Building Information Modeling

Safety Benefits & Opportunities

By Sathy Rajendran and Brian Clarke

Although construction worker safety and health has improved over the past decade, it continues to be a concern for the industry. Fatal work injuries in the private construction sector declined by 16% in 2009, yet construction incurred the most fatal injuries of any industry (BLS, 2010). Worker injuries and illnesses in construction cost billions each year (NSC, 2006). Everett and Frank (1996) examined the costs of construction injuries and report that the total cost of accidents has increased 7.9% to 15.0% of the total cost of nonresidential, new construction.

IN BRIEF
- **SH&E professionals in the construction industry should view building information modeling (BIM) as a tool to improve worker safety and health.**
- **BIM can be used in worker safety training and education, design for safety, safety planning (job hazard analysis and pretask planning), accident investigation, and facility and maintenance phase safety.**
- **SH&E professionals should encourage other construction disciplines to review safety issues while performing design or constructability reviews. BIM is a tool that can facilitate this process.**

The causes of injuries and illnesses in construction have long been recognized, and numerous interventions have been developed, yet their persistence continues to frustrate construction safety practitioners and researchers (Hill, 2003). New methods and tools are required to prevent these injuries and illnesses. One such tool is building information modeling (BIM).

Building Information Modeling

The term *BIM* is used to refer to two different things: the process of building information modeling and the resulting model (the building information model). This article introduces readers to the concept of BIM, its uses and benefits, particularly with respect to worker safety.

A literature review was conducted to define BIM. According to AGC (2010):

> Building Information Modeling (BIM) is the development and use of a computer software model to simulate the construction and

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operation of a facility. The resulting model, a Building Information Model (BIM), is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility.

The literature offers several other definitions, including Smith (2007), who states, "[T]he concept of building information modeling is to build a building virtually, prior to building it physically, in order to work out problems, and simulate and analyze potential impacts. The heart of building information modeling is an authoritative building information model."

Simply put, imagine walking into a building, walking through the lobby, removing the ceiling tiles and looking at the utilities in the ceiling space—before the building is even built. BIM can help construction professionals do that. For exam-

Figure 1

BIM for a Steel High-Rise Building

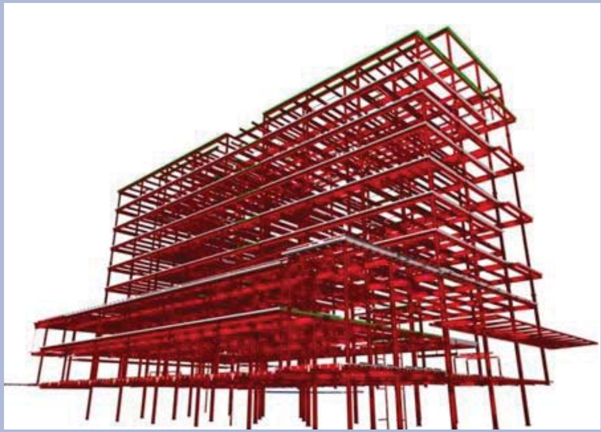
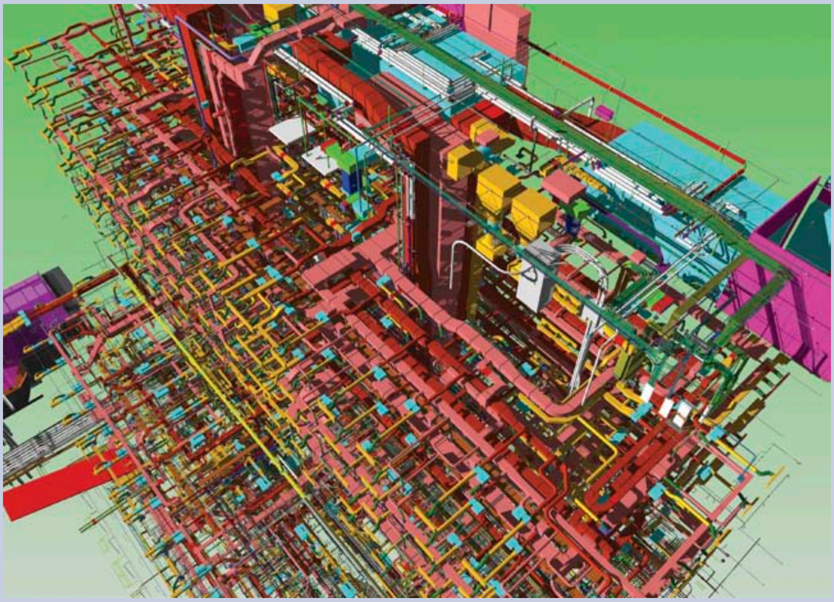


