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Analysis of Current BIM Execution Plans and Contract Documents to Support Automation of Clash Resolution

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Step one of MEP coordination process identifies the clash between MEP elements followed by step two identifying their potential resolution. Clash identification has been automated using software like Navisworks yet clash resolution remains a slow and manual process. Use of Machine Learning has been explored by researchers to automate clash resolution. These researches utilize graphical information and attributes embedded into Building Information Model (BIM) elements to develop a Machine Learning model making BIMs an integral part of the automation. The literature review shows that the successful implementation of BIMs is supported by well-executed BIM Execution Plans (BxP) and Standards. Therefore, it can be said that a successful implementation of clash resolution automation will require the support of these documents. To assess the readiness of BxP to support the automation of clash resolution, the authors in this paper reviewed three BxP and Standard guides. A comparative analysis of three industry standard BxP and Standard guides was conducted to reveal the topic covered by them. Results from the review show that the BxPs and Standards are lacking to support the automation of clash resolution. Suggested potential changes to make these documents ready for the implementation of automation of clash resolution are discussed.

Key Words: BIM Execution Plan, BIM Standards, Automated Clash Resolution, Machine Learning, Amendments

Introduction

Mechanical, electrical, and plumbing (MEP) coordination is considered one of the most challenging coordination activities in construction project delivery with 57% of design coordination errors directly impacting the cost of construction (Mehrbod et al., 2019). This makes management of the design coordination process critical to achieving a cost-effective and quality project delivery (Mehrbod et al., 2019). Building Information Modeling (BIM) has a significant capability to improve the design coordination process with design coordination and conflict detection being the most used aspect of BIM (Mehrbod et al., 2019). The design coordination process is defined as the identification and solution of a problem across multiple disciplines to deliver a project design that meets the expected functional, aesthetical, and economical requirements of a project. An important task in design coordination is clash management, which includes clash detection and clash correction (Hu et al., 2020). BIM coordinators use BIM software to integrate models from multiple disciplines and detect clashes using the built-in functionalities of these software. Once found these clashes are discussed in design coordination meetings with trade specialists for potential solutions. Compared to the automation of clash detection the level of automation in the clash resolution and correction process is low (Hu et al., 2020). However, research is ongoing in automating clash resolution. Radke et al. (2009) created a plug-in for Revit MEP to automate clash resolution. The plugin-allowed to detect all clashes and automatically resolve them as per the user's input. Hu and Castro-Lacouture (2019) used supervised machine learning to automate the distinction between relevant and irrelevant clashes. Out of the 6 different supervise machine learning algorithms tested, the Jrip algorithm came out to be superior with an average accuracy reaching 80% in both training and testing of the datasets. utilized spatial relationships among building components to assist in the identification of irrelevant clashes and reduce the number of objects required to be moved to resolve clashes. Using query searches, Hu et al. (2019) were able to identify irrelevant clashes effectively along with clashes that were critical due to lack of enough room, and group of clashes that can be resolved by moving a single element. used a back-propagation neural network and heuristic optimization to automate clash resolution in the basement of a student residence. These experiments showed the effectiveness and feasibility of using automation systems for clash resolution.

The literature reveals that implementing Machine Learning to automate clash resolution and improve clash detection requires using information (attribute-based and geometric-based) embedded within BIMs making BIMs an integral part of the automation process. The success of information extraction using BIMs is highly dependent on the quality of data in the model . Thus, it is important to make certain that relevant and correct information is embedded into BIMs. One way to properly leverage embedded information is through standardization (Weygant, 2011). BIM execution plans (BxP) and standards are often used as tools to provide standardized workflow and general guidance to facilitate BIM implementation (breakwitharchitect, 2021). Therefore, the authors believe that as more research is being conducted toward automating clash resolution, a similar effort needs to be put forward to analyze current BxP and BIM standards so that future BIM development can support the implementation of the automation models. The goal of this paper is to extend the knowledge in developing BxP and BIM standards that support automated clash resolution. To support this knowledge goal the authors have three aims:

1. Conduct a comparative analysis of existing literature focused on the automation of clash resolution and identify information extracted from BIMs to support automated clash detection and resolution.
2. Conduct a comparative analysis of existing BIM standards and BxP and identify the gaps in the BIM standards and BxP.
3. Suggest amendments and addition to current BxP and BIM standards in support of automated model checking, specifically automated clash resolution.

