International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 05 | May 2023 www.irjet.net p-ISSN: 2395-0072

BIM as a Design and Safety Tool for Construction Projects

Ar. N. Kanagadurga[1], Ar. Z. Fathima Taskeen[2], Ar. K. Indra Priya[3]

[1]Post Graduate Student, M. Arch - Construction Project Management, Faculty of Architecture, Dr MGR Educational and Research Institute, Maduravoyal, Chennai, India
[2]Additional HOD, Faculty of Architecture, Dr MGR Educational and Research Institute, Maduravoyal, Chennai
[3]Deputy HOD, Faculty of Architecture, Dr MGR Educational and Research Institute, Maduravoyal, Chennai

---***---

Abstract - *Building information modelling (BIM) has gained prominence in the construction sector in recent years, notably in the fields of design, scheduling, and costing. The purpose of this study is to examine how traditional health and safety practices may be used in conjunction with BIM technology and digitalization to enhance safety management in the construction environment. The study starts with an extensive review and analysis of the available literature and live case studies. A questionnaire survey was undertaken among construction professionals to examine the adoption of BIM as a design and safety tool in the Indian construction sector. The research finishes with findings about the software involved in using BIM as a design tool and the challenges and barriers to implementing BIM as a safety tool for construction, as well as recommendations for the proper application of the BIM-based theoretical model, which acts as a design and safety management tool used throughout the whole project duration for construction projects.*

Key Words: BIM – Building Information Modelling, OHS- Occupational Health and Safety, Design Tool, Safety Tool, BIM Software.

1.INTRODUCTION

Building information modelling (BIM) is a potential breakthrough in the fields of design, engineering, and construction. It is transforming the way contractors and engineers conduct business, but it is still in its early stages. BIM was established more than a decade ago, primarily to separate architectural 3D from traditional 2D drawings. It is a lifesaver for complex projects due to its capacity to detect problems early in the design stage. BIM is primarily composed of 3D modelling principles as well as information database technology and compatible software in a desktop computer environment that architects, engineers, and contractors may use to plan and simulate the building of a project. With the aid of this technology, project team members may create a virtual 3D model of the structure and every system within it and share it with one another.

1.1 Background of the study

The construction sector in India contributes significantly to the economic growth of the nation. It is one of the largest contribution factors in India after agriculture. Standard recording and notification procedures for building accidents are lacking in certain nations, while they do exist in others, like India, although their implementation is problematic. Occupational illness and accidents at work are global issues. National preventive efforts require statistics and information on workplace accidents. Due attention is not given to safety since statistics on construction accidents are either non-existent or grossly underreported. Safety precautions must be taken into account from the beginning of the project until its conclusion. Safe working conditions need proper coordination between contractors and employees, which is often missing in Indian construction areas. Regardless of sex, religion, location, age, or other factors, occupational health and safety (OHS) is an area that is concerned with the health and safety of people working in any occupation and it is essential for both employee and employer wellbeing. In order to promote OHS in the workplace and protect worker interests and health, the government of India periodically passes various laws, rules, and requirements. Construction has been significantly impacted by the Occupational Safety and Health Act (OSHA) and its rules.

1.2 Problem Statement

Construction-related occupational fatalities, injuries, and diseases cause significant human suffering, affecting not only those directly involved in the construction but also their families and communities, as well as contributing to the national expense of medical treatment and rehabilitation. There is a need to investigate various labour-related issues; there must be a welfare job plan and a safety plan in place, and contractors must adhere to various rules. Different activities must be considered throughout the design stage, and a safe design must be provided to reduce accidents. BIM is fundamentally altering the way construction is approached, from design to scheduling and budgeting to facility management. Automation through BIM is the key to improving the efficacy and efficiency of safety management.

1.3 Aim and Scope of the Study

The major aim of this study is to analyse the potentials of BIM as a design tool and a safety management tool. The scope of this research is to understand Occupational Safety and Health Administration (OSHA) regulation, collect safety management best practises, and identify the challenges involved in implementing the use of BIM for safety management.

1.4 Objectives of the Study

The objective of the research is to analyse the use of BIM as a safety and design tool and the methodologies involved in integrating safety management techniques into BIM software for construction projects.

2. METHODOLOGY

This research was performed to analyze the potential of BIM as a design and safety tool for construction projects. The research was divided into various stages starting from literature study to recommendations, as shown in Figure 1. A questionnaire survey was done to determine the use of BIM as a design and safety tool in the construction industry.

