Excellence By Design

A Holistic Life-Cycle Approach to Safety Improvement

By Peter G. Furst

IN BRIEF
- A holistic approach to creating a safe construction site requires a team effort to identify, evaluate and manage site risks. All participants—owners, designers, contractors and safety professionals—must contribute to achieve this goal.
- SH&E professionals must be cognizant of innovative approaches to understanding human error and the need to make the work environment as free of hazards and risks as possible.

Safety by design (SBD) is a comprehensive approach to the entire project delivery process and addresses the safety of all people who work in, use and build buildings. Generally, four groups of people may be exposed to harm when working in/on, or using a facility: 1) the public who accesses structures; 2) employees who work in them; 3) employees who maintain these facilities; and 4) those who construct them. Various codes and standards are designed to address the risks of potential harm to these groups. For example, building and life safety codes ensure that people can exit structures safely during emergencies. Design professionals are required through licensing mandates and codes of ethics to ensure that these standards are utilized in the design of structures. To ensure this outcome, various jurisdictions have code checking and enforcement control of projects slated to be built. City fire marshals routinely inspect buildings to ensure that various safety requirements are maintained during operations.

The safety of those working in these facilities is governed by OSHA 1910 standards. These general industry standards govern safety in relationship to work hazards, and they create the duty for employers to ensure that the work environment and work practices are in line with these standards. The expectation is that compliance will keep workers from harm while they perform their work.

Construction worker safety is covered by OSHA 1926 standards. These standards aim to protect workers as they build a facility. Although these standards have been around for more than 40 years, construction workers continue to be injured and killed on work sites. These outcomes have initiated a search for a more effective way to address construction worker safety.

Prevention through design (PTD), initiated by the International Labor Office (ILO, 1985), proposes that hazards should be "designed out" such that they are eliminated or reduced before workers are exposed to them. This will affect construction and maintenance workers. In the U.S., PTD was first initiated via a study sponsored by the Construction Industry Institute in the 1990s (Hinze & Gambatese, 1996). In 1995, the U.K. mandated PTD, which required designers to perform risk assessment of their design as it affected construction workers. Several other European nations and Australia have since mandated or strongly encouraged PTD.

More recently, NIOSH recognized PTD as a promising approach to worker safety. In 2006, it became one of 10 focus areas of the National Occupational Research Agenda Construction Sector Council. In 2007, NIOSH convened a PTD workshop with nearly 300 participants from eight industry sectors to identify ways to encourage application and use of the concepts.

A systematic review of the literature identifies nine broad safety improvement approaches in the construction industry: 1) personnel selection; 2) technological intervention; 3) behavior modification; 4) poster campaign; 5) quality circle; 6) exercise and stress management; 7) near-hit reporting; 8) safety climate; and 9) zero injury technique. Although all have some effect on site safety,

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they do not address it from a holistic standpoint (Gibb, Haslam, Hide, et al., 2004).

This article addresses the building process, which is complex. The process involves a large number of participating organizations that have unique goals, objectives, personnel, policies, practices and procedures that may or may not be in sync with those of the overall project. This creates a potential for complexity and ambiguity. Also, initial assumptions on productivity and other factors that may or may not occur during a project's life cycle add a level of uncertainty. Collectively, these factors create a potential for variability and will influence the risk that will manifest itself during the project delivery process (Klemetti, 2006) (see sidebar on p. 52).

Risks associated with construction include work production (meeting schedule requirements), financial risks (cost of the work), quality of the work, design problems and lack of safety (Edwards & Bowen, 2005). With the exception of safety, risks are usually controlled and driven by the contract terms. Safety rarely is managed by contract. Traditionally, worker safety is the responsibility of their employer, but the general contractor has overall site safety responsibility under the provisions of the governing safety standards. Generally, production shortcomings are noticed immediately, while risk taking goes unnoticed until an adverse outcome occurs (e.g., incident, loss). As a result, the industry focuses more on production deficiencies than safety shortcomings, meaning production tends to trump protection (Reason, 1997).

