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Potential and Limitations of BIM in Designing Fire Sprinkler System: An Expert's Perspective

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This research investigates the influence of Building Information Modeling (BIM) on the design of fire sprinkler systems, particularly in alignment with NFPA 13 requirements. Globally, fires result in significant human and property losses, emphasizing the need for effective fire prevention measures. Fire sprinkler systems, governed by stringent NFPA regulations, play a pivotal role in mitigating these losses. With the advent of BIM in the architecture, engineering, and construction (AEC) industry, questions arise regarding its efficacy in aiding the design and installation of these systems. Through a questionnaire survey targeting professionals in the field, this study seeks to understand the current capabilities and limitations of BIM in this context. Preliminary findings indicate a strong endorsement of BIM's role in 3D modeling and conflict detection. However, challenges persist in areas like sprinkler type selection and compliance with specific NFPA 13 rules. The research underscores the need for further advancements in BIM to better support fire sprinkler system design, ultimately aiming to enhance fire prevention and safety.

Key Words: BIM, Fire Sprinkler Systems, Limitation, NFPA 13

Introduction

Catastrophic fires worldwide cause significant human casualties, physical harm, and psychological trauma, impacting communities and societies at large (Rathnayake, Sridarran and Abeynayake, 2020). Effective fire prevention measures, safety education, and robust emergency response systems are crucial for mitigating these incidents. Building fires pose a significant threat to occupants, making understanding the factors affecting fire incidents essential for comprehensive fire safety measures and fostering the development of fire-resistant buildings in the future.

Fire sprinkler systems are crucial in building safety, containing fires, and limiting damage (Frank et al., 2013). The National Fire Protection Association (NFPA) enforces stringent regulations and standards for the design and installation of fire sprinkler systems (NFPA 13, 2013). NFPA 13 is a fundamental cornerstone in fire protection, and compliance requires more than just legal adherence. Navigating the intricacies of NFPA codes can be challenging during the initial design process (Bromann, 2001). Properly engineered and installed fire sprinkler systems can save lives and mitigate structural damage. Advanced technology, such as heat-sensitive sprinkler heads and reliable water supply networks, effectively combat and extinguish flames. Adherence to NFPA 13 standards is essential for averting disasters and ensuring the safety of buildings (Aaby, 2015).

In recent times, BIM has become a revolutionary technology in the architecture, engineering, and construction (AEC) sector (Azhar, Khalfan and Maqsood, 2012). It provides a thorough digital method for designing and constructing buildings, allowing stakeholders to develop accurate and collaborative representations of structures (Garagnani and Manferdini, 2013). Within the AEC sector, a pressing question arises: Can BIM serve as a valuable tool to assist designers, contractors, and project managers in achieving compliance with NFPA 13 standards for designing and installing fire sprinkler systems?

The goal of this paper is to identify existing limitations in current BIM tools concerning fire sprinkler system design and explore how these tools can be further enhanced to contribute to better sprinkler systems adhering to NFPA 13. It aims to identify limitations in current BIM tools and explore ways to enhance them for better sprinkler systems. Ultimately, our aim is to contribute to fire prevention, safeguarding both lives and property from the devastating consequences of fire incidents.

Literature Review

Firefighting systems are categorized into two active firefighting and passive firefighting. Active firefighting refers to a collective effort that necessitates physical movement or activity to be effective. Passive firefighting refers to construction components that are constantly present and available within the structure and are uniformly distributed across all floors. When designing a fire sprinkler system, many key variables must be taken into consideration adhering with NFPA 13 standards (Hurley and Rosenbaum, 2016). Currently, different software tools enable fire protection engineers to design sprinkler system plans based on their understanding of the NFPA 13 standard. Software applications such as AutoCAD, Revit, and HydraCAD assist in the design of these systems, and other software like AutoSprink and HydraCalc aid in performing calculations for these systems (Jia et al., 2023). However, a significant challenge exists in that none of these software applications automatically validate designs as compliant or non-compliant with NFPA 13 codes.

BIM has revolutionized the architectural landscape, enabling designers to create intricate 3D models that offer comprehensive insights into the structure's spatial design and aesthetics. BIM's collaborative environment facilitates seamless communication between architects, engineers, and stakeholders, streamlining the design process and enhancing visualization capabilities (Eastman et al., 2011). Moreover, it highlights the role of BIM in promoting sustainability in architectural designs by facilitating architects to assess the ecological consequences of different design features and materials, resulting in the creation of environmentally friendly and energy-efficient structures (Carvalho, Bragança and Mateus, 2019).

