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Topics in Construction Safety and Health
Prevention through Design (PtD):
An Interdisciplinary Annotated Bibliography

CPWR - The Center for Construction Research and Training

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8484 Georgia Avenue
Suite 1000
Silver Spring, MD 20910

PHONE: 301.578.8500

FAX: 301.578.8572

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Prevention through Design (PtD): An Interdisciplinary Annotated Bibliography

Behm, M. (2008). "Construction sector." *J Safety Res* 39(2): 175-178.
(Rapparteur's report of PtD construction stakeholder workshop)

Behm, M. (2012). "Safe design suggestions for vegetated roofs." *Journal of Construction Engineering and Management* 138(8): 999-1003.

Rooftop vegetation is becoming increasingly popular because of its environmental benefits and its ability to earn green-building certification credits. With the exception of one international guideline, there is little mention of worker safety and health in vegetated-roof codes and literature. Observations and field investigations of 19 vegetated roofs in the United States revealed unsafe access for workers and equipment, a lack of fall-protection measures, and other site-specific hazards. Design for safety strategies and the integration of life-cycle safety thinking with green-building credits systems are the preferred methods to reduce risk to workers on vegetated roofs. Design suggestions have been developed to add to the body of knowledge. The findings complement several National Institute for Occupational Safety and Health (NIOSH) construction and prevention through design (PtD) goals and are congruent with NIOSH's Safe Green Jobs initiative. Organizations that install and maintain vegetated roofs can utilize the findings to understand hazards, take precautions, and incorporate safety into their bids. © 2012 American Society of Civil Engineers.

Casanovas, M. d. M., et al. (2014). "Occupational Risk Index for Assessment of Risk in Construction Work by Activity." *Journal of Construction Engineering and Management* 140(1): 04013035.

The concern for occupational health and safety in construction work is reflected in the many preventive measures taken. However, examples of the systematic assessment of project alternatives aimed at minimizing occupational hazards are rare. This paper proposes a measure of occupational safety [occupational risk index (ORI)] that is based solely on the project design and resulting construction process, and is a function of the activities carried out and their specific occupational risk (probability and consequences of occurrence). The ORI can thus be used as an indicator to feed multicriteria decision-analysis tools. The proposal is illustrated with a simple example in which two alternatives (one precast and the other constructed in situ) are prioritized in terms of occupational safety, and certain aspects related to redesign are briefly addressed. With the ORI, occupational safety goes from having a passive influence (application to projects that have already been designed) to an active one (influence on the design concept itself) in the design stage of construction projects. The research is based on an analysis of the applicable legislation and interviews with experts.

Dewlaney, K. S. and M. Hallowell (2012). "Prevention through design and construction safety management strategies for high performance sustainable building construction." *Construction Management and Economics* 30(2): 165-177.

Recent studies have found that Leadership in Energy and Environmental Design (LEED) buildings have a higher injury rate than traditional non-LEED buildings and that 12 of the LEED credits increase risks for construction workers. The objective was to identify and describe risk mitigation strategies that reduce the safety risk associated with the design and construction of high performance sustainable projects by conducting extensive interviews with

experienced designers and constructors. Fortunately, feasible prevention techniques through design and construction safety management strategies exist and can be used to mitigate the safety risk associated with the design features and means and methods of construction used to achieve LEED certification. Most commonly, designers and contractors identified prefabrication, effective site layout and alternative products as methods to prevent injuries that specifically relate to the hazards of each sustainable element. The results of the interviews and results from previous research were organized into a decision support tool built in Adobe LiveCycle. Practitioners may use the findings and the tool to enhance safety for construction workers, an aspect of sustainability that is not currently addressed in the LEED Program. Researchers may also use the techniques described as a starting point for lifecycle safety analyses for sustainable buildings. © 2012 Copyright Taylor and Francis Group, LLC.

Dewlaney, K. S., et al. (2012). "Safety risk quantification for high performance sustainable building construction." *Journal of Construction Engineering and Management* 138(8): 964-971.

