Enhancing Safety throughout Construction using BIM/VDC

Carla Lopez del Puerto, Ph.D.
Colorado State University
Fort Collins, CO 80526-1584
carlalp@cahs.colostate.edu

Caroline M. Clevenger, Ph.D.
Colorado State University
Fort Collins, CO 80526-1584
caroline.clevenger@colostate.edu

Abstract

Construction jobsites are some of the most dangerous workplaces. According to the Bureau of Labor, in 2008 1005 fatalities resulted from construction accidents, and cost industry approximately $11.5 billion annually. Many construction accidents could be avoided through better engineering and administrative controls, and improved safety training. 3D visualization and analyses are situated to play a critical role in enhancing safety. This paper discusses specific examples where BIM-enabled safety controls can be used to detect and alert designers and contractors to potential project hazards. If hazards are identified through simulation during the design phase, elimination and substitution of hazards may be substantially less inexpensive and easier to implement. This paper discusses the use of BIM to enhance safety for construction workers, building users during renovations/ expansions and building end-users. Using specific real-world examples this paper demostrates ways that BIM can be used to foresee potential construction hazards and motivates and informs future tool and process development.

Keywords

Construction Safety, BIM, VDC, Planning, Administrative Controls, Engineering Controls,

1. INTRODUCTION

Next to mining and agriculture, construction jobsites are the most dangerous workplaces in the US. In 2008, 1005 fatalities resulted from construction accidents costing industry approximately $11.5 billion (Bureau of Labor Statistics, 2008). Many construction accidents are the result of improper use of personal protective equipment by construction workers. Such accidents highlight the fact that personal protective equipment is, generally, an imperfect and last resort to protect workers from work and health hazards, since its effectiveness depends on its adequate use by the employee. Reducing the need for personal protective equipment through better design solutions provides a higher level of protection to all workers by providing protection independent of worker action. As build projects increase in complexity, a greater need exists for successful “design-for-safety” strategies. Incorporating design-for-safety strategies in a project requires risk identification, analysis and assessments early in the design process. Traditionally such strategies are implemented through engineering and administrative controls. Engineering controls eliminate safety and health hazards through better design or process substitution. Administrative controls are changes in work procedures such as written safety policies and rules, with the goal of reducing the duration, frequency, and severity of exposure to hazardous situations. BIM provides a powerful new platform for developing and implementing “design-for-safety” tools and methods to facilitate both engineering and administrative controls during design and construction.

For example, early in the design process, tie-off points can be included in precast concrete design. Perimeter guardrail protection systems can be designed into structural steel members. As construction technical requirements increase, and the workforce becomes more diverse, effectively training construction workers to use personal protective equipment properly is a growing concern, particularly for immigrant workers who speak a language other than English. Therefore, as construction projects become more complex engineering and administrative controls are becoming more critical to project success and safety.

3D visualization and analyses are situated to play a critical role in enhancing construction site safety. On-going research and industry practice provide examples of successful use of BIM for clash-detection and circulation analysis. Building Information Modeling-enabled (BIM-enabled) virtual safety controls can be used to detect and alert designers and contractors to potential project hazards. Using Virtual Design and Construction (VDC) buildings can be simulated at various stages of the construction process to allow engineers, architects and contractors to identify potential safety and health hazards at an early stage of the project. For example, temporary scaffolding systems can be modeled to avoid clashes and facilitate different construction stages of the project. If the hazards are identified during the design phase, elimination and substitution of hazards may be inexpensive and simple to implement. Furthermore, involving the contractor early in the design process creates a collaborative process that brings together architects' and engineers' design expertise and construction personnel field expertise to develop highly effective administrative and engineering controls.

Mortenson Construction is a company committed to safety and holds it as one of its core values (Mortenson, 2010). In this paper we use project examples from Mortenson to exemplify the current application of and potential for BIM to enhance construction safety throughout the construction process for a variety of stakeholders. Examples include increasing worker safety by identify potential "pinch-points" earlier in the process; better accommodating user safety during renovation projects through enhanced 3D pre-planning; and insuring better building-user safety through better and more accessible building documentation. The company does not claim to change their basic approach and process with regard to safety with the use of BIM, rather they see BIM as an additional and powerful tool used to enhance existing processes. Construction Management faculty at Colorado State University (CSU) are working directly with Mortenson Construction and other industry leaders to understand and accommodate the imminent transformational shift necessary in construction management education to evolve and facilitate better and interactive learning and understanding through the use of 3D visualization and BIM. Next, we use specific real-world examples to illustrate these concepts and their implementation.