Literature Review

There has been research into using BxP to support effective BIM implementation in support of facility operation and maintenance (O&M). Wu and Issa (2015) developed a BIM execution process model to support green BIM practices and improve LEED project outcomes. proposed and developed a BxP to support BIM model management for facility management during the O&M phase and tested its effectiveness using a building project case study. Rodrigues and Andrade (2021) proposed a BxP be implemented in the design sector of a Brazilian Public University. Their work highlighted the benefits and broad importance of the execution plan.

The authors reviewed three different industry standard Building Information Contract Guides that explain and supply guidance for how building information should be created, modified, and maintained to facilitate construction, planning, facility operations and maintenance, and space and asset management. The three guides are General Services Administration (GSA) Building Information Modeling (BIM) Guide 07 (GSA, 2007), ConsensusDocs 301 Building Information Modeling (BIM) Addendum (ConcensusDoc, 2016), and American Institute of Architect Digital Practice Documents (AIA, 2022).

GSA uses automated model checking in addition to manual checking to perform quality control at all design milestones and recommends its use by the design and construction team (GSA, 2016). The current GSA BIM Guide 07 Building Elements explains different types of building information and provides guidance on how such information can be created, modified, and maintained to support planning, construction, facility operation and maintenance, and space and asset management. The guide covers topics including levels of detail and level of development, model progression matrix, model element general requirements, naming conventions, guidance for modelers, model quality control using clash detection, and BxP.

As explained in ConsensusDocs 301 BIM Addendum Guidebook (2016) the ConsensusDocs 301 BIM Addendum is intended to be used on projects where early in the project, the project owner and major project participants commit to using BIM or virtual design and construction (VDC) and the design model is intended to be a contract document. The ConsensusDocs 301 BIM addendum incorporates what is believed to be the best practices in BIM use. The BIM addendum covers topics like the As-Built Construction Model which may include attribute-based information, level of detail specification, geometric modeling, BxP, data collection protocols, and model sharing and networking infrastructure.

The American Institute of Architects (AIA) Digital Document Guide (2022) explains the AIA 2022 Digital Practice Contract Document. These contract documents include BIM Exhibits E201, E202, E401, and E402, G203 BIM Execution Plan (BxP), and Model Element Table G204 and G205. These BIM exhibits focus on expectations related to the scope and authorized use of Digital Data and BIM. G203 serves as a framework for project participants in creating a project-specific BxP. G204 and G205 have detailed and abbreviated Model Element Tables respectively.

Methodology

To support the author's first objective, a comparative analysis of how BIM was utilized by researchers to develop their automated clash resolution models was conducted including information extracted from BIM that supports automated clash resolution. The comparative analysis is shown in Appendix A. The identified information was classified as either geometric or attribute information. Three BIM guides were then reviewed to identify topics related to 1) information required to be embedded into the BIMs, 2) project stages BIM can be utilized in, 3) BIM ownership and authorship, 4) BIM quality control, and 5) scope of BIM utilization. The selection of the three BIM guides was based on ease of availability and access to the documents. Additionally, selecting these three guides allowed an understanding of the point of view of different stakeholders when writing these guides. AIA (2022) provides insight on how designers want to utilize BIM. GSA BIM Guide (2016) is written from an owner's perspective, while the ConsensusDocs (2016) is written by a coalition of 40 national associations that includes Associated General Contractors of America, Association of Builders and Contractors, Construction Owners Association of America, American Subcontractors Association and Mechanical Contractors Association of America. The authors are also aware that the US Army Corps of Engineers (USACE) and Military Construction (MILCON) also use BIM Standards and BxP. Due to security considerations for the military and the Department of Defense (DoD), these standards and guides are firewall-protected and access has not been granted at the time of paper preparation. As a result, these guides have not been reviewed.

