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Adopting BIM Technology in Fall Prevention Plans

Hayder R. Abed [a*], Wadhah A. Hatem [b], Nidal A. Jasim [a]

[a] *Civil Engineering Department, University of Diyala, Baquba, Diyala, Iraq.*

[b] *Baquba Technical Institute, Middle Technical University, Baquba, Diyala, Iraq.*

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Abstract

Building Information Modeling is a modern technique that has contributed in improvement of construction industries. Early detection of hazards during the life cycle of the project will contribute to protect the working environment from exposure to risks that will affect the time and cost. The changing nature of the sites makes it difficult in identifying the fall risks accurately. Based on BIM 4D simulation, the objective of this study is to create a computer model by using BIM technology to help accurately determine (a) the hazards of falling from the edges (b) the hazards from struck by falling objects, by relying on the opinions of safety experts in identifying potential risks and demonstrating the effectiveness of this technique in facilitating hazards acknowledgment. In this research, Iraqi safety rules and safety rules of OSHA were adopted. The research idea was applied to a school building project under construction as a case study to benefit from the research outputs in improving the safety of school's buildings projects. The results displayed that the model prepared by the researchers helped the safety managers in understanding the details and sequence of work easily, thus contributed to the precise identification of the falling hazards, use suitable safety equipment for each risk, in addition to the possibility of using this model as a training program for workers in the workplace to help give an idea of the nature of risk which they may be exposed it, increase safety communication and generate time schedule empty from risks. Safety managers believe that this model can contribute to improve workplaces safety and prevent time and cost losses due to reliance on inaccurate methods based on static 2D schemes and sense in risk identification.

Keywords: BIM; 4D Simulation; Safety; Falling; Construction Project.

1. Introduction

The most dangerous consequence in the construction industry is losing lives, economic resources and time when workers are injured due to bad safety planning on the job site. Some practitioners think that construction sites are under-planned when coming to safety planning [1].

The accidents have a significant impact on the construction companies as they lead to losses in costs and losses in time in addition to the loss of these companies to their reputation in this industry and inability to enter the tenders. [2]. With the development of construction projects and increased statistics on injuries, especially after being audited by the competent authorities, it became clear that these incidents have a great and negative impact on the cost and time of projects [3]. A part of accidents which happened in construction site are reported. Some of these accidents not reported due to many reasons like communication difficulties, geological location, cultural barriers, governmental interference etc. [4].

Previous accident assessments indicate that there are five main sources of accidents in construction worksites. The first cause is falling from the edges and heights which is the most dangerous types of accidents, injuries due to hitting

* Corresponding author: alhussaniee@gmail.com

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by fallen objects, in addition to accidents of machines and electric shocks [5]. The OSHA confirms through statistics recorded in 2017 that out of the (4674) fatalities there are (971) fatalities in the construction sites, where the statistics explained that about (381) fatalities were from falling with percent more than (39%) [6]. The position becomes worse when the design of the building is more complex [7]. In fact, 60% of the injuries recorded in the construction industry in China were caused by falling from the heights, and it can be said that human factors contribute in most of these incidents [8]. It is difficult to avoid incidents effectively, despite the existence of many theories, due to the lack of understanding of the causes of accidents, so the best way to solve this problem is to remind people of the causes related to accidents and do the right thing [9]. The failure of governments to force contractors to implement safety measures, and the lack of awareness and culture among workers about the importance of safety at worksites consider the main reasons that lead to increase injury rates [10].

BIM technology is a comprehensive and integrated system for all project. It is a technology that includes procedures, policies, and applications that enhancing project performance [11]. BIM technology considers a good tool in creating a virtual environment similar to the actual environment of a job site that can help in identifying and solving safety problems in the early stages of the project [12]. The integration of safety requirements and construction planning through the use of BIM technique can have a positive impact on enhancing the safety of construction projects. The using of BIM will encourage other project stakeholders in sharing in both planning and risk assessment [13]. Azhar et al. (2012) and Azhar (2017) [14, 15] believes that (3D BIM and 4D BIM) models can help the project team in identify and evaluate incidents early and allowing the project manager to provide all possible strategies to ensure site safety. It can be said that modern technological systems and techniques such as BIM technology can provide good solutions in support of improved safety and security [16].

The research is trying to find solutions to the risks of fall because of these risks have a bad impact on the safety of workers. It is necessary to solve all safety problems in the early stages of the project and find solutions that mitigate these risks. By using BIM technology, the researcher tries to link the safety procedures with schedule time of the project and linking it to the BIM 3D model to produce BIM 4D model. The mean of adding different information to BIM process is to contribute in creating a dynamic model that is very similar to reality, making it easier for safety officials to identify risks and identify conflicts that would pose a threat to the lives of employees. Therefore, researchers are seeking to generate a practical platform that is applicable and depends on available software instead of relying on traditional methods based on 2D drawings that have proven is inadequate in accurately defining hazards according to safety managers' opinions.