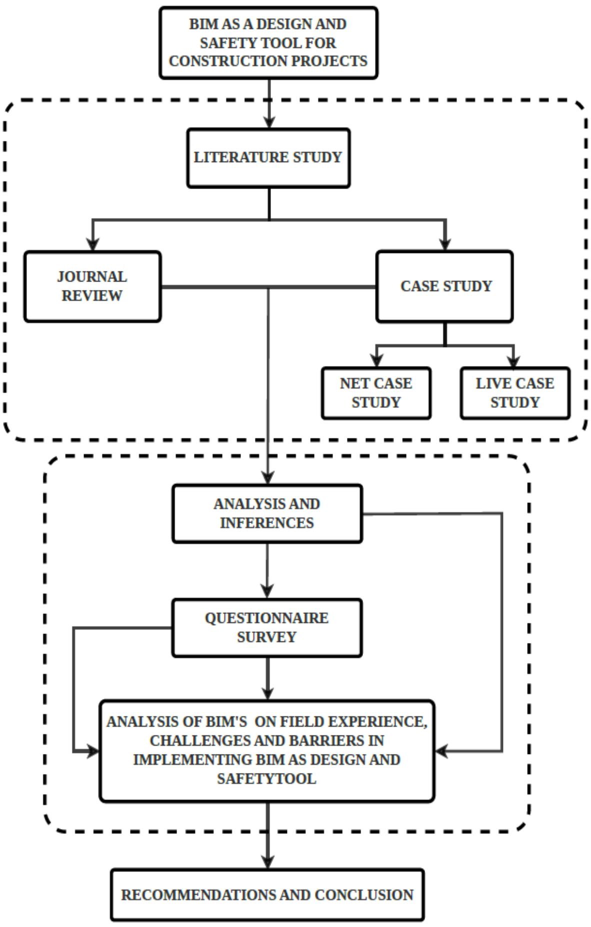

Chart -1: Methodology

3. LITERATURE REVIEW

The literature review consists of the most relevant papers related to emerging BIM-based safety management and conventional safety practices in the construction industry. A total of 16 journals published between 2016 to 2022 were taken into consideration and reviewed. The literature review was then classified into five parts based on the type of journal selected: 1. Safety Management; 2. Causes and Effects of Construction Accidents; 3. Accident Prevention; 4. BIM and Safety; 5. BIM Trends and Advancements.

Effective Safety Management in Construction Projects can be achieved if the top five most important factors affecting construction site safety, such as safety training and awareness, worker attitude towards safety, availability of safety equipment, safety inspections, and organizational safety policy, are addressed and closely monitored. Safety affects all levels of the construction organization, including the government (Othman et al., 2018). Some of the top ranked causes of accidents are failure to follow safety rules, ignorance of PPE, space congestion, and improper use of safety equipment. The top-ranked effects of accidents are: cost of medical expenses, time loss of project execution, productivity loss, distrust of the firm, and cost of training given to new workers (Sakthi et al., 2017). The age group of less than 30 was more prone to accidents, and the most common body parts exposed to injury were the upper limb, lower leg, head, and neck. Construction workers lack PPE (Jesline Serrao, 2020). The major preventive techniques to reduce construction site accidents are following the safety clauses, conducting safety audits, safety training programmes, safety drills, safety education, and pre-job meetings (Dheeraj Benny, 2017).

The Acci Map technique, BIM-based fall hazard identification approach, safety management real-time location system, fuzzy analytic hierarchy approach, video camera technique, multi-criteria decision making (MCDM) technique, BIM-based 4D integrated technique, safety-based model, RFID (Radio Frequency identification)-based locating system, are some of the safety prevention techniques for high-rise building construction through emerging technology (Bilal Mansoor, 2021).

Linking the professional model with the BIM 5D platform that is developed with hazard identification, collision detection, and real-time monitoring of the unsafe states of the objects results in better safety model development and effective safety management planning for the construction site (Zhihong, 2021). BIM and safety (SIM) technology will create a huge revolution since it will be very helpful for all construction workers to review the safety measures in each and every stage of construction. Incorporating safety rules into BIM will not only help the designers do proper safety planning, but it will also be helpful in educating the construction workers about health and safety practices, which in turn will develop a good working environment (Isabelle YS Chan et al., 2016). To build a proper safety rule system, one must first categorize safety rules and then extract the basic and required information. Each and every rule must be formulated, and each component must be assigned a unique component code that corresponds to its properties and parameters. Component information should be collected from BIM, and each component should be matched with a safety rule by matching the IDs of the safety rule and the component. Through this process, unsafe design factors are identified and corrected by comparing component parameters and their related information in safety rules (Guo Hongling et al., 2016). The demonstration of safety culture at different maturity levels will lead to a proper understanding of safety culture and practices among workers. This model can be included in safety training and practiced for effective outcomes and achieving safety goals on construction sites (Oluseye Olugboyega, 2016). BIM usage shall not be limited to design purposes; it shall be extended to various scopes in the management of construction projects. Awareness programmes and training sessions can be conducted to diverge the knowledge of BIM in India (Shalaka Hire, 2021). The suitable tools for 3D BIM are Revit, AutoCAD, Sketchup, and Part Builder in civil 3D, and to develop 4D Simulation for safety management, the suitable tools with 3D BIM are Google Sketchup, ArchiCAD, Tekla Structures, Tekla Construction Management, Navisworks, Solibri Model Checker, etc. These tools can also be included with VR and AR to make effective safety management in construction (Nguyen Quoc Toan et al., 2021).