From the literature review and the BIM guides, an analysis was done to assess and propose:

1. How the current BIM guides can support automated clash resolution,
2. How BIM guides can be improved upon by comparison among the guides reviewed,
3. Recommended changes and additions to BIM guides to enhance support of automated clash resolution.

Results

It was determined from the literature that Machine Learning was the focus point to automate and improve clash resolution and that both graphical and attribute information are being used to support the automation process (shown in Appendix A). Therefore, it can be assumed that at the stage where automated clash resolution will be implemented the BIM needs to be sufficiently developed in terms of embedded graphical properties and attributes. Without both graphical properties and attributes embedded in the model, automated clash resolution will be less successful. Appendix B compares the topics covered by the industry standard BIM guides reviewed.

The BIM implementation guides cover topics of BIM coordination with the GSA BIM Guide supplying the most comprehensive clash detection instruction focused on clash detection in both design and construction. GSA (2016) also provided three tiers of clash types based on how they can be resolved.

1. Tier 1 clash includes clashes that can be resolved by a single entity internally.
2. Tier 2 clash includes clashes that can be resolved by coordination between multiple consultants or subcontractors.
3. Tier 3 clash includes clashes that exist due to design issues and can only be resolved by design changes, budget changes, or both.

All three guides cover topics of BIM coordination, BIM quality control, and clash detection, yet lack meaningful direction on clash resolution. Absent from standards or guidelines are who is responsible for clash resolution, a dedicated project stage for clash coordination, who owns the resolved changes, building system resolution priority, and needed tools for clash resolution. Given the information required to be present in the BIM models to facilitate automation of clash resolution and the ownership of this information, the authors suggest that the guides recommend to owners that the Design-Build delivery method is the preferred method in support of automated clash resolution. Design-Build delivery will allow for early involvement of trade partners (sub-contractors) on the project, facilitating ease of information sharing and more time to make beneficial design decisions. Design-Build will also assist in mitigating the contract issues with authoring the model and owing the changes as both the project design and building firms are the same entity in Design-Build.

All three guides address Schematic Design Stage, Design Development Stage, Construction Document Stage, and Operation and Management stage but lack directions for a clash coordination stage. For example, the AIA Digital Document Guide (2022) in section 2.6 Model Coordination states, “If Project Participants discover or become aware of any discrepancies, inconsistency, errors, or omission in any Model Version, they shall promptly report the discrepancy, inconsistency, error, or omission in writing to the Author and the Architect.” This lack of a dedicated project stage for clash coordination has led to a missed opportunity to create standards for clash coordination in terms of what Level of Development (LOD) elements should exist by default during clash coordination and what information should be embedded into the model to support clash coordination and resolution. Furthermore, while reviewing the guides cases were noted where non-graphical (attribute) information was mentioned to be embedded into the BIM, but only to prepare the model for facility O&M. This was done to 1) support owners and facility managers’ needs to use the handover/as-built BIMs for facility maintenance, and 2) to confirm that the BIM objects include necessary information like manufacturer, space type, model number, serial number, and O&M requirement.

The AIA guide (2016) acknowledges the industry trend toward Industry 4.0 and the development and utilization of Digital Twin. The guide notes how LOD 500 can support Digital Twin modeling (DTM) as DTM represents existing or as-built conditions using 3 primary frameworks.

1. LOD 500 model elements are field verified therefore they convey the as-built field conditions.
2. LOD 500 allows authors to embed non-graphical information into the model elements.
3. LOD 500 model elements must be accompanied by their level of accuracy. This can be reported using the U.S. Institute of Building Documentation (USIBD) Standard Level of Accuracy or a custom accuracy system.

