



Alternative Approaches to Incorporate Design for Safety into Construction Engineering Curricula

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Introduction

From both an ethical and practical viewpoint, civil and construction engineers must design safety into buildings, facilities, and the associated construction processes. The pre-construction phases of design clearly involve information processing, and therefore to change how design is practiced, one must change the knowledge civil and construction engineers use in their design decisions. The *objective* of this paper is to review design for safety (DfS) principles and practices, then identify and evaluate alternative approaches to incorporate DfS into construction engineering curricula. As BS and MS programs in construction engineering multiply, the appropriate inclusion of safety topics is an important decision for the program faculty. The *specific purpose* of this paper is to provide construction engineering faculty with a basis for this decision. The approach chosen by faculty at The University of Alabama (UA) is presented.

In this paper, we will touch on both design for safety (facility, operators, maintainers, users, public) and design for construction safety (DfCS), the process of addressing construction site safety and health during the design process. An Internet search found one engineering course explicitly focused on DfS and DfCS offered at U.S. universities, and one master of engineering degree based on the related practice Prevention through Design. This course and program will be identified in the appropriate sections that follow. In addition, one finds short courses in DfS and DfCS taught either by consulting firms or university continuing education organizations. After a discussion of what drives engineering curriculum and course content changes, we identify specific options for “Design for Safety” course content. Several textbooks, handbooks, articles, websites, and consensus standards are identified as suitable sources for instructors to familiarize themselves with government, professional society, and academic information on DfS and DfCS. A mix of “good practice” processes, guidelines, checklists, tools, and case studies are available.

Five alternatives to incorporate DfS into construction engineering curricula are identified. These are evaluated and ranked with one being already proven at many institutions, and chances of success with two others judged to be good and excellent, respectively. One alternative is judged unlikely to be accepted, and a final alternative is seen as a future development, perhaps as a senior elective or first year course in a master’s degree.

Background

There are many institutions of higher education that provide degreed design professionals to the U.S. construction industry: schools of architecture, colleges of engineering, and engineering technology programs. This discussion will address primarily accredited engineering degree programs as found in colleges of engineering at private and state-assisted universities. The accreditation agency for both engineering and engineering technology degrees in the U.S. is ABET, originally known as the Accreditation Board for Engineering and Technology. ABET defines *engineering* to be “the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefits of mankind. “ Design has

been recognized as the central purpose of engineering, and ABET defines *engineering design* to be “the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.” The pre-construction phases of design clearly involve information processing, and therefore to change how design is practiced, one must change the knowledge the architect and engineer utilize in their design decisions.

Safety is defined by the American Society of Safety Engineers (ASSE)¹ to be “the state of being relatively free from harm, danger, injury, or damage” and *safety engineering* as “the application of engineering principles to the recognition and control of hazards.” More specific to the design process, the National Institute of Occupational Health and Safety (NIOSH)² has defined the concept of *Prevention through Design* (PtD) to be “addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment.” The recently-created Master of Engineering: Advanced Safety Engineering and Management degree at the University of Alabama at Birmingham uses PtD as the unifying concept for its curriculum. The application of PtD to construction has come to be known as *Design for Construction Safety* (DfCS), the process of addressing construction site safety and health during the design of the project. A synonym for DfCS one sometimes encounters is Safety Constructability. An earlier version of PtD was called Safety through Design. There was an Institute for Safety through Design established by the National Safety Council (NSC) 1995-2005.

The application of PtD to the facility being constructed is part of the more general practice of *Design for Safety* (DfS), which is concerned with the facility and equipment user’s and maintainer’s health and safety. Design for Safety has been recognized as one of the product design practices “Design for X” along with constructability, quality, reliability, maintainability, usability, and others. These design-for practices are all desirable, but how to implement them in specific product types, for instance in design of civil structures, has been an on-going debate for the past 50-60 years dating back to the original edition of the NSC’s *Accident Prevention Manual*³ and the origins of systems engineering of products. Behm⁴ takes a cautionary approach to promoting PtD in academic programs: “Given that practicing design professionals do not incorporate PtD in their design work, an educational effort aimed at colleges and universities may be ineffective until the industry standards changes to incorporate PtD in practice at some level.”

Toole⁵ identified five major tasks performed by civil and construction engineers, and indicated how the engineer could increase his role in assuring worker safety:

1. Review for safety (peer review of completed design documents, design reviews within organizations)
2. Create design documents for safety (consider worker safety throughout the design process)
3. Procure for safety (recommend to the owner that criteria for selecting the winning bidder include safety, e.g. safety record, safety management process, selection and coordination of subcontractors for safety)

4. Review submittals for safety: submittals include shop drawings of materials, layout, and sometimes the construction procedure.
5. Inspect site operations for safety. Many designers represent the owner in periodic site inspections to assure work complies with plans and technical specifications. If the engineer is knowledgeable about construction safety, he is more likely to identify potential hazards to workers that are technical (equipment and environment) in character.