The parametric features of BIM allow for the thorough modeling of structural components, facilitating accurate analysis and simulation of performance. Additionally, it facilitates engineers in identifying design conflicts, improving coordination, and optimizing structural integrity and functioning (Cheung et al., 2012). BIM significantly improves structural safety and risk management by detecting potential vulnerabilities and optimizing designs to meet strict safety standards and regulations (Hamidavi, Abrishami, and Hosseini, 2020).

BIM technology with its federated model has provided substantial assistance to designers and engineers in various fields, such as architecture, structural engineering, as well as mechanical, electrical, plumbing, and fire protection (MEPF), within the construction industry (Liete, 2020). Despite the significant progress made by BIM in these areas, it has not received adequate attention in the realm of fire sprinkler systems, which is a crucial aspect of the construction field. BIM tools, while proficient in facilitating 3D modeling and cost estimations (Mehrbod et al., 2019). Often fall short in effectively addressing critical components such as selecting the appropriate type of sprinkler heads, ensuring compliance with obstruction rules, and accurately determining the coverage area for each sprinkler head (Davidson and Gales, 2021).

The interpretation and integration of NFPA 13 requirements within the Building Information Modeling (BIM) framework pose significant challenges, hindering the seamless translation of regulatory standards into practical design solutions. To bridge the gap between regulatory compliance and technological capabilities, innovative approaches are needed to address the complexities of NFPA 13 and expand BIM's functionalities to meet fire safety engineering demands, thereby enhancing the efficacy and efficiency of fire sprinkler system design processes.

Methodology

With the field of architecture or structural engineering, BIM rigorously verifies the accuracy of the design. For example, with software such as Revit, if there is an inaccurate or unfeasible connection between two walls or beams, the program will create an error and prevent the designer from proceeding with that mistake. However, when it comes to designing sprinkler systems, if the designer does not adhere to the requirements outlined in NFPA standards and poorly build the system, BIM software does not offer any error signals. The main author of this study has been working in fire sprinkler design for sixteen years and working with BIM for more than decade and realized the limitation of BIM in fire sprinkler design. Hence, the study aimed to assess the potential and limitation of BIM in designing fire sprinkler systems in accordance with NFPA 13 requirements. The answer to this study can be achieved only through a questionnaire survey approach employed to gather data from professionals and experts in the BIM and fire sprinkler design. Questionnaires play a crucial role in obtaining statistically relevant information about specific groups or populations (Roopa and Rani, 2012). This methodology was chosen to elucidate the challenges and limitations associated with integrating BIM technology in the context of fire safety system design, particularly focusing on areas such as selecting the appropriate type of sprinkler heads, compliance with obstruction rules, and accurately determining the coverage area for each sprinkler head.

An online questionnaire was designed using the Qualtrics platform, hosted by Texas State University, for the purpose of conducting the survey. The questionnaire was carefully structured into sections, with the first section dedicated to gathering demographic information of the respondents, including their roles and expertise in the field of fire safety engineering and BIM integration. The second section was designed to delve into the specific challenges faced by professionals when utilizing BIM tools in designing fire sprinkler systems according to NFPA 13 requirements.

The survey link was distributed to a targeted group of professionals and experts engaged in the design and implementation of fire safety systems, including sprinkler system designers, fire protection engineers, mechanical engineers, and project managers who have also experienced with BIM. The survey aimed to gather comprehensive insights into the practical constraints and obstacles experienced by industry practitioners when employing BIM technology for the design and installation of fire sprinkler systems.

Results and Discussion

The study's findings, depicting the descriptive statistics on the influence of BIM on the design of fire sprinkler systems, are based on 81 responses out of the 116 surveys distributed. Out of these, 74 complete responses were thoroughly analyzed, forming the foundation for the data analysis and subsequent outcomes of this research.

Demographic Responses

Within the dataset of qualified responses, the research findings revealed that 35.62 percent (26) of the participants were engaged as project managers, followed by 32.88 percent (24) as fire sprinkler system designers, 16.44 percent (13) as fire protection engineers, and 15.07 percent (11) as mechanical engineers. Table 1 outlines the distribution of participants' expertise based on their years of involvement in the design and installation of fire sprinkler systems in compliance with NFPA 13 regulations and BIM overall. The data indicated that, more than 60 percentage of participants (46) demonstrated a comprehensive understanding of NFPA 13 at the levels of excellent and good however more than 54 percentage of participants (40) displayed average and poor levels of familiarity with BIM. This result shows 16 percent of participants having excellent in NFPA 13 has average level of experience in BIM.

