# Chapter 21
# BIM for Construction Safety and Health

**Jochen Teizer and Jürgen Melzner**

**Abstract** Large to small organizations throughout the entire construction supply chain continue to be challenged by the high number of injuries and illnesses. Although the five C's (culture, competency, communication, controls, and contractors) have been focusing on compliance, good practices, and best in class strategies, even industry leaders experience marginal improvements in occupational health and safety (OHS) for many years. BIM for construction safety and health identifies three major focus areas to aid in the development of a strategic – as opposed to tactical – response: (a) OHS by design, (b) pro-active hazard detection and prevention at the workplace, and (c) education, training, and feedback leveraging state-of-the-art processes and technology. This chapter explains the motivation for developing a strategic roadmap towards the use of BIM in OHS. It highlights meaningful predictive, quantitative, and qualitative measures to identify, correlate, and eliminate hazards before workers get injured or other incidents cause collateral damage. Using selected case study applications, the potential of BIM in practical implementation as well as the social implications on conducting a rigorous safety culture and climate in a construction business and its entire supply chain is shown.

## 21.1 Introduction

Although the construction industry has been seeing some dramatic shift towards adapting and developing modern information and communication technologies for the past decade, its occupational safety and health performance worldwide remains very poor. Statistics show that in many countries the construction sectors experience one of the highest accident rates. Among the 60,000 construction workplace

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A. Borrmann et al. (eds.), *Building Information Modeling*,
https://doi.org/10.1007/978-3-319-92862-3_21

deaths worldwide, falls remain a major concern as they contribute to very serious injuries or even fatalities on construction projects. Despite stricter work conditions, environments and labor requirements, standards and rules for adequate protection change too slowly to have a significant impact. Regulations also may vary vastly by the location of a project. Increasingly international operating organizations that must deliver ever larger and more complex projects are in need of simple tools that allow ubiquitous understanding and planning of safety and health regardless in which country they operate in. The problem with construction safety and health therefore can be examined by responding with methods and tools that advance best practices in place and make use of technological innovations. These also must empower a new generation of technology-savvy engineers in design and planning offices and leaders in all operational fields of construction and facility management.

Due to the large number and severe consequences of construction workers falling from heights, this chapter focuses on fall-related incidents only. The next two sections introduce the most noteworthy fall-related accident statistics of Germany and the United States and the current practices that are being employed to prevent such accidents from happening. The section following thereafter introduces research on an intelligent safety-rule checking platform using Building Information Modeling (BIM). Lessons learned from real use cases demonstrate the feasibility of the selected approach. The final section discusses the constraints and provides an outlook of further work necessary to advance the developed approach for field readiness.

## 21.2 Accident Statistics and Root Causes

Construction offers some of the most dangerous workplaces and has historically seen one of the highest work-related injury and fatality rates. Compared to other industry sectors in Germany for the past two decades, the German construction industry reported most of the accidents. In Germany, a reportable case is an accident during occupation or commuting which is either fatal or leads to an incapacity to work for more than three days. When relating the accident rate in construction to the amount of full-time employees, construction in Germany has 55.49 reportable accidents based on 1,000 full-time workers. Though the accident rate in the German construction industry decreased over the past two decades, more than 100,000 reportable work accidents are still witnessed annually.

In the US, for example, the construction industry continues to rank among the most dangerous industries to work for (Hinze and Teizer 2011). 751 construction workers died in 2010 alone, while these numbers are equal to a fatal work injury rate of 9.5 workers per 100,000 full-time equivalent workers (U.S. Department of

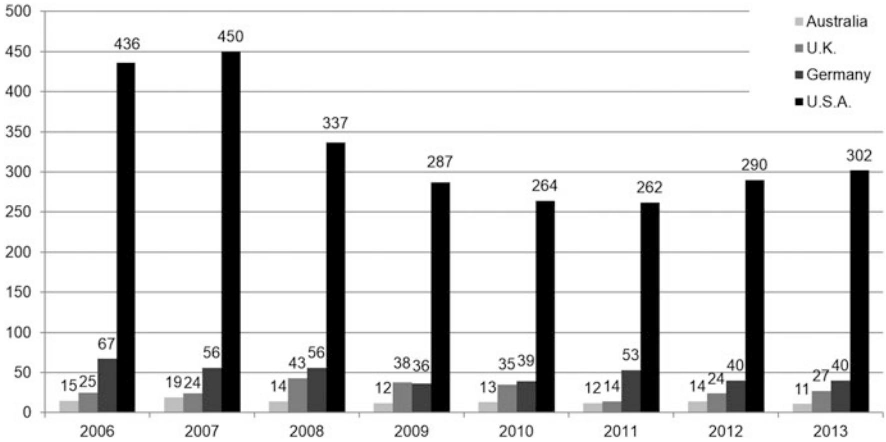


**Fig. 21.1** Overall number of construction fatalities and reported fall-related fatalities in the United States, Germany, Australia and the UK. (© J. Teizer, reprinted with permission)