In each of these roles, there is an underlying assumption that the engineer has been educated in safety, either in his formal degree program or by his employer.

Toole and Carpenter⁶ observed that “although PtD offers practical and important benefits, its diffusion across the U.S. engineering and construction industry has been hampered by a number of significant practical barriers.” They listed four barriers:

1. “Nearly all designers lack the construction safety knowledge and design tools to perform PtD,” citing Gambatese⁷ whose survey in 2002 found that while 64% of civil engineering programs offered courses that included some amount of construction safety content, the average course content was only 10%. He also noted that in the U.K. and Canada, the teaching of construction safety is mandatory for civil engineers.
2. “PtD implementation would increase both the direct and overhead costs for designers.” The direct costs would increase due to additional tasks for designers; the overhead costs would increase due to training, and increased insurance premiums.
3. “The traditional design-bid-build process does not allow the constructor to provide the designer with safety constructability input during design.”
4. Resistance by design professionals participating in traditional design-bid-build projects.” The concern is with potential lawsuits brought by injured construction workers, concerns which outweigh ethical obligations to the workers and benefits to the owner and constructor.

This paper only addresses barrier number one.

Referring again to the 2002 survey by Gambatese⁷, we now consider the construction engineering student. Gambatese observed “it is important that construction personnel working in management, supervisory, and engineering roles also have an understanding of construction site safety. Many project personnel work as estimators, schedulers, project engineers, project superintendents, and project managers... incorporating construction safety in university curricula provides the opportunity for these employees to have an immediate impact on safety.”

Gambatese received 20 survey responses from 89 programs with construction in their title: 14 were accredited by the American Council on Construction Education (ACCE), 5 were ABET-accredited, and one was accredited by the National Association of Industrial Technology (NAIT). “Eighteen of the 20 construction programs (90%) offer a course wholly devoted to construction safety, the majority (72%) offering 3 credits.” The average frequency of offerings was around twice per year. Furthermore, 61% of the courses included OSHA 30-hour certification; 28% included OSHA 10-hour certification. Finally, these course on average had content divided as follows: 68% OSHA regulations with the remaining content generally safety management. Only 5 (25%) of the construction safety courses contained PtD (DfCS) content, and even then only around 7% of course content. Gambatese closed with these conclusions in 2002:

- Safety of design is covered in only a small percentage of university civil and construction engineering courses on safety;

- In construction degree programs, the OSHA standards are the primary course content;
- Coverage of safety in construction programs has increased since the mid-1990s, when only 45-50% of programs offered safety courses.

Safety as an absolute ethical principle is certainly part of any engineering curricula and is at least mentioned in almost every engineering course. Safety appears in ABET's general criteria¹ for any B.S. level engineering degree, including architectural, civil, construction, electrical, industrial, and mechanical, all of which will be discussed below. Safety engineering courses are offered most frequently in industrial engineering and construction engineering programs, because these focus on work processes—means and methods, if you will. Civil engineers may take safety engineering, most likely as an elective. If safety is addressed in any detail in an architectural, electrical, or mechanical engineering degree programs, it is probably in lab courses or as a special topic during capstone design courses. What will it take to change the status quo? Read on.

What Drives Engineering Curricula and Course Content?

Anyone who pays attention to a particular engineering curriculum and the content of courses within that curriculum will realize that both evolve over time. Every year, in fact every time a course is taught, small changes are made. Periodically, larger curriculum revisions occur: courses are added (or dropped); lab activities expand, contract, or are eliminated; credit hours change; and certainly prerequisites, topics, and titles of courses change. The driving forces behind curriculum and course content are:

- ABET accreditation standards
- Industry/government employers needs
- Professorial judgment and interests
- Administrative constraints (Department Head, Dean, Provost, President, Board)

For example, here is the totality of what ABET has to say about safety in the several B.S. engineering degree programs relevant to the construction industry (underlines added for emphasis):

- General Criterion 3(c): the program must demonstrate their students attain an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
- Program Criteria (written by the respective professional society of the discipline) where there is no “call out” for safety: Architectural and Similarly Named Engineering Programs; Industrial; Electrical; Mechanical.
- Program Criteria (written by ASCE) that offer some mention of safety, implicit or explicit: Civil Engineering requires “an understanding of professional practice issues such as...how the design professionals and the construction professions interact to construct a project...”; Construction Engineering requires “an understanding of construction processes, communications, methods, materials, systems, equipment, planning, scheduling, safety, cost analysis, and cost control...an understanding of

management topics such as economics, business, accounting, law, statistics, ethics, leadership, decision and optimization methods, process analysis and design, engineering economics, engineering management, safety, and cost engineering.”