BIM technology with AR can be used to establish a construction safety index and realize real-time and effective monitoring of construction site-related information. Through the relevant 3D model data and progress linking using BIM, 4D simulation can be done, which results in orderliness and improved safety in construction activities (Zhenxian Huang, 2021). Integration of BIM and IOT will enhance effective safety management planning. Early investment in safety planning enables zero accidents in construction. Algorithm development for effective computer graphics enhances BIM and IOT systems effectively. A remote monitoring system by comparison of IOT + BIM and on-site activities with CCTV will have proper tracking and monitoring of construction safety, which in turn will reduce the cause of accidents (Haiyang Yu et al., 2022). The challenges that restrict the application of BIM to construction safety are legal issues, technology, cost, management, and human resources.

4. CASE STUDY

The case studies chapter has been divided into two categories according to the usage of BIM: case studies using BIM as a safety tool and case studies using BIM as a design tool. The case studies were conducted in the form of a net case study and a live case study. A total of three case studies were taken into consideration and studied. Two case studies were reviewed, and inferences were drawn utilizing BIM as a safety tool. One live case study has been studied and inferred using BIM as a design tool.

Case Studies on Using BIM as a Safety Tool:

4.1 The Recreation and Wellness Centre at Auburn University [15]:

Figure -1: Recreation and Wellness Centre at Auburn University [15]

The location of the project is Auburn, Alabama, USA. The total cost of the project is $50,000,000, and the total area of the project is 2, 40,000 sq. ft. The project's start date is October 2011, and its completion date is May 2013.

The list of software used for this project includes: Autodesk Revit for modelling; Google Sketchup for creating 3D equipment, characters, and related families; Synchro for 4D phasing simulations; MS Project for scheduling; Camtasia and MS Movie Maker for producing videos. In this case study, a safety plan is developed through BIM technology to address the "fatal four" construction fatalities and injuries: falls, electrocutions, being struck by an object, and being caught in or between. The workflow followed in this project by the team for developing BIM-based safety plans, simulations, and videos is shown in Figure 3.

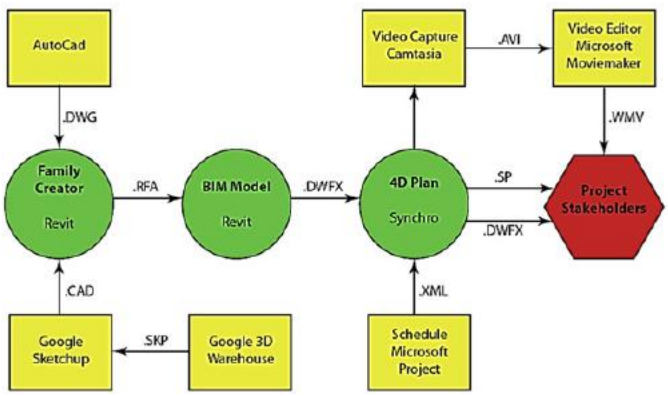

Chart -2: Work Flow Process [15]

The crane management plan is done to identify the crane's swing radius to ensure its safe distance from the power lines and nearby temporary and permanent structures, and to identify the crane's usage time by the crew. The excavation risk management plan is done to coordinate with jobsite equipment used for earthwork phase operations to avoid cave-ins and accidents while installing sheet piles. A fall protection plan for leading edges is prepared according to OSHA Subpart M: Fall Protection Standards. Two types of fall protection railings are modelled and placed on the structural BIM model. Using the 3D view, the developers identify multiple falling risks that will not be found with the 2D plan view. They are exported to Synchro for developing 4D simulations. The 4D simulation provides the contractor with complete details, including location and date. A fall protection plan for roofers is done as the roof is constructed in two phases, consisting of decking the roof and then fusing membrane sheeting on top of the decking with rigid insulation. The entire operation is simulated to identify safety issues related to that activity. These animations were used to brief workers who are exposed to fall protection hazards by working on a constantly changing roof structure.