Project Delivery

Research over the past couple of decades has shown that many work site fatalities can be attributed to decisions made before any construction work starts (Hecker, Gambatese & Weinstein, 2004). These studies focus attention on the decisions made during the design process that create physical conditions that produce risks that contractors and construction workers must deal with during the building process. Solutions proposed by researchers focus on what the design professional could or should do to mitigate these risks. Some designs result in potential exposure to harm by construction workers, and designers should try to mitigate this when possible. However, in reality, risks originating in the actual design are part of a greater body of risk that exists in this endeavor as a whole.

To properly address this, let's look at the process from inception (the decision by an owner that some sort of facility or structure is required) through the completion of the construction process (Furst, 2002). Key participants in this process are the facility owner (owners, users and facility managers), the designer (architects, engineers and other consultants) and the constructors (the contractor, subcontractors and perhaps a construction manager). The decisions made by this diverse group over the long and complex process affect the body of risks that construction workers, in some way, must deal with in the building process.

Therefore, it follows that to provide a safe work environment, potential risks to construction workers must be identified throughout the system and evaluated for mitigation, then an acceptable solution must be implemented. The three key players must be studied for their risk contribution and their ability to eliminate or reduce such risks or implement mitigating solutions in order to diminish their impact during construction (Figure 1, p. 53).

One area in which researchers have found some implementation of safety considerations during design has been with industrial (heavy engineering) contactors. Several reasons drive this. It is one area of construction industry where design/build is the preferred project delivery method. Owners create performance specifications, then ask a contractor to find the best way to accomplish this. This allows for a more comprehensive approach to project delivery.

Many of these firms have in-house engineering, fabrication and building capabilities. Their construction and safety personnel brainstorm with their engineers during the design process to create a design that takes specifications, fabrication requirements, and construction means and methods into consideration with a focus on efficiency as well as cost control (Hergunsel, 2011). This process maximizes prefabrication, uses pull thinking during workflow, aligns temporary construction needs with permanent maintenance access requirements (where possible), and incorporates efficiency and injury risk assessment into the design development process.

Steel Erectors Association and National Institute of Steel Detailing have produced "erection friendly" details for designers. These groups recommend self-supporting connections in lieu of hanging ones, list awkward and dangerous connections common in the industry, address tripping hazards, sharp corners and space required for making connections providing standard tool dimensions as well as physical space the worker may need while engaged in the erection process. The focus on inte-

Project Delivery Process Outline

Project inception	Project preliminaries Project program
Design	Schematic design Design development Working drawings
Preconstruction	Develop construction schedule Establish construction cost estimate Constructability reviews Logistic and operational plans
Procurement	Create bidders list Issue bid documents and bid requirements Issue addenda as requires Accept bids and review Identify acceptable bid Issue notice to proceed
Construction	Mobilization Contract execution Progress management/scope changes Progress evaluations and payment
Commissioning	Punch list work O&M plus "as-builts" Turnover Final acceptance/closeout
Occupancy	Use Maintenance Upgrades

Note. *Adapted from* Quantity Surveyor's Pocket Book, *1st ed., by D. Cartlidge, 2009, Oxford, U.K.: Butterworth-Heinemann (as cited in "Risk Management in the South African Construction Industry," by P.K. Opolot, N.S. Buys and J.M. Slabber. Retrieved from* ***http://nmmu.ac.za/documents/faniebuys/Slabber%20Buys%20Opolot%20-%20Risk%20management.pdf***

grated project delivery by some astute owners has brought designers contractors and subcontractors together to collaborate in producing a project that is better coordinated, with fewer inherent defects and problems. This collaborative approach has the added benefit of improving the professional and business capabilities of participants and creates greater value for all (Figure 2).

Economic Considerations

The holistic life-cycle approach to evaluating the various risks associated with project delivery as well as potential exposure to building maintenance personnel (Anderson, Marsters, Dossick, et al., 2012) is a system that will not only identify impediments to safe operations but will invariably pinpoint barriers to efficiency, flow, quality and productivity. This process will directly link construction and maintenance performance indicators to the key business metrics and become an integral part of the overarching financial perspective.

Adaptation of this approach will become the driving force in handling the key resource of the project delivery process: money. From this perspective, all three players in process—owner, designer and constructor—have a common method to evaluate the potential value of every decision.