A recent study found that Leadership in Energy and Environmental Design (LEED) certified buildings have a recordable injury rate that is 9% higher than traditional, non-LEED buildings. A follow-up study showed that there are distinct aspects of the design elements and means and methods of construction used to achieve LEED certification that have negative impacts on worker safety. The research described in this paper builds on previous knowledge by quantifying the percent increase in base-level safety risk resulting from the design strategies and construction methods implemented to earn specific LEED credits. A total of 26 interviews and 11 validation interviews were conducted with designers and contractors who had completed an average of four LEED projects, 100 traditional projects, in their average of 18 years of experience in the architecture, engineering, and construction industry. The results indicate that design elements and means and methods of construction implemented to achieve 12 of the 49 LEED credits increase the frequency of injuries or exposure to known, high risk environments. The most significant impacts are a 36% increase in lacerations, strains, and sprains from recycling construction materials; a 24% increase in falls to lower level during roof work because of the installation of on-site renewable energy (e.g., PV panels); a 19% increase in eye strain when installing reflective roof membranes; and a 14% increase in exposure to harmful substances when installing innovative wastewater technologies. These results can be used to understand the safety impacts of sustainable building design, will enhance designer awareness, and help contractors to better prioritize safety resources. © 2012 American Society of Civil Engineers.

Dharmapalan, V., et al. (2015). "Quantification and Assessment of Safety Risk in the Design of Multistory Buildings." *Journal of Construction Engineering and Management* 141(4): 04014090.

Research has shown that construction worker safety and health is influenced by the design of the permanent structure being constructed. Architects and design engineers have the opportunity to positively affect construction worker safety and health through the choices they make in the design process. Lack of designer knowledge about construction processes and limited availability of tools to assist in assessing the safety risk associated with a design are considered as inhibitors to implementation of the design for construction safety (DfCS) concept. This paper presents research conducted to quantify the construction safety risk of each of the design elements present in typical multistory buildings in the United States. The major

research efforts were (1) identification of the typical building design elements and associated construction activities; (2) quantification of the unit and cumulative risks of the design elements and construction activities; and (3) development of an online design risk-assessment tool. Absolute safety risks were quantified for 141 design elements and 683 construction activities using the survey-analytical research method. The risk factors developed were incorporated into an online tool titled Safety in Design Risk Evaluator (SliDeRule). The research contributes to the construction industry body of knowledge by providing quantitative values that link specific design features to construction safety. The website is designed to assist building designers with assessing the level of construction safety risk associated with their designs and is intended for use by designers during the design phase to create buildings that are safer to construct.

Fortunato III, B. R., et al. (2012). "Identification of safety risks for high-performance sustainable construction projects." *Journal of Construction Engineering and Management* 138(4): 499-508.

The United States Green Building Council (USGBC)-sponsored Leadership in Energy and Environmental Design (LEED) green building program represents the largest program in the United States for the measurement, verification, and certification of green buildings. A recent study found that LEED-certified buildings have accounted for a higher injury rate than comparative traditional non-LEED buildings. This finding served as the impetus for the present study, which aimed to identify and evaluate the safety and health risks associated with the design elements and construction management practices implemented to achieve LEED certification. To explore this topic, six detailed case studies and two validation case studies were conducted following a strict protocol developed from guiding literature. The results indicate that (1) workers on LEED construction projects are exposed to work at height, with electrical current, near unstable soils, and near heavy equipment for a greater period of time than workers on traditional projects; (2) workers are exposed to new high-risk tasks such as constructing atria, installing green roofs, and installing photovoltaic (PV) panels; and (3) some credits result in a positive impact on construction worker safety and health when low volatile organic compound (VOC) adhesives and sealants are specified. It is expected that these results can be used by practitioners to focus attention and resources on new high-risk work environments. © 2012 American Society of Civil Engineers.

Gambatese, J. and K. AlOmari (2016). "Degrees of connectivity: Systems model for upstream risk assessment and mitigation." *Accid Anal Prev* 93: 251-259.