It has been inferred through the case study that site safety planning using BIM will enable designers, engineers, and project managers to formulate safety plans for construction sites. BIM 3D and 4D can visualize the process of construction activity on a day-to-day basis, and possible site-related risks can be observed. BIM also visualizes which hazard prevention and safety control measures are to be implemented during each and every construction activity. These visualizations will help the construction workers with effective safety management and safeguard them from hazards.

4.2 The Recreation and Wellness Centre at Auburn University [6]:

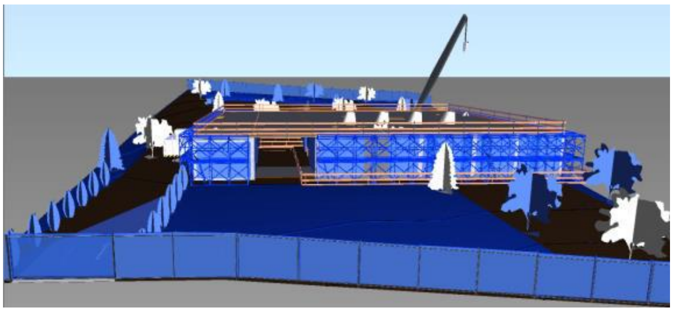

Figure -2: Radio Therapy Centre at Madeira [6]

The location of the project is Madeira, Portugal. The list of software used for this project includes: Autodesk AUTOCAD; Google Sketchup for creating 3D equipment, characters, and related families; Autodesk Navisworks; and Autodesk Revit. The building plans were developed in AutoCAD. It consists of two floors: a basement and a ground floor. In addition, the BIM 4D model also contains safety documents for the construction phase linked to it. The safety files focus on preventing risks in different activities, such as assembly and disassembly of temporary elements, formwork, scaffoldings, and the pouring of concrete in structural elements.

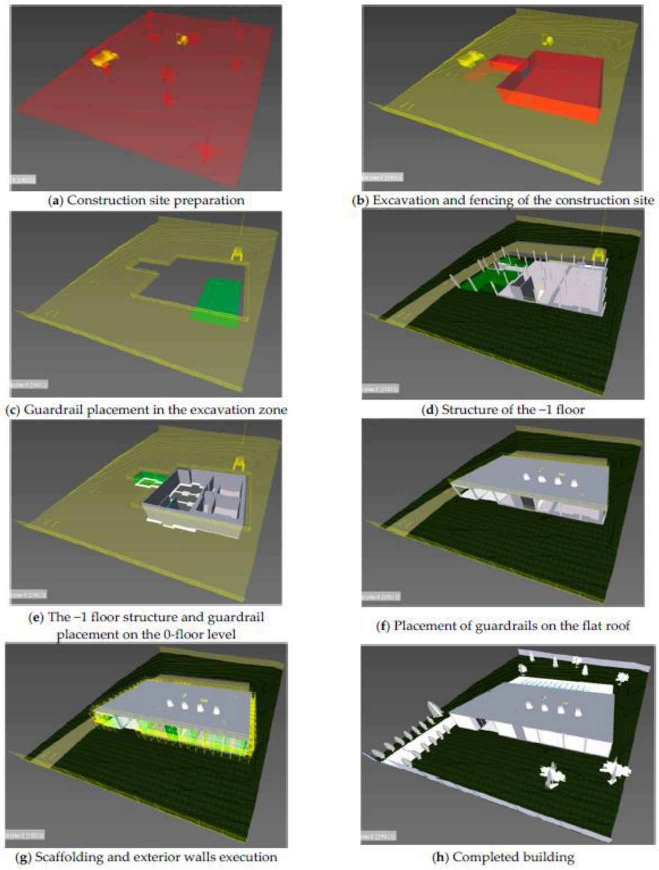

Figure -3: Safety Model using BIM [6]

The designers used architectural and structural 3D models developed in Revit. They encouraged the use of temporary construction while allowing the use of safety precautions. Scaffolding, platforms, and construction fences were imported using external web libraries (Revit City.com, Bimstore.co, BIM objects, and BIM&CO). The designers developed a variety of guardrail families, such as those with a clamping mechanism, guardrails with spikes, and hole coverings. In Navisworks, the two 3D models were finally overlapped to create a federated model. By including the time factor in the Navisworks federated model, a 4D model was produced. The activity schedule created in Microsoft Project served as the basis for the generation of the time component. In order to prevent falls from height, this schedule took into account both the primary construction operations and the temporary tasks, which correspond to the employment of safety mechanisms and the planned starting and finishing times for each activity. Additionally, safety files were created. Tools were added to the 4D model, such as comments and links to these safety files, to promote safety. These documents include thorough explanations of guardrail and scaffold setup and disassembly, as well as of dangers, risks, and preventative actions. By using the Navisworks simulation tool on the 4D model, it was possible to visually follow the evolution of the workplace through time and identify the management and safety actions that were required at any given time. Each color on a color-coded graphic created by Navisworks simulation represents a different sort of task, such as construction, demolition, or a temporary task. This case study gave extra consideration to the scheduling of temporary safety equipment for reducing risks due to falling from heights and its proper sequence of disassembly and assembly from the excavation to the finishing works.

