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Construction

Safety in Design: A Proactive Approach to Construction Worker Safety and Health

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Safety through design is a familiar concept to occupational hygienists. Indeed, the primacy of engineering controls in the hierarchy of controls that is fundamental to the discipline derives from the principle of safety through design. The use of ergonomic redesign to reduce risk factors for work-related musculoskeletal disorders is another prominent example of the application of this concept. Unfortunately, construction workers comprise one group of employees that has previously received limited benefit from safety through design. While architects and engineers clearly consider safety in their designs, the target of their efforts has traditionally been the end user of the facility rather than those who will construct it. This is slowly beginning to change. This article describes the current state of activity in safety through design for construction, including barriers and the efforts to overcome them. Also presented are preliminary findings from a case study of a safety-in-design effort on a large industrial construction project in which the authors are involved.

Research has identified a number of barriers to designer involvement in construction worker safety. Designers often mention that they lack training to address construction worker safety, and that there is no central body of knowledge available to them to compensate for this.[1] In many cases, designers report that legal advisors and insurance companies specifically advise them not to address safety in construction to avoid assumption of liability.[2,3] In the traditional design-bid-build construction model, there is a strict separation between the design process and personnel, and the constructors. The building contractor typically bears the responsibility for worker safety in keeping with that entity's control over the "means and methods" of construction. The cases in which construction worker safety is considered during design tend to be in design-build firms where the design and construction components are part of the same company.[2]

Recent evidence suggests that the construction industry is paying increasing attention to this issue, and that addressing construction worker safety from the design side is becoming more common. The push comes in part from Europe, where the European Union (EU) has recognized these issues in legislation promulgated in 1992 on the "Control of Hazards on Temporary and Mobile Construction Sites."[4] The national laws that implement this directive, such as Britain's Construction (Design and Management) Regulations, place duties on construction owners, designers, and contractors for consideration of safety issues from design through execution of construction projects.[5]

The European effort stems from studies of construction accidents and injuries, suggesting that a significant proportion of such events have their origins upstream from the building process itself and are connected to such processes as planning, scheduling, and design.[6,7] One such analysis contends that 60 percent of construction accidents could have been eliminated, reduced, or avoided with more thought at the design stage.[8] According to Gibb,[9] the impact of these regulations on changes in practice is highly variable across European countries, and it is too soon to see any significant impact on safety outcomes. However, there has clearly been an increase in the profile of construction safety among designers in several countries.

In the absence of legal mandates, two other factors are driving the role of designers in construction worker safety. Some large consumers of construction services who recognize the cost impact (financial and otherwise) of worker injuries on their large, time-sensitive projects, are looking at all elements of the design and construction process for opportunities to improve safety. Second, the rapid growth of the design-build contract delivery system in recent years facilitates greater involvement of designers in the construction process, including the aspect of worker safety.[10]

Tools are becoming available to assist designers in these efforts. Gambatese et al.[1] developed the "Design for Construction Safety ToolBox," a safety-in-design project planning software package based primarily on input from construction and design-build personnel. The software provides a flexible tool for designers to see a variety of project- and system-specific design suggestions as they are developing the design. Following are examples of suggestions from this package for consideration by design professionals when creating designs:

- Design windowsills and roof parapets to be 107 cm (42 in) above the floor/roof level. Windowsills and parapets at this height meet the guardrail height requirement prescribed by OSHA. This eliminates the need to install guardrails during construction and when future

maintenance work is conducted on the completed structure.
- Provide anchorage points for safety lines on the roof and at locations surrounding elevated work areas. Anchorage points designed into the permanent structure can be incorporated into the construction activities to provide personal fall protection systems and control fall hazards.
- Design the reinforcing steel in mat foundations and slabs to be closely spaced. Reinforcing steel placed in a closely spaced grid pattern provides a continuous walking surface free of tripping hazards.

An obvious addition to these suggestions from the occupational hygiene perspective is the consideration of toxicity and exposure potential to construction workers in the specification of coatings, adhesives, and other construction materials.