Labor 2011). A comparative overview of statistics related to fatal falls is highlighted in Fig. 21.1. These numbers do not account for the circumstance of the construction economy being cyclical (between 2008 and 2012 was a downturn in construction activity). They also do not adjust for the different sizes of the economies.

Falling from height is one of the most common causes leading to fatalities in construction. Existing research conducted revealed that inadequate or inappropriate use of fall protection equipment and inoperative safety equipment contributed to more than 30% of all fall accidents (Huang and Hinze 2003). According to Bunn et al. (2007), falls also incurred the highest workers' compensation and hospitalization costs in construction. The average absent days for construction workers suffering from falls from heights was 44 days (Gillen et al. 1997). The root causes for such poor accident statistics in the construction industry can be, according to Hinze and Teizer (2011): physical tasks are very demanding, the work environment is complex and constantly changing, best operating techniques are not always available when needed, a company's organizational structure and commitment to safety and health is imperfect, and allows human error. While close to 26,000 German construction workers retire early from their work life due to musculoskeletal injuries, the building industry sees a significant shortage of qualified labor. Hence, severe accidents limit the quality of a person's and probably a family's life but also limit a country's competitiveness and lower its productivity.

Many safety and health related organizations, owners and contractors, and other stakeholders in a construction project have well understood the consequences that are caused by injuries and fatal falls. Their first mission since then has been to provide safe working conditions. One of its goals is to pursue appropriate safety design and planning. As many researchers already pointed out, awareness of safety during design and planning phases can improve the safety standard throughout the entire construction phase and beyond (Gambatese and Hinze 1999; Frijters and

Swuste 2008; Hinze and Wiegand 1992). Much research has also been done to improve safety in construction by focusing on improvements of safety awareness or technical developments for on-site safety (Garrett and Teizer 2009). However, it is evident that more attention should be paid to safety as it is used in the early design and planning stage of a project (Qi et al. 2011). As Building Information Modeling (BIM) has already been proven as a promising tool to support construction management in the earlier project phases, BIM has yet to impact construction safety and health (Zhang et al. 2013).

## 21.3 Legal Obligations and Responsibilities Differ by Country

As an example the United States' Occupational Safety and Health Administration (OSHA), sets forth minimum guidelines to protect the health and safety of those working in the construction industry and other occupational fields. OSHA's regulation 1926.16 defines that (1) the prime contractor is generally responsible for work site safety, and (2) each subcontractor remains responsible for keeping their workers safe. A similar law exists in Germany (§4 BaustellV). Dividing up the roles in construction safety can cause problems, for example, a prime contractor that often provides general safety equipment and coordinates work site safety may not be aware that subcontractors perform unsafe work at height on a project. Communication of essential hazard-related information and needed safety equipment can be an issue and often has led to issues on projects.

Under German law, a health and safety coordinator should be present if a contractor cannot perceive the tasks him- or herself. Typical reasons for a contractor to hire a safety coordinator are lack of expertise or a small project. The relationship is illustrated in detail in Fig. 21.2. In Germany mainly the "Employers' Liability Insurance Association for Construction" (in short "BG Bau") is responsible for maintaining and controlling safety in the construction industry. It publishes regulations to set safety objectives as well as defines industry and process-specific rules. Such rules include fall protection regulations. These rules are legally binding.