It has been inferred through the case study that incorporating safety measures, including documents, in the safety structural model and combining it with the existing model gives a clear picture of when and where safety is to be implemented.

Case Studies on Using BIM as a Design Tool:

4.3 Statue of Unity, Gujrat

This project is located at Sadhu Bet, Sardar Sarovar Dam, Gujarat. The total cost of the project is Rs 3000 crores, and the total built-up area is 20,000 sq.m. The height of the statue is 182 m (597 ft) from the road entry, or 240 m with an overall base. The total project duration is 56 months (15 months for planning, 40 months for construction, and 2 months for handover). The sculptor Ram V. Sutar created handmade models for the project, and the digital conceptual sculptor was Joseph Menna. The list of software used for this project includes: Autodesk Revit; Stadd Pro; AutoCAD; Sketchup; Navisworks; and Rhino.

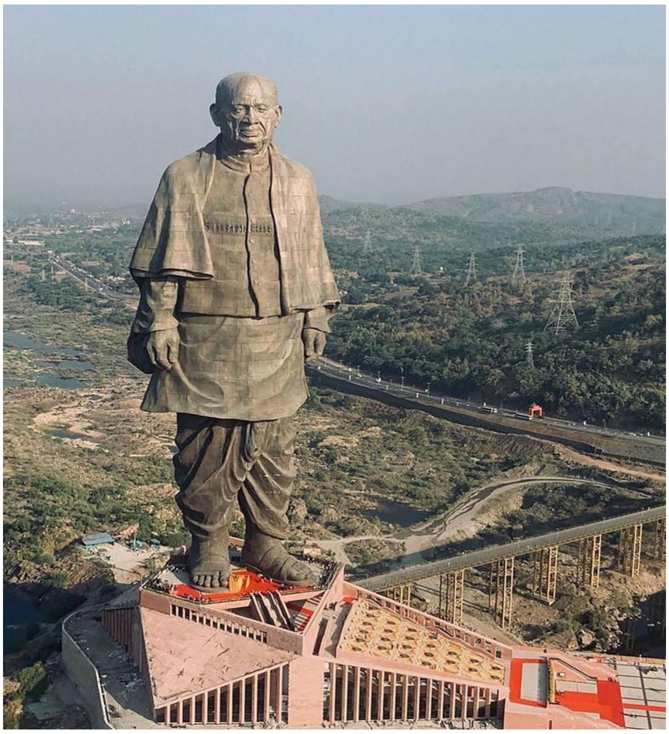

Figure -2: Statue of Unity, Gujrat

The Statue of Unity is a bronze replica of India's first deputy prime minister, Sardar Vallabhbhai Patel. The models were created in various sizes: 3ft, 18 ft, and 30ft.

Design Process:

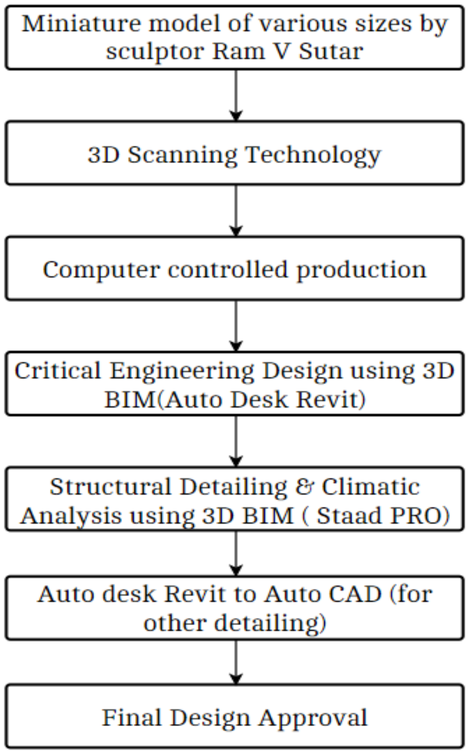

Chart -3: Design Process of Statue of Unity

It is inferred through the study that BIM acts as an effective tool for critical engineering design. 3D BIM and its tools help find design errors and improve designs. The accurate calculation of the number of resources required for the project by 3D BIM will help to reduce wastage of resources. The traditional safety management method included HIRA for all activities and ways to avoid accidents. Proper monitoring and following the dos and don'ts will help in human error reduction and accident prevention. Assessing each and every hazard in the activities for various categories and ranges will help in understanding the severity of risk in each category. Conducting a training programme for the workers based on the risk assessment will improve their awareness of the importance of safety in construction. Education about the problem and its solution will remove the fear of working at heights or in other accident-prone zones. The safety planning for this project took two months to complete. Though SOU is a very successful project that utilizes BIM as a complete design tool, incorporating safety management into BIM during the design phase will help reduce the time consumed by traditional safety management methods.

5. QUESTIONNAIRE SURVEY

The survey has been divided up into five parts, and professionals in the construction industry responded to 18 questions: Part A: General Questions; Part B: BIM Awareness; Part C: BIM as a Design Tool; Part D: BIM as a Safety Tool; Part E: Barriers to the Development of BIM as a Safety Tool. The questionnaire survey was circulated to 150 professionals through online mode. A total of 120 replies were received in response to 150 inquiries. 30 replies were considered invalid due to missing or irrelevant information. 90 replies were evaluated, analyzed and the findings has been discussed.

Some of the major questions that were marked mandatory to answer and circulated among the professionals were: List of BIM software used by the organization or firm for designing projects; usage of BIM as a design tool; benefits of using BIM as a design tool; challenges faced by the organization or firm for implementing BIM as an integrated tool for safety management; factors affecting the upgradation of BIM usage to a higher level in the organization or firm; and type of safety management practice followed by the organization or firm. The received responses are listed and discussed below.