There is growing recognition that in order to further improve safety performance, attention needs to be given beyond the immediate working conditions and worker actions. A systems approach to construction safety enables considering: multiple project elements simultaneously; connections between different elements; and all system elements affected by safety risk. This paper describes recent and current research to conceptualize a typical building project in terms of connections between workers, activities, and design elements, and to verify and analyze impacts of the design and worker interactions on worker safety. Prior research provides the basis for a network tying the design elements, construction activities, and work crews on a typical building project together along with the extent of interaction between each of the system elements in terms of safety. In conjunction with this systems approach, the researchers propose a concept for viewing and managing construction safety through four different types of connections, or "degrees of connectivity," between the different workers,

activities, and design elements in the system. The degrees of connectivity are defined as: interacting with the design element during its construction (DoC #1); interacting with the design element in its final form to attach another component to it (DoC #2) or by working in the vicinity of it (DoC #3); and indirectly interacting with the design element through another worker (DoC #4). To support and verify the presence of the concept in practice, the researchers conducted a survey of construction personnel. The survey results confirm that the four different degrees of connectivity are present and felt during construction operations, and indicate that attention should be given to all design elements, activities, and workers to which a worker is "connected". According to the survey respondents, DoC's #1 and #2 are recognized as the most widely present on construction sites. Eighty percent of the respondents believe that the design element has a moderate or greater impact on worker safety while it is being constructed. These initial research steps provide the starting point for continuing study that aims to develop and demonstrate the degrees of connectivity concept linking workers and design elements, with the goal of understanding how to design a project and work operations in order to improve safety during construction.

Gambatese, J. A., et al. (2008). "Design's role in construction accident causality and prevention: Perspectives from an expert panel." *Safety science* 46(4): 675-691.

Improving the safety and health of construction workers through design practices upstream of the construction phase is the objective of the design for construction safety concept. Ease of implementation and effectiveness of this intervention in practice are dependent on there being a link between the design and safety hazards. This paper presents research conducted to confirm the findings of a previous study, which revealed a link between construction site fatalities and the design for construction safety concept. Previous research demonstrated that in 42% of 224 fatality cases reviewed, the incidents could be linked to the design for safety concept. To validate the model previously utilized, an expert panel was established to review a sample of the 224 fatality cases and judge whether the design was a factor in the incident. The previous research results and expert panel responses were in agreement for 71% of the cases reviewed. The present research results provide further evidence of design's influence on construction site safety. If safety performance in the construction industry is to improve, design professionals need to play a role in addressing safety in their designs.

Gambatese, J. A., et al. (2017). "Alignment between Lean Principles and Practices and Worker Safety Behavior." *Journal of Construction Engineering and Management* 143(1).

Alignment and synergy between the areas of lean construction and safety management are expected because all near misses and injury incidents represent waste from the lean perspective. This paper describes a research study of lean and safety principles and practices with regards to worker behavior and safety practices. Specifically, the study aimed to investigate the extent of alignment between lean construction principles/practices and worker behaviors associated with construction safety. To conduct the study, the researchers used a multistep process involving a comprehensive literature review, document content analyses by an expert panel, and a survey of industry practitioners knowledgeable about lean construction. The findings support the perspective that many similarities exist between the application and impacts of lean and safety principles and practices. Lean practitioners surveyed believe that implementation of the last planner system as a lean practice is most beneficial to the following

safety practices: management commitment, preproject planning, and pretask planning. The present study revealed that lean principles and practices can provide a valuable opportunity to further improve construction worker safety; however, the findings show that there is a difference between lean construction and safety management practices, revealing a gap with respect to worker behavior. Understanding and eliminating this gap is important for the industry to realize the full benefit that lean principles and practices can have on worker safety. To do so, the authors suggest expanding lean practices to further directly engage field workers and address worker behavior issues along with carefully communicating the lean message to construction personnel. © 2016 American Society of Civil Engineers.

Golabchi, A., et al. (2015). "An Automated Biomechanical Simulation Approach to Ergonomic Job Analysis for Workplace Design." *Journal of Construction Engineering and Management* 141(8): 04015020.