2. CONSTRUCTION WORKER SAFETY

Due to the nature of the construction industry workers are exposed to many hazards. To prevent or minimize hazards in the field, it is necessary to optimize engineering controls through considerable pre-planning efforts. In the case of either, traditional and BIM-enabled pre-planning, Mortenson holds team meetings where various stakeholders with different roles and expertise collaborate to analyze the design for potential hazards. Participants in these meetings include but are not limited to: modeler, architect, construction manager, safety supervisor, quality manager, subcontractors and owner's representative. At these meetings the team analyses drawings, schedules and/or models for potential hazards and "pinch points" that may present increased risk to worker safety. Several primary features of BIM significantly increase the effectiveness of this process: the ability to model and analyze in both 3D and 4D (3D + time), and the increased level of communication afforded. 3D visualization increases the ease and level of understanding, and assessment capabilities of individuals reviewing de-

sign documents. In particular, issues involving proximity and alignment are more readily identified and analyzed in 3D rather than 2D environments. Furthermore, the ability to virtually observe rather than imagine construction sequences also serves as a powerful tool to increase the understanding of the proposed construction process. As a result, 3D and 4D models fundamentally facilitate better communication among diverse team members since such viewing environments reduce the amount of verbal description required to produce common understanding. In sum, these features of BIM enable more effective safety planning at pre-planning meetings. We use the following project application of BIM to illustrate this point.

Figure 1 shows views from a 4D model for a brick veneer wall mock-up. On this project, members of the VDC team virtually constructed the wall mock-up and its construction process prior to actual construction of the physical mock-up, prior to actual construction of the final wall assembly. This level of pre-planning allowed for a high degree of understanding and scrutiny of the construction process prior to any physical construction, either mock or in-situ. As Figure 1 reveals, this particular wall assembly requires a high number of scaffolding "round-trips." Members of the pre-planning team carefully analyzed this model to ensure the highest level of safety, ergonomics and productivity would be maintained for all workers operating and working on the scaffolding both during the mock-up and final construction.