Although the involvement of a safety and health coordinator adds up to about 0.3–1.0% to the total construction budget, savings can be expected by lowering construction interferences, accident and loss rates/costs, providing better coordination, and sharing of construction equipment. Furthermore, the implementation of a coordinator on a project does not exempt the contractor from the responsibility for maintaining safe construction sites. The safety and health coordinator has to

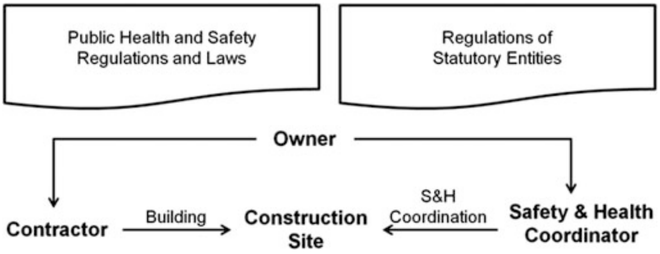


**Fig. 21.2** Safety relationship between German regulative entities and contractors. (© Taylor & Francis, reprinted with permission)

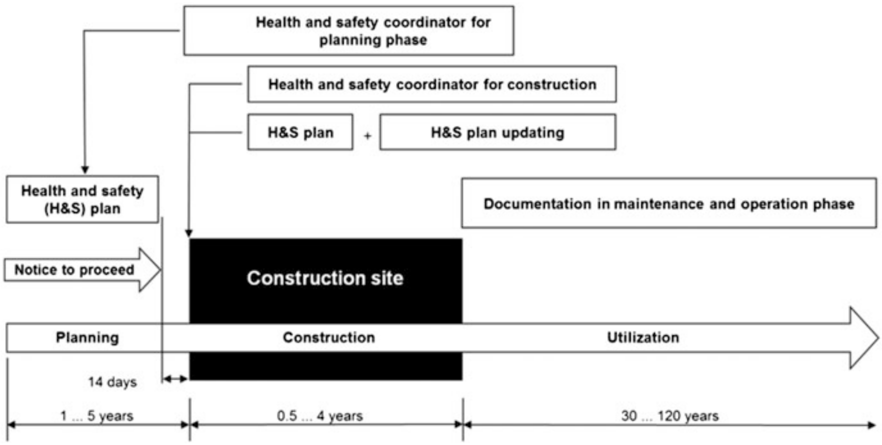


**Fig. 21.3** Responsibilities of a German safety and health coordinator in project development. (© Taylor & Francis, reprinted with permission)

actively participate in design and construction planning. Figure 21.3 shows the responsibilities of the safety and health coordinator during the project development. During design he/she has to elaborate the safety and health plan and communicate the protective measures to the contractor and planners. Further, he/she has to coordinate safety and health issues during construction.

## 21.4 Problems in the State-of-the-Art Safety Planning

Safety planning in the construction industry is complicated due to the dynamic nature of the construction environment and active involvement of various stakeholders. Construction is typically seen as a one-of-a-kind business. Each project is built "for the first time" and only very few building types are constructed repeatedly. Consequently, construction planning has to start again with the start of a new project or phase. Traditionally, safety planning in construction is separated from the other planning phases. Frequently experienced issues arise when (1) decisions of the architectural/engineering design and layout planning team are made without considering safety factors, and (2) the project layout keeps changing throughout the project.

A further well known characteristic of the construction industry is the large number of trades involved in a project. An architect/engineer might as well be responsible for the preliminary design and construction documentation. However, the contractor remains responsible for construction site safety (Gambatese et al. 2009). The current state of many construction businesses shows that contractors participate relatively late or very little in the design or planning process. Therefore, the time between contract award until construction starts is often too short for detailed safety planning. This defers safety planning into the construction phase. Another often proclaimed problem in construction is the lack of human resources for construction planning as well as for site supervision during the execution phase (Egan 1998).The introduction of an external health and safety coordinator leads to an active involvement of safety experts in the construction process planning. However, the safety coordinators may not be present at all times on a project; especially if the projects are small in size. As a result, safety responsibilities are delegated to staff or personnel that might not be familiar with safety rules and regulations.

Another problem that exists in safety planning is the method to detect potential hazards that put workers at risk or in dangerous work environments. Manual observation and marked up and printed (two-dimensional) drawings are only two of the very common traditional practices that exist to interpret existing health and safety hazards. As seen on projects, safety risk analysis is based on long-time experience of personnel, observations of progress at site, tasks actually performed, and looking at drawings. Such analysis is often referred to Job Hazard Analysis (JHA) but is ultimately conducted in detail a few days before the work is actually performed.

It has been widely acknowledged that safety planning in construction needs improvement. It is in the nature of the construction business that quality planning and work preparation is directly linked to the knowledge of the executing and experienced personnel. Therefore, knowledge-based decision support tools can help humans to improve the quality of planning. An example is to assist a safety planner or engineer with tools that detect hazards, shifting the focus of the engineer on problem solving rather than problem finding. As an important note, humans should always be involved in the decision making process, in particular when it comes to safety. Therefore, the proposed framework brings together human experience, best practices, and legal requirements in a knowledge-base and applies BIM to safety.