Work-related musculoskeletal disorders (WMSDs) are reported to be the most common category of nonfatal occupational injuries that result in days away from work and are also a leading cause of temporary and permanent disability. One of the most effective approaches to preventing WMSDs is to evaluate ergonomics considerations early in the design and construction planning stage before the worker encounters the unsafe conditions. However, a lack of tools for identifying potential ergonomic risks in a proposed workplace design has led to difficulties in integrating safety and health into workplace design practice. In an effort to address this issue, this study explores a motion data-driven framework for ergonomic analysis that automates and visualizes the evaluation process in a virtual workplace. This is accomplished by coupling the ergonomic analysis with three-dimensional (3D) virtual visualization of the work environment. The proposed approach uses motion data from the 3D model of the jobsite to evaluate the risk factors that can produce excessive physical loads on the human body through a biomechanical analysis. A global risk assessment of musculoskeletal disorders is performed on worker motions first, and a biomechanical simulation is then used to further analyze unsafe motions by estimating internal loads on each selected body joint of the worker and redesigning the motion and workplace accordingly. As a case study, several tasks taking place in a construction prefabrication shop are modeled and analyzed to modify the workplace and ensure improved ergonomic safety. The results indicate that the proposed approach enables identification and minimization of awkward worker postures in the virtual model to mitigate ergonomic risk during workplace design.

Hanna, A. S., et al. (2013). "Impact of crew scheduling on project performance." *Practice Periodical on Structural Design and Construction* 18(1): 35-44.

Contractors have responded to the growing pressure from owners to shorten project duration by employing a variety of crew-scheduling techniques. Unfortunately, only a limited knowledge base exists for determining the impact of different crew schedules on project performance in terms of cost, duration, productivity, and safety. Standard crew schedules include those that require crews to work 40 h per week, including five 8-h days, four 10-h days, or a second shift. Overtime schedules are also common, which require crews to work additional hours beyond the standard 40 h per week. These overtime schedules include five 9-h days, six 8-h days, or five 10-h days. In addition to the standard and overtime schedules, several other crew-scheduling techniques have been used successfully by contractors. This paper presents the results of a study on the impact of crew-scheduling techniques on overall project performance.

The paper identifies the proper application and conditions for successful use of various crew-scheduling techniques and provides a comprehensive comparison that outlines a variety of crew-scheduling options, along with their impact on labor efficiency, project duration, worker safety, and project cost. Contractors can use the results to aid them in the selection of a scheduling technique to best meet the specific requirements of a project. © 2013 American Society of Civil Engineers.

Hecker, S. and J. A. Gambatese (2003). "Safety in design: a proactive approach to construction worker safety and health." *Appl Occup Environ Hyg* 18(5): 339-342.

Howard, J. (2008). "Prevention through Design--introduction." *J Safety Res* 39(2): 113.

We believe that the Prevention through Design (PtD) initiative is an extremely worthwhile endeavor. Putting safety into design practices is the natural next step in the construction business, as well as all other industries. PtD is part of our Continuous Improvement Program. This also embodies a social improvement aspect, which includes the welfare of the workforce, and green construction and design elements. These efforts are driven not only by social responsibility, but also by commodities costs, which are rising faster than anyone expected. The expense of having an inefficient or unsafe environment is enormous. The entire company needs to be up to speed on safety practices and protocols. We've been incorporating safety in design because it's the next step in our industry and in our continuous improvement process to meet the goal of zero injuries. We should all assist the universities in incorporating safe design curricula. Those discussions and training sessions should include different disciplines working together to solve the same problem.

Jin, Z., et al. (2023). "Analysis of prevention through design studies in construction: A subject review." *J Safety Res* 84: 138-154.

INTRODUCTION: The concept of addressing and minimizing construction site safety risks in the early phase of a project has generated research interest, especially since the National Institute for Occupational Safety and Health (NIOSH) launched its national Prevention through Design (PtD) initiative in July 2007. In the last decade, several studies on PtD with differing goals and methods have been published in construction journals. To date, few systematic examinations of the development and trends associated with PtD research have been conducted in the discipline. **METHOD:** This paper presents a study of the latest PtD research trends in construction safety management through analysis of publications in prominent construction journals from 2008 to 2020. Both descriptive and content analyses were conducted based on the number of papers published annually and clusters of topics covered in the papers. **RESULTS:** The study shows an increasing interest in PtD research in recent years. Research topics covered mainly focus on the perspectives of PtD stakeholders, PtD resources/tools/procedures, and technology applications to facilitate PtD implementation in practice. This review study provides an improved understanding of the state-of-the-art of PtD research in terms of accomplishments and research gaps. The study also compares the findings from journal articles with industry best practices related to PtD to guide future research in this domain. **PRACTICAL APPLICATION:** This review study is of significant value to researchers to overcome the limitations of the current PtD studies, and to extend the scope of PtD research, and can be used by industry professionals when considering and selecting appropriate PtD resources/tools in practice.