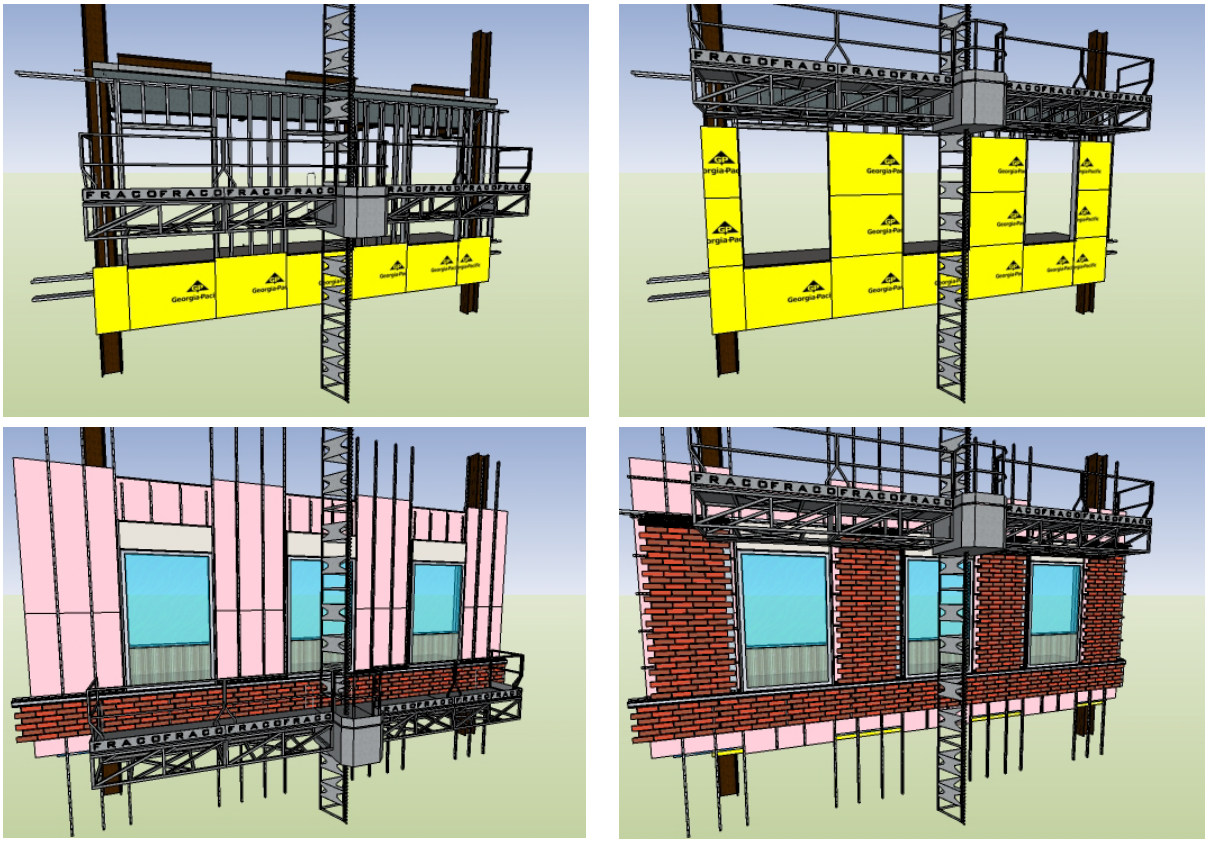

Figure 1: Screenshots illustrating a 4D model of a virtual wall assembly mock-up. This model was used during pre-planning meetings to enhance communication, and identification and analysis, of potential complications or safety risks due to the required "round-tripping" of the scaffolding.

3. CONSTRUCTION RENOVATIONS/ EXPANSIONS USER SAFETY

Expanding existing buildings introduces additional risks for contractors. In addition to protecting their own construction workers and sub-contractors they also have to protect building

tenants during the construction phase. In renovation and expansion projects, building owners also seek to minimize inconvenience to building users and maintain their productivity while maximizing safety. Particularly on urban, tight, busy or high-occupancy sites, construction site circulation can be difficult to optimize. In these cases, BIM can be an effective tool to maximize safety and convenience while minimizing costs.

In the example shown in Figure 2, the construction site entry was identified as a potential area of increased risk to both workers and community. The first solution proposed was to have pedestrians avoid the construction entry and area by walking on ground-level behind the staging areas, adjacent to the building under-construction, to finally reach the building in operation on ground level. However, the pedestrian route initially proposed was indirect and brought the community closer to rather than further away from the building under construction. By looking at the 3D BIM model, a better alternative was identified during pre-planning. Instead of having pedestrians circumvent the site entry horizontally, it was better to have them do so vertically. The solution was an enclosed pedestrian bridge that enabled pedestrians to walk over rather than around the busy site entry at minimized risk. BIM was next used to reconcile ADA and construction traffic clearance 3D requirements. Finally, the BIM model was then used to successfully communicate this plan to the owner and to assist the owner in selecting the placement of benches and emergency telephone in the elevated, covered-walkway. In the end, the BIM-enabled solution was not only safer, but more convenient for the existing building users. While it is likely that such a solution would have been realized at some point during pre-planning, construction team members feel it was identified earlier and more expediently using BIM.