Figure 2

BIM Showing All Utilities of a High-Rise Building



ple, Figure 1 (p. 45) shows a model for a 10-story steel building and Figure 2 shows all the conduit, pipes and ductwork for that building. To create such a model, myriad details must be provided by different interests, including architects, engineers, contractors, subcontractors, fabricators, detailers, suppliers and others (Fortner, 2010).

BIM & Current Industry Trends

BIM is slowly changing the way owners, designers, engineers, contractors, subcontractors and fabricators approach building design, construction and operation. Currently, several U.S. companies are using BIM as part of their project development process. A few years ago, BIM was not used widely in the U.S. architecture, engineering, construction and operations industry (Suermann, 2009).

In 2006, the annual American Institute of Architects (AIA) survey indicated that only 16% of firms surveyed had acquired BIM software and that only 10% were using it for billable work (AIA, cited in Suermann, 2009). Gudgel (2008) reported that 62% of users surveyed indicated they would use BIM on more than 30% of their projects in 2009 (as cited in Suermann, 2009).

A recent nationwide survey on BIM usage among 115 different firms (including full-service engineering, engineering/architecture, multidisciplinary engineering, architecture or interiors, environmental consulting, single discipline engineering and design/build firms) found that one-quarter of firms are using BIM in at least 25% of their work; among the top quarter of firms at least 17% of their staff are currently using BIM; and more than 69% of firms planned to increase their use of BIM in 2010 (Yoders, 2010). Clearly, BIM is gaining momentum and BIM usage will likely become a norm in the construction industry at some point.

BIM & Safety

The current industry trend toward using BIM raises questions about whether the concept of including these models affects construction worker safety. According to AGC (2010), BIM uses include visualization; scope clarification; partial trade coordination; collision detection/avoidance; design validation; construction sequencing planning/phasing; plans/logistics; marketing presentations; options analysis; walk-throughs and fly-throughs; virtual mock-ups; and sight-line studies. Major benefits of BIM include:

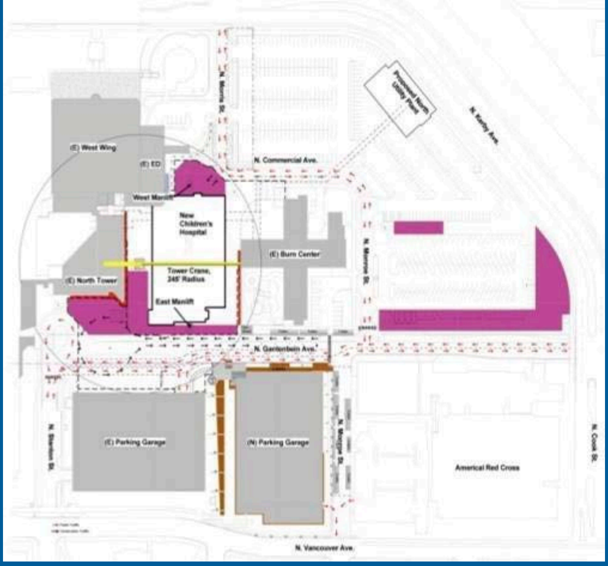
- assisting with scoping during bidding and purchasing;
- reviewing portions of the scope for analyses such as value engineering;
- coordinating construction sequencing (even if only for two trades);
- demonstrating project approaches during marketing presentations;
- ability to identify collisions (e.g., identifying ductwork running into structural members);
- ability to visualize what is to be built in a simulated environment;
- fewer errors and corrections in the field;
- higher reliability of expected field conditions, allowing for opportunity to do more prefabrication of materials off site, which is usually a higher quality at a lower cost;
- ability to consider more "what if" scenarios, such as looking at various sequencing options, site logistics, hoisting alternatives and costs;
- ability for nontechnical people (e.g., clients, users) to visualize the end product;
- fewer callbacks and, thus, lower warranty costs.