## 21.5 Integrating BIM in the Safety Planning Process

As explained before, safety planning can be a tedious and time-consuming task that currently relies on many manual tasks. For large structures, for example, a high-rise building, such tasks are repetitive in nature. Floor plans that may look the same can consist of different drawings and the sections that are shown might be in several different building plans. As site conditions also change frequently, it is inadequate to analyze the construction project concerning safety issues only based on information/drawings that represent the final, built status. It therefore very essential to take project schedules and modifications into account. All such information is already an integrated part of BIM.

An experienced issue in safety hazard detection is the understanding of spatio-temporal relationship of work space and time. Many decision makers have yet to adapt using the full potential of three-dimensional (3D) and time-based visualization/simulation (4D) of information models. Education and training in handling BIM technology for experienced personnel is lacking as a new generation of BIM technology-savvy engineers is still growing. Thus it takes the spatial imagination of a safety engineer to study the coherent structure of a building. Such manual hazard analysis is generally time-consuming and can be an error-prone procedure. Since it is worthwhile to avoid a hazard at the design stage rather than waiting for controlling the hazard or simply protecting the workers during the construction stage (Manuele 2003), Ku and Mills (2010) discussed in their research the need for design-for-safety tools. One potential solution to fill the gap is to provide (manual) tools that assist a safety engineer in the task of modeling protective safety equipment in BIM (Sulankivi et al. 2013). BIM-based cost estimating, risk management, clash detection and 4D visualization have become established features to support construction management (Hartmann et al. 2012). Many other advantages are witnessed by using BIM for project planning. Even safety applications in BIM were suggested (Zhou et al. 2012). While digital building models are widely used in the AEC industries in design and construction, further investigation needs to been done for safety planning.

The limitations of current applications for safe design and planning of construction work ask for change towards: (1) hazards will be semi- and automatically detected near real-time to keep up with the dynamic construction progress, (2) existing software will assist humans to fit safety equipment to the identified hazards in a digital model, and (3) hazards, work space conflicts and prevention methods will be visualized in 4D (3D plus schedule) and communicated in form of multilingual work instructions and procedural instructions to all project stakeholders and process levels.

## 21.6 Safety and BIM in the Project Lifecycle

Safety, which overlaps with all project phases, is a generally accepted goal. The piecemeal strategy of separating the information flow of construction hazard prevention through concepts that are only shared among design personnel, construction workers, and operations and maintenance personnel is not benefiting safety on a project. While recent years have been showing an increased interest for automation in construction, novel concepts also emerge for the planning of preventive safety and health protection systems. BIM in conjunction with the use of mobile field devices, for example, has already shown a positive influence on project outcomes.

However, many of these concepts have not found entry in construction yet. Safe-BIM is a novel concept that leverages existent safety-relevant data and implements it in existing processes over a project's lifecycle (Fig. 21.4). It gives project stakeholders foremost early access and control over some of the following important tasks in construction safety:

- *Owner/clients:* standardizing its safety program(s); selection of construction companies, subcontractors, producers and suppliers on the basis of good safety records; investing in modern safety methods; early involvement and intervention at any time in order to avoid pre-known hazards.
- *Construction industry associations:* availability of up-to-date data, including statistics; creation of proactive policies; rule compliance; lower insurance premiums.
- *Construction companies:* effective employment protection methods that are actually implemented and controlled on construction sites; application of modern information and communication methods; monetary benefits.

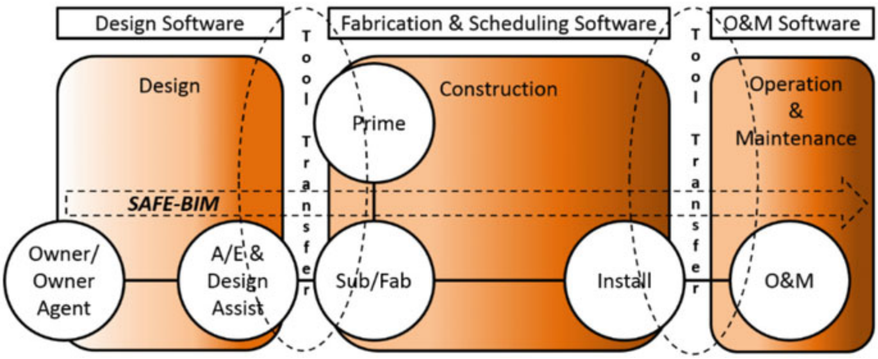


**Fig. 21.4** Safe-BIM project lifecycle. (© J. Teizer, reprinted with permission)

- *Architects, engineers, facility manager:* influence of design guidelines on safe project execution and maintenance; make available and share safety expert knowledge in the entire project lifecycle; early coordination of owner, contractor, and facility manager.
- *Suppliers:* delivering safe and reliable products in the safety supply chain.

