Identifying Dynamic Hazardous Zones & Visualizing Safety Plans by Integrating Construction Schedule and BIM Model

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IDENTIFYING DYNAMIC HAZARDOUS ZONES & VISUALIZING SAFETY PLANS BY INTEGRATING CONSTRUCTION SCHEDULE AND BIM MODEL

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ABSTRACT

The objective of the study is to identify the dynamic hazardous zones, develop the safety plan, and quantify the safety budget in building construction using 4D simulation for different tasks. The simulation will illustrate the safety equipment and tools required during the project construction phase. The simulation can also identify the hazards that may happen and inform safety strategies before the execution of the task with the help of a 4D BIM model. To illustrate the study's proposed methodology, excavation work is considered which is the initial work for most of the construction works. The Hazards related to excavation activity are listed out with the help of a literature study, the 3D model is developed with the help of BIM software, and the construction schedule is prepared with the help of Synchro Bentley 4D simulation software. The demarcation of safety protocols will be depicted through a 4D simulation. The same process can be developed for other activities and hazards like brickwork, laying of services, fall of materials, etc. The study would contribute efficient planning and budget allocation for safety and also help to visualize the safety plan in construction.

KEYWORDS

Construction phases hazard, Safety Budget, BIM, 4D simulation

INTRODUCTION

The construction industry is known for its inherent safety risks, with numerous accidents occurring on construction sites each year. Effective safety planning and management are crucial to mitigate these risks and ensure the well-being of workers(HONG AND TEIZER 2024). 4D simulation, which integrates 3D building information modeling with the construction schedule, has emerged as a powerful tool to enhance safety planning in the construction industry(Raza et al. 2023). This study proposes the use of 4D simulation to quantify safety planning and budgeting in the construction of buildings. Previous studies have highlighted the benefits of using information visualization techniques, such as Building Information Modeling and

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Virtual Reality/Augmented Reality, to advance current safety management practices.(BENJAORAN AND BHOKHA 2010A)

Integrating safety planning into 4D simulation can provide a comprehensive understanding of potential hazards and the required safety measures throughout the construction process. This study aims to develop a framework for using 4D simulation to plan and quantify safety resources, thereby improving worker safety and project efficiency(BENJAORAN AND BHOKHA 2010B). In the construction industry, calculating a safety budget involves navigating several uncertainties, making it a complex but critical task. One of the primary challenges is the unpredictable nature of safety risks, which vary based on project type, size, location, and specific activities involved. From hazardous materials and working at heights to heavy equipment usage, each project introduces unique risks that can be difficult to quantify with precision. As a result, safety budgets often need to account for potential variability in both the likelihood and severity of incidents, adding an element of uncertainty to the planning process.

Given these uncertainties, many companies opt to calculate safety budgets as a percentage of the overall project cost, typically ranging from 2% to 5%. This percentage-based approach provides flexibility, scaling the safety investment in proportion to the project's scope and risk level. It ensures that larger, more complex projects, which tend to carry greater safety risks, receive appropriate funding for necessary precautions, training, and safety equipment.

Alternatively, some organizations may prefer to allocate a lump sum for safety expenses. This method is often used when specific safety requirements are identified early in the planning process, such as compliance with regulatory standards or the need for specialized safety personnel. While the lump-sum approach can simplify budgeting, it carries the risk of underestimating unforeseen costs, especially if unexpected hazards or delays arise during the project.

Ultimately, both percentage-based and lump-sum safety budgets aim to address the inherent uncertainty in construction projects. By carefully considering factors such as risk assessment, regulatory compliance, safety training, and equipment needs, construction companies can better ensure the safety of workers while maintaining project efficiency and compliance with legal standards. However, the dynamic and unpredictable nature of construction environments underscores the importance of maintaining a contingency within the budget to handle any unforeseen safety issues that may emerge during the project.

METHODOLOGY: 4D SIMULATION FOR SAFETY PLANNING

The proposed methodology involves the use of 4D simulation to plan and quantify safety resources during the construction phase. The 4D simulation will be developed by integrating a 3D Building Information Model with the construction schedule, allowing for the visualization of the construction process over time.

My approach leverages 4D simulation, integrating time as the fourth dimension with 3D models, to enhance safety planning and budget calculation in construction projects.

This method offers a comprehensive visualization of the construction process that facilitates better safety measures and efficient budget allocation.

The 4D simulation process involves several steps:

1. Modeling in BIM Software: The first step involves modeling the project using Revit. This includes elements such as walls, lift pits, and slab outlines. Revit enables us to create detailed and accurate 3D models that serve as the foundation for our safety planning.