Neither list directly specifies worker safety. However, benefits such as the ability to identify building element collisions may affect safety. For example, consider ceiling work in utility plants. Utility plant buildings consist of extensive amounts of pipes and conduit in the ceiling, which are typically installed with fire sprinkler piping along with other mechanical and electrical elements. Any collisions of these elements identified in the field after installation results in rework, such as removal and reinstallation of pipes and conduit. Often, construction workers must work in tight spaces because of existing components, creating access, fall protection and ergonomic concerns.

Therefore, collisions detected before the start of construction can prevent rework in the field. Less rework means better safety. BIM improves worker safety because more items will be preassembled off site and trucked to the site (Smith, 2007). For example, structural members can be preassembled off site at fabrication yards in a controlled environment compared to a construction site.

However, the construction industry has yet to look at BIM as a tool to improve worker safety. Suermann (2009) assessed the effect of BIM implementation on construction projects with the help

Figure 3
BIM Site Layout for New Employee Orientation



of six key performance indicators (KPIs) commonly used to assess project performance: 1) quality control (rework); 2) on-time completion; 3) cost; 4) safety (lost workhours); 5) dollars/unit (sq. ft) performed; and 6) units (sq. ft) per workhour. Suermann conducted three surveys among industry practitioners to rate their perception of BIM's effect on the six KPIs. Respondents were predominantly associated with the architect, engineering and construction industry, and most felt that BIM does not affect safety or lost workhours.

Another survey of 38 electrical contractors collected information about BIM benefits and opportunities (Azhar, 2009). Twenty-three companies (61%) responded. BIM's effect on the overall business was assessed by examining how KPIs have changed since adoption of the modeling. Respondents were asked to consider changes in quality control (amount of rework), cost, timely completion, safety and productivity. The survey found that BIM has the greatest effect on quality control, followed by productivity, cost, schedule and safety (Azhar). Few respondents reported that BIM has a positive effect on safety. Despite this, it is well documented that higher quality work (less rework) is better for safety. Rework can cause workers to lose focus, which increases the chances of incidents and injuries.

Construction Safety Benefits

As BIM becomes more commonplace, construction safety professionals should examine how it can improve worker safety. Once a 3-D model is created, it can be used for many purposes, including worker safety training and education, safety planning and employee involvement. Safety professionals need not be experts in model creation or its technical aspects; they simply need a basic understanding of BIM, which is essentially a 3-D computer-aided design drawing. Consider these areas in which BIM can positively affect safety.

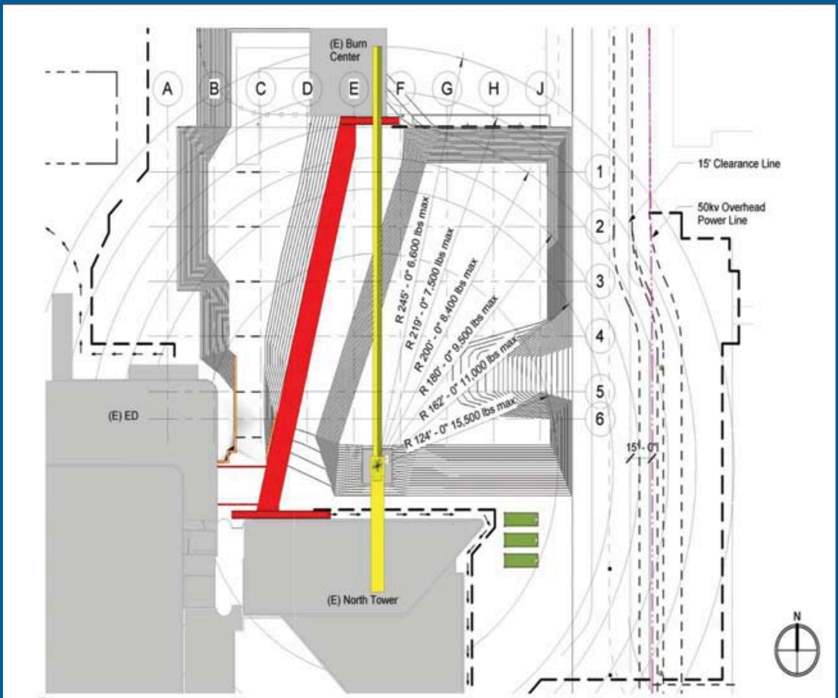
New-Employee Orientation

Craftspeople new to a jobsite are at a higher risk of injuries until they understand a site's working environment. BIM can help them understand the environment better and faster. This adds value on complex projects and/or projects inside operating facilities, such as renovation work inside hospitals, high-tech facilities and manufacturing facilities. Figure 3 shows a site layout derived from a BIM identifying craft parking area, laydown area, traffic control methods and existing buildings, as well as site hazards such as overhead power lines and crane swing radius.