Kim, K., et al. (2016). "Integrating work sequences and temporary structures into safety planning: Automated scaffolding-related safety hazard identification and prevention in BIM." *Automation in Construction* 70: 128-142.

Construction remains as a hazardous industry that can expose construction workers to fatal accidents and illnesses. With recent advances in BIM technology, project information in BIM can be analyzed in the early design and planning stages to address potential safety issues. However, despite the impact on safety and productivity of the entire construction project, temporary structures, such as formwork and scaffolds, are often omitted from drawings or BIM. In practice, it is challenging to consider temporary structures in current manual jobsite safety analysis which is time-consuming and error-prone. As a result, in construction plans, potential safety hazards related to temporary structures are unknowingly created which need to be identified and prevented during the construction phases. Focusing on scaffolds, this research integrates temporary structures into automated safety checking approach using BIM. A safety planning platform was created to simulate and visualize spatial movements of work crews using scaffolding. Computational algorithms in the platform automatically identify safety hazards related to activities working on scaffolding and preventive measures can be prepared before the construction begins. The algorithms were implemented in a commercially available BIM software as a plug-in and validated with a real-world construction project. The results show that the algorithms could identify safety hazards that were not noticed by project managers participating in the case study project. The simulated results are visualized in the developed safety planning platform to potentially facilitate early safety communications. © 2016 Elsevier B.V.

Kim, S., et al. (2011). "Low back injury risks during construction with prefabricated (panelised) walls: effects of task and design factors." *Ergonomics* 54(1): 60-71.

New technology designed to increase productivity in residential construction may exacerbate the risk of work-related musculoskeletal disorders (WMSDs) among residential construction workers. Of interest here are panelised (prefabricated) wall systems (or panels) and facilitating an ongoing effort to provide proactive control of ergonomic exposures and risks among workers using panels. This study, which included 24 participants, estimated WMSD risks using five methods during common panel erection tasks and the influences of panel mass (sheathed vs. unsheathed) and size (wall length). WMSD risks were fairly high overall; e.g. 34% and 77% of trials exceeded the 'action limits' for spinal compressive and shear forces, respectively. Heavier (sheathed) panels significantly increased risks, although the magnitude of this effect differed with panel size and between tasks. Higher levels of risk were found in tasks originating from ground vs. knuckle height. Several practical recommendations based on the results are discussed. STATEMENT OF RELEVANCE: Panelised wall systems have the potential to increase productivity in residential construction, but may result in increased worker injury risks. Results from this study can be used to generate future panel design and construction processes that can proactively address WMSD risks.

Lee, H. W., et al. (2017). "Applying Prevention through Design (PtD) to Solar Systems in Small Buildings (CPWR Report)."

Nussbaum, M. A., et al. (2009). "Development of a decision support system for residential construction using panellised walls: approach and preliminary results." *Ergonomics* 52(1): 87-103.

There is a high prevalence of work-related musculoskeletal disorders (WMSDs) among residential construction workers, yet control in this industry can be difficult for a number of reasons. A decision support system (DSS) is described here to allow early assessment of both ergonomic and productivity concerns, specifically by designers. Construction using prefabricated walls (panels) is the focus of current DSS development and is based conceptually on an existing 'Safety in Construction Design' model. A stepwise description of the development process is provided, including input from end users, taxonomy development and task analysis, construction worker input, detailed laboratory-based simulations and modelling/solution approaches and implementation. Preliminary results are presented for several steps. These results suggest that construction activities using panels can be efficiently represented, that some of these activities involve exposure to high levels of WMSD risk and that several assumptions are required to allow for ease of mathematical and computational implementation of the DSS. Successful development of such tools, which allow for proactive control of exposures, is argued as having substantial potential benefit.