2. Creating Safety Zones: Using Revit, we create 3D safety zones around critical elements. These zones, indicated in transparent red represent danger areas where workers must exercise caution. Each safety zone contains text or comments highlighting specific safety concerns and precautions. Examples include:

- Excavation: Indicating the danger of cave-ins, requiring proper shoring and protective systems. Barricading for the excavated area and maintaining a safe distance from the excavated area to prevent cave-in Lift Pit: Comments on warnings about the risk of falling, necessitating barricades around the pit. Refer Figure 4
- Scaffolding: Highlighting the risk of falls from heights, with precheck and mandatory use of safety harnesses and guardrails.
- Wall Construction: Safety comments about potential tripping hazards from materials and equipment on the ground. Refer Figure 2
- Heavy Machinery Operation: Emphasizing the risk of being struck by moving equipment, with guidelines for maintaining a safe distance. As shown in Figure 1
- Electrical Stations: Electrocution hazards, with safety precautions detailed in the comments section.
- Material Handling: Indicating the risk of back injuries from lifting heavy objects, with guidelines for proper lifting techniques and equipment.
- Falling Material: Alerting about the risk of falling materials from above floors, necessitating the use of hard hats and proper overhead protection, along with guidelines for securing materials at higher levels.

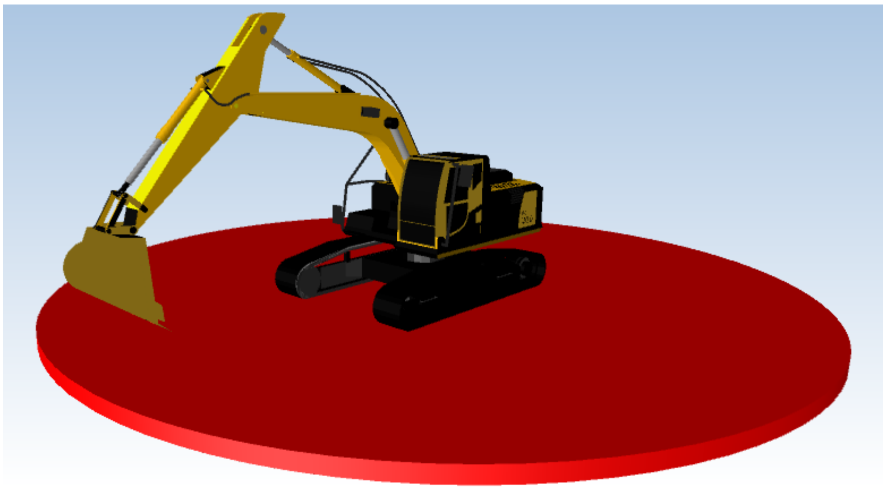
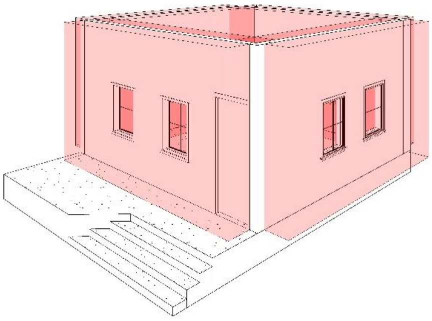
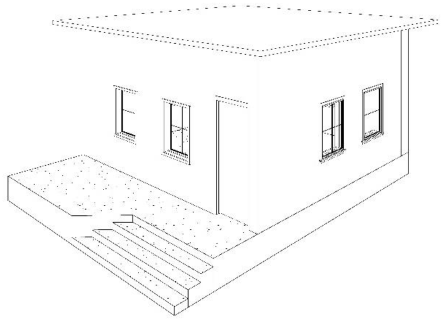


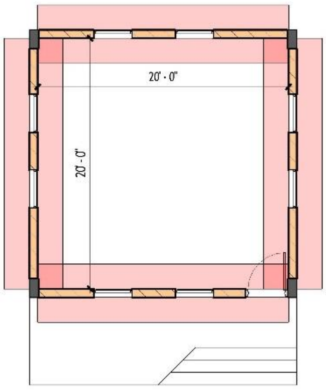
Figure 1 – Excavator with hazard zone demarkated

The Red Zone depicts the danger area around excavator movement.

