Proposal for Temporary Safety Facilities for Fall Protection Using 4DBIM to Meet OSHA Standards

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Abstract

Temporary Safety Facilities (TSFs) constitute a vital support infrastructure ensuring the safety of workers throughout construction operations, with the overarching goal of averting accidents onsite; However, the schedule and location of installation and dismantling of technical support facilities is still based on work experience, and is often omitted from official drawings or documents. This leads to thousands of accidents in the construction sector, especially in small and midsize construction enterprises construction firms due to many limiting factors; Therefore, this study proposes automatic workspace planning for temporary safety facilities (in our case guardrails for fall protection) based on construction activities, which is a structured approach for SMEs working in construction to practice Occupational Health and Safety (OHSA). By employing Building Information Modeling (BIM), safety facilities can be simulated and visually incorporated into the assigned workspace. Utilizing 4D-BIM, the devised system facilitated the installation of temporary safety features, such as fall protection railings, which underwent validation via a case study involving a mall project. The results indicated that integrating temporary safety facilities with the model enhances comprehension of safety protocols throughout project execution. Additionally, temporary facility workspace planning provides an affordable approach that stimulates safety practices; Thus, significantly enhancing the management effectiveness of construction safety measures

Keywords: Safety; 4DBIM; Temporary Safety Facilities; Railings.

1. Introduction

The construction sector is one of the most important economic sectors in any country in the world. [1, 2]. The construction project progresses through multiple phases, with different individuals participating in each stage, each with their own distinct role and often conflicting goals. The final outcome in the construction sector is typically achieved through a variety of contracting and sourcing strategies, each varying in their appropriateness for different types of projects. These elements have contributed to escalated costs, project delays, and diminished quality across the global construction sector. Specifically, in Syria, the construction sector encounters more significant challenges compared to others regarding economic growth rates and technological advancements. This is due to obstacles in achieving project objectives related to schedule, cost, and quality, as well as various constraints faced during project completion. [3, 4, 5]. In order to comprehend the intricacies and obstacles within the construction sector, it is essential to embrace a new operational approach that aligns with global technological advancements, or develop an updated approach. This will enhance the sector's efficiency and streamline the exchange of information in the appropriate format and timeframe. The utilization of BIM has gained importance in recent years. [6, 7,8,9]. Existing practices encounter challenges and

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gaps that hinder this transition, forming the essence of the investigation [10]. The concept of BIM is a technological revolution in the construction sector [12]. As it rapidly revolutionized the conception of buildings are imagined, planned, built, and managed, it also revolutionized communication among project stakeholders (such as owners, designers, contractors, suppliers, and project managers) throughout the entire project life cycle. This has led to improved quality, profitability, and performance of projects, enhancing efficiency and addressing significant challenges in AEC industry. [12,13,14]

4D BIM technology effectively aids in improving occupational safety and health. by providing a safe virtual work environment before starting the actual implementation of the project. Three-dimensional models provide an opportunity to inspect designs, activity sequences, and early detection of deficiencies that could threaten worker safety. Models can also be used in proactive awareness programs and training workers on proper procedures when facing risks, which reinforces a culture of safety among all workers. Statistics indicate construction projects rank among the most hazardous endeavours in terms of occupational safety, as many accidents and injuries are recorded at work sites annually. One prevalent danger is workers falling from significant heights, frequently resulting in severe injuries or fatalities. Where building information modelling

reduces 61% of construction errors, and between 20-30% of project cost, and 20% of project duration (2), not to mention the benefits of the resulting models in the process of managing building facilities and achieving sustainability of the facility.

