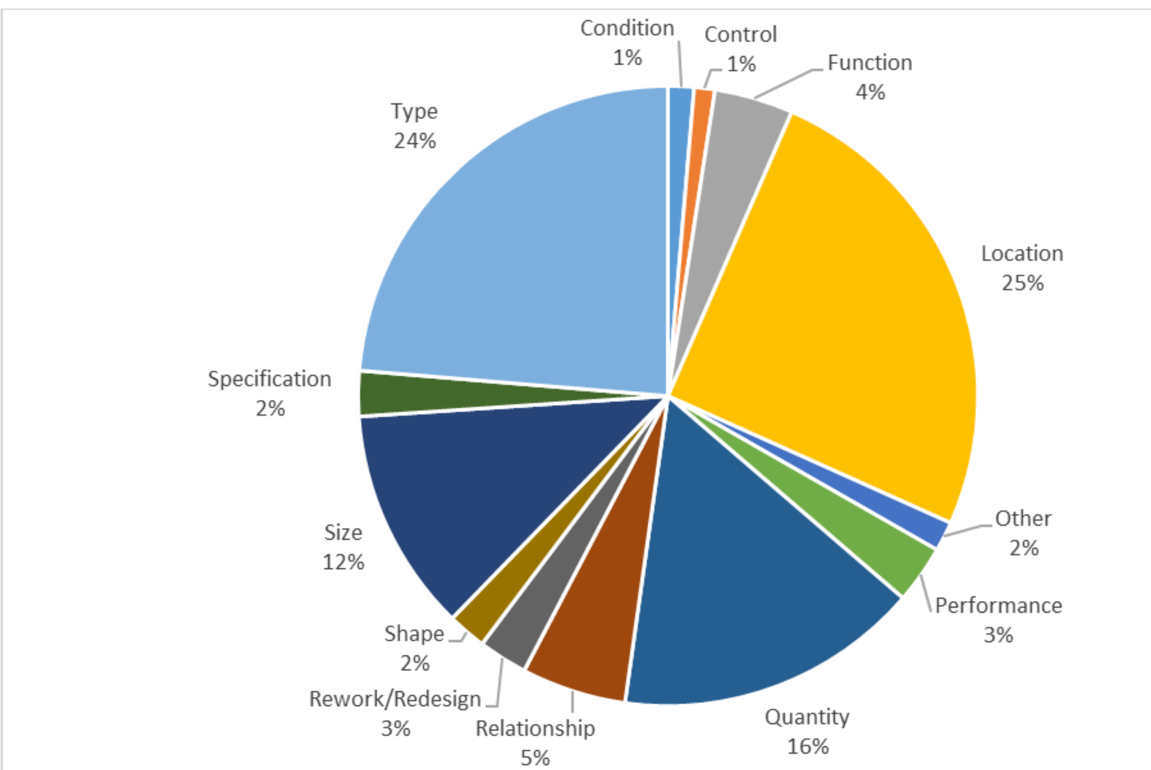

Figure 3: Distribution of RFI's across Different Property Categories

Also the results of our analysis showed that almost one-fourth of the total issues analyzed in this study focused on the location of the design element and another one-fourth is regarding the type of the design element.

3.3 Model Analysis

Once we finished the analysis of the written construction communication documents, the next step was to trace the issue back in the model and assess why the issue was not identified earlier using BIM. For this research task, we chose 14 significant issues that belonged to the most frequently occurring categories according to our content analysis results and analyzed the issue in the 3D model. Here, we will try to explain this with the help of few examples that belong to the top most frequent categories in the framework. We used Solibri Model Checker and Autodesk Navisworks to analyses the issues in the model.

a. Example 1

"Relocate the dangerous Chemical Lab from the west to east side of the building to reduce the duct run for safety purposes."

This construction communication's theme is design revision in the location of the chemical lab and the size of mechanical duct system for safety reasons as the mechanical exhaust duct system was running all along from west to east of the building. As a result, the lab had to be shifted to the other end of the building which lead to electrical and plumbing revisions as well. When we traced this issue back to the model, we saw that the exhaust system was modeled as shown in Figure 4 and it can be noticed that the duct system runs all the way from east to west of the building. Since the system was already modeled to reap more benefits out of the already modeled 3D model, if the size, i.e., length of the mechanical system was checked using a model checker the issue could have been identified without necessitating the subsequent significant design changes.