As an example of how industry needs can change a curriculum, an industrial advisory board for a B.S. Construction Engineering degree could urge the faculty to convert two electives, Construction Scheduling and Construction Cost Estimating, into required courses. Similarly, faculty professional judgment and teaching interests can influence changes in curricula over time. Finally, administrative decisions often affect the curriculum in various ways. They often dictate a core curriculum for all majors on campus. They may mandate all degree programs to have no more than 128 semester hours, or they may mandate no more than 16 hours per semester as a full load of courses (charging extra for each additional hour). These sorts of constraints affect engineering curricula.

Options for “Design for Safety” Course Content

Engineering course content is a mix of theory, methodology—processes to follow in design or analysis, tools—typically mathematical or computational, and case studies. This content is drawn from textbooks, handbooks, and other published literature on the subject in question. One searching for such DfS material could start very broadly, looking at textbooks on the design process for their discipline, the systems engineering process in general, and perhaps books on Design for X or the more recent movement known as “simultaneous” or “concurrent engineering.” Organizational processes that bring together designers with representatives from later stages of the product life-cycle (e.g., constructors, operators, maintainers) in concurrent design teams have been shown effective in influencing the design decisions toward products that are easier and safer to construct, operate, and maintain. Success with such processes is probably better illustrated with case studies than with process diagrams and descriptions. Design-build project delivery certainly enhances the probability of concurrent engineering in a construction project.

Another practice that is more prevalent than concurrent design is the use of checklists, which in some sense try to remind the designer about lessons learned and what the “representatives” would have said about design decisions, if they had been consulted. Checklists are often found in handbooks, articles, or the architectural/design company’s own design standards and reference files.

The DfS book most often referenced in current magazine and journal articles is *Safety through Design* by Christensen and Manuele⁸, published in 1999. Textbooks on safety and health written for engineers will have either a chapter or at least a section on DfS, but less likely a section on DfCS. For instance, the textbook *Safety and Health for Engineers* by Brauer⁹ has a chapter on DfS for facilities that actually includes hazards for the site, the facility, the equipment, and the production and logistics operations. Brauer also addresses loss prevention in the context of DfS.

Several articles^{10,11} on the subject have appeared in *Professional Safety*, the journal of the ASSE, and the *Journal of Safety Research*¹², a journal of the NSC published by Elsevier. The latter journal had a special edition dedicated to PtD in April 2008; see a NIOSH website² on PtD at www.dcd.gov/niosh/topics/ptd and a DfCS website www.designforconstructionsafety.org, as

well. These sites contain reference lists and links to other resources. A major recent development was the publication of a voluntary U.S. consensus standard on PtD in October 2011, ANSI/ASSE Z590.3-2011, *Prevention Through Design*¹³. This consensus standard on PtD helps promulgate standards to engineering designers in the U.S., and provides a useful reference to engineering faculty. U.S. professors who teach design of structures, power systems, HVAC systems, and so on typically use the consensus standard as a supporting document to their classroom textbook in such courses. The Health and Safety Executive in the United Kingdom, the equivalent of the U.S. Occupational Health and Safety Administration (OSHA), has developed several documents that help designers comply with the requirement that they design for construction safety. There are consensus standards for DfS in certain countries, for instance Western Australia's *Safe Design Code of Practice*¹⁴ and Singapore's *DfS Guidelines*¹⁵.

Alternatives to Incorporate Design for Safety into Engineering Curricula

To those experienced with the introduction of new topics or courses into established engineering curricula, there are five obvious alternatives to increase the DfS knowledge of degreed engineers:

- A. In all engineering courses, safety hazards could be identified as the subject matter progresses, and could be noted to the students (with options for elimination/reduction)
- B. In all engineering design courses, only
- C. In all senior capstone design courses, as a criterion each design team must address in data collection, analysis, creation of alternatives, and evaluation of alternatives
- D. In a course on safety engineering
- E. In a course on "design for safety"

Evaluation of Alternatives A-E

- A. Alternative A requires a broad array of modules be developed, one for each course, and disseminated. The engineering professoriate broadly defined would have to be educated and convinced to cooperate. Chance of success: Unlikely.
- B. Courses that have design content almost always refer to multiple criteria, including safety, and instructors would likely be receptive to either written or electronic information on design for safety in their particular design focus (e.g., steel structures, masonry, power systems, mechanical systems, etc.) Reference to design standards or guidelines would help "sell" the relevance of safety to the course of study. Because of already squeezed time to cover current subject matter, safety topics should take no more than one week out of a fifteen week course, and would perhaps best be exposed as case studies or special topics for students to read and report on. Chances of success: Good.
- C. Requiring DfS on all senior capstone design projects, whether the project involves design of a system, component, or process, is an excellent approach to familiarize the students with the concepts and practical aspects of DfS (most likely in architectural, mechanical, or electrical engineering programs) or DfCS (most likely in civil, construction, or industrial engineering programs). It would expose the students to the subject in a realistic design environment. The responsibility could be shared among the team members, or assigned to one of the team playing the role of the safety engineer in the design team. Chances of success: Excellent.