Site-Specific Safety Plan

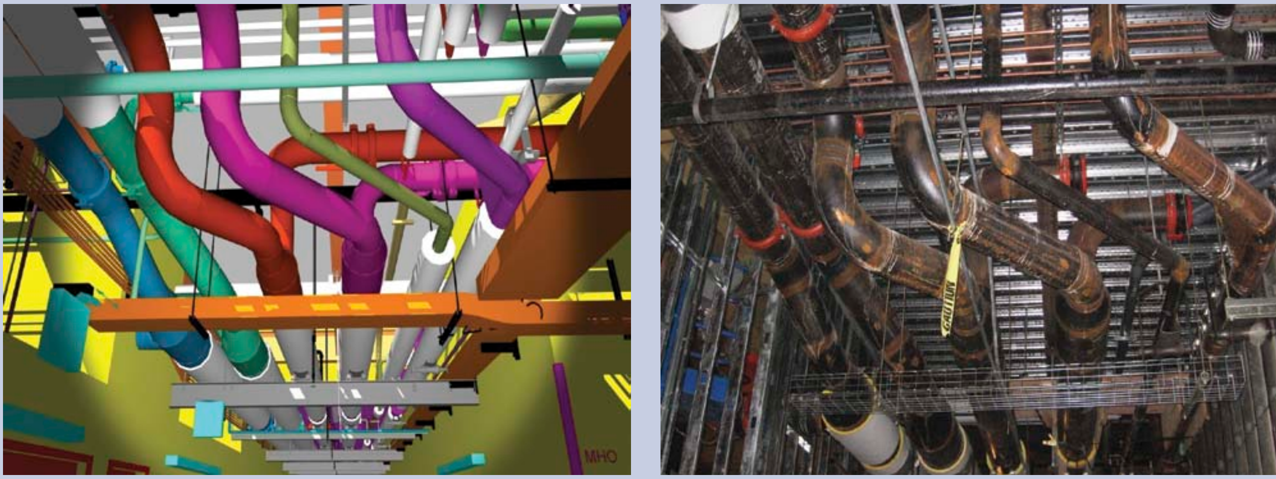
The site-specific safety plan helps identify and eliminate a project's potential hazards. BIM can be used to identify project hazards (e.g., hazards posed by site utilities and their proximity to construction work before breaking ground). For example, the

Figure 4
Identifying Site Hazards



Figures 5 & 6

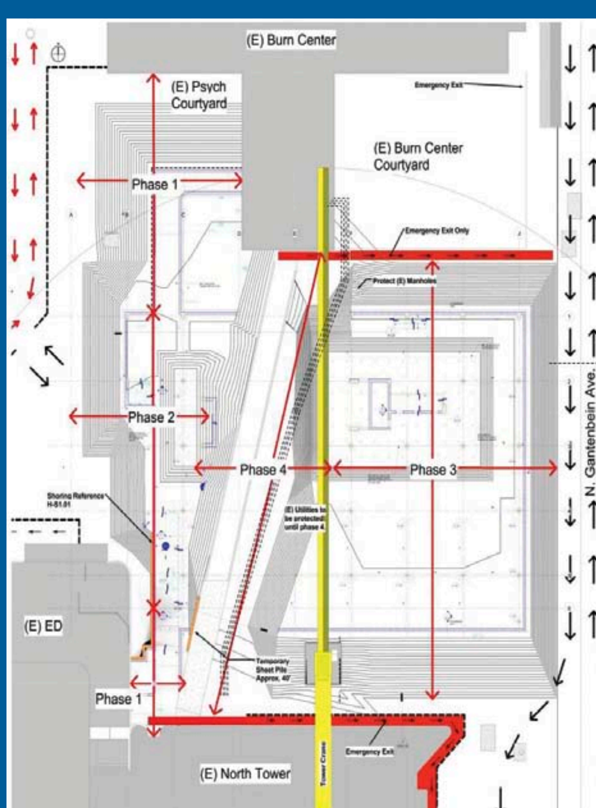
Pretask Planning & BIM: Model vs. Actual As-Built



authors consulted on a project that consisted of a 230-ft tower crane with a 250-ft jib operating adjacent to an overhead power line and a low-voltage communication line. BIM was used to simulate the tower crane operations in relation to the overhead power line. Based on the analysis, the authors determined that to maintain safe working distance from the power line, the power pole must be 8 ft from the tower crane. As a result, power lines were moved, which helped the project to establish sufficient clearance for the crane's safe operation. Figure 4 (p. 47) shows a 15 ft clearance in relation to the temporary construction roads and the site staging/loading area. This drawing was posted on trailers and in work areas to help on-site crafts plan crane work safely and efficiently.