2. Literature Reviews

In this section, the researchers will explain a set of previous studies on the use of modern technologies in studying safety issues in different countries.

Table 1. Explains literature reviews in different countries

Researcher	Country	Year	Study
Matej [17]	Croatia	2018	In this thesis, the researchers aim to benefit from the possibilities of BIM technology in the development of an automated system that contributes to the improvement of occupational safety by linking the BIM model with the developed hazards databases of the construction, where the researcher explains that any project is composed of a group of real elements and each element associated with numbers of hazards that pose danger to the lives of workers. This integrated system has thus contributed to the identification of risks for different building elements.
Tomi Zlatar [18]	Brazil	2019	In this study, researchers summed up the fact that falling from the edges poses a great risk to workers. In this research, risk management measures were analyzed for more than 114 cases recorded by "Health and Safety magazine". The safety regulations issued by the NEBOSH were adopted. Results showed falling happened due to several causes, where 81.6% from a procedure of work, 65.8 % due to lack of guardrail and edge protection, 60.5% hazards assessment and 60.5% from scaffolds.
Ziyu Jin [19]	USA	2019	The researchers believe that the issue of improving safety should begin by preparing a safe design for the project and encouraging engineers to take care of safety in the design and planning stages. The methodology of this research is a set of steps that identify the hazards related to each element in the model, 4D model integration with hazards values. The appropriate alternatives are chosen if any element has high risks to reduce the risk of work. The main reason for adopting this idea is a weakness of safety culture at the side of designers.
Mark [20]	United Kingdom	2019	The purpose of this research was to demonstrate the extent to which the 4D model was adopted in the field of occupational safety and what are the benefits and challenges of its use. In this research, a survey was conducted by experts from the construction industry. The results explained that (70%) of managers and (74%) of experts recognize of the importance of the 4D, but only (31.2%) of the respondents use this technology in their work. The study also pointed out that one of the most important obstacles to use this technique is the cost of training and the time required for implementation.

3. Research Methodology

The research methodology aims to create a computer model to help safety managers in accurately determine the fall hazards throughout adopting the BIM technique by using 3D visualization and 4D simulation concepts. The research idea will be applied to a project (under construction) to identify the associated fall hazards and provide solutions which can help in mitigate these hazards and provide them to the executing company to benefit from the research outputs. To achieve the goal of methodology, these steps will be followed:

1. Collect all information related to the project (schedule time, 2D drawings).
2. Adopting the occupational safety standards (OSHA specification and Iraqi safety blog).
3. Modeling all necessary safety equipment according to safety rules and opinions of safety managers (by using Revit software 2017, where the software library lacks safety equipment).
4. Create a 3D BIM model for all project details and components (by using Revit 2017).
5. Export the 3D BIM model as SPX file.
6. Inserting the time schedule of the project to the Synchro software 2017.
7. Import SPX file (3D BIM model) to Synchro software.
8. Link the architectural and structural elements of the 3D BIM model with the tasks of the project schedule to generate 4D BIM model.
9. Inserting 3D graphics to 4D model like workers, materials and linking to time schedule to give more reality in this model.
10. In this research, a group of safety experts will be selected to determine the fall hazards and make their observations on the computer model prepared.
11. The research will study two plans related to fall hazards:
    - Fall prevention plan for edges.
    - Fall prevention plan from struck by falling objects.
12. Identify proper safety equipment for each fall hazards in project.
13. The use of special features (bird eye and walk) provided by the Synchro software to walk within the project easily and identify the fall risks accurately.