## 21.7 Safety Rule Checking in BIM

Existing safety rules, guidelines, and best practices can be used in conjunction with existing three-dimensional (3D) design and schedule information (4D) to formulate an automated safety rule checking system. The goal is to automatically identify hazards and eliminate these conditions before construction starts. While construction is underway, safety rule checking can be performed continuously. In addition, decision makers on a project are able to identify the locations of the hazards in a virtual 3D space and can, interactively or automatically, provide solutions and visualization of protective systems to mitigate the identified hazards.

Such a platform developed by Zhang et al. (2013) can function as a tool for providing easily accessible and understandable visualization of up-to-date progress on construction and safety over time. The indication of safety measures also provides the right quantities that helps understand the investment in safety. Based on the contractual arrangement, safety managers can start planning already at the front end of a project, while they can plan for safety conveniently throughout the construction phase.

The rule checking process is similar to spell checking. It enables all project stakeholders with early detection and proactive elimination of dangers, potentially well before a project enters the construction phase. Safety rule checking in BIM strengthens therefore existing Prevention through Design (PtD) concepts and enables personnel to interact with the workforce via jobsite hazard analysis report cards and visualization. Latter can finally leverage its full potential and provide personalized safety education and training specific to project- and schedule-related work environments, worker qualifications and age groups. Rule checking consists of the following procedures (Fig. 21.5):

1. *Rule interpretation:* The interpretation of safety rules from safety regulation or best practices (e.g., BG Bau or OSHA) is a logic-based mapping from human language to machine readable form. The name, type, and other properties in the rule can be analyzed and extracted from the written rule.
2. *Building model preparation:* A building model must be well constructed to include required objects, attributes, and relations used to carry out the rule checking. In addition, since the need of fall prevention equipment depends on the status of the construction work, a 4D model including the installation schedule/order of building assemblies is required.