Omar, M. S., et al. (2013). "Are green building features safe for preventive maintenance workers? Examining the evidence." *Am J Ind Med* 56(4): 410-423.

BACKGROUND: Many newly constructed green buildings (GB) are certified using the United States Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) rating system for new construction and major renovation which focuses on architectural and mechanical design to conserve energy, reduce environmental harm, and enhance indoor quality for occupants. This study evaluated the preventive maintenance (PM) worker occupational safety and health (OSH) risks related to the design of GB. **METHODS:** PM job hazard analyses (JHA) were performed on the tasks required to operate and maintain five GB features selected from 13 LEED certified GB. A 22-item JHA and OSH risk scoring system were developed. **RESULTS:** Potentially serious OSH hazards included: green roofs made of slippery material without fall protection; energy recovery wheels and storm water harvesting systems in confined spaces; skylights without guard rails; and tight geothermal well mechanical rooms constraining safe preventive practices. **CONCLUSIONS:** GB can present PM OSH risks and these should be eliminated in the building design phase.

Osburn, L., et al. (2022). "Formal Prevention through Design Process and Implementation for Mechanical, Electrical, and Plumbing Worker Safety." *Journal of Management in Engineering* 38(5): 05022011.

There are many studies that focus on Prevention through Design (PtD) for construction workers and developing formalized PtD processes for construction projects. However, few studies have aimed at developing a formalized PtD process for mechanical/electrical/plumbing (MEP) worker safety. A formal process for implementing PtD for MEP worker safety is badly needed because MEP work onsite and during operation and maintenance (O&M) can lead to injury and death. To address this knowledge gap, our research team aimed to create a formalized PtD process for MEP safety and developed case studies that detail how the process can be implemented in the field. The formalized process and case studies would then be used in an implementation guide created specifically for the industry. This project was completed

through expert interviews, six case studies, and ongoing discussion and review by an Industry Advisory Council. Using these methods, the team identified factors for implementation success and developed a formalized PtD process specific to the MEP worker context. The process consists of five phases: (1) hazard identification, (2) risk assessment, (3) design review, (4) implementation, and (5) learning. We anticipate that this study will contribute to the field of PtD research through creating one of the first formalized PtD processes for MEP construction and O&M worker safety, and through a cross-case analysis of the six PtD cases that indicated not only the importance of stakeholder engagement and cross-disciplinary dialogue, but that effective PtD implementation can occur even outside of a collaborative project delivery context at any point during design and construction.

Rajendran, S. and J. Gambatese (2013). "Risk and financial impacts of prevention through design solutions." *Practice Periodical on Structural Design and Construction* 18(1): 67-72.

Falls from roofs are a significant risk for both construction and maintenance workers. A roof anchor system is the common design solution to eliminate the falling hazard. This paper presents the findings of a case study to serve as a preliminary investigation of the financial impact and risk of roof fall protection solutions. The research began with the selection of a project that featured a roof anchor system and a parapet that does not meet Occupational Safety and Health Administration (OSHA) guardrail height requirements. The intent of the research was to compare the cost of design and installation of the roof anchors and parapet with that of two other design options on the same project: only a parapet that meets the OSHA guardrail requirements; and no anchors or parapet. Data used for the study were collected through interviews of project personnel and reviews of project documentation. The parapet system was found to be an expensive, but safer, alternative compared with the roof anchor system. The roof anchor system creates more risk to worker safety because of the extensive amount of temporary fall protection measures required during construction. This requirement puts more workers at risk of injury during installation of temporary guardrails and while working near the leading edge. The roof anchor system indirectly affects worker productivity by at least 15% compared with the parapet system. Using this study as a starting point, more research is recommended that examines the costs and risks associated with various prevention through design (PtD) solutions. Such research will assist owners and designers in making informed decisions while choosing PtD solutions. © 2013 American Society of Civil Engineers.

Rajendran, S. and J. A. Gambatese (2009). "Development and initial validation of sustainable construction safety and health rating system." *Journal of Construction Engineering and Management* 135(10): 1067-1075.