According to statistics, workers falling accounts for about 40% of occupational fatalities in the construction sector. However, most fall accidents can be avoided by taking simple preventive measures such as installing scaffolding, safety nets and personal fall protection systems. Unfortunately, these safety requirements are often overlooked at construction sites in order to achieve faster production gains. Therefore, it is necessary to incorporate strict safety standards related to fall prevention into the initial design and site planning using techniques such as BIM to ensure maximum possible protection for workers throughout the project phases. The primary goal of this thesis is to ascertain the advantages of utilizing the fourth dimension of BIM technology in planning and managing space in construction projects so that safety standards are applied in small and midsize construction enterprises-sized building projects. It also provides a brief definition of BIM and occupational safety standards according to OSHA. BIM tools have been applied to a case study to find solutions to reduce fall accidents at the construction site.

OSHA shows that the percentage of deaths resulting from falls is 39.2% of the deaths occurring in the construction sector, while the percentages of deaths from impact and electric shock are 8.2% and 7.3% respectively. On the other hand, occupational safety planning is influenced by factors such as the scale of the construction site, the operational structure, and the methods employed for project delivery. A comparison between companies of different sizes shows that a high proportion of accidents in terms of number or severity occurred in small companies [5]. OSHA Fall Protection Safety Standards: - There are many choices for fall protection available, the employer will choose the method that best fits the work area hazards. Guardrail systems are commonly used for fall protection. - Guardrails must meet strict design specifications. The top rail height must be between 99 and 114 centimetres. The top rail must withstand a force of at least 200 pounds. - The mid-rail must be halfway between the top rail and the working surface, and must withstand at least 68 Kg of force. - Guardrails must also be designed so they do not cause lacerations or injuries and must not extend beyond landing platforms.

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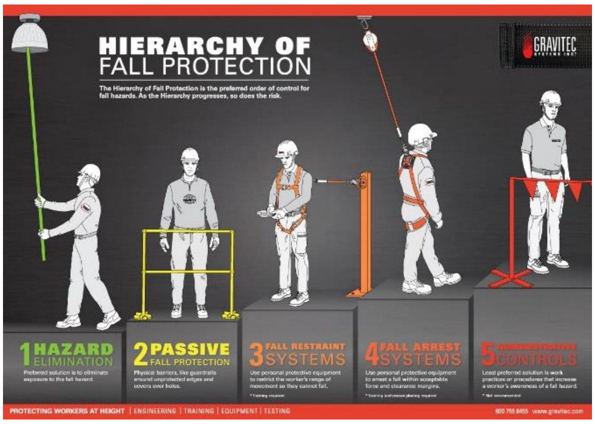

Figure 1: FALL PROTECTION HIERARCHY SOURCE (HIERARCHY OF FALL PROTECTION)

The Need for Effective Workspace Planning for Temporary Safety Facilities (TSFs) Based on 4D BIM Platform As construction is rapidly transforming into a data-driven industry, digitization of building information is one of the first steps towards smart management. Accordingly, to enhance competitiveness in the construction market, BIM small and midsize enterprises need to transform their traditional approach to smart construction. However, most small and midsize construction enterprises construction firms operate under several constraints such as time, cost and lack of skilled employees, which restrict them from using expensive innovative techniques in the construction process [43], especially for safety applications. Therefore, to facilitate the smart implementation of safety requirements in small and midsize construction enterprises construction companies, it is imperative to have an easy way to identify when, where and what type of safety facilities need to be installed or removed at a given workplace. Incorporating BIM into the safety planning process brings capabilities that assist not only small and midsize enterprises to increase their productivity, save labour, unify data blueprint, and submit it consistently when participating in recurring projects but also improve their reputation and operation quality to compete with larger companies. The system with BIM integration is expected to be a cost-effective approach for small and midsize enterprises since its long-term benefits and advantages it brings to small and midsize enterprises far outweigh the invested cost. From this motivation, the study proposes an approach to conduct workspace risk identification automatically based on activity. Risk Investigation: This unit consists of the following two-phased process: Data Input process and Safety Contents Allocation process. The Data Input process is setting up a 3D model of the project and 2D data such as project schedule and Fatal Four data collected from OSHA website. After that, the Safety Contents Allocation is a procedure that is analysed and evaluated for the Fatal Four data. At the same time, customized tools for exchanging 2D and 3D data such as Graphical Algorithm and BIM were used to develop database linkage for the next unit.