Discussion

Although the guides demonstrate the potential for ease of implementation of an automation model for clash resolution there needs to be considerations made in terms of language changes and additional clauses to fully support the increased potential of fully automated clash resolution. Therefore, as part of the objective of this paper, the authors recommend amendments and changes to these guides in support of automated clash resolution. These changes are divided into two categories, one that directly supports implementing an automation model by providing the necessary information embedded into the model at the time of automation, and a second that indirectly supports the automation by suggesting administrative clauses that will address issues like automation change authorship. Recommendations to directly support the implementation of an automation-capable clash resolution model are:

1. Establish a dedicated phase for design/clash coordination: All three guides divide the project into multiple project phases along with providing tools like “Model Element Table” to make sure model elements are of an appropriate LOD and include agreed-upon non-graphical information. The inclusion of clash coordination as a project phase will allow project participants to contractually discuss and define all information to be included in the model during the clash coordination stage. This information can include both graphical information and attributes required by the automation model to predict clash resolution options.
2. Provide a detailed discussion on clash resolution and the automation option: Following the AIA lead in introducing Digital Twin, the author proposes a similar introduction be added to the guides regarding the automation of clash resolution. Similar to the Digital Twin introduction the guide can propose a preferred LOD for automated clash resolution and provide justification for how the chosen LOD can support the automation model.
3. Include non-graphical information as part of LOD: Currently, LOD focuses on the graphical representation of the model elements and categorizes the graphical development of the model elements. The authors suggest that the definition of LOD and its level be expanded to include non-graphical information as well. This will allow project participants to accurately choose at what LOD level they can receive both appropriate graphical and non-graphical information for clash resolution support.
4. Expanding non-graphical information beyond O&M usage: Currently, the guides focus on using non-graphical information during the O&M project phase. As seen from the analysis of previous automation research non-graphical information in model elements is essential to support automating clash resolution. Therefore, the authors recommend that the scope of non-graphical information be expanded to include what information is essential at the clash coordination stage. This also ties back to the recommendation of considering a dedicated clash coordination phase in BxP and contracts.

While the above recommendations directly support a working automation model, consideration should also be made to support the implementation of the automation model at the administrative level. Therefore, proposed recommendations to indirectly support the implementation of automated clash resolution at the administrative level are:

1. The owner, designer, contractor, and trade contractors should agree on which elements they will perform clash tests on, and the need to model these particular elements at a specified LOD.
2. Currently, the guides do not comment on 1) how the machine learning clash resolved model will be named or transmitted, 2) who has the right to run the automated software and make changes to the model, and 3) what file format the resolved model will be transmitted. The owner, designer, prime, and trades contracts should determine the model author to finalize the automated changes. This can be the same party as the existing model authors or another party different from the one running the automated clash resolution. The project stakeholders also need to decide on whether the changes suggested by the automation model will be taken as suggestion that can be considered by the model authors or as mandatory changes that the authors have to make to the model.
3. Identification of the responsible party for running automated clash resolution and identification of model author to incorporate changes from automated clash resolution.
4. Language to propose the use of automation to support clash resolution can also be added to the guide such as, "To expedite the clash resolution process the Model Element Author(s) should use the specified automated clash resolution software. The Model Element Author(s) can use the clash resolution generated through the software as suggestions on how the clash can be potentially resolved."
5. For the automation to work, all text-based values will have to be converted into a numerical value, selecting an appropriate Classification System to describe clashing element system types can help the automation to work better. While selecting the Classification System attention should be given to selecting a classification system that accurately describes the system type the model elements belong to as a numerical value.

Conclusion

Automating clash resolution that is correct and timely is on the horizon. The authors have attempted to initiate the thought process of looking at current industry BIM Guides/Standards and analyze if they are at par with the research being conducted in the construction industry to support construction workflow through automated processes such as the automation of clash resolution. Though research in the field of automation of clash resolution is still in its nascent stage, the literature shows significant advantages in the application of an automation model to support clash resolution and improve project delivery. Previous research relied heavily on the use of both graphical information and element attributes embedded into the BIMs. This makes the BIMs a critical component for the successful implementation of the automation model. Research has also shown that any successful implementation of BIM in a construction project is supported by a strong implementation of BxP and supporting document (breakwitharchitect, 2021; Lin et al., 2016; Rodrigues & Andrade, 2021; Weygant, 2011; Wu & Issa, 2015).