This paper presents a study to develop and validate a sustainable construction safety and health (SCSH) rating system. The rating system provides an opportunity to rate projects based on the importance given to construction worker safety and health and the degree of implementation of safety and health elements. A Delphi survey using an expert panel of 12 experienced safety and health professionals representing different sectors of the construction industry was employed to develop the SCSH rating system. The study resulted in a rating system consisting of a total of 50 safety and health elements organized into 13 categories. Each category contains safety and health elements which carry credits based on their effectiveness in preventing construction worker injuries and illnesses. The rating system was initially validated

based on data from 25 construction projects and found to accurately represent the safety performance of large projects. The SCSH rating system can be used as an effective tool to develop and plan construction safety and health programs and evaluate the potential safety performance of construction projects.

Saunders, L. W., et al. (2017). "Developing an inter-organizational safety climate instrument for the construction industry." *Safety science* 98: 17-24.

In the construction industry, recent literature has promoted a design for safety approach that discusses the benefits of considering safety from the very start of the project lifecycle. With this approach, non-construction personnel, such as owners and designers, need to work alongside constructors and subcontractors to consider safety during design and procurement stages of a project. This is a difficult process, particularly with the degree of fragmentation in the industry. Safety climate survey instruments have been developed to identify these sources of fragmentation among stakeholder groups, but most of these tools are directed toward on-site construction personnel. This paper describes the development of an inter-organizational safety climate instrument for measuring attitudes toward safety of construction industry stakeholders including owners, designers, construction managers, and subcontractors. Overall, the measurement model demonstrated a good fit with the data based on a confirmatory factor analysis. Therefore, the survey instrument provides a useful tool for researchers and practitioners to identify the sources of fragmentation in attitudes of construction project personnel toward worker safety that can affect occupational health and safety within the industry. © 2017

Saunders, L. W., et al. (2016). "International benchmarking for performance improvement in construction safety and health." *Benchmarking* 23(4): 916-936.

Purpose – The purpose of this paper is to advance knowledge on the advantages of integrating safety earlier in the construction project lifecycle. **Design/methodology/approach** – A case study approach is used to collect data from construction sites in the USA, which performs poorly in construction safety and health, and Australia (AU), which performs well in construction safety and health. Qualitative data are collected to determine how and when safety is considered in the project lifecycle in both countries, and then the results are benchmarked to determine the benefits of addressing safety earlier in the process. **Findings** – Data show that addressing a potential hazard earlier in the project lifecycle has performance benefits in terms of the level of hazard control. **Research limitations/implications** – The processes that are identified as possibly explaining the performance difference are just based on qualitative data from interviews. Targeted research addressing the relationship between these processes and safety outcomes is an opportunity for further research. **Practical implications** – The case study data are used to identify specific processes that are used in AU that might be adopted in the USA to improve performance by integrating safety earlier into the decision-making process. **Social implications** – This paper highlights the advantages of integrating safety as a decision factor early in the process. Worker safety is not just an issue in the construction industry, and thus the findings are applicable to all industries in which worker safety is an issue. **Originality/value** – This paper advances the safety in design literature by quantitatively supporting the link between when a hazard is addressed and performance. It also links the results to specific processes across countries, which advances the literature because most

research in this area to data is within a single country. © 2016, © Emerald Group Publishing Limited.

Tayabji, S., et al. (2012). "Joint load transfer and support considerations for jointed precast concrete pavements." *Transportation Research Record*: 74-80.

Many agencies recently have started investigating strategies for pavement rehabilitation and reconstruction that are faster to implement and can produce longer-lasting pavements than previous strategies. Most highway agencies no longer consider expedient rehabilitation that results in a shorter pavement lifespan acceptable. One promising alternative rehabilitation strategy is the effective use of modular pavement technologies, principally precast concrete pavement (PCP) systems, which provide for the rapid repair and rehabilitation of pavements and also result in durable, long-lasting pavements. Rapid construction techniques can significantly minimize the impact on the driving public because lane closures and traffic congestion are minimized. Road user and worker safety also are improved by reduced road users' and workers' exposure to construction traffic. The renewal focus area under Strategic Highway Research Program 2 (SHRP 2) emphasizes the need to complete highway pavement projects rapidly, with minimal disruption to highway users and local communities, and to produce pavements that are long lasting. One goal of this focus area includes applying new methods and materials to preserve, rehabilitate, and reconstruct roadways. The effective use of PCP technologies for rapid repair, rehabilitation, and reconstruction of pavements addresses this goal. One of the projects funded under SHRP 2 is Project R05, Modular Pavement Technology. The objective of Project R05 was to develop better guidance for use by highway agencies to design, construct, install, maintain, and evaluate modular pavement systems, principally PCP systems. Findings related to joint load transfer and support considerations for jointed PCP from the Project R05 study are presented.