2. Literature Review

This section provides an overview of current research on accident data analysis, temporary safety facilities, and BIM-based safety planning initiatives in the construction sector. Importance of Analysing Causes of Construction Fatalities Some research has emphasized the importance and role of identifying accident causes to prevent their recurrence. Betsis [16] highlighted the correlations between different accident characteristics and causes and construction stages. Recent studies have shown that fall-related hazards are major concerns [17-19], and most construction accidents and fatalities relate to small or medium-sized companies [14]. Arboleda and Abraham [13] analyzed the causes of accidents to find key relationships between accident patterns and behavioral causes leading to fatalities. Numerous studies focused on risk analysis based on accident severity, frequency, and risk distribution [18,20]; however, the investigations only provided relevant information without discussing practical application for safety planning purposes. For example, Kim et al. [22] analysed scaffolding-related workplace conditions, which are automatically shared in BIM.

Kim et al. [23] conducted research on automated decision-making for selecting appropriate customized temporary structures for scaffolding works; however, the study did not include sufficient safety planning to allow the use of different safety facilities throughout the entire construction process.

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Hence, there is a need to explore the viability of integrating safety measures by incorporating cutting-edge methodologies into suitable safety planning procedures. These methodologies should embrace a straightforward approach to promote broad utilization, ensuring they are user-friendly, easily updatable, and modifiable. Additionally, they should facilitate automated selection of temporary safety features. Temporary Safety Facilities in Construction Temporary safety facilities in construction are essential equipment/facilities used for a limited period, depending on the change in construction conditions, in order to provide adequate safety and protection at the construction site. Although there is extensive research on planning permanent structures in construction, temporary structures are still being ignored or given minimal attention [24]. Therefore, there are still problems that need to be solved by conducting an in-depth investigation using potential techniques. Often, hazards arise from the operation of temporary structures, which is partly due to the thinking that activities related to these structures are secondary tasks [25]. Most previous studies reveal that temporary structures have been installed without proper planning [22] because current safety planning has neglected to consider safety issues when using temporary facilities. Developing a paper plan for a temporary safety structure is certainly a lengthy, inefficient process that requires labour-intensive. This work requires the preparation of various documents for detailed planning with reviews of several aspects such as building engineering, design generation, structure type, and impact on time and cost [23].

Given the lack of time, cost and labour in small and midsize construction enterprises construction companies, implementing safety measures should be a concern for these companies. In contrast, several studies have affirmed that by comparing the distinctive characteristics of company size, it was noted in small and midsize enterprises, especially with regard to safety management and implementation, that weak OHSA practices lead to an increased risk of accidents during construction. Some studies have claimed that the greatest constrained factor in Small and midsize enterprises in the construction sector is skilled labour, while others have attributed this to cost [11,19]. Due to the multitude of safety guidelines in construction, workers or even inexperienced managers might not be aware of certain safety requirements or might disregard them during the construction process.14].

Additionally, it cannot be denied that safety awareness in the construction sector is not sufficiently high in small and midsize enterprises. Therefore, problems such as forgetting to comply with safety guidelines and misunderstanding the guidelines are common, leading to accidents. Moreover, creating safety plans necessitates

participation of safety specialists; therefore, Small and midsize enterprises claim that they lack the requisite funds to hire specialists to overcome this, small and midsize enterprises need to take a strategic approach to adopt new technologies and BIM processes. On the flip side, not all of these traits are negative, but they also have positive points. Small and midsize enterprises can have greater capabilities than larger companies in simplifying BIM integration by turning their weaknesses into opportunities [15]. Although small and midsize enterprises have limited human resources, they attract new and young workers to this sector, who are often interested in new technologies and innovative working methods. With small to medium amounts of building information, small and midsize enterprises can be more flexible and simpler than large companies in implementing, synchronizing and integrating digital information. In addition, decisions are generally made faster and more manageably in small institutions than in intensive execution institutions that require a long time for review and activation.