The movement of excavator can be depicted in 4d simulation to avoid collision and see clashes



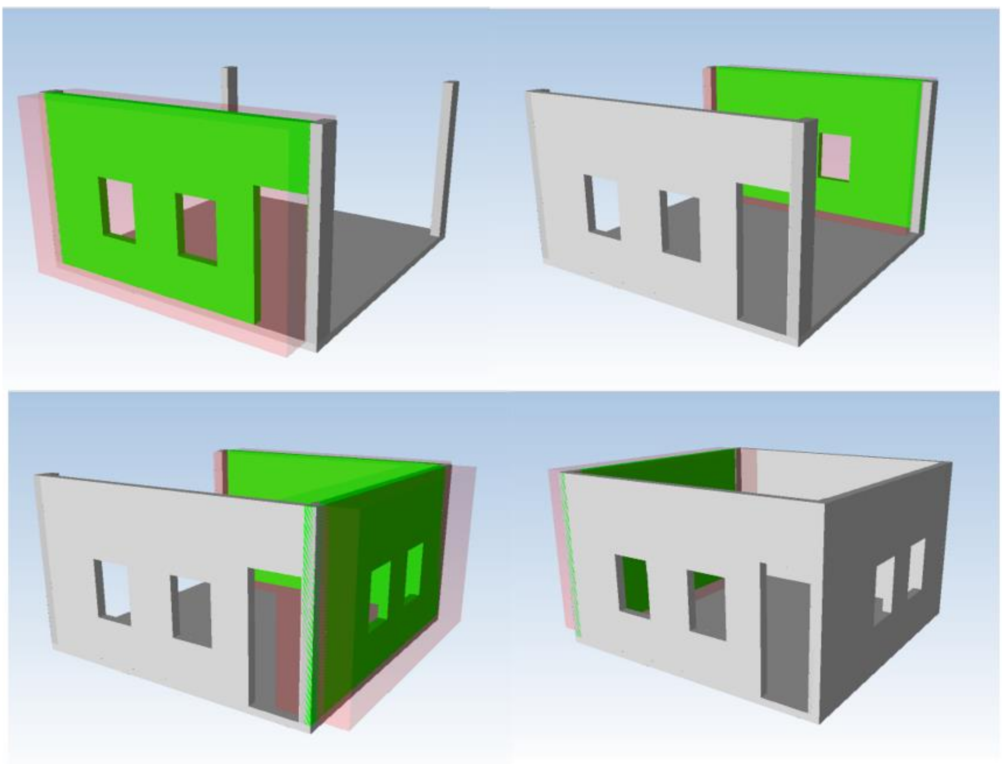




This is just a sample plan which shows brick work. During the modelling a temporary mass can be modelled around the walls which shows the danger area around the brickwork.

Each Red region modelled contains the information related to safety hazard of that particular activity and the safety measures

3. Integration of Time Dimension: We take the 3D model to Bentley Synchro and link each element to the project schedule. This process transforms the static 3D model into a dynamic 4D simulation, allowing us to visualize the construction sequence and identify potential safety hazards at each stage.



4. Hazard Identification and Risk Assessment: The 4D simulation enables us to pinpoint critical safety risks associated with each construction activity. We conduct thorough risk assessments to understand the likelihood and impact of these hazards, ensuring that all potential risks are identified and addressed.

5. Safety Planning: Based on the identified risks, we develop targeted safety plans incorporating preventive measures and safety protocols. The 4D simulation provides a platform to test these plans and make necessary adjustments in a virtual environment, ensuring the effectiveness of our safety measures.

6. Budget Calculation: By linking safety zones to the schedule, we can anticipate the timing and quantity of safety equipment required for each construction stage. This enables us to calculate the safety budget by avoiding the repetition of safety equipment and ensuring efficient allocation of resources.

7. Implementation and Monitoring: We implement the safety plans and continuously monitor their effectiveness throughout the construction process. The 4D simulation is updated with real-time data, ensuring ongoing risk assessment and timely intervention. This dynamic approach allows us to adjust our safety measures as needed, based on real-time conditions and feedback.

8. Training Module: We develop training modules for workers and engineers, focusing on the specific hazards they may encounter at different stages of construction. These modules provide detailed methodologies and safety precautions, ensuring that everyone on-site is well-prepared and informed. The training includes practical demonstrations, simulations, and safety drills to reinforce the importance of adhering to safety protocols.

This methodology not only enhances safety outcomes but also contributes to budget calculation by proactively addressing safety concerns and preventing costly delays and incidents. The integration of 4D simulation in construction safety planning represents a significant advancement in our ability to manage and mitigate risks effectively.

RESULTS

CASE SCENARIO 1 :
IMPROVING CONSTRUCTION SITE VISIBILITY WITH 4D VISUALIZATION
STREAMLINING SAFETY TRAINING USING 4D SIMULATION

The experiment is performed on a sample training project provided in Bentley Synchro's training module. A 4D simulation is performed to show excavator movement with Red Zone.