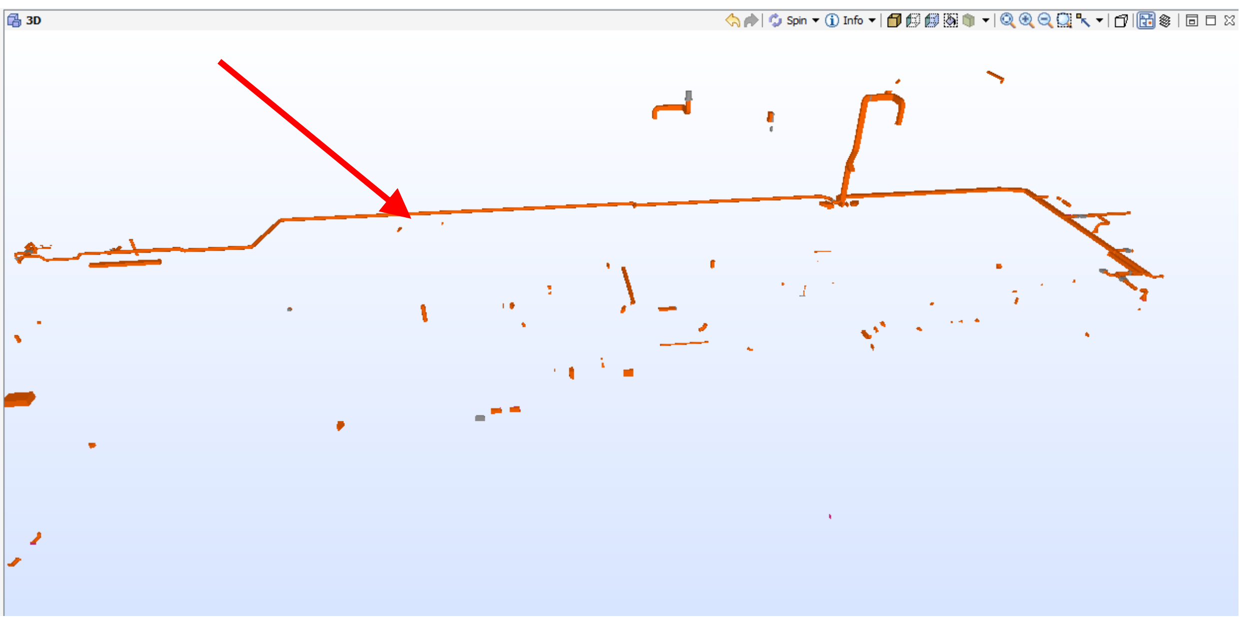

Figure 4: Snapshot of 3D Model Analysis for Example 1

b. Example 2

"Relocate the domestic water meter and domestic water booster pump as outlined in the attached RFI. The City of Edmonton and utility provider (Epcor) typically require the domestic water meter be located as close as possible to the water service entry point."

According to the developed categorization, the subject of the document focuses on a design revision for the requirement. The change here is the location of the domestic water meter and pump. The water meter was moved about 18m close to the entry point. We checked the model to see whether the necessary information to identify this issue was built in the model. The domestic water pump and meter were modeled and with project-specific model based rule checking for the location of the domestic water pump, this issue could have been identified and addressed before without leading to the entire process of initiating and RFI followed by a construction communication.

c. Example 3

“the concrete block wall in this location be shifted 300mm to the east to allow for the water closet carrier”