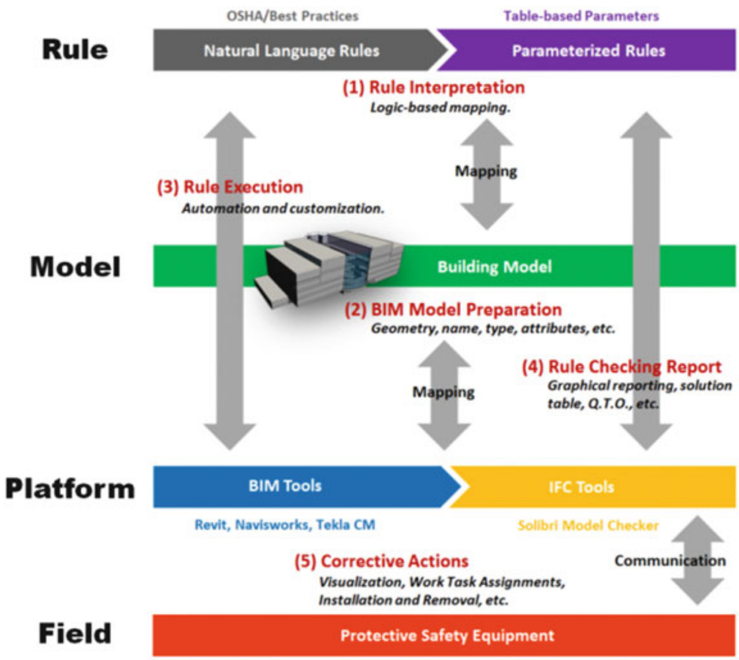


**Fig. 21.5** Safety rule checking in BIM (Zhang et al. 2013). (© Elsevier, reprinted with permission)

3. *Rule execution:* The rule execution phase brings together the translated rule sets with prepared building model. The rule may apply to thousands of condition cases, requiring combinatorial tracking. The rule execution has two steps: (a) automatically check the model to identify unsafe conditions, and (b) identify and apply candidate solution actions to correct the unsafe condition. This last step can be variously controlled, manual intervention for each condition, to completely automatically resolve through the application of rules to determine the best correction.
4. *Rule checking reporting:* The checking results can be reported in multiple forms: (a) visualization of applied safety protective equipment in the model, and (b) Excel-based reports of unsafe conditions and the corrective actions taken. In addition, quantity-take-off information for resource leveling of safety equipment and importing the generated information into project schedules is also possible. The report can then be integrated into Job Hazard Analysis (JHA) processes as shown by Zhang et al. (2015b).
5. *Safety correction:* The primary corrective actions that will take place on construction sites are to schedule and track logistical movements of protective safety material. Based on the rule checking reports, an exemplary implementation in the field would report via a commercial BIM software platform and assign work tasks for the installation and removal of safety equipment on a building floor.

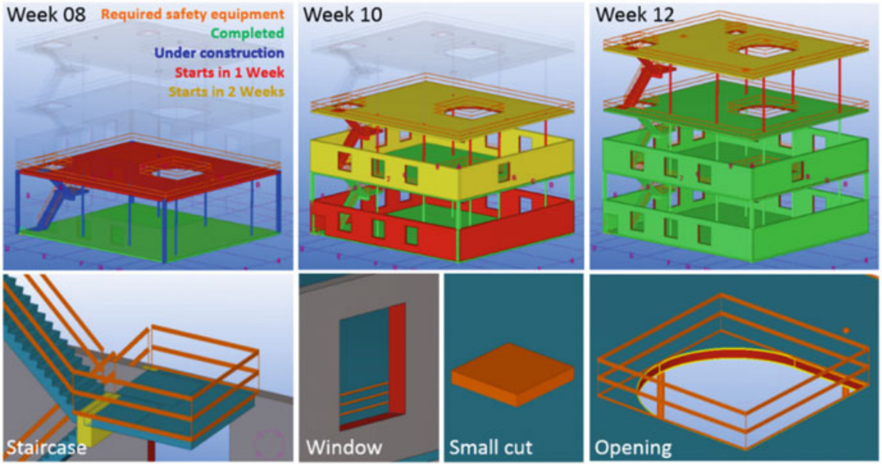


**Fig. 21.6** Safety rule checking automatically detects and models required fall prevention methods for slab edges, cuts, and openings. (© J. Teizer, reprinted with permission)

Once the building information model has been well constructed and the connections between the model objects and the schedule have been established, digital rules related to fall hazards, for example, are applied for detecting each one of the hazards. As the results show in Fig. 21.6, the building model visualizes and links required safety equipment and ties it to a construction schedule. This information can be used in weekly project meetings and allows human decision makers to implement or modify the solution, if needed.

## 21.8 Real World Applications of Safety Rule Checking in BIM

Building information modeling (BIM) has been taking on a greater role in the industry, moving beyond clash detection and coordination to a valued resource in the field for real-time jobsite safety monitoring. Field tests of the safety rule checking had the goal to validate the approach. The case studies extended BIM to include several important issues (see some selected examples in Fig. 21.7):

- a graphical software user interface that allows humans to steer the process of the rule checking, for example, by defining the rules and overriding automated results,
- Job Hazard Analysis (JHA) report cards based on a safety ontology visualize the hazards and provide multi-lingual instructions to work crews in the field work or for education and/or training courses,