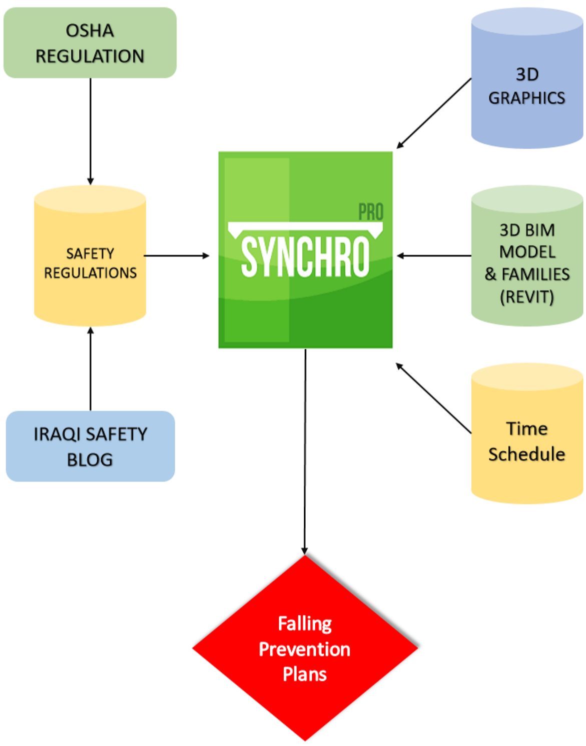


Figure 1. Illustrate framework of methodology

4. Experimental Works

4.1. Case Study (Scholar Building)

This kind of projects considers common in Iraq. Which consists of (7) buildings. The whole area of this project is (8848 m2). It was assigned to a local company. The project still under construction with duration (300 days). The more details summarized below:

- Project Name: Secondary School Building (16 Class)
- Project buildings (Classroom building, Laboratory building, Administration building, Guard building, Student toilet buildings, Assembly Hall)
- Height of buildings from (3- 7.36) m.
- Deep of excavations are 2 m.

Figure 2 shows 3D BIM model of the proposed case study:

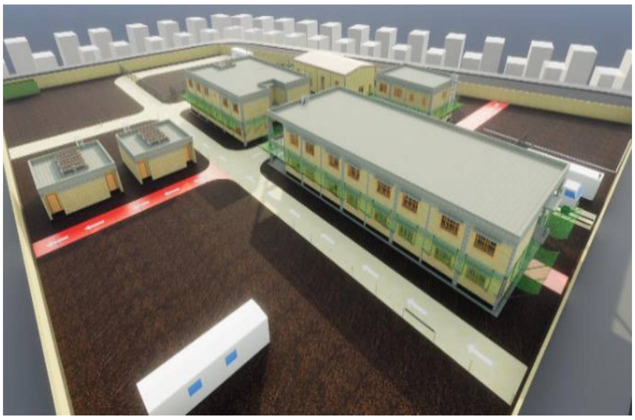
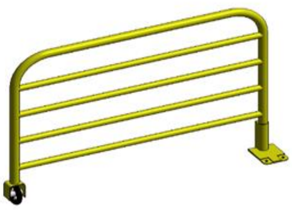


Figure 2. Illustrate 3D model

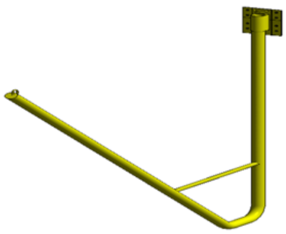
4.2. Create Safety Equipment (Families)

Actually, in Revit library, there are not families created as safety equipment. A family considers a group of elements having a set of properties, called parameters. Family Editors use to create new elements or modify existing ones to meet the necessary needs of a project [21]. The researcher will create new families have dimensions and information according to OSHA standards, Iraqi safety blog and opinions of safety managers to use it in case study like a guardrail, safety nets or safety signs etc. Creating families are depending upon understanding its changeable dimensions, its geometrical details. So, it is important to use the original template's contents [22]. Figure 3 explains some of safety equipment created by researchers according to safety regulations:

(3a) plastic ribbon

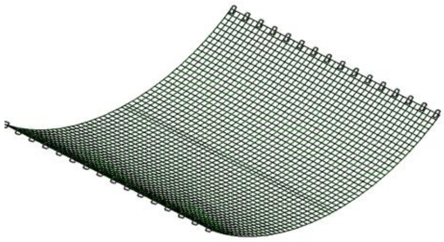


(3b) moving guardrail

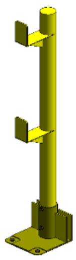


(3c) steel frame of net

(3d) cover plate



(3e) safety net



(3f) guardrail

Figure 3. Illustrate safety equipment by Revit

5. Results and Discussions

After preparing the BIM 4D model for the proposed case study, the model was run (the Synchro software, as shown in Figure 4. contains the run tools of the 4D model, allowing to present the work as well as the ability to record video clips of the model) for safety managers to see the dynamic model and using the walking techniques and the bird's eye technique in the Synchro software, and identify the hazards related at any time and put mitigation plans for these hazards. Then, over time, safety managers check these plans and safety equipment which they have proposed so that they do not pose any conflict or clash with other work tasks. Safety managers will focus on the risks associated with falling from buildings and prepare prevention plans to reduce these risks.