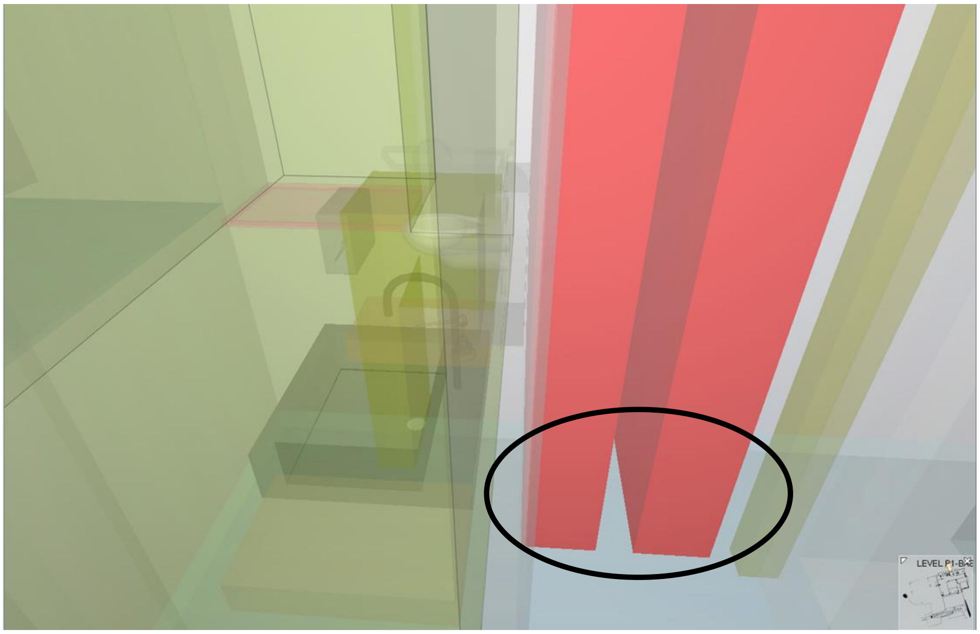

Figure 5: Snapshot of 3D model for Example 3

Again, this issue focuses on a design revision for coordination between a mechanical component and a wall in the water closet. When we analyzed this in the model, we observed that the water closet carrier was not modeled and hence the conflict between these two components could not be identified during clash detection. If the location of the water closet carrier was present in BIM, then during conflict detection the issue would have been identified and been addressed without leading to these design changes in the location of the wall.

d. Example 4

“revise the L53's shown on the east side of the building, under the soffit to L54’s, as these fixtures are to be adjustable, aimed at sculptures.”

This example is a design revision issue because of the requirement of the light fixture type to suit the needs of the project. On analysis of the model, we observed that the fixtures were modelled as blocks without any details which make it difficult to check for the requirement in the model using rule-based model checking.

4 DISCUSSION

Based on the content and model analysis findings, we can say that in this BIM-enabled multi-disciplinary project, all the benefits of BIM were not reaped to the fullest. After analyzing the RFI and CC documents containing information about the issues identified over the course of the project and then identifying why the issues were not captured in the model, we can suggest that with better implementation and use of BIM like project specific rule-based model checking. BIM has the potential to reduce RFI’s which can save time and money for the project participants. To develop these rule sets for model checking, similar studies should be done on a large number of projects to identify significant patterns and trends in design and construction coordination issues.

Another reason this project could not reap the complete benefits of BIM was because of missing components or low level of detailing with respect to mechanical and electrical systems even though the mechanical and electrical engineers were active participants in the modeling process. Further analysis is required to analyze the value of the consequences resulting from these issues not being identified in BIM and comparing it to the effort and value required to capture the issues in the model as in this study; the research team did not have access to the cost impact of these issues. In addition to this, when the issue can be identified is also significant as earlier the changes are made, less effect on the cost and schedule of the project.

5 CONCLUSIONS

The scope of this study was to identify if the current use of BIM was effective in addressing project delivery issues to its full potential. For this, we employed a case study approach and analyzed 1,400 RFI's to identify the nature of the design and construction issues and the root cause behind these issues. To achieve this, we first developed a framework to categorize the RFI's based on their type of RFI, reason for the RFI initiation and property of the element in the question. After analyzing the documents, we observed that about 60% of the construction communications were about design revision. Out of this 60%, 28% was because of design coordination issues while another 20% were initiated to meet the project requirements. Another significant observation was that about one-fourth of the 1400 RFI's were about the location of the element and another one-fourth was about the type of the element. Further, we selected few common issues and traced it back to the 3D model to identify why the issue was not identified earlier. We observed that in some cases, the issue could have been identified with better implementation of BIM like rule-based model checking using project specific or code specific rules. On the other hand, some of the issues were not identified because of insufficient information in BIM which was required to identify the issue. Hence, we observed that in this case study, the project team was not able to reap the complete benefits of BIM. But, in this study, the issues from a single case study was analyzed and only a selected number of recurring issues were analyzed in the model. Further studies should be conducted to identify what type of issues can be identified earlier using BIM, the effort required to include additional required information and the value of identifying the issue earlier. In future, we want to further drill into the information available in the construction communications through other lenses like time, location, discipline and so on to identify recurring trends to learn from past mistakes which will help in better decision making.

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