In fact, many small and midsize construction enterprises construction firms, especially start-ups, have been pioneers in catching up with BIM technology and new trends, enhancing their competitiveness and narrowing gaps with larger companies. As a result, BIM implementation in small and midsize enterprises is an inevitable trend for the construction sector in the future. This study proposes automated 4D-BIM-based workspace planning that allocates temporary safety facilities (TSFs) to specified template objects/conditions that incorporate activity-based risk assessment and corresponding prevention. The assessment data was arranged specifically according to the severity rate of accidents related to individual activities and then the associated fall protection was calculated. The suggested method was applied to a commercial mall project. It has shown that 4D-BIM can automatically position TSFs at the right place and time. The system is expected to be able to provide general safety planning without the involvement of safety experts. Therefore, it reduces the manager's workload, improves safety management, saves small and midsize enterprises' resources, and helps

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small and midsize construction enterprises adopt an approach closer to a smart and safe work environment.

OSHA Standards in Construction OSHA standards in the construction sector include a number of requirements, such as wearing personal protective equipment, conducting periodic medical consultations, and providing training programs for all workers on safe equipment and tool use. Employers must also comply with specific safety procedures while performing operations, such as using fencing around the work area and providing emergency exits and warning signs. Additionally, all construction workers must follow general safety principles, such as avoiding smoking in the work area, maintaining cleanliness of the site, and ensuring materials are securely fastened. These standards must be strictly enforced to ensure the safety of all persons involved in the construction process, including workers and visitors. The integration of innovative information and communication technologies (ICT) is rapidly leading to the transformation of traditional construction to smart construction.

However, the nature of the construction process makes it prone to hazards and accidents; additionally, innovations in the construction sector have led to new safety-related issues arising. According to recent public reports, construction is widely regarded as one of the most perilous professions with a much higher number of work-related injuries and fatal accidents compared to other industries [1-3]. OSHA reports show that construction worker fatalities in 2017 accounted for 20.7% with 971 cases. OSHA described the "Fatal Four" as the leading causes of workplace deaths, which are responsible for over 60% of construction worker deaths, according to reports from the Bureau of Labour Statistics. These four key hazards consist of falls, struck by object, electrocution, and caught-in/between [4].

3. Research Methodology

The research information will be collected through:
Theoretical Tools: Books, previous research, articles, master's and doctoral theses that deal with BIM techniques.
Practical Tools: Site plans for the project and its documents as they are on site and information about the project and its implementation period provided by studying engineers and supervisors.
(1) Autodesk Revit 2018
(2) Dynamo 2.0.2: A visual programming language (VPL) that enhances the power of Autodesk Revit
(3) Microsoft (MS) Excel 2016
(4) Primavera: Project management software product
(5) Navisworks Manage 2019

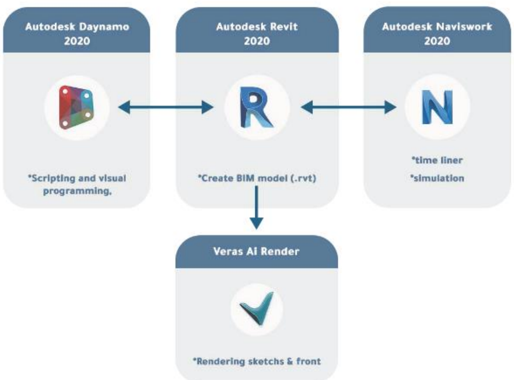

Figure 2: PROGRAMS USED IN THE SEARCH PROCESS

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A. Case Study

Revit is of the most widely used programs in the BIM process. It allows the creation and design of building models in a three-dimensional view. It provides extremely accurate 3D models with negligible errors. The 3D BIM model is an important tool in the construction planning process as it is essential for both clash detection tests and design error and accurate quantity calculations in the early design stages and is the cornerstone for all other BIM dimensions. Architectural Visualization on Veras AI 2023: With the advancement of artificial intelligence technology, the field of architectural engineering is undergoing a radical shift beyond the traditional traditions of design and innovation. The use of smart technology in the architectural conceptualization process is an opportunity for architectural engineers to expand the boundaries of design and engineering in unprecedented ways.