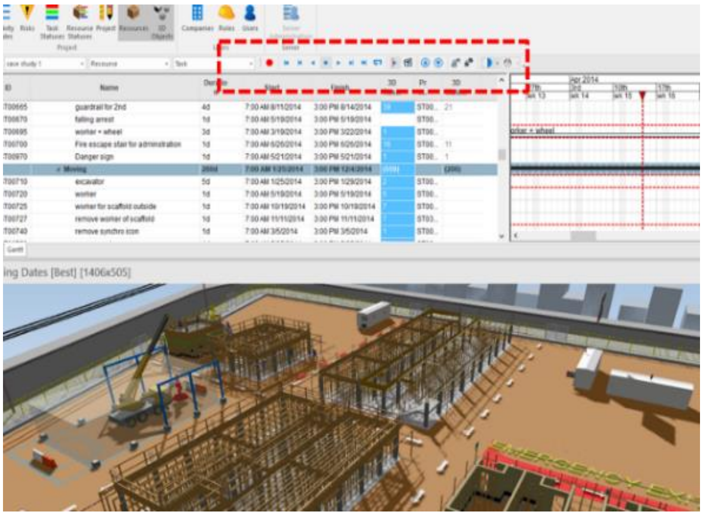


Figure 4. Run of BIM 4D model in Synchro software

5.1. Fall Prevention Plan from Edges

According to OSHA regulations [23], safety managers explain that the contractor should use guardrail system with the following properties:

- Vertical height (42 inches)
- Top rails able to resist (200) pounds of pressure
- Mid rails able of (withstanding 150 pounds) of pressure
- Rail and post diameters of 1-1.5 inches or more.
- Using toe board that shall be a minimum 3.5 inches.

The safety managers proposed a guardrail system consist of metal poles and timbers used together. Figure 5 explains that:

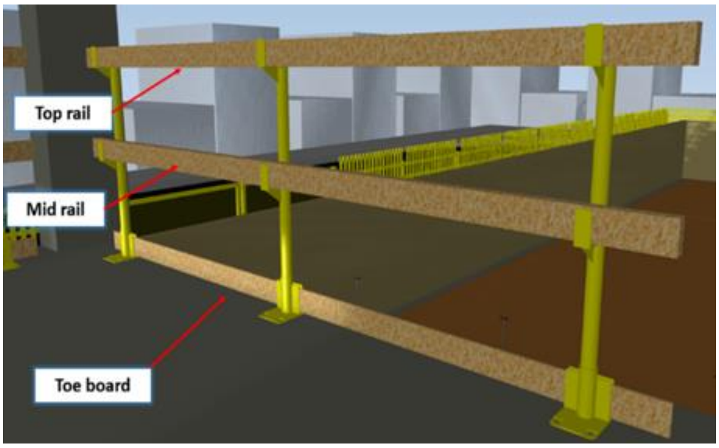


Figure 5. Illustrate proposed guardrail system

According to 4D model, the safety managers found the followings:

By following up on the 4D model, safety managers noted that during the installation of the wooden frameworks of the buildings' roofs, it is necessary to protect the edges of roofs by installing wooden guardrails during framework installation to provide protection for the reinforcement workers. Figure 6 explains timber guardrail and Figure 7 explains lack of guardrail in real site.

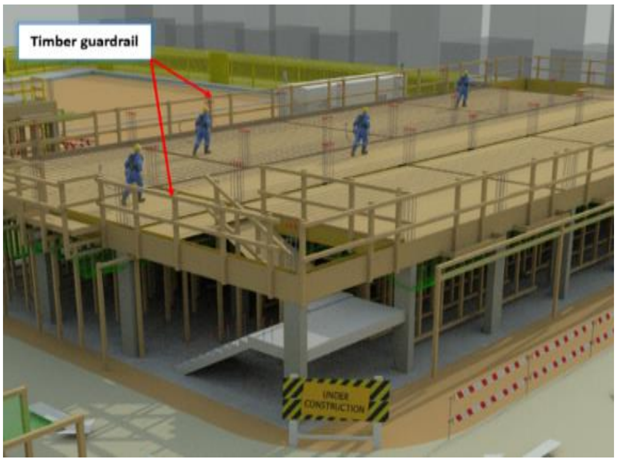
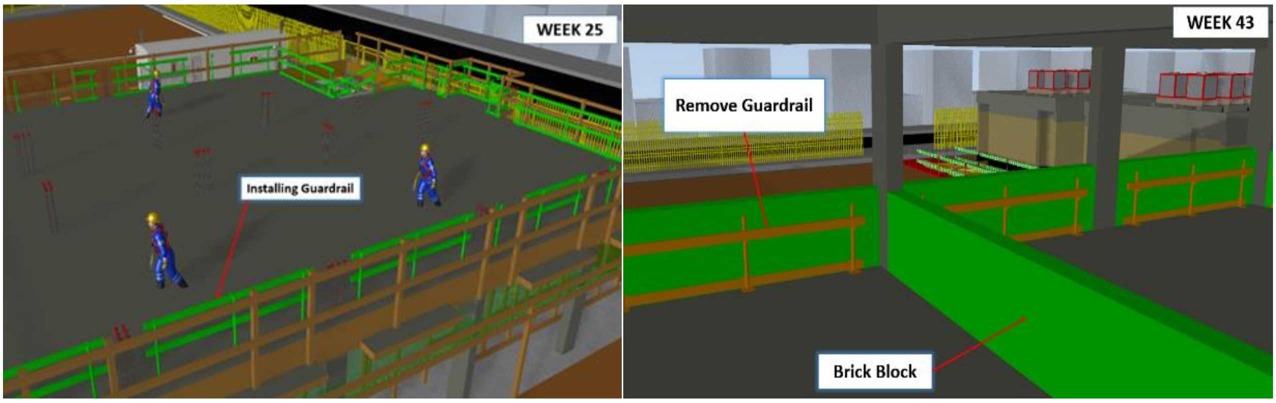