In this paper, the authors have reviewed three different BIM implementation guides, namely the AIA Digital Document Guide (2022), the General Service Administration BIM Guide 07 (2016), and the ConsensusDocs 301 BIM Addendum (2016). The goal was to understand how these documents presently support clash resolution and what changes would be required to support the future implementation of an automated clash resolution model. Based on the review of literature for automation of clash resolution and BIM guides, the authors have suggested several changes and additions both directly (changes focused on preparing BIMs for automation) and indirectly (administrative changes) to support the implementation of an automated clash resolution model. There are considerable opportunities to incorporate automated clash resolution guide requirements into industry BIM standards and BxP.

One of the limitations of this paper is that it does not consider the contractual liabilities and risks associated with the changes proposed. The main objective of this paper was to compare the BIM guides and BxPs to assess their readiness in supporting the implementation of the automated models for clash resolution. Based on this assessment, the authors propose how this documents can be amended to make them more automation ready to act as a starting point of discussion into amending our BIM guides and BxP. A study into the contractual liability and risk assessment of these proposed changes would require a deeper review of the literature and understanding of contractual liabilities associated with the use of BIM in construction projects. The authors look forward to inviting additional researchers in the area of construction contracts to further the research and contribution of knowledge in this area.

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Appendix A

Appendix A

BIM information used to support automation of BIM clash resolution

Mark	Category	BIM Information	Radke, et. al., (2009)	Hu and Castro-Lacouture (2019)	Huang and Liu (2019)	Hsu et al. (2020)
1		**Start Point:** Clashing elements' X/Y start point.	X			X
2		**End Point:** Clashing elements' X/Y end point.	X			X
3		**Base Level:** Z coordinate of clashing element.	X			
4		**Thickness:** Clashing element's thickness.	X			
5		**Radius:** Circular clashing element's radius.	X			
6		**Height:** Square clashing element's height.	X			
7		**Width:** Square clashing element's width.	X			
8		**Shape:** Clashing element's shape.		X		
9		**Clashing Volume:** Volume of clash.		X		
10	G I	**Spatial relationship:** If the clash exists beyond the ceiling or not.		X		
11		**Available space:** Available space around clash.		X		
12		**Clearance:** Clashing elements' clearance requirement.	X			
13		**Cross-sectional area:** Clashing element's area.		X		
14		**Clash Type:** Parallel or cross-type clash.				X
15		**Intersection Type:** Penetrating or punching clash.				X
16		**Distance:** Clashing elements' overlap distance.			X	
17		**Clash Point:** 3D coordinates of the clash.			X	
18		**Material:** Material of clashing element.		X		
19		**System Type:** Clashing elements'building system.	X	X		X
20	AI	**Class:** Class of clashing element. Eg. pipes, ducts.		X	X	
21		**Information Uncertainty:** Uncertainty regarding the clashing element.		X		
22		**Location:** Location of the clash. Eg. floor, room.		X	X	
23		**Priority:** Clashing elements' movement priority.		X		

GI = Geometric Information AI = Attribute Information

Appendix B

Appendix B

Topics covered in different BIM Guides

Mark	Topic	AIA Digital Document Guide	ConsensusDocs 301	IM Guide 07
1	BIM as Contract Document	X	X	
2	Level of Development	X	X	X
3	BIM Execution Plan	X	X	X
4	Non-Graphic Information in BIM	X	X	
5	BIM Sharing	X	X	
6	BIM Reliance	X	X	
7	BIM Coordination	X	X	X
8	Operation and Management Project Stage	X	X	X
9	Digital Twin	X		
10	BIM Authorship	X	X	
11	Modeling Software	X	X	X
12	Data Security	X	X	
13	File Naming Conventions	X	X	X
14	Project Participants Responsibility	X	X	X
15	BIM Quality Control	X	X	X
16	Conceptual Planning Project Stage		X	
17	Schematic Design Project Stage	X		X
18	Design Development Project Stage	X	X	X
18	Construction Document Project Stage	X	X	X
20	As-Built Model	X	X	X
21	Civil Information Modeling		X	
22	Coordinated Construction Model		X	X
23	Design Model		X	X
24	4D Scheduling		X	X*
25	5D Scheduling		X	
26	Model Ownership		X	
27	IFC Models			X
28	COBie		X	X
29	Project Delivery Method			X

X* topic covered in GSA BIM Guide 04