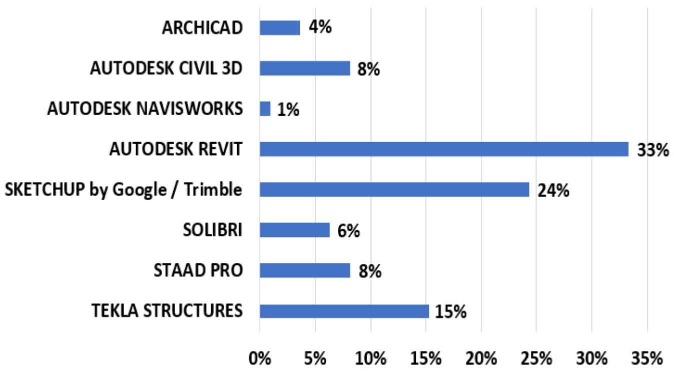

Chart -4: List of BIM software used by Organization/Firm for designing Project

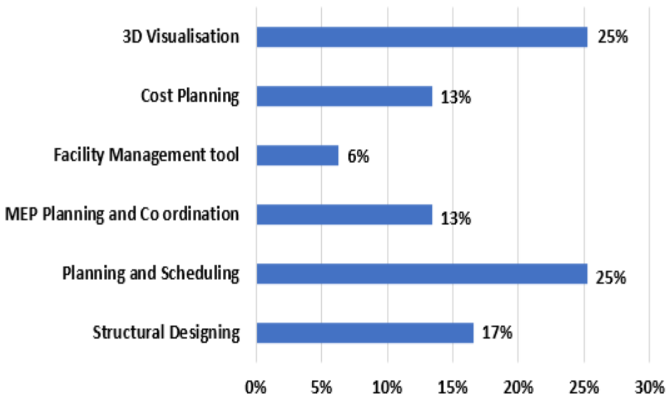

Chart -5: Usage of BIM as a Design Tool

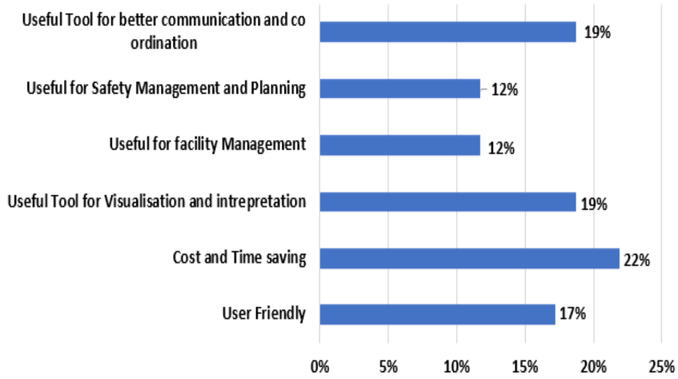

Chart -6: Benefits of using BIM as a design tool

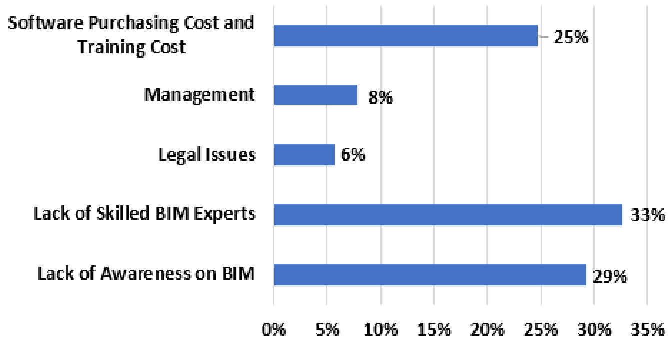

Chart -7: Challenges faced by the organization or firm for implementing BIM as an integrated tool for safety management

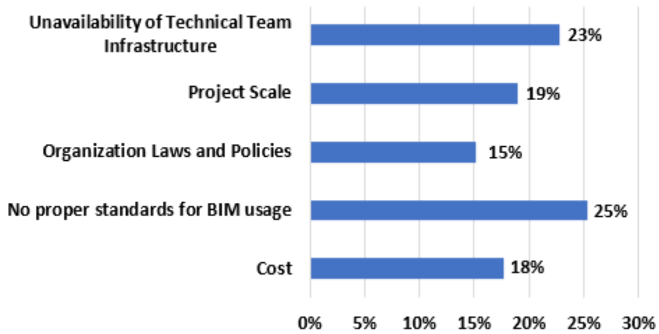

Chart -8: Factors affecting the upgradation of BIM usage to a higher level in the organization or firm

5.1 Questionnaire Analysis:

The questionnaire survey analysis revealed that awareness of BIM and understanding of implementing BIM as a safety tool in the construction sector is still insufficient. Approximately 51.1% of firms/organizations have been using BIM for designing projects. Some of the most essential and widely used software for designing projects include Revit, SketchUp, and Tekla Structures. BIM is most often utilized as a design tool for scheduling and planning, 3D visualization, structural design, MEP design, cost estimating, and planning. BIM is used as a design tool for approximately 10 to 50 projects in an organization / firm. According to the survey, the benefits of using BIM as a design tool include cost and time savings, a helpful tool for visualization, a valuable tool for interpretation, a useful tool for improved communication, and it is user-friendly. It is also discovered that, in general, BIM hasn't been used as a safety tool until now, and 68.4% of respondents support the use of BIM as a safety tool. The main challenges in implementing BIM as a safety tool include a lack of experienced BIM experts, a lack of BIM awareness, software purchase, training, and cost. The main constraints to the advancement of BIM in firms are a lack of appropriate standards, the scale and cost of the project, the lack of technical staff, and organizational regulations and policies. It has been found that most of the respondents use traditional methods for risk management and safety management for their projects.

6. FINDINGS AND DISCUSSIONS:

Failure to follow safety standards, ignorance of PPE, space congestion, and improper use of safety items and equipment are some of the major causes of accidents. Accidents have a significant impact on the cost of medical expenses, project execution time, productivity loss, firm distrust, and the cost of training offered to new workers. The study discovered that those under the age of 30 were more likely to be victims of an accident. Safety training and awareness, worker attitude towards safety, availability of safety equipment, safety inspections, and organizational safety policy are the top five most significant elements impacting construction site safety. Over the last decade, BIM has grown tremendously. The growth of BIM and its features will propel the construction sector to new heights. Integration of BIM with AR, VR, and IOT will make BIM-based safety management more efficient. Component information should be obtained from BIM, and each component should be linked with a safety rule by matching the IDs of the safety rule and the component. Through this process, unsafe design problems are found and addressed using BIM automation by comparing component parameters and associated information in safety standards. BIM is most commonly used as a design tool for planning and scheduling, 3D visualization, structural design, MEP design, cost and planning. According to the survey, the most significant advantages of adopting BIM as a design tool are cost and time savings, a useful tool for visualization, interpretation, and user friendliness. The main challenges observed while using BIM as a safety tool are a lack of skilled BIM experts, a lack of understanding about BIM, the purchase of software, training, and the cost. The main factors influencing BIM adoption in firms include a lack of adequate standards, project scale, cost, technical team availability, and organizational rules and policies.