Figure 3: RENDERING BY VERAS AI 2023

Creating the Timeline Envelope, A level of detail (LOD) 200

Envelope was created by Navisworks software to schedule the project. Simulating and displaying the construction process using Navisworks requires a logical hierarchy and sequencing of project works with an approximate duration estimate for each work. Site works started from the structural model and moved in successive steps to the architectural model steps, where we have a Gantt chart as shown in the figure.

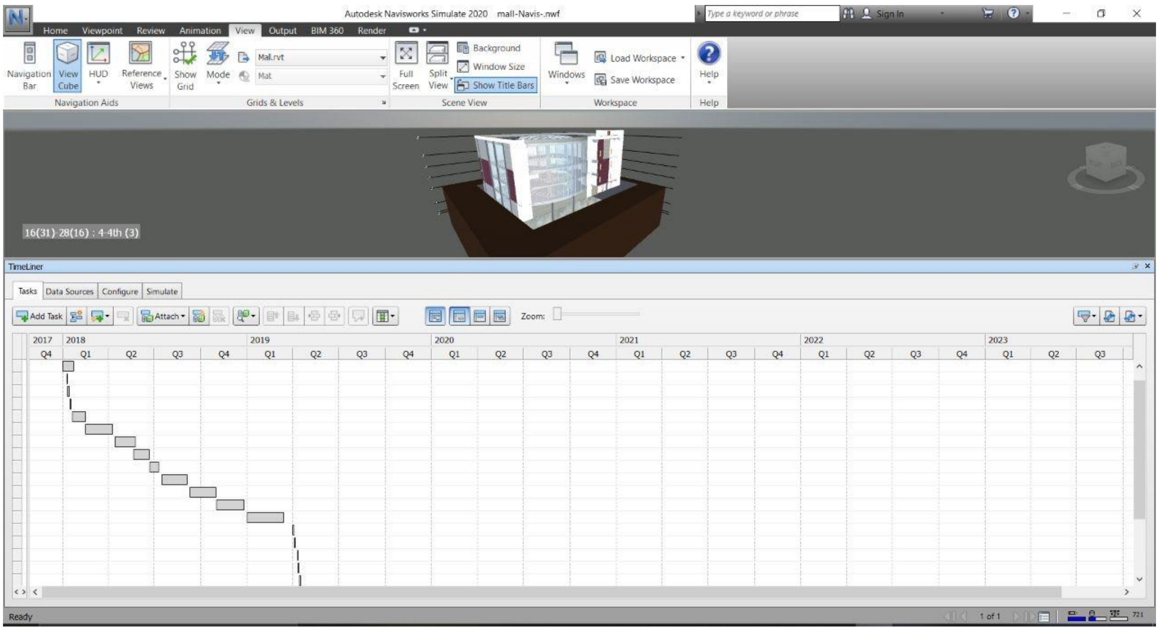

Figure 4: GANTT CHART ON NAVISWORKS FOR THE BUILDING

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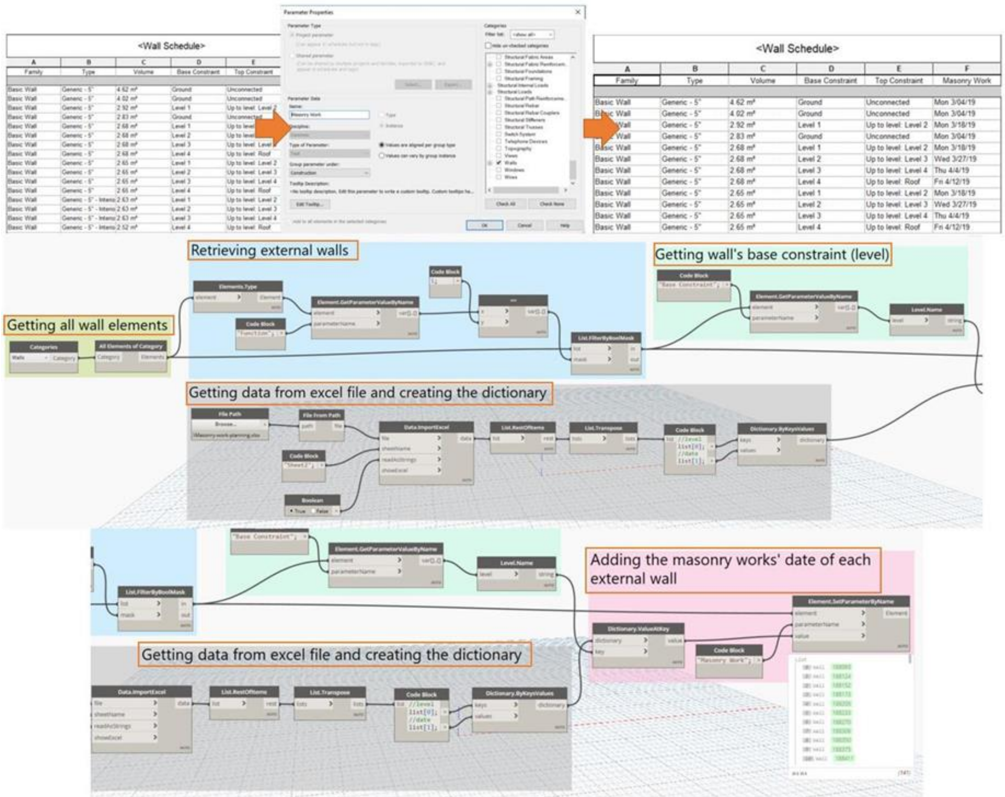
Scripting and Visual Programming Using Dynamo

The first step is to get the data (construction work schedule) from the project schedule that was prepared in Excel .xls format. Accordingly, this information was added to all the exterior walls through visual programming using Dynamo. The figure illustrates the workflow for integrating the schedule with the wall schedule (exterior) in Revit: The property named "Work Masonry" in the wall schedule was added in Revit

and represents the actual construction date in Revit. This column will be automatically populated when running the first script in Dynamo. Where the first script performs the following tasks:



• Retrieve all wall elements including exterior and interior walls in the Revit model.

• Retrieve all exterior walls. In Revit, each wall type has a different function: Wall function: exterior is termed 1 in Dynamo and wall function: interior is termed 0 and accordingly, the "Filter By Bool Mask .List" node was used to filter all the exterior walls in the model and put them in a list.

• The next node: Gets the height of each wall from the exterior walls.

• In parallel, Dynamo processes all data from the Excel file consisting of the planned date for the creation of each wall and creates a "dictionary" in the visual programming environment. In this case, the dictionary is a data type consisting of a set of key-value pairs, instead of index or list. The dictionary sorts the walls according to the planned construction date coupled with the floor or level on which the wall will be built, where the dictionary contains the floor (height) as the "key" and the corresponding date for building the exterior walls at this elevation is the value that will be used in the next node.

• Accordingly, Dynamo will get the value (the corresponding date for building each wall) at the specified key (wall height). The "By Name.Element Set Parameter" node will automatically add the information (construction work date) to all exterior walls. (Here Revit knows the planned date for creating each wall).