Factors that will foster efficiency, minimize waste, improve flow, reduce cost, while improving worker safety include the use of prefabrication, modularization, preassembly and standardization in design and construction (Huang, Kong, Guo, et al., 2007) as well as building operations. Preassembly makes the task easier while reducing exposure time. It is also easier to control quality in the fabrication shop than in the field due to greater mechanization, specialization of work activities, standardization, control of the work environment and reduction of variability. Shop fabrication also lends itself to error-proofing techniques, which not only improve the quality of the output but also reduce complexity and make operations safer.

This process replaces higher-risk activities with lower-risk ones, substitutes simplicity for complexity, reduces exposure time, and generally makes it easier and safer to perform tasks. When holistically addressing worker exposure, one must critically evaluate the building design, project operational plan, processes and procedures. This approach improves quality and identifies ways to enhance efficiency and productivity, with improved safety as an added bonus. It is based on cooperation and sharing of information between the parties who have a wealth of information, specific knowledge and experience, and the ability to assess risk early on, which leads to implementing meaningful risk reduction changes.

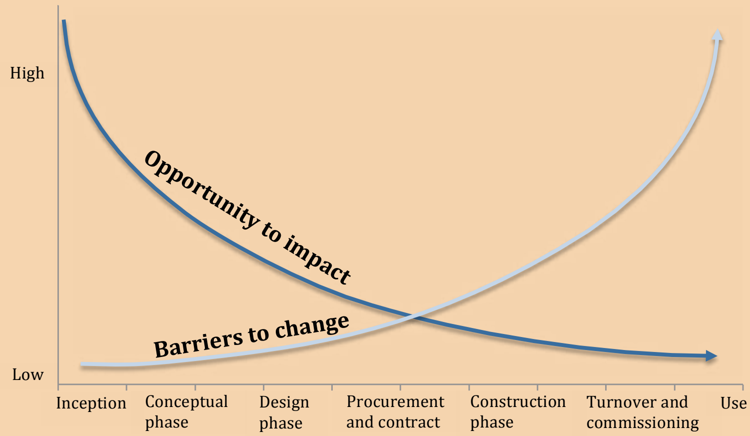
The Owner

Because the owner starts the process, selects the key players, controls the budget, establishes the contract terms and selects the project delivery process, the owner has the greatest influence over the project (Huang, 2003). Therefore, the decisions made at project inception should be carefully assessed for their potential influence on the design and construction process and the resultant risks created during this effort (Bower, 2009). The owner decides what is needed and establishes a project budget and timeline based on financial and business considerations. The owner selects and procures the site, and may also influence the selection of other project participants (Samelson & Levitt, 1982). To some extent, during design development, the owner influences the cumulative project risk faced by contractor teams.

The project owner's initial decisions can influence the quantity and quality of risks that construction workers ultimately face (Mills, 2001). These decisions also may create barriers to elimination strategies at some later point. The type of facility planned, its operational requirements, the site acquired, its location and similar factors present associated risks that flow downstream. In addition, financial and business considerations may dictate certain project duration and completion requirements that will require a contractor to implement scheduling and planning strategies. The owner's budget also affects the contractor's operational and procurement plans. These, too, pose inherent risks that must be considered and balanced against the requirements.

The owner also influences the risk picture through the designer and contractor team selection process (Huang & Hinze, 2006). The services the owner requires from designers and contactors as well as the contract terms affect the risk picture, as do the owner's involvement level in the design process and the extent of the owner's oversight of the actual construction process. The quality of the owner's staff involved in the overall process plays a role as well. Designers, contractors and safety professionals can play a critical role at the project's inception by providing the owner with input on the safety consequences of decisions, and can help selection of alternative solutions that may result in lower system-driven risks (Furst, 2011).

Figure 1
Influencing Building Safety



Note. *Adapted from "Construction Project Safety Planning," by R.T. Szymberski, 1997,* TAPPI Journal, 80*(11).*

The Design Team

From a purely architectural or design sense, SBD is a methodology applied to identify and mitigate risks and hazards that construction workers will encounter while building a facility. This involves systematically incorporating hazard identification, analysis and mitigation steps (Manuele, 2008) during the design phases (Van Well-Stam, Lindenaa & Van Kinderen, 2004). The challenge is to take a conceptual creation and determine what the physical hazards may be during the building process. Some of these risks may be mitigated through design changes while others will not. However, the extent of the risk or its possible outcome may be influenced by the contractor's selected means and methods. Therefore, the constructor must work with the designer to identify solutions that will eliminate the risk or reduce its adverse effects during construction (Walewski & Gibson, 2003).