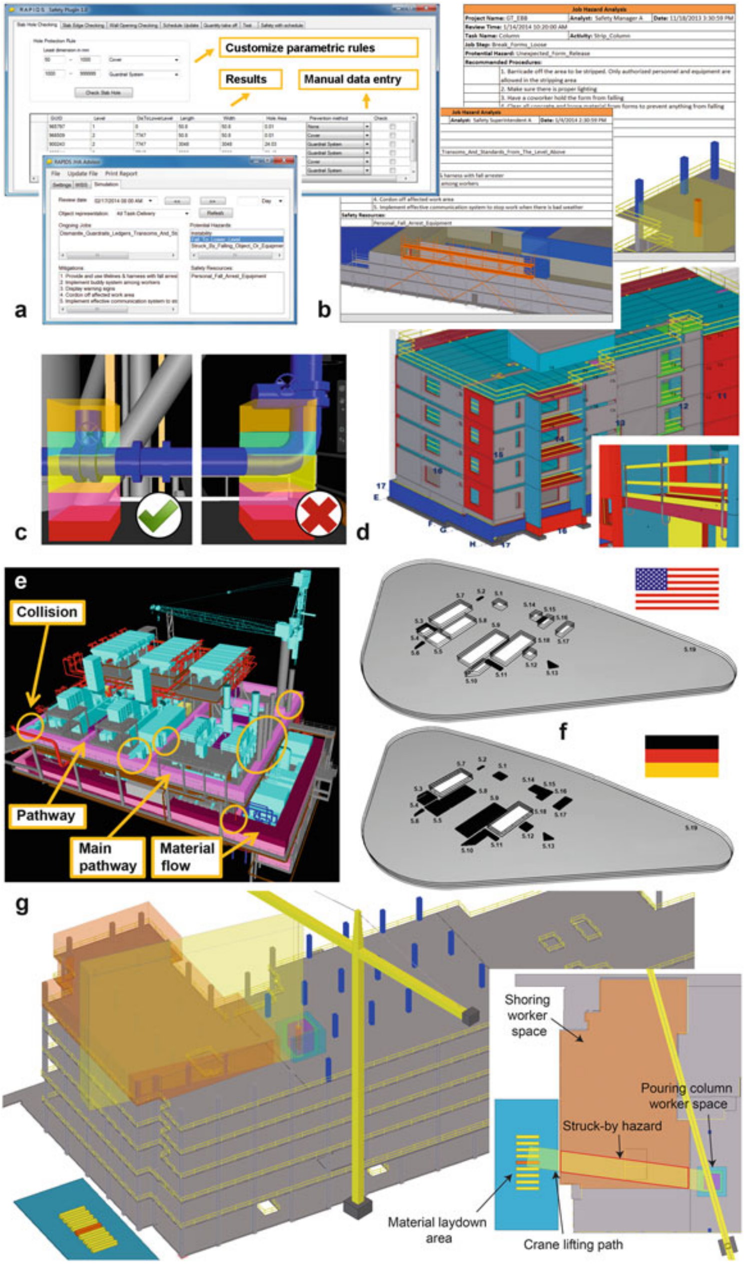


**Fig. 21.7** Safety rule checking in BIM: (**a**) Software user interface, (**b**) Job Hazard Analysis (JHA), (**c**) ergonomics, (**d**) safety equipment, (**e**) access and obstructions, (**f**) comparison of international fall prevention regulations, and (**g**) simulation of logistics, swing and work spaces. (Zhang et al. 2013, 2015a,b; Melzner et al. 2013; Kim et al. 2014; Wang et al. 2015). (© Elsevier, reprinted with permission)

- checking for ergonomically correct positions of valve and turning wheel heights in a downstream oil refinery to prevent workers from having long term illnesses,
- detection of fall-related hazards such as openings and leading edges for a multi-story apartment building along with modeling and scheduling the installation and removal of safety equipment as part of the building sequence (4D),
- clash detection of physical installations and obstructed walking spaces in an off-shore oil platform,
- comparison of the rule checking results for an identical building floor based on two different international fall prevention regulations, and
- 4D work packaging and site layout sequence planning that detects and adjusts crane load paths over pedestrian work crew spaces.

These results demonstrate that the developed rule checking approach was successfully integrated into best of class safety engineering and management systems. For the use case fall protection, it has become possible to inform construction safety engineers and managers by reporting where, when, what, and why safety measures are needed.

## 21.9 Return on Investment

The results from a survey among 263 planning and construction firms in the US highlight the benefits from very good safety programs: (1) smaller number of accidents, (2) improved reputation, and (3) increased yield or return (McGraw Hill 2013). The survey also showed that the bigger the firm the higher the investment in innovation including safety was. The study stressed more advantages which are connected to applying excellent labor safety programs:

- 50% of all surveyed companies reported a decrease in the overall construction time,
- 73% of all observed projects reached cost savings of at least 1%, while 24% of all projects with a very good safety program saved more than 5% of the project costs, and
- 73% of projects improved their profits by more than 1%, while 20% of all projects reached an improvement of more than 5%.

Participating companies mentioned further benefits: (a) reputation, (b) improvement in the acquisition of new projects, and (c) reached an overall higher quality in the execution of project. These and more results to the survey are illustrated in Fig. 21.8.