- D. Including DfS in courses with titles such as Safety Engineering, Safety and Health Management, or Construction Safety is a common practice. We have already indicated that if one uses the textbook by Brauer, there is a chapter on design for facility safety, which might take a week to cover. In CE 464/564 Safety Engineering at UA, we continue from Brauer's presentation into the last four weeks of the course devoted to the OSHA 10-hour Construction Industry Outreach Course, which includes many new insights for the senior civil engineering student on design for safety. So, one can say that at many institutions including the UA Department of Civil, Construction, and Environmental Engineering, essentially one-third of a one-semester safety engineering consists of DfS and DfCS material for the B.S. civil and construction engineering students enrolled. Chances of success: 100%--already proven, on a wide scale.
- E. A course on "Design for Safety" would most likely be offered as a senior elective cross-listed with a masters-level course, with Safety Engineering as a prerequisite. It assumes the student understands: 1) His/her discipline's design process; 2) Wants to extend his/her safety training; and 3) Wants to consider this topic as a possible master's thesis theme. One such course exists at Virginia Tech, CEE 4064/5064 Design for Hazard Control, offered annually since Fall 2007 by Dr. Deborah Young-Corbett¹⁶. The course description reads "Design of construction projects, materials, equipment, and systems to control inherent hazards to the health and safety of construction workers, inhabitants of the built environment, and general public. The emphasis in this course is on Prevention through Design... The format of the course will involve lecture and participatory activities." Ideally, there would be a textbook that in a systematic way captured the aspects of PtD, DfS, and DfCS that we have discussed in this section, and presented theoretical background, best practice processes, methods and tools, perhaps cases, and most definitely exercises. Such a textbook will be written in the future by a committed author or author team, backed by an interested editor and publisher. Changes of success: 100%--already proven, but on a limited basis.

Continuing Education

Employers of engineers and those engineers with professional development hour (PDH) requirements to maintain their PE licenses look to their local universities for continuing education courses on topics pertinent to current engineering practice. Our Internet search turned up multiple continuing education courses on either DfS, DfCS, or PtD. The DfS/DfCS materials mentioned above for use with degree-seeking engineering students could certainly be adapted to the continuing education arena, whether those learners are attending in person or via distance education technology. Those writing standards for their engineering society and those writing handbooks or textbooks are often in the best position to convert such materials into continuing education type presentations and course notes. Professors teaching safety engineering to degree-seeking students often find it relatively easy to combine some of their campus course materials with case studies and practical experience (assuming they have such) to create a continuing education course for practicing engineers. Finally, when faculty members are reluctant or not qualified to teach DfS/DfCS topics to practicing engineers, nationally-recognized experts (e.g., consultants, authors, industry authorities, or professors at other institutions) can be hired as continuing education instructors, with the local institution providing the facility, equipment, registration services, catering, etc. to hold the course. This is in fact happening today.

Conclusions and Recommendations

In conclusion, there appears to be enough reference materials available for a professor of construction engineering in any design-content course, or directing a capstone design course, to introduce lectures or outside reading on DfS and/or DfCS. A mix of “good practice” processes, guidelines or checklists, tools, and case studies could be integrated into lectures. This information could be extracted and incorporated from the many references mentioned earlier, putting the responsibility on the professor. If instead outside reading is used, the responsibility for reading and integration shifts more to the student. Finally, a guest lecturer who has practical experience with DfS or DfCS could perhaps make a lasting impression on the students.

The recommendation for the faculty interested in incorporating DfS/DfCS in their department’s undergraduate curriculum is to consider Alternative D first. This is an easy route, following what has worked at other institutions and using proven materials already published. The only drawback is someone on the faculty has to have the academic or professional background to develop the course, and the desire to teach it regularly. Next, one should consider Alternative C. Those who teach capstone design often have PE licenses and can educate their design teams on the ethical and practical aspects of including safety as a criterion in their design and evaluation of alternatives. This is admittedly more of a brief exposure than a full course in DfS/DfCS, but it can be implemented by the design project instructor within his authority over the projects, with excellent chances of making an impression and having the students leave campus with knowledge of available written and electronic resources. The habit of thinking about safety aspects of design will hopefully have been planted. Alternative B has a good chance of succeeding if the faculty members responsible for design in the curriculum view safety (as they should) as the number one obligation of the engineer, and design for safety as simply bringing consideration of safety from a corrective procedure done during operations or retrofit/redesign, back into planning and design as a preventive procedure.

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