Many researchers have suggested solutions that designers may implement to address construction worker exposures. For example, some suggest building parapet walls that are 42-in. high to eliminate fall exposure for employees working on roofs. Assuming this does not adversely affect other requirements, it should be incorporated into the design.

However, some solutions may not be viable in certain situations. For example, in northern climates, high parapets may cause snow accumulation on roofs, which could require stronger, more

Figure 2
Project Delivery Integrity

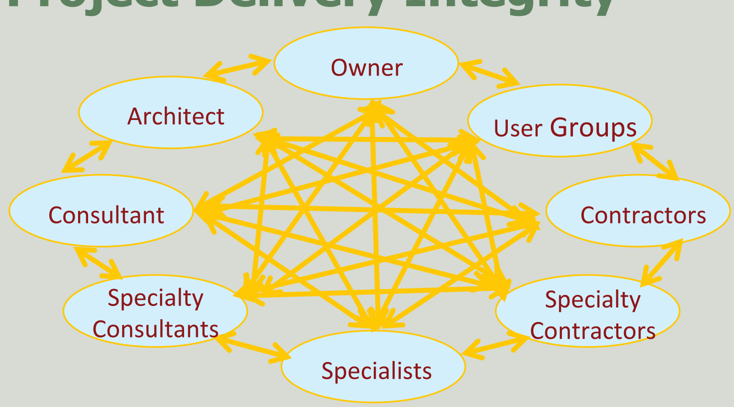


Photo 1: Preinstalling handrails where possible eliminates issues with temporary protection and improves overall safety.

expensive building frames; may require rooftop snow removal, affect the roofing material's life span and additional concerns. In some cases, higher parapets may conflict with zoning restrictions or design board requirements.

Let's consider a building's structural frame, where fall exposures have serious consequences. The frame can either be steel or concrete, each presenting unique hazards and risks. Some fundamental reasons may influence the selection of one over the other, where fall exposure is not a deciding factor. The challenge is to devise a solution that will reduce hazards for workers who are erecting that structural frame. Steel frame erection will create fall exposures if the contractor elects to have workers walk the steel. In buildings with less than 10 stories, a contractor can provide aerial lifts with which the employees access the work area, which eliminates the need to walk the steel. In addition, beam clamps can replace the choker cable, which also eliminates the need to walk the steel. Consequently, the contractor's means and methods play a key role in reducing the work site risk (Furst, 1999).

Other considerations help improve job safety. Creating design solutions that are inherently safe to install may need input from contractors. For example, equipment placement and prefabrication of assemblies will reduce worker exposure time. To some extent, contractors can address this during the shop-drawing phase to reduce risk. The design should provide adequate space to allow workers to safely perform installation. Creating a design that lends itself to prefabrication, modularization or make-ready also minimizes exposure time. Designers should be open to such modifications in the interest of risk reduction. Reviewing the constructability of details also reduces the risks faced by construction workers, and costs much less and is less disruptive than adjusting during construction.

The design team will require some education in construction means and methods (Gambatese, 2003) as well as an appreciation for the risks faced by construction workers. They must gain an understanding of how to use design tools to identify risks and hazards (e.g., building information modeling, virtual modeling, risk focus). Then, contractors and safety consultants must help identify additional risks and hazards, recommend mitigating solutions that meet design requirements and intent, and create a safer work environment. Designing for safety also entails communicating to all the involved contractors the remaining risks and hazards that could not be eliminated during design so that they may implement appropriate controls or select means and methods that reduce their effect.

Architects, engineers and other consultants are reluctant to address construction worker safety as part of their standard practice for many reasons (Behm, 2004). Design professionals' codes of ethics, such as the code established by American Institute of Architects, set ethical priorities for ensuring final occupant safety and safety of the finished facility, but do not address worker safety during construction. These professionals also avoid addressing worker safety based on concerns that doing so may create legal liabilities (Gambatese, 1998).