After that, the second script performs the following tasks: Stage 1: The engineer enters the current work day date for the program to distinguish between the walls that have been built and those under construction Stage 2: It identifies the edges on which the exterior walls have not been erected until the work day date entered by the engineer, then the program creates guardrails on these edges, and displays them in a new View.

• The node retrieves the exterior walls with the construction date of each wall

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. • The engineer enters work day date
• Exterior walls are sorted into built and under construction.
Guardrails are created on the unfinished external edges of the building that have been pre-prepared according to safety specifications as a new (Type) in Revit.
• A new View is created under the name Under Construction.
• Guardrail elements are displayed in the new View to be guided on site.
when the script is successfully implemented that the protection elements (guardrails here) have been automatically placed in the places that require it, based on the date entered and compared to the project's schedule from the Excel file. • As by combining the model developed in Revit, the design team uses Dynamo to read the schedule data available for the exterior walls from the MS Excel format. VPL will automatically retrieve the data and consolidate it to obtain information about the progress made in building the architectural walls on the sub-floor (including exterior and interior walls, excluding structural walls and other walls). The user can select any work dates in the schedule to estimate the required tasks and continue using Dynamo to distinguish between constructed walls and those under construction. • After retrieving all the walls that have not been built yet, a new guardrail system is created at the locations of these walls. A new 3D view was also created in the Revit model to demonstrate temporary safety facilities (TSF) systems. Figure 12 illustrates a comparison between the corresponding temporary guardrail system on specified dates April 10 and April 16. Therefore, temporary guardrail systems are installed on elevation levels where walls have not yet been built. If the specified date is changed, a new Revit 3D view will be displayed to simulate temporary safety systems at that time. Automatically created by Dynamo on chosen date 04/10/2019

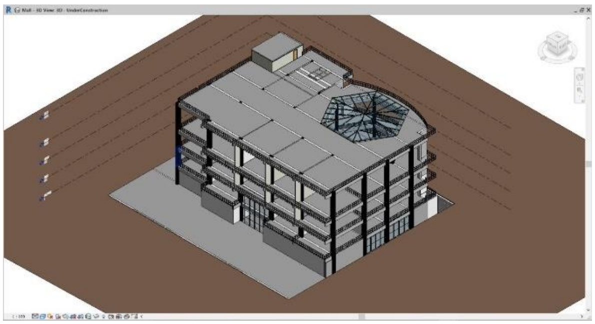

Figure 5: CHOSEN DATE 3 04/10/2019

6. Conclusion

- This study demonstrates the scalability of BIM and the application of graphic algorithms to automatically allocate temporary safety facilities based on the construction schedule in small to medium-sized constructions.

- The aim of targeting small and midsize enterprises in the construction sector in this research is to encourage them to implement digital transformation in their daily operations.

The main function of the designed system is to suggest Temporary Safety Facilities (TSF) automatically for specific time and space in the workplace. When using this system, cost savings can be achieved by reducing labor resources and addressing safety management deficiencies.

- It also saves time and reduces accidents due to system automation, adaptability, and accuracy (e.g., automatic recommendation of Temporary Safety Facilities (TSF), quickly providing construction information, reducing defects, and accidents at the construction site) compared to traditional methods.

- Small and midsize enterprises will have various options to choose targeted support elements with suitable materials, patterns, and prices in the supply market. This provides effective data for estimating detailed quantities of Temporary Safety Facilities (TSF) and plays a crucial role in reducing time and workload in the cost planning process.

- The relationship between 4D BIM and the implementation of important safety standards on the construction site is vital in the construction sector. Three-dimensional Building Information

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Modelling (3D BIM) and time-based (4D BIM) modelling are effective tools to improve project management and ensure worker safety.

- 4D BIM provides an accurate visualization of how the project progresses over time, helping identify potential risks and points that may be hazardous to worker safety. Thanks to this technology, engineering and management teams can identify critical areas and implement appropriate safety measures.

Conflicts of Interest: "The authors declare no conflict of interest."

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