Figure 6. Using timber guardrail with framework

Figure 7. Lack of using any guardrail in site

Safety managers noted that the 4D model is more visible and realistic than relying on 2D drawings. Safety equipment can be linked to the project schedule and thus easier to appear and remove automatically. In Figure (8a) we notice the installation of the guardrail (in green), while in Figure (8b) explains that the time of removal of guardrails should be after the height of building blocks reach to 1 m at least to ensure the safety of workers. Where in Synchro software the green colour refers to (installing) while orange colour refers to (remove). (It is important to explain that timber guardrail in No.1 will be removed when wooden frameworks are removed, so it is necessary to use proposed guardrail system in Figure 5 to make the edge safely all the time of the project)



(8a) **(8b)**

Figure 8. Automatically install and remove guardrail system according to record time

Safety managers noted that the contractor would need to lift the materials like (reinforcement, timbers, bricks and any necessary materials) to the upper floors by using the lifting machine, but the presence of the safety guardrail would impede the lifting of these materials. Safety managers suggested removing part of the guardrail and replacing it with a moving metal guardrail.

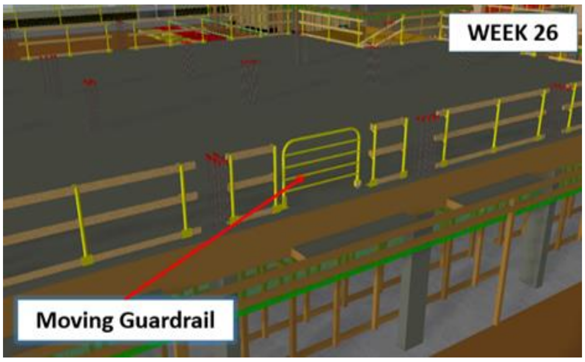


Figure 9. Moving guardrail

But, as a result of using moving guardrail, that will create a new hazard not identified previously, where during open guardrail and install lifting machine the worker who responsible this machine will be under a falling hazard, so in this case, the safety managers proposed that the worker should use fall arresting tool to protect him from falling. The safety managers assigned that the lifting zone should be surrounding with caution ribbon and put danger sign in site (Figure 10).

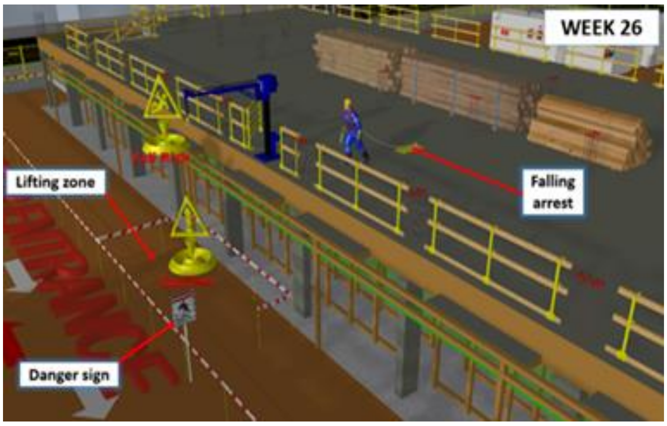


Figure 10. Lifting zone and danger sign

During the run of the 4D model in Synchro software, the safety managers noted that the timbers used in the guardrails could interfere with the wooden frameworks of the concrete columns, so it is necessary to select suitable lengths of timbers to prevent these conflicts and prevent delay in work. These accuracy details cannot explain in the traditional approach (Figure 11).