Table 1

Years of Experience

SLO	Years of experience	NFPA 13	BIM
1	Less than 5 years	37.8%	54.1%
2	5-10 years	41.9%	33.8%
3	Over than 10 years	20.3%	12.2%

BIM Model and NFPA 13

Participants were asked about situations in which BIM models for fire sprinkler systems failed to meet the requirements outlined in the NFPA 13 standards during the design phase of the fire sprinkler system. Based on the data depicted in Figure 1, a significant proportion of participants, specifically 54 percent (40 experts from all position), indicated that most of the time BIM is non-compliance with the NFPA 13 criteria. Furthermore, a total of 38 percent (28) acknowledged occasionally witnessing these phenomena, while 5 percent (4) reported encountering them often. Conversely, a mere 3 percent (2) claimed to have never encountered them.

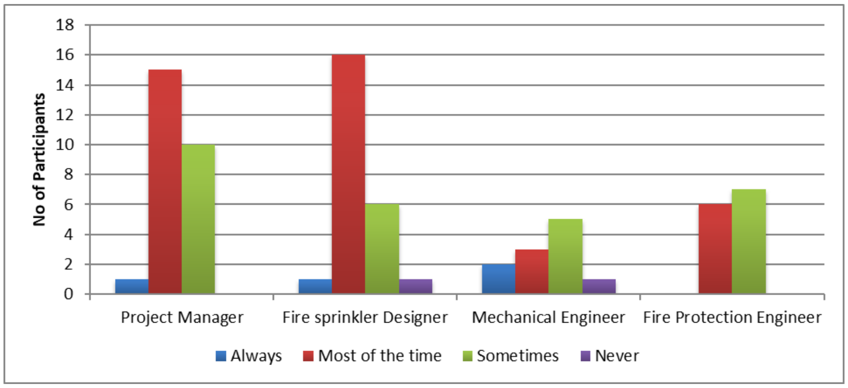

Figure 1. Occasions where BIM model failed to comply NFPA13 standard

Furthermore, in the subsequent inquiry, respondents were requested to express their viewpoint about the extent to which BIM tools, such as Revit, Navisworks, and other relevant applications, aids in complying with the design specifications outlined in the NFPA 13 standards for fire sprinkler systems. Majority of the experts, specifically 91.87 percent (67), expressed their disagreement with the notion that BIM tools greatly assist designers in complying with NFPA 13 rules.

Challenges Integrating Fire Sprinkler Systems into BIM Models

In this section, we invited participants to address the challenges encountered during the integration of fire sprinkler systems into BIM models. As indicated in Table 2, several factors contribute to these challenges, with the most significant issue being the lack of awareness of standards, identified by 30.68 percent (54) of respondents. Additionally, 29.55 percent (52) cited software limitations as a significant challenge, while 24.43 percent (43) identified data accuracy and updates as a notable contributing factor to these challenges.

Table 2

Challenges integrating fire sprinkler systems into BIM models

SLO	Challenges	Percentage
1	Lack of knowledge about standards	30.68%
2	Software limitations	29.55%
3	Resistance from team members	3.98%
4	Coordination with other building systems	2.84%
5	Data accuracy and update	24.43%
6	Hydraulic Calculation Integration	5.68%
7	Complex Piping Layout Adjustments	2.84%

BIM Enhancement for Fire Sprinkler System

In the subsequent phase of the study, respondents were prompted to provide their insights on the potential enhancements of BIM in its support for fire sprinkler systems in the future. As detailed in Table 3, a notable portion, comprising 30.73 percent of the participants, advocated for improved integration with existing fire sprinkler codes and standards. Additionally, 26.26 percent of the respondents suggested the implementation of AI-assisted design recommendations, and 25.70 percent supported the incorporation of automated code compliance checks.