In general, no legal, contractual or regulatory requirements mandate incorporating SBD. In addition, a large body of legal opinion and court cases may discourage design professionals from engaging in site safety issues. Design professionals interested in engaging in SBD will find it difficult to find insurance coverage for such an activity, since risk transfer products are not readily available in the marketplace (Toole, 2005).

The Construction Team

A contractor and its subcontractors play a significant role in project safety and the risks encountered by workers (Osipova, 2008). The two major concerns are the means and methods a contractor selects to execute the operational plan (Furst, 2000), and the procedures employed to create a safe work environment (Furst, 1999). An initial operational plan, including a project schedule, establishes the project bid price and/or preconstruction services. Safety is rarely a consideration, except perhaps some major exposures (e.g., falls during steel erection, excavation engulfment protection, scaffolding issues). These considerations and protective methods usually are devised to meet production goals and minimum OSHA standards. This is when some key decisions are made on how best to meet the contract terms and expectations. These core decisions have associated risks and must be evaluated for their ultimate implications on worker safety.

The contractor's means and methods usually are based on elements such as familiar and tried methods, past project experience, equipment and personnel, and financial considerations (Samelson & Levitt, 1993). At this juncture, project risk and worker exposures are often not a key consideration. Therefore, the contractor must use innovative construction management processes to minimize such risk.

For example, tools for scheduling and a lean project delivery process all help minimize work site uncertainty and variability risks. Such risks play a critical role because they are a product of partners failing to deliver on promises, which causes the project to enter reactive or recovery mode. Due to time pressures, project staff may not perform a robust risk assessment of the modified plan; this allows more risk to enter into the process, which increases the probability of adverse safety outcomes. A contractor's use of innovative tools and approaches also creates fewer challenges for the designer in eliminating risk through design.

At this point, execution of the safety plan is key. If safety is not perceived as a core value and production levels are affected, the field supervisors may push production at the expense of safety. Workers' thought processes are also a factor; if faced with a choice between working safely and being more productive, workers may decide to take risks so as to stay employed. Furthermore, since risk taking does not always result in incidents or injuries, it can become routine for workers, and may be accepted and rewarded by field supervision. Construction supervisors often have received little management, interpersonal or motivation skills training and, thus, may have limited understanding of why people do what they do, which limits effectiveness in identifying and mitigating worker-initiated risks (Furst, 2007).

Established safety standards do not necessarily create risk-free conditions. For example, falls from heights are treated differently in various standards. Fall exposure for most trades is limited to requiring protection if the fall distance is greater than 6 ft (Subpart M). Yet, scaffold erectors do not require fall protection until workers are exposed to falls greater than 10 ft (Subpart L). Metal deck installers, welders and several other tasks (trades) do not require fall protection until the fall exposure exceeds 15 ft (e.g. Subpart R). In addition, steel connectors do not require fall protection until workers are exposed to falls greater than 30 ft (Subpart R). So, following these standards, especially for steel erection projects, will produce considerable risk to workers. To provide an injury-free work environment, a contractor should exceed these minimum standards in devising employee protections.

A case in point is assessing means and methods selected for fall protection implemented to protect workers from falls when disconnecting the sling (choker) from the middle of the beam after it has been placed and connected. The usual method of providing an anchor point is to install a cable in the beam's flange area to which the worker is directed to attach a lanyard. Should a worker fall, the total fall distance (the distance from where the feet are before the fall to where feet end up after) can be 14 to 18 ft depending on some variables (Ellis, 2001). Since many commercial buildings have a floor-to-floor height of around 12 ft, this worker may hit the lower-level steel and suffer serious injury despite the fall protection solution. Therefore, the fall protection system the contractor selects (typical for the industry) to protect employees is ineffective. This presents a design element in the contractor's area of control that needs to be addressed when selecting ways to protect the workforce. Furthermore, some subcontractors can produce shop drawings and have an opportunity to incorporate (design) risk reduction interventions into the process and, thereby, reduce the cumulative project injury risk.

Looking at another specific situation, depending on the structure's height, workers may be able to perform such a task from an aerial lift, which eliminates the need to "walk the steel" and the fall exposure. Should the steel member weight be within the capacity range of clamps, another option is to replace the sling (choker) configuration with a safer option. It may also be possible to use a different sling configuration that will eliminate the choker and can be performed from the beam ends; this eliminates the need to walk the steel.