Life Cycle Safety: A Safety in Design Case Study

The authors of this article are part of a research team currently studying a safety-in-design intervention in the United States. The intervention site is a greenfield semiconductor factory (fab) being constructed on a large existing campus of an electronics manufacturer. This fab is a prototype for a new generation of fabs and will likely be replicated a number of times. The owner has been involved in the construction of semiconductor fabs in the United States, Europe, and the Middle East, several of which were in conjunction with the construction manager and design firm involved in the current project. A number of separate but related events and experiences led to the focused safety-in-design effort on the current project.

The company has a strong history of continuous improvement and bringing forward "lessons learned" from earlier projects. The design firm had developed a safety-in-design checklist, a database of design issues identified as potential problems for construction or facility operation, and was striving to make this into a more interactive and open-ended tool for the designers, rather than simply a "check the box" exercise. The owner's interest in pursuing design implications for construction and operations had been heightened during the construction of a fab in western Europe some years earlier, during a time when the EU directive was being transposed and ratified into regulations in the member states.

The same campus had also been the site of an ergonomics intervention research project in 1995–1996 and 1998–1999.[11] This project had heightened awareness of risk factors for musculoskeletal injuries during construction and had identified a number of specific instances of design decisions that exacerbated some of these risk factors. For instance, the concrete floor of the cleanroom level of a fab is typically poured as a "waffle deck," containing thousands of circular openings covered by steel "popouts." This accommodates many electrical and mechanical utilities that must penetrate from the utility level below to the cleanroom level, without having to core-drill concrete each time a pipe or conduit needs to be rerouted.

In an earlier fab at this site, a value engineering decision resulted in a section of this floor being poured without the circular openings. However, two years later during a retrofit of this fab, this section was converted to cleanroom use. As a result, thousands of 14-inch concrete cores had to be drilled from above and handled from below, creating exposure to ergonomic risk factors among the workers, especially those doing overhead work. In addition to the safety and health risks, the initial savings from not incorporating the openings was exceeded many times by the core-drilling contract.

The campus also had an ambitious injury-free workplace program in place for more than five years prior to the current project. While successful in many areas, the owner's construction program manager was particularly interested in gaining greater subcontractor involvement in safety programs prior to the construction phase.

Development of the Safety-in-Design Process

In the early stages of the programming phase of the project, when major building concepts were evaluated against a plan of record and the building layout was determined, a safety-in-design task force was formed. The charge of the task force was to develop a process for increasing the focus in the design stage on safety issues in construction and subsequent building phases. Membership included senior representatives of the three main parties to the design process: the owner, the design firm, and the contractor serving as construction manager (CM), along with an outside safety consultant who facilitated the process. The CM was retained as the construction manager for the programming phase in recognition of the importance of bringing the knowledge and experience of the construction community into the process early, but at that point was not guaranteed the construction management contract for the building phase.

Owner members of the group represented different departments within the company. Some were from the construction group, which oversees capital projects and delivers them to the production part of the company. One member represented the owner's facilities operations because operating and maintenance technicians, along with construction workers, were key groups affected by design decisions.

As one of its early activities, the task force organized focus groups with trade contractor personnel who had worked on previous projects at the campus. Four disciplines: structural/architectural, dry mechanical, electrical, and piping provided input concerning design-related elements that they felt affected safety and constructability for members of their trade on these previous projects. Subsequently, the owner operations member of the group conducted a similar exercise with facilities maintenance personnel. The focus groups provided a database of

196 items with issues and suggested design solutions identified. This data went to the work groups who participated in the programming phase of the new fab design.

The task force also developed a process and tools for these work groups to use in evaluating design options during programming. The plan of record (POR), or baseline design, was the last fab built on this campus. Seven work groups representing different disciplines (e.g., electrical, mechanical, civil/structural/architectural, etc.) conducted the actual reviews. Each group included at least one representative of the owner, designer, and CM organizations.

The task force benefited from a concurrent emphasis by the owner's factory group on putting safety in design as one of its goals for the new building along with such traditional goals as cost, energy consumption, emissions, and schedule. An early and significant decision made by the task force was to change the name of the process from Safety in Design to Life Cycle Safety (LCS). The group felt the former name implied that all safety responsibility lay with the design firm, and they wanted it to be clear that all parties had something to contribute in creating a safer design. Also, the owner's overall goals for the new fab were aimed at designing and constructing a facility that would satisfy needs throughout all life cycles: programming, detailed design, construction, operations and maintenance, retrofit, and decommissioning.