Figure 7

Excavation Hazards Identified & Corrected



Pretask Planning

Pretask planning offers the most opportunities to use BIM for construction safety. Figures 5 and 6 provide an example of BIM used for pretask planning. In this case, the task involved installing hot and cold water pipes in the ceiling. By virtually looking at the elements to be built (Figure 5), employees were able to better identify the hazards and control measures so the task could be completed faster and more safely (Figure 6).

Crafts were able to identify the sequence of activities, and material and tool requirements before work started. Those involved identified access as a significant concern and were able to bring in aerial lifts. The crew identified falls as a hazard and devised control measures (e.g., tie-off points, fall protection devices). The piping was installed in a tunnel and required much welding. This issue was captured during pretask planning, and the model was used to identify the best location to create an exhaust for ventilation purposes.

Job Hazard Analysis

BIM can be used to help subcontractors perform job hazard analysis (JHA) and develop safe work methods. Consider the following examples that include excavation work and equipment planning.

Excavation is among the most dangerous construction operations (OSHA, 2011). Possible hazards include lack of a protective system, unsafe soil placement, equipment operation near excavation and unsafe access/egress. In one case, BIM was used to conduct a JHA of a project that involved a 30-ft-deep mass excavation. The construction team used BIM to visualize the project (Figure 7).

As a result, the team found that in two locations a 1:1 slope (Type B soil) could not be achieved due to a roadway on one side and an existing structure on the other. SH&E professionals suggested shoring piles on the existing structure side to avoid structural settlement.

On the roadway side, it was determined that a 1:1 slope was not feasible without demolishing the roadway that provided site access. A geotechnical engineer was consulted and it was determined that a 10-ft clearance should be maintained on the roadway side, to dig a steeper slope.

The geotechnical engineer approved the steeper slope with the condition of setting up a 10-ft barricade on the roadway, which was created to prevent any loading (e.g., equipment, traffic) in that area. The slope condition was checked frequently by the excavation contractor's competent person. The slopes are indicated by stripes in Figure 7; closely packed stripes indicate steeper slope.

In addition, BIM was used to map on-site equipment flow. The project required extensive use of dump trucks to transport materials from the excavation pits. A gravel ramp was the best solution for the trucks to enter and exit the excavation area. Locating the ramp correctly, in relation to other construction activities, is critical for proper truck access and avoids congestion/trade stacking. BIM helped simulate the ramp to confirm that no conflicts existed with other construction activities (Figure 8).

Another example of a BIM use in job planning involves installation of a construction hoist. The hoist had to be erected at a high-rise building to provide crafts access to upper levels. The hoist was added to the BIM based on specifications from the hoist vendor and steel erection contractor. Project managers used the new model to plan hoist erection, which eliminated several conflicts with other work in that area before activities commenced (Figure 9).