All such options must be explored during a contractor's planning stage so that costs can be discussed and considered in the bid price. If an owner does not consider the safety aspects of the operational plan, then the contractor must make a business decision; typically, this means matching industry standards (which competitors will use in bids) to remain competitive. This outcome highlights an owner's impact on a contractor's choices.

Now, let's consider safety procedures that a contractor may employ to provide a safe workplace for its workers. Common techniques include orientation, meetings, programs, rules, training, engineered controls and inspections. Any construction planning performed may consist of completing job hazard analyses for high-risk tasks (usually only by large contractors), and the use of a 2- to 3-week look-ahead schedule designed to resolve any safety issues.

Safety discussions during construction are usually a small part of the production/coordination meetings. This is an ineffective application of the planning process, which is a powerful tool contractors can use to create an injury-free work site (Furst, 2004). Most organization's safety programs rely heavily on OSHA standards, which do not necessarily provide a safe work environment. Furthermore, like many other organizations, contractors are usually vertically organized; this introduces the inherent barriers to effective communications and departmental silos with potentially conflicting goals that add to the possibility of risks being imposed into the project delivery process.

Safety Management & the Safety Professional

Based on early studies (e.g., Heinrich, 1959), safe performance has often been attributed to employee performance. As a result, safety programs, policies and procedures have generally focused on controlling the physical environment and worker behavior. The underlying assumption is that fixing workers will resolve safety problems.

While workers control their own behavior and make choices that may lead to incidents, much more is at play in the workplace. Job site management can exercise considerable control over virtu-

A contractor's use of innovative tools and approaches also creates fewer challenges for the designer in eliminating risk through design.

Figure 3
Holistic Approach to Safety

ally everything that transpires in the workplace, including workers behavior and decision making. This is especially true of the immediate supervisor's role in fostering safe work practices (Furst, 2007).

Consider a case where an owner requires an accelerated schedule and a competitive bid structure. These influence the risks at the work site. For example, based on accelerated production, a contractor may not be able to eliminate the imposed risks. Aggressive pricing may limit resources available for instituting mitigating interventions that would diminish identified work risks.

Safety improvement strategies often start with a review of past losses. This analysis establishes future interventions, which often encompass more training, emphasis on certain program elements or more rigorous inspections. In the short term, such interventions produce improved safety outcomes.

However, long-term results rarely live up to expectations because the future never replicates the past, and data analyzed may not present a true picture of all contributing causes. The focus generally is on the worker, not on the systems, processes, culture and related factors. Since the worker is a part of the system that takes the design information and builds the physical structure, trying to change worker behavior does not remove the underlying cause of the behavior. That remains to manifest itself in the actions of the next injured worker.

Several areas in the safety management process do not align with innovative thinking. For example, safety is generally end-of-the-line focused and vertically managed, while it should have a cross-departmental focus and a functional horizontal value flow. Safety objectives are usually misaligned with business goals (Furst, 2003) and are not integrated into operational processes. Too often, safety metrics are not related to measures used to manage an organization. Ideally, safety should report to senior management and be an organizational core (Furst, 2006).

Conclusion

A holistic approach to creating a safe construction site (Figure 3) requires a team effort to identify, evaluate and manage site risks. All participants—owners, designers, contractors and safety professionals—must cooperate and contribute to achieve this lofty goal. Paying close attention to the risks associated with the owner's requirements, the facility's design, integrating safety processes into contractor operations and using innovative approaches to managing the safety process are crucial. SH&E professionals must be cognizant of innovative approaches to understanding human error (Dekker, 2006) and the need to make the work environment as free of hazards and risk as possible. Project owners play a crucial role in orchestrating and managing the construction process via cooperation between the design team and the contractor team with support from a construction-process-knowledgeable SH&E professional. **PS**

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Photo 2: Alternatives to walking the steel can improve efficiency while greatly reducing risk to workers.


Photo 3 (far left): Use of aerial lifts eliminates some walking the steel needs while greatly increasing productivity and safety.

Photo 4 (left): In addition, preassembly of roof components increases efficiency and reduces the exposure time of working at heights.

Photo 5: Use of 3-D modeling by a general contractor in work sequencing improves job coordination, subcontractor efficiency and overall job safety.

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