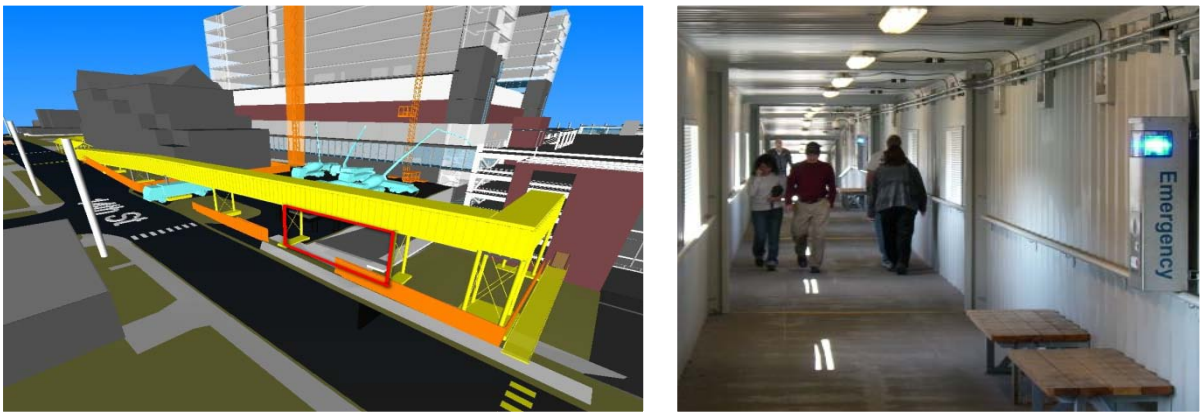

Figure 2: Using BIM during pre-planning on this renovation project, an effective solution was identified for worker and building user site-circulation safety. By having pedestrians walk over rather than around the construction site entry, safety and convenience were maximized.

Construction sites are complicated systems with many elements and variables moving in three dimensions. The interactive and flexible nature of BIM models are well suited for developing and testing solutions in site logistics. Other examples include analyzing egress from neighbouring buildings, and virtual tests of equipment coverage and clearance for constrained construction sites.

4. BUILDING END-USER SAFETY

A growing area of interest for the application of BIM is as a facility management tool. To address this opportunity, Mortenson Construction is providing a new area of services related to buildings operation and maintenance. They are currently developing tools and processes to

support “electronic maintenance and operation” (EMO) of the buildings they construct. Traditionally, as-built drawings are provided to owners and facilities operators. In this case, after building handover, individuals are charged with manually updating and maintaining these documents. As such, the value and relevance of these documents in duration and accessibility is limited to and relies upon on the knowledge level and familiarity of the facility operator with the building and the operation and maintenance documents. In an emergency or even normal day-to-day operation, traditional as-built documents are inefficient and imperfect. While BIM modelling does not resolve all information maintenance, access and communication issues facing building operators, by using BIM fluidly during design, construction and operation, it has the potential to increase end-user safety.

For example, as shown in Figure 3 as part of their EMO services, BIM was used to analyze, document and effectively communicate a shut-off value sequence for facility managers. Such information could be used in a training or emergency situation. The data-rich, interactive 3D environment the BIM provides serves as a consolidated and easily editable repository for a wide range of operation and maintenance information. Construction photographs can also embedded directly into the 3D model. Such information can be used directly by facility managers to locate hidden components, such as electrical and plumbing, during maintenance and repairs. A 3D interface can also provide greater access and understanding to a wider number of individuals in an emergency situation. For example, firefighters might be better able to reliably and efficiently locate a shut-off valve based on the information contained in a BIM than using 2D as-built drawings, operation manuals or relying on an individual facility manager. Finally, the ability to access a BIM remotely, and over the web provides an entire level of supervision, analysis and security previously unavailable to building operators.