Table 3

BIM Enhancements for Fire Sprinkler Systems

SLO	Enhancements for Fire Sprinkler System	Percentage
1	Enhanced Fire Safety Simulation Tools	7.82%
2	Improved Integration with Fire Sprinkler Codes and Standards	30.73%
3	Streamlined Collaboration and Communication Features	2.79%
4	Expanded BIM Training and Education	3.91%
5	Automated Code Compliance Checking	25.70%
6	AI-Assisted Design Suggestions	26.26%
7	Seamless Integration with Other Building Systems	2.79%

Significance of BIM

As we are aware, that application of BIM has been increasing for the design of the integrated model of the commercial building. The perspectives shared by respondents well-versed in the benefits and challenges of BIM implementation are invaluable for understanding its implications in the design of fire sprinkler systems. Thus, individuals with expertise who are involved in fire sprinkler design and utilizing BIM were specifically asked whether the integration of BIM has been supportive in the design of fire sprinkler systems or not. The significances of BIM were assessed on a four-point Likert scale of 1 to 4, a weight of 1 for "highly disagree", 2 for "disagree", 3 for "agree" and 4 for "highly agree". The frequencies of each factor affecting the significance of BIM are tabulated in Table 4. The Relative Important Index (RII) based on the formula shown in equation is used to determine the relative ranking (Bhattarai and Kisi, 2022).

$$RII = \frac{\sum W}{AN}$$

Table 4

Assessing significance of BIM in supporting the design of fire sprinkler systems according to NFPA 13

Significance of BIM	Frequency				Overall	
	1	2	3	4	RII	Rank
Help to identify conflicts with other systems	0	6	35	33	0.841	1
Help to design a 3D model of a system	3	4	37	30	0.818	2
Estimate the cost of operating the system	1	8	38	27	0.807	3
Help to calculate and choose the correct fire pump	6	21	27	20	0.706	4
Support to choose the correct temperature rate of the sprinkler head	24	26	18	6	0.520	5
Support to choose the correct type of sprinkler head	30	34	5	5	0.449	6
Support to comply with obstruction rules	26	41	4	3	0.446	7
Help to determine the optimal approach for designing in each specific area	35	27	7	5	0.439	8
Support to comply with coverage area for each sprinkler heads	32	35	4	3	0.426	9

The Relative Importance Index (RII) is meticulously calculated to systematically evaluate the significance of BIM in the design of fire sprinkler systems. The RII is derived from responses, quantified on a scale from 1 to 4, where 'W' denotes the assigned weight, 'A' represents the maximum weight of 4, and 'N' signifies the total number of respondents. The resulting RII values, which range from 0 to 1, serve as quantitative indicators of significance, with values approaching 1 denoting higher levels of importance. To illustrate, in the context of assessing the significance of BIM in helping to identify conflict with other systems, the responses yielded an RII value of (0.841). This value results from using the formula $(33\times4+35\times3+6\times2+0\times1)/ (74\times4)$. Table 4 provides a hierarchical ranking of significance of BIM in the design of fire sprinkler systems. Based on the results obtained, BIM has been found to greatly assist in certain factors such as creating 3D models and conflict identification with other systems in general. However, the low value of RII indicates that significance of BIM has low impact in choosing the correct type of sprinkler head, complying with obstruction rules, and determining the optimal approach for designing in each specific area, have not provided much assistance.

Conclusion

The goal of this study is to investigate the potential of BIM model to create and implement fire sprinkler systems that meet the standards set out by NFPA 13. Professionals working in the AEC industry, such as sprinkler system designers, fire protection engineers, and project managers, were surveyed for this study. The findings underscored the transformative potential of BIM in the realm of fire safety engineering, with a significant percentage of respondents affirming BIM capability in creating 3D models and detecting conflicts. However, the study also highlighted areas where BIM falls short, particularly in selecting the appropriate type of sprinkler heads and ensuring compliance with obstruction rules and coverage area requirements as per NFPA 13. This study shows there is need for improvement in fire safety to fulfill the promise of BIM from the perspective of MEPF. According to the responder, the procedure of clash detection could have better interaction with fire sprinkler codes and an automatic code compliance check. In the end, stakeholders in the AEC sector may benefit from automated regulatory compliance, which reduces the likelihood of mistakes while also making buildings safer and more efficient.

This study is limited by the number of responders which are directly involved in the fire sprinkler design and not directly involved in construction from contractor side. It would be worthwhile if the survey was targeted with the expert from contractor, BIM manager and stakeholders of software developers; however, time limitation prevent that from happening at present. Additional studies are also warranted to explore more research related to NFPA 13 standard and BIM collaboration to mitigate the fire risk and improve the safety in the AEC industry.

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