Programming Outcomes

One major programming decision illustrates the role played by LCS. Though many factors are in play in the design process, and we cannot say with assurance that the choices made would have been different without LCS, our review of documents and interviews with participants strongly suggests that the process gave a greater airing to issues and perspectives that contributed to the ultimate outcome.

Fabs are multi-level structures that typically include a utility level just below the cleanroom (or fab) level. Below this utility level in the POR fab were trenches, while previous designs had included a full basement. The electrical and mechanical focus groups had expressed a strong preference for a basement over trenches to relieve utility congestion and avoid trades regularly working on top of each other. The work groups devoted substantial attention to this issue during the programming discussion. The added costs and hazards associated with constructing a basement were weighed against the legitimate concerns over congested work areas and adequate space for utilities. The final design called for a second utility level on grade, satisfying the need for the additional space that a basement would provide, but with far less excavation, and improved access. In a related decision, additional headspace was added to the utility level to provide more space for utilities and to reduce the incidence of "head-knocker" injuries among the trades.

Detailed Design Phase

As the project moved from programming to detailed design, a concurrent LCS review step was incorporated into the design review process. The LCS reviews were conducted on each design package with input coming from trade contractors, operations and maintenance personnel, and other stakeholders with knowledge of the systems being designed. Each organization (owner, CM, and design firm) provided an LCS facilitator to organize and manage these reviews. The watchword of the LCS process was "Right people, right ideas, right time," indicating the value of knowledgeable input but also the importance of that input coming at a time when it could still be practically incorporated into the design.

Comments collected in these reviews were logged and passed on to the design team for adjudication, after review and filtering by appropriate discipline-based owner representatives. The comments could be 1) accepted "as is" or in modified form, 2) rejected for a variety of reasons, or 3) referred for mitigation during the construction phase if they raised legitimate safety concerns but were more appropriately addressed in construction than through design. The latter included cases where sequencing of work or availability of specific types of equipment would address the hazard.

Data collection and analysis are still underway on this project to assess both process and outcome measures. (Our research focuses on the construction phase, though there is obvious interest in impacts on operations, maintenance, and other phases as well.) Exit interviews are being conducted with field supervisors for all major trade contractors who have worked on the project to gather data on what actually happened in the construction phase and to determine whether issues identified either in the preconstruction focus groups or during the LCS review process were adequately addressed. We are analyzing LCS review comments to assess their relevance to safety as well as their potential collateral impact on productivity, quality, and other aspects of construction. These data are supplemented by extensive qualitative data from interviews and focus groups with owner, CM, designer, and trade contractor participants in various stages of the LCS process.

Conclusion

A full reporting of outcomes from our research is premature, but several preliminary conclusions can be drawn. The bridging of the gap between constructor experience and knowledge and the design process is a promising step toward improved construction worker safety, and perhaps toward improvements in productivity, quality, and other important aspects of construction work as well. Most participants in the LCS process, regardless of organizational affiliation, expressed the belief that the input of trade contractor personnel adds value to the design process, and that the cross-disciplinary review process generates ideas and concerns that might not otherwise emerge.

LCS is not a panacea for safety improvement, but its high profile in this intervention does give greater visibility to safety issues at all stages along the design-construction continuum. As construction has progressed, we have already seen that there have been both "hits" and "misses" in terms of items that LCS has identified and remedied and those that, for whatever reason, it did not. One gap that has been identified is that a significant portion of design work, notably the design of temporary structures, takes place under the trade contractors' direction. Therefore, a safety-in-design effort needs to consider other design processes in addition to that conducted by the owner's design contractor.

In the broader picture, the advance of safety in design for construction is likely to be evolutionary. We will need more and better education and tools for designers on construction safety and health issues, improved data linking design decisions to safety and health outcomes, evidence that the benefits outweigh the costs, and greater clarity regarding liability issues. A growing dialogue between constructors and designers can offer benefits to both groups, with an ultimate outcome of improved construction worker safety and health. It is our hope that large construction consumers will increasingly recognize these benefits, and that they will create demand for, as well as facilitate, the process.

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