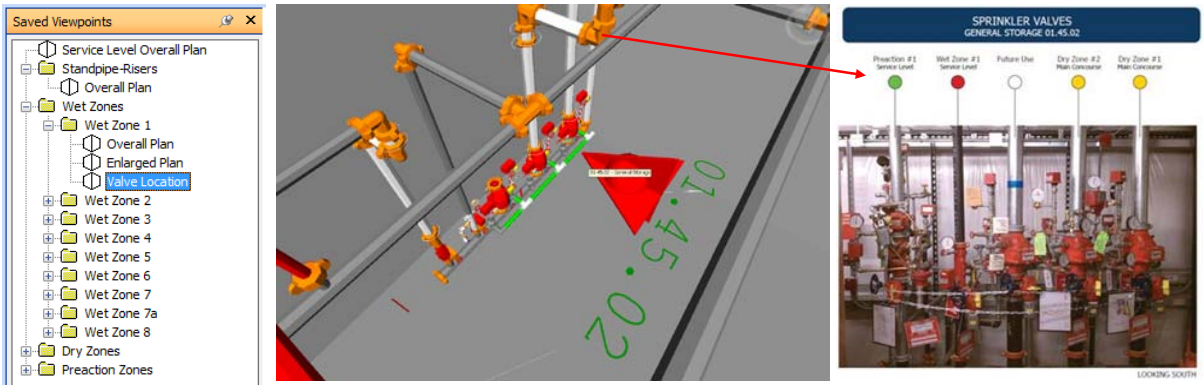

Figure 3: BIM supports electronic operation and maintenance (EOM) documents. The building model can store information such as building photographs and shut-off value sequences that can be used by facility operators for training purposes or in emergency situations.

5. CONCLUSIONS

This paper highlights the potential for using Building Information Modeling as a method to enhance safety controls during building construction and operation. 3D modeling can assist teams identify and correct errors and omissions that may lead to safety hazards earlier in the design process. BIM analysis enhances team member’s ability to visualize and conceptualize the construction process, which reduces the range of interpretation and facilitates better communication and understanding among various stakeholders. In this paper, we used specific project examples to highlight instances and opportunities for increased safety for construction workers and building users both during and after construction. Traditional construction safety strategies rely primarily on engineering controls, administrative controls and, less

reliably, personal protective equipment. By using BIM, safety controls which would most likely have been identified using these traditional strategies during pre-planning or on-site are frequently identified earlier and more efficiently by the project team following existing safety procedures but supported by new technology. BIM is a process which provides opportunities to virtually analyze design, construction and operation of buildings. As the complexity of these buildings continue to increase, the role of BIM in the identification, development and implementation of safety controls will continue to increase. Future research will further examine the role that modeling and BIM analyses can play in both engineering and administrative controls. With more time and attention spent during pre-planning, contractors will continue to rely less and less on personal protective equipment. In the future, there may be additional reduction on the use of administrative controls, those changes enacted on-site with the intent of reducing the level of risk, since the large majority of risk mitigation may shift to engineering controls as identified and implemented during more robust and effective BIM-enabled pre-planning.

Future research will consist of a strategic and collaborative effort between CSU, the Department of Construction Management at CSU, and industry to develop an integrated approach consisting of hands-on learning and stand-alone lesson plans that demonstrate the power of BIM as a transformative process essential to industry best practices. Additional future research will examine the role BIM and 3D visualization can play in enhancing worker safety training, particularly for immigrant workers who may speak a language other than English.

6. ACKNOWLEDGEMENTS

The authors would like to thank and acknowledge Mortenson Construction for generous and expert support of this research. Project examples and illustrations were provided and discussed by Ricardo Khan. Ricardo Khan is an Integrated Construction Manager for Mortenson Construction in Denver, Colorado. Ricardo leads the development of new processes for virtual design and construction and manages Mortenson's Denver-based VDC team.

7. REFERENCES

Bureau of Labor Statistics. Construction: NAICS 23. Retrieved from: http://www.bls.gov/iag/tgs/iag23.htm#iag23iifs.f.P

Gambatese, J. (2000). Safety Constructability: Designer Involvement in Construction Site Safety, Proceedings of the American Society of Civil Engineers (ASCE) Construction Congress VI, Orlando, FL, 650-60.

Gambatese, J. (2004). An Overview of Design-for-Safety Tools and Technologies, Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium, Eugene, OR: University of Oregon Press, 109 – 117.

Ku, K., and Mills, T. (2010). Research needs for Building Information Modeling for Construction Safety, International Proceedings of Associated Schools of Construction 45nd Annual Conference, Boston, MA.

Mortenson (2010). Our Purpose, Mission, Values. Retrieved from: http://www.mortenson.com/OurPurposeMissionAndValues.aspx

Sullivan, C.C. (2007). Integrated BIM and Design Review for Safer, Better Buildings. Architectural Record, 2007. Retrieved from: http://continuingeducation.construction.com/article.php?L=19&C=213.

Weinstein, M. Gambatese, J. Hecker, S. (2005). Can Design Improve Construction Safety? Assessing the Impact of a Collaborative Safety-in-Design Process, Journal of Construction Engineering and Management, 131(10), 1125-1134.