Figure 8
Site Equipment Traffic Planning

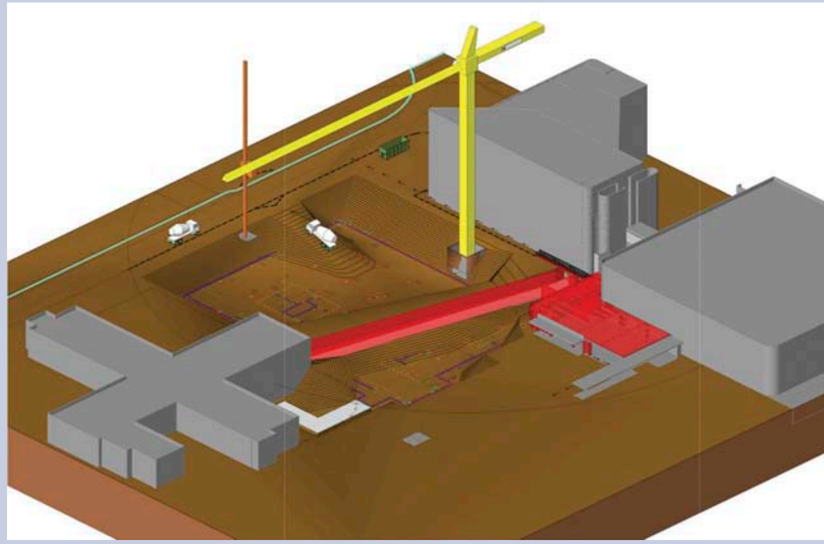
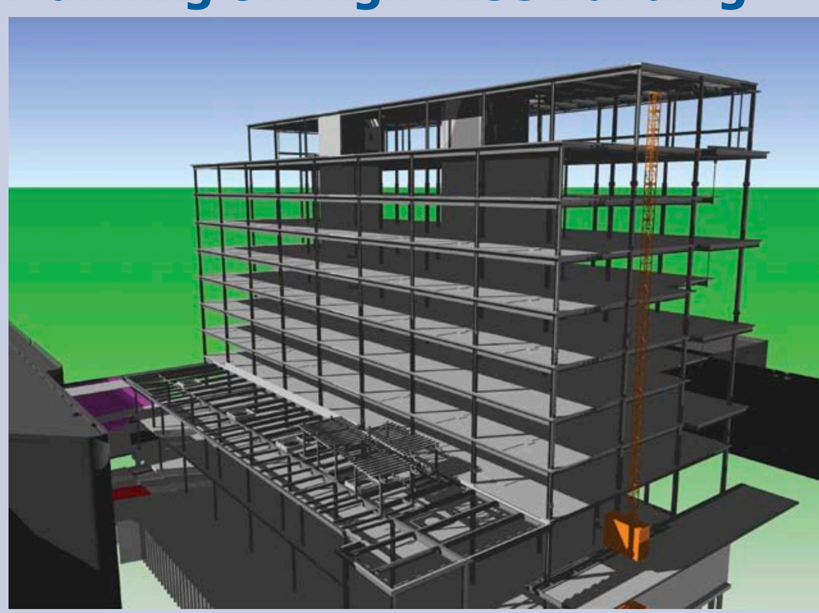


Figure 9
Construction Hoist Installation Planning on High-Rise Building



Accident Investigation

BIM can be used during an incident investigation to recreate event sequence and the incident scene. In one case, a worker was injured when he fell off a leading edge. The project had not used BIM, but during the incident investigation, laser scanning was used to identify existing conditions at the scene, such as location of pipes and HVAC ducts; location of stored equipment; materials storage; and worker position.

With these data, an existing-condition BIM was created, which captured the incident scene. This model eliminated hundreds of pictures and answered numerous questions related to the scene. It seems logical that BIM can be used during legal proceedings to save resources.

Design for Safety

The safety by design/prevention through design concept has continued to gain momentum in SH&E. According to Szymberski (1997), the potential to influence site safety and health conditions decreases exponentially as the project commences. Furthermore, designing for safety is recognized as the best method for eliminating hazards and reducing risk regardless of industry (Gambatese, Behm & Rajendran, 2006).

Designing for safety requires one to consider construction site safety during project design. This encompasses modifications to permanent features as well as preparing plans and specifications that

Table 1

BIM Trade-Specific Safety Intervention Opportunities

BIM safety intervention opportunities	Discipline/trade
• Consideration of safe, easy access for operators/maintenance staff to instrument control areas to take readings. • Proximity of gauges to control valves. • Size and type of valves appropriate for operational concerns and facility operator. • Backup control systems identical layout, gauge, location of board, valve size/type, etc.	Instrument/controls
• Location of piping with hazardous material in relation to pedestrian and vehicular traffic patterns. • Location of piping near electrical equipment. • Location of drain system. • Air intake location safe from external and facility (internal) generated air contaminants such as vehicles exhausts, forklifts, etc. • Pressure relief ports/valves located so as to not cause additional damage to facility and/or personnel when activated. • Proper clearance for construction crafts to use aerial lifts to access and to install mechanical systems between tanks and walls.	Mechanical
• Access/clearance to control panels that meets National Electrical Code (NEC) requirements. Ensuring NEC 110 clearance on all panels. NEC compliance is usually overlooked and can be a major issue if a mechanical/electrical room is designed and does not have 42-in. clearance and 6-ft clearance above electrical panels and equipment. Using BIM, NEC compliance can be verified and conflicts can be resolved before work begins. • Space in front (all sides) of panels for future expansion needs. • Parking and pedestrian lighting adequate for security concerns. • Proper lighting over emergency and other walkways. • Adequate lighting for maintenance operations. • Location of electrical panels in sight of related equipment • Overhead lines located not in laydown yards or in travel paths of cranes/over-height loads.	Electrical
• Location of fall protection anchor points for maintenance personnel. • Swing radius for gates/doors near sensitive equipment. • Fall protection on catwalks for maintenance personnel. • Guardrails and future tie-off points for fall protection can be identified using BIM by looking at roofs, utility shafts, elevator shafts and leading edges for fall hazards. • Location of covered structural members (e.g., post tension cables) for future needs for wall or floor penetrations. • Access location of roof, tank, confined spaces, ladders vs. stairs (enclosed, fall protection, hands free) for facility maintenance, cleaning, etc. • Mitigate trip hazards and head knockers.	Structural