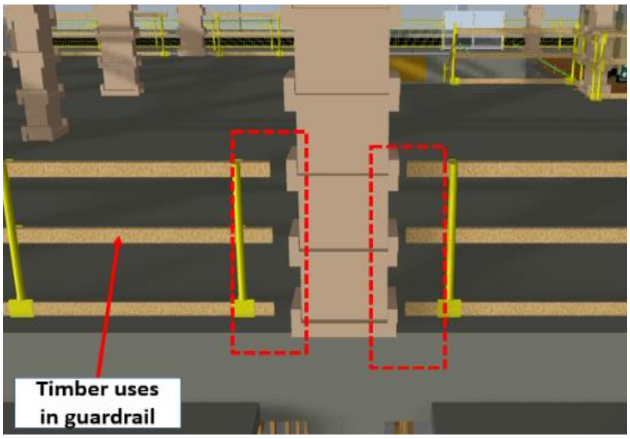


Figure 11. Proper distance between columns framework and guardrails

At the beginning of modelling, safety managers suggested that guardrails should be installed at the edge of the building's slabs, but the 4D model shows that after (110) days (from the beginning of the project) the location of guardrail system will clash with bricks walls. So they proposed to move the guardrail system with distance (27 cm) from the edge of the slab. In fact, they believe this early conflict detection will save time and prevent the additional cost, compared to the traditional process which depends upon 2D static schemes which not appear these details. Figure 12 explains moving guardrails 27 cm from edges:

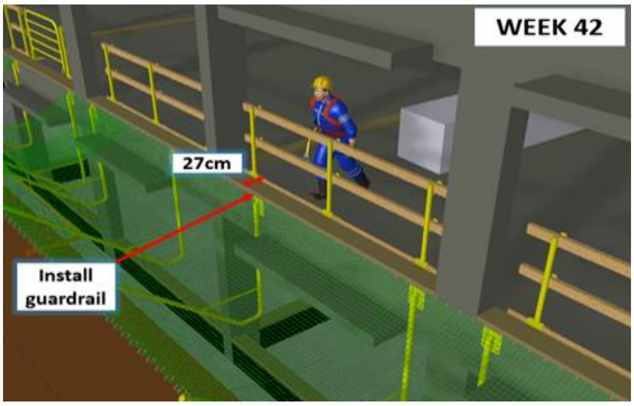


Figure 12. Proper place of guardrail system

The safety managers explain it is necessary to protect the workers from falling when they work in the scaffolds during finishing works, they noted during the run of the 4D model that it is necessary to provide workers with safety ropes as well as the use of scaffolding with a handrail. These scaffolds should support in its bases by using timber panels to prevent collapse it. It is difficult to explain these necessary details in 2D schemes. Figure 13 explains these necessary details, and Figure 14 explains lack of using safety scaffolds in real site:

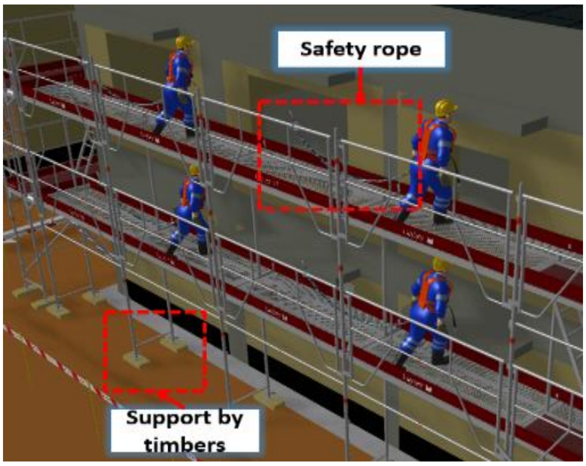


Figure 13. Using safety scaffold for workers

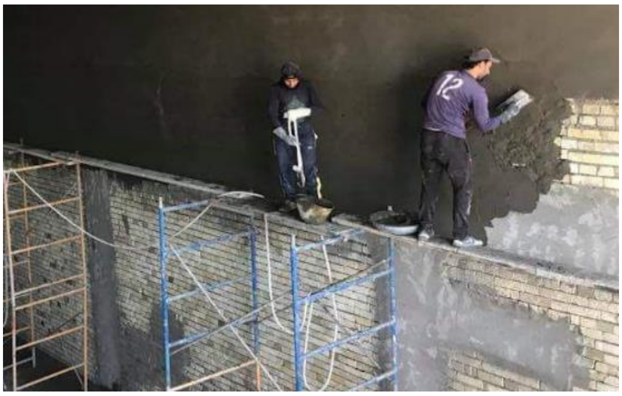


Figure 14. Lack of using guardrail with scaffolds

Also they found with help of 4D model, that during casting the concrete columns they need to protect workers from falling. The safety managers proposed creating moving scaffold for this type of works, Figure 15 explains this scaffold and Figure 16 explains actual process in projects:

Figure 15. Illustrate safety moving scaffold

Figure 16. Using unsafe stair in site

Through 4D BIM model and using the feature of (bird eye in synchro software), the safety managers noticed a square opening in the slab of classrooms building with dimensions (1×1) m. This opening poses a danger to the lives of the workers responsible for the roof's finishing , so safety managers found the need to use a cover plate with dimensions (1.25×1.25×0.008 m) for this hole to protect workers from falling and put a warning to this zone (Figure 17)

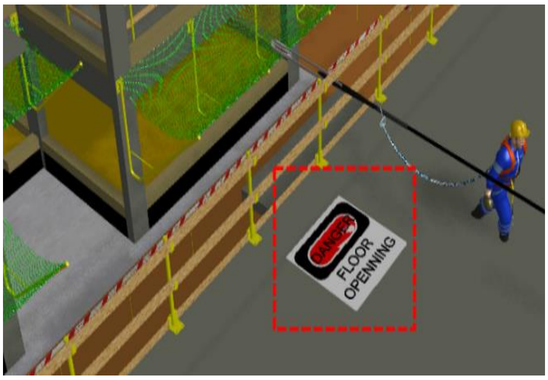


Figure 17. Illustrate cover plate for openning

5.2. Fall Prevention Plan from Struck by Objects

Safety managers believe that one of the most important hazards in the site is the exposure of workers to strike by falling objects from the top floors while working on the lower floors. Or the exposure of some workers to fall, especially during the installation of wooden panels of the wooden frameworks of slabs. The Safety managers have suggested using safety nets in the frameworks of the slabs to protect the roofers from falling when they install timber panels and protect the workers in ground level from struck by falling objects. According to OSHA [23] the nets should be bear (180 kg) and minimum breaking strength of rope is (22.2 kN) and according to Iraqi safety blog [24] the net should be with vertical deflection equal to this equation ((0.2-0.25)×L) where L is the shortest dimension of safety net.

In the 4D model, the safety managers show ability in identifying exact places of safety nets and how installing:

The safety managers explained that the wooden poles that support the wooden framework of slabs must be fixed at the beginning as shown in Figure 18. The horizontal wood is then installed, followed by the installation of the wooden frameworks for the concrete beams as shown in Figure 19. In this order, the safety managers ensure that the workers are not exposed to any danger.

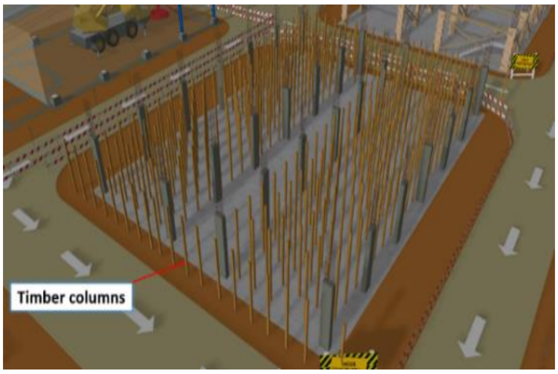


Figure 18. Installing wooden columns of framework

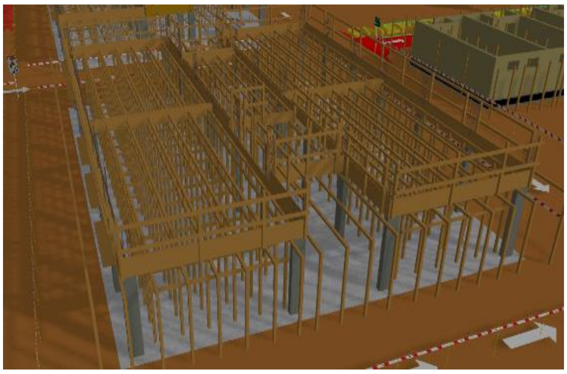


Figure 19. Installing wooden frameworks of beams

In the second phase, safety nets should then be installed because subsequent works can pose a threat to the lives of workers (Figure 20).

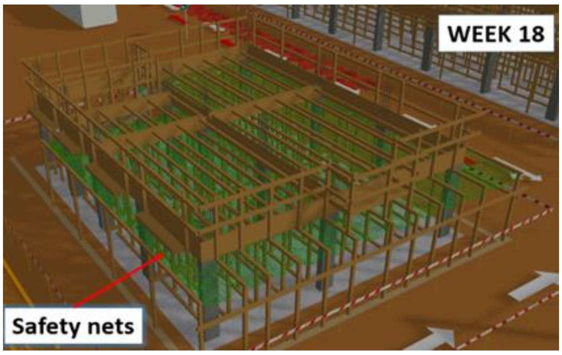


Figure 20. Installing safety net with timber framework of slab

The last phase is installing timber panels. The 4D model explain to them that the safety net should be stretched more than the slab framework at least (1 m) in each side to prevent struck by falling objects in walkways, Figure 21 explains that. These nets will be removed when the frameworks of slabs remove.

