THE FUTURE OF DESIGNING FOR CONSTRUCTION SAFETY
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ABSTRACT
Designing for Construction Safety (DfCS) is a process in which engineers and architects explicitly consider the safety of construction workers during the design process. Although the process has been required in the UK since 1995 and the initiative is gaining momentum in the U.S. on a voluntary basis, there has been little theory to date to predict or guide the evolution of DfCS. This paper suggests there are four trajectories along which DfCS will likely evolve.

1. Designs will increasingly facilitate prefabricated construction because prefabrication shifts work to safer environments, such as from the field to the factory and from elevation to the ground.
2. Designers will increasingly choose materials and systems that are inherently safer than alternatives.
3. Designers will increasingly apply their expertise in engineering principles to perform construction engineering.
4. Designers will increasingly apply spatial considerations to reduce worker hazards, such as ensuring plans consider ergonomics, minimum working clearances for typical tools and equipment, and proximity to site utilities.

The paper also discusses what changes will be needed in engineering education and practice due to the growth of DfCS in general and the four trajectories identified above.

Keywords: Design, Safety, Constructability, Trajectories.

INTRODUCTION
Designing for Construction Safety (DfCS) is a process in which engineers and architects explicitly consider the safety of construction workers during the design process. One can think of DfCS as another aspect of designing for constructability, i.e., the design is reviewed to ensure it can be constructed safely, as well as meet cost, schedule and quality goals. DfCS has three compelling theoretical merits. First, because it is recognized that construction is one of the most dangerous industries, it makes sense to assume that all professionals associated with the construction process—including owners, contractors and designers—should be willing to work towards reducing construction injuries. Second, because many injuries are associated with forces, stresses, dynamic motion and electricity, it makes sense to expect that individuals with a strong educational background in these topics would consider safety as they make their design decisions. Third, as is true for cost, quality, and schedule, decisions that dramatically influence project safety occur early in the project life cycle and are usually made by designers. While DfCS is still somewhat rare in the U.S., there are many signs that it is gaining momentum. For example, the American Society of Civil Engineers’ Construction Institute has recently established a DfCS Committee. The National Institute of Occupational Safety and Health

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(NIOSH) NORA Construction Sector Council named DfCS as one of its Top 10 priority areas and NIOSH is holding a 300 person national conference on Prevention through Design in July 2007. OSHA has a DfCS workgroup that has met quarterly since 2004 and made presentations at conferences across the U.S. (OSHA 2007). Yet the U.S. lags other countries in the diffusion of DfCS. The UK passed a law requiring designers to perform DfCS in 1995, which has been adopted throughout the European Union. Australia is also moving towards mandating DfCS. Although the literature on DfCS (summarized in the next section) is growing, design engineers do not know enough about construction site safety, much less how to perform DfCS. The Construction Industry Institute funded the development of a DfCS toolbox in the mid-1990s (Gambatese, Hinze and Haas 1997) and information and tools for DfCS are available on international government websites (SID 2007, New South Wales 2007). Yet the literature has not addressed technical principles underlying DfCS to help designers better perform DfCS, to facilitate the development of additional DfCS tools, and to predict the future path of DfCS. The goal of this paper is to address this gap in the DfCS literature by suggesting there are four trajectories along which DfCS will likely evolve.

The paper’s structure is straightforward: the existing literature on DfCS is reviewed, the four DfCS trajectories are explained, and the implications of these trajectories on engineering design practice and education needs are discussed.

LITERATURE REVIEW

Prevention through Design (PtD)—the concept that significant reductions in injuries can occur when safety is designed into a product, service or process—has been established within the general occupational safety field for many decades (Manuele 1997). Applying the concept to construction—often called Designing for Construction Safety—is a more recent development. The journal article on DfCS that garnered industry attention was published in the *Journal of Construction Engineering and Management* in 1992 by Frances Wiegand and Jimmie Hinze (Wiegand and Hinze 1992). Gambatese completed his doctoral dissertation in 1996 (Gambatese, 1996) and drew industry attention to the topic through papers published shortly thereafter (Gambatese 1998, 2000). In 2003, a symposium focused on DfCS attracted over 100 engineers, architects, safety researchers, and government employees (Hecker et al 2004). In 2005, articles on DfCS were published in *Safety Science* (Behm 2005), the *Journal of Construction Engineering and Management* (Weinstein et al 2005) and the *Journal of Professional Issues in Engineering Education and Practice* (Rubio et al 2005, Toole 2005). (A full list of DfCS articles can be found at www.designforconstructionssafety.org.)

Although these publications in leading journals and other DfCS publications have articulated the concept and application of DfCS and shown it to be viable despite the existence of significant practical barriers, no article has articulated how the principles and processes that underlie DfCS will likely evolve over time. By understanding how DfCS will be manifested in the engineering-procurement-construction (EPC) industry, practitioners can better prepare for adopting DfCS within their organizations and construction and engineering educators can better prepare their graduates to perform DfCS.