PS EXTRA

For the authors' complete list of opportunities by trade, visit www.asse.org/psextra.

consider site safety. It also includes utilization of design for safety suggestions and the communication of risks regarding site design and the work to be performed (Behm, 2005; Gambatese, Behm & Hinze, 2005).

SH&E professionals should focus on this concept and make use of tools such as BIM to identify where design for safety suggestions can be incorporated. For example, in one project, fall protection tie-off points were determined using BIM. BIM review revealed many areas where workers would be exposed to fall hazards, but no tie-off points were present. The project team identified several hundred locations where concrete embedded straps could be installed for tie-off. BIM helped identify potential conflicts with overhead or underslab utilities. Table 1 identifies, by discipline, some safety specifics that can be considered using a BIM.

Construction Safety Challenges

BIM has the potential to improve construction project safety performance. However, several challenges will hinder its use:

1) BIM availability and use. BIM is new to the construction industry. Not all contractors and designers are familiar with or use BIM. Many small contractors cannot afford to purchase and install the required software and hardware, and train their staff. It will be some time before BIM use becomes a norm in the construction industry.

2) Contractor selection. To implement BIM, owners/general contractors must select subcontractors with BIM experience. This changes the contractor selection process, which traditionally focuses on the lowest bidder.

3) Cost. BIM is expensive and requires a significant up-front investment. BIM involves a large group of individuals, ranging from designers, mechanical, electrical and plumbing trade detailers, structural detailers and more. In addition to the initial cost, once the model is created, each change order issued requires detailing fees to keep the model live. Project owners are not accustomed to this expense.

4) Lack of training. Individuals (e.g., designers) working with BIM often lack safety expertise and will not consider construction safety during the BIM development process.

5) Model access. Construction safety professionals' access to BIM could be limited and the technical skills and tools to use the model are not widely in place. Furthermore, safety professionals often are involved late in the project development process, which does not allow them to contribute to BIM effectively.

6) Technical challenges. Getting construction safety elements (e.g., blockouts for equipment loading, temporary systems such as scaffolding, boom lifts, cranes and scissor lifts) added to BIM can be a challenge.

7) Field management support. In the authors' experience, construction line (field) management does not believe in BIM and its use for safety.

Safety Professionals' Role

Safety professionals have a huge opportunity to contribute to the project success with the help of BIM. Safety professionals should engage with other disciplines (e.g., controls, mechanical, electrical, structural) to encourage them to look at safety issues while conducting design or constructability reviews. This will help them identify safety hazards and address the hazard or engage the safety professional for counsel during the design phase.

Furthermore, safety professionals should look at BIM of buildings. They need to examine the drawings during a project's design phase to identify safety concerns. For example, is lighting over walkways sufficient? Ideally, the general contractor/construction manager should invite specialty contractor safety professionals to spend a day reviewing the 3-D model.

Although the subcontractor may not have to buy into the BIM program, the safety professional can participate in the BIM review process and provide valuable input. In addition, during the pretask planning review, the safety professional can show the crafts different building elements using the BIM. For example, the professional might explain that water pipe should not be installed in a particular location because conduit goes in that location.

Conclusion

BIM offers several benefits that can improve construction safety. Currently, including BIM in safety discussions is not common in the construction industry. Research has shown that industry practitioners perceive BIM has little effect on safety. This perception needs to change. With a significant effort from construction project teams and SH&E professionals, using BIM for safety can become the standard. Safety professionals should encourage team members to use BIM for safety and educate them on how to look for safety concerns during the BIM review process. **PS**

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