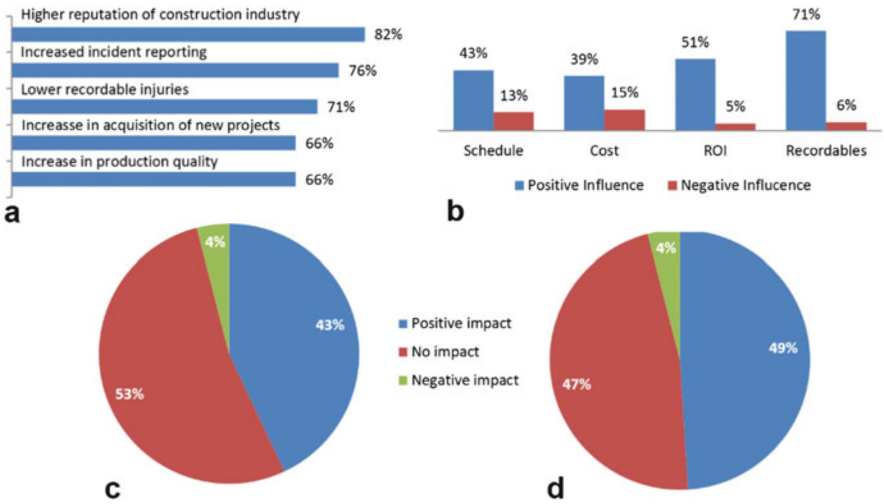


**Fig. 21.8** (**a**) Advantages of an excellent safety program (% of firms that reported a positive impact), (**b**) financial advantages observed by applying an excellent safety program, (**c**) reported impact of BIM on work site safety and health, and (**d**) impact of prefabrication and modularization on safety and health. (After McGraw Hill 2013)

## 21.10 The Future Role of BIM in Safety and Health Planning

Only a few research activities worldwide are focusing on the use of BIM for construction safety and health. Integration in commercial BIM products are far from reach. Particular issues seem to hinder the integration of Safe-BIM in commercial applications:

- *Quality of models, norms and standards:* Although BIM sees widespread uses in construction, most applications focus on planning. Most models today lack standardization, use proprietary formats, have low detail, and are not kept up to date during the construction phase.
- *Investment vs. costs:* Since the construction industry is a lagging industry, general thoughts on the return on investment may favor current over transformative approaches. Investment in safety though might require regulative steps.
- *Lean supply chains:* In order for processes related BIM to work effectively in con-junction with construction safety and health applications, all stakeholders need to buy in. Safe-BIM becomes efficient, if the owner commits resources to it, planners design out hazards at the front end, and contractors, subcontractors as well as safety equipment suppliers advance workflow management by collab-orating on an effective supply chain that mitigates project risk.
- *Lagging vs. leading indicators:* The goal to predict and proactively eliminate hazards before injuries and fatalities occur needs to be set.

- *Knowledgeable workforce:* The existing workforce is not skilled to execute transformative processes. A technology-savvy workforce that is familiar with BIM, mobile and sensing technologies has to be educated and trained before a widespread application among all stakeholders becomes feasible.
- *Variability of methods and technology on processes:* The application of safety rule checking, for example, might work well for parametric rules. Though intelligent concepts must be developed for other safety and health topics, such as risk originating from human factors.
- *Explore related domains:* While safety is an important topic, the impact it has on lean production and productivity should be explored. Probably, lean and injury-free work environments need to explore the benefits that real-time remote data sensing and intelligent data processing provide (Cheng and Teizer 2010, 2014; Teizer et al. 2013; Wang et al. 2015; Golovina et al. 2016).

## 21.11 Summary

Despite existing rules and regulations, safety remains a significant problem in construction. Proposed is an innovative BIM-based platform that allows practitioners to check, among others, for fall-related hazards in building construction. The novel method of detection and prevention these hazards early on in BIM and before construction starts has been successfully implemented in several case studies. The developed computational algorithm are able to detect the location of potential fall hazards in concrete slabs and leading edges, and provide installation guidelines (e.g., bill of quantities, construction schedules) of the corresponding fall protection equipment that solve the identified hazards virtually in a BIM. Furthermore, the results show the effectiveness of the proposed approach in visualizing the fall hazards for work site specific education and training.

Although the automatically generated fall prevention plan and job hazard analysis reports must always be checked by a safety specialist, it allows adjustment if other safety guidelines or best practices need to be followed. Future work might be directed towards commercialization efforts as well as transformation of existing safety industry best practices. As BIM-based safety planning might become part of the standard building construction planning process, early involvement can also increase the safety understanding and communication among all project stakeholders. Requirements for using a formal standardized process and the generation of high quality models that are frequently updated while construction is underway must be set before the developed approach may yield acceptable rates of return.

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