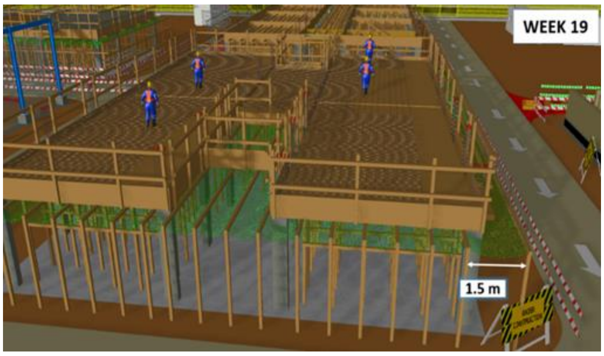


Figure 21. Stretch of safety nets and install timber panels

In the 4D model, the safety managers found during removing timber frameworks for columns of the second floor, the workers who working and moving in walkways around buildings may be exposed to struck-by falling some of these timbers, so they will need to protect them by using nets tied on each side of buildings, Figure 22 explains using safety net to provide protect for walkways. Also, they found after (84 days from installing these nets), the nets will protect workers in the ground floor from struck by falling bricks during the brick works stage. This type of hazard cannot discover in 2D drawings. Figure 23 explains protect workers during bricks works. The safety managers proposed to create steel frames to bear side nets. These nets will be according (Iraqi safety blog) with dimension 2.5×2.3 m.

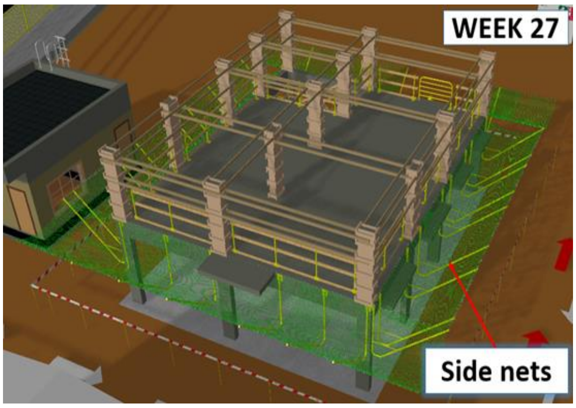


Figure 22. Side net around buildings

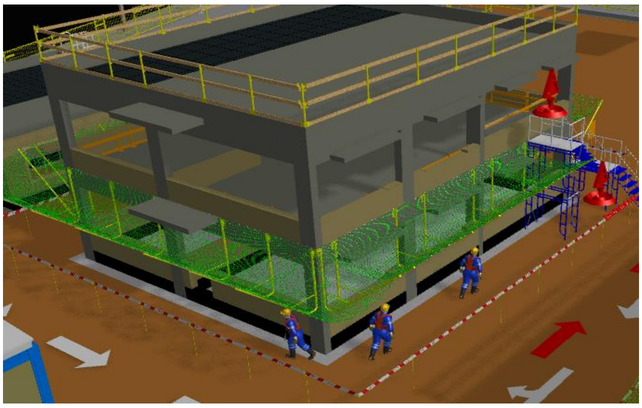


Figure 23. Protect workers from struck by falling bricks

6. Benefit from Using 4D BIM Technology in Fall Prevention Plans

According to the results obtained from the BIM 4D model, the benefits are:

1. A good platform to generate a time schedule free from hazards.
2. Choose the necessary safety equipment.
3. Increase safety communication.
4. A good tool uses as training program for workers.

The 4D model can help make complex construction projects more visible and easy to safety managers and thus the identification of hazards will be easier than relying on 2D drawings.

7. Conclusions

Falling risks are the most dangerous type of occurrence in the world. Safety managers attributed this to the poor procedures for implementing safety regulations, as well as to the difficulty of predicting these risks as a result of reliance on traditional methods based on two-dimensional schemes and the expertise. The objective of the research is to create a computer model using BIM technology to help in early predict of fall hazards by creating a BIM 4D model that is like to the environment of the workplace. The safety managers found the followings:

- This model helps to give a clear picture of the work site in all its details, which facilitates the process of identifying risks.
- This model will greatly facilitate the process of identifying risks and identifying the protection systems necessary for each risk.
- The possibility of using this model as a training program for workers to clarify the risks that will face them in the workplace. Also, increase safety communications and create safe time schedule for the project.
- This model is able to prevent any conflicts that could result from the use of safety equipment and thus prevent any waste of time or cost, while traditional methods based on two-dimensional drawings lack these features.

8. Acknowledgements

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9. Conflicts of Interest

The authors declare no conflict of interest.

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