7. CONCLUSION:

In order to prevent construction site accidents Safety clauses should be followed, and safety audits, training programmes, and pre-job meetings should be conducted. Linking the professional model with the BIM 5D platform, which is built with hazard identification, collision detection, and real-time monitoring of the unsafe states of the objects, results in enhanced safety modelling and effective safety management planning for the construction site. The potential of BIM should be spread, and its usage should be increased.

REFERENCES

[1] Abdulkadir Ganah, Godfaurd A. John ,2014, Integrating Building Information Modelling and Health and Safety for Onsite Construction, UK, https://doi.org/10.1016/j.asej.2022.101723

[2] Ali Saad, Saheed O. Ajayi & Hafiz A. Alaka ,2022, Trends In Bim-based Plugins Development For Construction Activities: A Systematic Review, UK, https://doi.org/10.1080/15623599.2022.2093815

[3] Anita Jesline Serrao, 2020, Occupational Injuries Among Building Construction Workers In Mangalore, India: A Cross sectional Study, India, DOI:10.4103/ijhas.IJHAS_44_19, https://www.ijhas.in/text.asp2020/9/2/116/282136

[4] Bilal Mansoor,2021, Accidental Safety Factors And Prevention Techniques For High-rise Building Projects – A Review, Malaysia, https://doi.org/10.1016/j.asej.2022.101723

[5] Dheeraj Benny, 2017, Construction Safety Management And Accident Control Measures, Volume 8, Issue 4, April 2017, pp. 611–617 Article ID: IJCIET_08_04_069

[6] Fernanda Rodrigues João Santos Baptista and Débora Pinto, 2022, BIM Approach in Construction Safety—A Case Study on Preventing Falls from Height, Portugal, https://doi.org/10.3390/buildings12010073

[7] Guo Hongling, Yu Yantao, Zhang Weisheng, Li Yan, 2016, Bim And Safety Rules Based Automated Identification Of Unsafe Design Factors In Construction, China, https://doi.org/10.1016/j.proeng.2016.11.646

[8] Haiyang Yu, Feng Liu, And Yujin Wang, 2022, Construction And Evaluation Of Construction Safety Management System Based On Bim And Internet Of Things, China, https://doi.org/10.1155/2022/1541241

[9] Isabelle Ys Chan, Hy Leung, 2016, How Can Bim Support Construction Safety Management? Development Of Sim, Hongkong, China, MATEC Web of Conferences 66, 00018 (2016), DOI: 10.1051/matecconf/20166600018

[10] Nguyen Quoc Toan,thi Tuyet Dung,thi My Hanh , 2021, 3d-bim And 4d-bim Models In Construction Safety Management, Vietnam, https://doi.org/10.1051/e3sconf/202126302005

[11] Oluseye Olugboyega And Abimbola Windapo, 2019, Building Information Modeling—enabled Construction Safety Culture And Maturity Model: A Grounded Theory Approach, 2019, South Africa, Front. Built Environ. 5:35. doi: 10.3389/fbuil.2019.00035

[12] Othman,i1, Nasir Shafiq1, Nuruddin,m.F1, Effective Safety Management In Construction Project, 2018, IOP Conf. Series: Materials Science and Engineering 291 (2017) 012018, doi:10.1088/1757-899X/291/1/012018

[13] M. Ramya, 2017, Analysis On Causes For Accidents In Construction And Its Safety Measures, India, International Journal of Modern trends in Engineering and Science. 03. 127-132.

[14] Sakthi Ganesh.G, Rajesh.M, A Study On Identification Of Causes And Effects Of Accidents In Construction Industry- Indian Scenario, India, https://doi.org/10.14445/23488352/IJCE-V4I6P108

[15] Salman Azhar, 2016, Role of Visualization Technologies In Safety Planning And Management At Construction Job Sites, USA, https://doi.org/10.1016/j.proeng.2017.01.329

[16] Singaram.A, Priscil Nidhu ,2019, Investigation Of Causes Of Accidents In Construction Industry, India, http://www.aasmr.org/jsms/Vol8/Vol.8_No.3_4.pdf

[17] Shalaka Hire, Sayali Sandbhor, 2021,bim Usage Benefts And Challenges For Site Safety Application In Indian Construction Sector, India, https://doi.org/10.1007/s42107-021-00379-8

[18] Zhenxian Huang, 2020, Application Research On Bim+ar Technology In Construction Safety Management, China, Zhenxian Huang 2020 J. Phys.: Conf. Ser. 1648 042019, doi:10.1088/1742-6596/1648/4/042019

[19] Zhihong Yu, 2021, Research On Safety Management Of Construction Site Based On Bim, Beijing, China, Zhihong Yu 2021 IOP Conf. Ser.: Earth Environ. Sci. 719 032012, doi:10.1088/1755-1315/719/3/032012