FOUR DFCS TRAJECTORIES

A classical problem in physics is to calculate the trajectory of a moving body, such as a projectile fired from a cannon. If one knows the initial velocity and direction of the projectile and environmental variables such as wind, one can calculate when and where the projectile will land.
Social science constructs such as innovation have also been discussed as following trajectories (Dosi 1992). For example, Toole (2001) showed how the characteristics of the construction task, process and industry have caused innovative building products to follow one or more of four specific trajectories. The concept of trajectories can also be applied to DfCS. Using the analogy of a projectile, if we know the initial direction of the DfCS projectile (that is, the underlying concept or goal), the initial velocity (the current publication rate and breadth of professional organizations promoting DfCS), and the environmental conditions (the engineering design task and process, the construction task, and the structure of the EPC industry), we can better predict how DfCS will evolve as it is diffused within the industry. The authors have identified four specific trajectories that DfCS is likely to follow:
1. Increased prefabrication
2. Increased use of less hazardous materials and systems
3. Increased application of construction engineering
4. Increased spatial investigation and consideration

1. Prefabrication

Construction has traditionally involved the assembly of relatively small pieces (i.e., pieces that can be lifted by one worker or at least transported on a truck) in their permanent location. Prefabrication involves the assembly of pieces in one location, followed by the transportation of the assembled component to its permanent location and the final fit up. Prefabrication has increased steadily over the past 100 years because it facilitates improvements in cost, schedule and performance (Toole 2001; CII 2002; Hewitt and Gambatese 2002). Prefabrication also reduces the hazard level of a task in two ways. First, it allows the location of the work to be shifted to a lower hazard environment (Gambatese et al 1997). For example, work can be shifted from a high elevation to the ground (where fall injuries are much less likely), from an excavation to grade (where there is no risk of cave-in), or from a confined space to a clear space (where there is less risk of hazardous air quality). Second, prefabrication allows the work to be shifted from the field to a factory, which allows the use of safer, automated equipment, such as for cutting and welding. Factory equipment reduces the incidence of musculoskeletal hazards through improved safeguards and reduces air quality hazards through engineered ventilation.

Bridge segments, structural steel column trees, steel stairs, concrete or wood wall panels, metal and wood joists and trusses, HVAC ducting, and plumbing pipe trees are all common examples of components that can be prefabricated and erected using inherently safer processes and environments.

How fast will DfCS through prefabrication diffuse? It is important to note that prefabrication will increase gradually due to cost, schedule and performance benefits regardless of whether DfCS diffuses through the industry. Although shipping costs and size limitations will continue to limit the growth of prefabrication, the improved application of information technologies to facilitate information flow and mass customization will drive increased prefabrication. Such information flow will play an important role in the growth of DfCS because designers typically lack sufficient knowledge about specific opportunities to design and specify prefabricated assemblies on their projects. Due to the fact that designers are not yet seeking safety-related aspects of prefabricated assemblies and manufacturers of prefabricated assemblies are not yet using information technologies to communicate the safety benefits of their products, it will likely be at least ten years before significant diffusion of DfCS through prefabrication occurs.

2. Increased use of less hazardous materials and systems
Engineers and architects typically specify *materials* based on perceived or experienced performance and cost (or sometimes simply by what is included in the boiler plate technical specifications), rarely on the inherent safety of the materials for construction or maintenance workers. Progressive owners and designers are becoming increasingly aware that some materials offer essentially similar performance and cost as that of competitive products, yet are considerably less hazardous to apply. This is particularly true for coatings, adhesives and cleaners, which are associated with air quality, flammability and skin hazards (Weinstein et al 2005). As information technology makes it easier for designers to obtain information about the inherent hazard level of various building materials, designers will increasingly be expected to apply this information in their design decisions.

Designers will also be expected to consider the inherent hazard level of various building *systems* during the design process. Continued safety research will eventually identify the conditions that make concrete, steel, or wood building systems safer than alternative systems, and designers will be expected to consider this criteria along with cost, quality and schedule. The use of prefabricated, integrated (i.e., such as wall or roof panels that provide both structural and exterior finish functions) are other examples of building systems that may offer inherently safer installation processes and will therefore need to be considered by designers.

As was the case with the diffusion of DfCS through prefabrication, diffusion of DfCS through designers’ explicit decision to use safer materials would likely not be significant for at least ten years because designers are not yet seeking such information and manufacturers are not effectively providing it. It is likely, however, that designers’ increasing interest in sustainable (i.e., “green”) design will likely have spill over effects on DfCS. That is, designers’ increasing specification of materials that are less hazardous to the environment will lead to increasing specification of materials that are less hazardous to construction workers. Consequently, DfCS through safer materials may begin to increase significantly in as little as five years.