Around the Excavation area for the safety of Cave-In hazards and falling inside the pit the Safety barricades can be placed and the quantity and time of procurement can be taken care of by 4D simulation that will be given to the site team

1. Enhancing Construction Site Safety through 4D Modeling
   Excavation area in the center of the field
   Leveraging 4D Simulation for Proactive Safety Planning

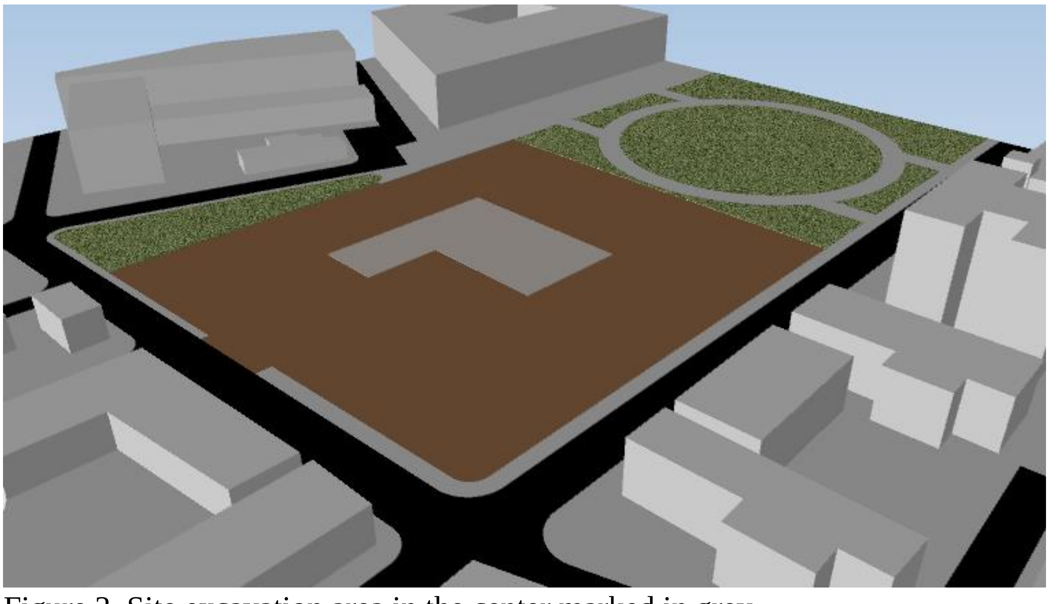


Figure 3. Site excavation area in the center marked in grey

2. Excavator with Red zone, Barricades around the excavation area
   Integrating Safety into the Construction Workflow
   Predicting Potential Safety Risks with 4D Simulation

3. Whenever in the 4d simulation the red zone appears the comment section/illustration will pop up with the list of hazards that can happen

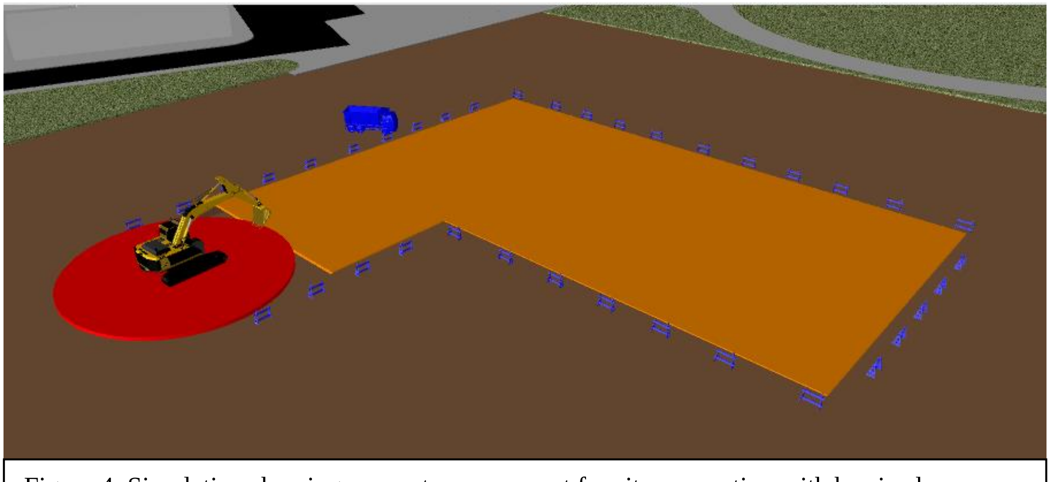


Figure 4. Simulation showing excavator movement for site excavation with barricades alongside excavation area and tipper lorry for muck collection

Table 1.1 List of Hazards that can happen during excavation which will be mentioned in the comment section of the Red zone(Feng et al. 2024)

1. Absence of soil protection
2. Objects or load near edges
3. Absence of safe access and egress
4. Workers or mobile plants close to dangerous utilities and objects
5. Absence of safety barriers and signage
6. Workers working in an unsafe excavation site

CALCULATING SAFETY EQUIPMENT AND INVENTORY

Quantifying safety equipment is crucial for the well-being of construction workers and the overall success of projects. Traditionally, safety budgets are allocated as a percentage of the total project cost. However, this approach can lead to inefficiencies and misuse of resources. Over time, companies may purchase unnecessary equipment or fail to account for changing project demands, resulting in budget overruns.

When projects exceed their budget, there is a risk that safety measures may be compromised. Companies might cut corners to save costs, leading to inadequate safety provisions. This not only endangers workers' lives but also increases the likelihood of accidents and associated costs in the long run.

By implementing strategies to quantify safety equipment and inventory, such as prioritizing critical resources, minimizing redundancy, and using real-time data for inventory management, companies can ensure that safety measures are both effective and cost-efficient. This approach not only protects workers but also helps to prevent budget overruns and improve project outcomes. Ultimately, a well qunatified safety plan is an investment in both the safety of the workforce and the financial health of the project.

1. Prioritize Equipment Allocation: Identify the most critical safety equipment based on the risk levels of various construction stages. Allocate resources to high-risk activities first, ensuring that the most hazardous tasks have adequate safety measures in place.
2. Minimize Redundancy: Utilize your 4D simulation to track the use of safety equipment throughout the project timeline. This helps to identify and reduce redundancy by reusing equipment across different stages, thereby preventing over-purchasing.
3. Dynamic Safety Zones: Adjust the size and coverage of safety zones dynamically as the project progresses. This way, you can ensure that safety equipment is used only where necessary, thus quantifying the number of items needed.
4. Bulk Purchasing: Forecast the total quantity of safety equipment required for the entire project based on the 4D simulation. Purchase these items in bulk to take advantage of discounts and reduce overall costs.
5. Maintenance Schedule: Implement a maintenance schedule for reusable safety equipment to extend their lifespan. Regular inspections and timely repairs can prevent the need for replacements, thereby saving on costs.

6. Training and Awareness: Develop comprehensive training programs for workers and engineers. Educated personnel are more likely to use safety equipment efficiently, reducing wear and tear and preventing misuse.
7. Recycling and Repurposing: Where feasible, recycle or repurpose safety equipment after use. This not only reduces waste but also lowers the cost of procuring new items.

Implementing these strategies ensures that safety measures are both effective and cost-efficient, protecting workers and improving project outcomes. By quantifying safety equipment and inventory, companies can prevent budget overruns and avoid compromising safety, ultimately safeguarding the workforce and ensuring project success.

CONCLUSION

The application of a 4D simulation approach to construction safety planning represents a significant advancement in managing both safety protocols and budget efficiency. By combining Building Information Modeling (BIM) with time-phased construction schedules, this method improves the identification of potential hazards zones, quantifies the deployment of safety equipment and tools, and offers a flexible framework for ongoing safety management. This proactive strategy allows for early detection of risks, leading to more effective preventive measures and streamlined resource usage, ultimately enhancing site safety and project efficiency.

The use of 4D simulation in dynamic safety planning significantly enhances the management of construction projects by linking schedules and safety plans in a time-based visual context. By enabling real-time updates, 4D models allow project teams to foresee and address safety hazards as the project progresses, rather than relying solely on static plans. This adaptability ensures that safety strategies evolve with the construction phases, leading to a more responsive and safer worksite. The integration of safety protocols within 4D simulations also promotes a more efficient workflow and reduce incidents.

The ability to visualize construction progress in real time aids in accurately forecasting safety requirements. Furthermore, continuous monitoring and real-time updates allow for prompt adjustments to safety protocols, ensuring that risks are mitigated as the project evolves. The incorporation of detailed safety training modules based on the 4D simulation ensures workers are well-prepared to handle specific hazards.

In conclusion, this approach not only enhances worker safety by addressing risks before they materialize but also ensures project timelines and budgets are adhered to. By improving both safety outcomes and resource management, the 4D simulation method marks a critical improvement in the way construction projects are planned and executed, leading to safer, more efficient, and cost-effective outcomes.

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