### 3. Increased application of construction engineering

There are numerous instances during the construction process when engineering is required to plan or execute the construction task. Soil retention systems, crane lifts and other major material handling tasks, soil bearing analysis for supporting construction equipment, temporary structures, fall protection anchorage points, and temporary load analysis are all examples of construction tasks that require the application of engineering principles. Traditionally, contractors have been required to provide these construction engineering tasks through in-house employees or consultants and design engineers hid safely behind the typical contract clauses that they had no responsibility for means, methods or project safety. The industry is changing in this area as well. It is the authors’ perception that OSHA and progressive owners are realizing that when design engineers perform no engineering related to the construction process, important construction engineering tasks may be performed by unqualified personnel or not performed at all. In addition, the growth of design-build is increasing the ability and willingness of design engineers to perform construction engineering tasks. The authors therefore believe that design engineers will increasingly be required to apply their expertise in engineering principles, their detailed understanding of the structure their firm designed, and their familiarity with the site based on months of site investigation to perform construction engineering less expensively and more effectively than contractor personnel. Progress along this trajectory is likely to start within the next few years due to the aggressive (and appropriate) initiative by several national construction trades organizations to have the
locations and details for fall protection anchorage devices shown on structural drawings (Gambatese et al. 1997, Behm 2005).

Other factors may slow the progress along this trajectory, namely, designers’ fear of incurring liability and their lack of sufficient knowledge of construction means, methods and hazards. In other words, many design engineers do not want to and do not know how to perform many construction engineering tasks. Legislation that would allow designers to perform DfCS without incurring inappropriate liability and the increased use of information technology that provides a graphical depiction of the construction process (i.e., process visualization) will help alleviate these two barriers.

4. Spatial investigation and consideration

When asked if they consider during the design process the proximity of site hazards such as overhead power lines, underground pipes and adjacent structures, most design civil engineers would respond affirmatively. Conversations the authors have had with dozens of construction professionals, however, suggest this is not the case. Design engineers typically obtain site utility plans from the local municipality or the site owner that contractors do not obtain, yet such utilities are often not shown on the plans, much less considered during the design phase.

The growth of both DfCS and design-build will elevate the standard of care for design to include depicting all potential site hazards on the project drawings. Furthermore, design engineers will be expected to possess at least a crude understanding of necessary working distances for each of the various construction trades and common tools. Examples include the minimum legal proximity for cranes to powerlines, the minimum trench width necessary to allow efficient pipe placement and connections, and the minimum spacing between electrical raceways and adjacent structures to allow safe and efficient installation.

Spatial considerations for constructability will also include ergonomic issues. For example, the design of structural steel connections will not only include consideration of the clear space needed around structural steel members to install bolts or field weld, but also whether the connection requires the worker to work over his or her head or at an awkward angle that is more likely to result in musculoskeletal injuries (NISD/SSEA 2001, Toole et al. 2005).

Progress along this trajectory will likely occur slowly over the next ten to fifteen years because (with the exception of steel erection, as referenced above), the necessary clearances and ergonomic issues for specific trades have not been published.

IMPLICATIONS AND CONCLUSIONS

This paper began by suggesting that the increasing national activities relating to researching and promoting DfCS indicate DfCS will become diffused in the EPC industry. To fill a gap in the growing DfCS literature, this paper suggested that the application of DfCS concepts will evolve along four trajectories: increased prefabrication, increased use of less hazardous materials and systems, increased application of construction engineering, and increased spatial investigation and consideration.

The paper identified various factors that will slow the progress along these trajectories, chief among being that most civil engineers possess neither the knowledge of construction safety nor the knowledge of construction processes necessary to effectively perform DfCS (Hecker et al. 2005, Toole 2005). The primary implication of the diffusion and evolution of DfCS predicted in this paper, therefore, is that civil engineering curricula and perhaps engineering licensure requirements must be modified to include more construction courses, including site safety. Civil
engineering educators must increase their emphasis on design for constructability and broaden it to include safety constructability, including considering safe and efficient working clearances for each construction trade.

Another implication of the growth of DfCS is that design civil engineers will need to become better information gatherers and communicators on project-related information that they currently do not sufficiently address. Such information includes site utilities and the applicability and availability of prefabricated components. Design engineers will need to establish procedures for communicating with prefabricators before projects are awarded in order to ensure their designs lend themselves to prefabrication whenever possible.

The gaps in knowledge and communication channels that hinder DfCS adoption will be less for one group of design engineers: those that are part of design-build teams. The growth and evolution of DfCS is therefore expected to be led by the design-build market segment.

REFERENCES