Toole, T. M. (2005). "Increasing engineers' role in construction safety: opportunities and barriers." *Journal of Professional Issues in Engineering Education and Practice* 131(3): 199-207.

A number of factors suggest engineering and construction professionals should discuss increasing designers' role in construction safety. Design civil engineers could contribute to construction worker safety by performing five tasks differently than current custom and practice: reviewing their designs, creating design documents, assisting the owner in procuring construction, reviewing submittals, and inspecting work in progress. However, four sets of major barriers would prevent designers from increasing worker safety through these tasks: lack of safety expertise, lack of understanding of construction processes, typical contract terms, and professional fees. Potential ways for reducing these barriers are suggested. The United Kingdom regulations requiring engineers to design for safety are summarized, but it is concluded that similar legislation in the United States would not be appropriate.

Toole, T. M. and G. Carpenter (2013). "Prevention through design as a path toward social sustainability." *Journal of Architectural Engineering* 19(3): 168-173.

Design and construction professionals who have studied sustainability know that sustainability encompasses not just environmental equity but also social equity and economic equity. Most of the literature on social sustainability in the built environment focuses on regional urban planning issues, not on specific actions capital project owners and design

professionals can take. Prevention through design (PtD) (also known as design for construction safety) is an emerging initiative in the design and construction industry in which design professionals consider the safety of construction workers during the design phase. This paper provides an overview of the PtD concept and suggests that PtD should be a required aspect of social equity on capital projects. A recent survey (n=103) indicates that the expected challenges to diffusion of PtD - lack of knowledge, higher costs, industry structure, and fear of liability - may not prove to be significant barriers, but these challenges may be relevant to other social-sustainability initiatives as well. © 2013 American Society of Civil Engineers.

Toole, T. M. and J. Gambatese (2008). "The trajectories of Prevention through Design in construction." *J Safety Res* 39(2): 225-230.

INTRODUCTION: Construction Hazards Prevention through Design (CHPtD) is a process in which engineers and architects explicitly consider the safety of construction workers during the design process. Although articles on CHPtD have appeared in top construction journals, the literature has not addressed technical principles underlying CHPtD to help designers better perform CHPtD, to facilitate the development of additional CHPtD tools, and to predict the future path of CHPtD. **METHOD:** This theoretical paper uses the existing literature on CHPtD and current action research associated with several CHPtD workgroups to analyze how CHPtD will likely evolve over the coming decades. **RESULTS:** There are four trajectories along which CHPtD will progress. (a) Designs will increasingly facilitate prefabricated construction; (b) designers will increasingly choose materials and systems that are inherently safer than alternatives; (c) designers will increasingly perform construction engineering; and (d) designers will increasingly apply spatial considerations to reduce worker hazards. **IMPACT ON INDUSTRY:** By understanding how CHPtD may be manifested in the engineering-procurement-construction (EPC) industry, practitioners can better prepare for adopting CHPtD within their organizations and construction and engineering educators can better prepare their graduates to perform CHPtD.

Toole, T. M., et al. (2016). "Owners' Role in Facilitating Prevention through Design." *Journal of Professional Issues in Engineering Education and Practice*: 04016012.

Exploratory research was performed on a promising safety intervention concept, prevention through design (PtD), also known as designing for construction safety (DfCS). The overall research goal was to increase understanding of the role that owners of constructed facilities can play in adopting PtD on their capital projects. A total of 65 face-to-face interviews and 79 anonymous surveys were completed at four case-study organizations in addition to 103 surveys completed online by members of national construction associations and organizations. Industry survey data indicate that while the majority of owner firm employees had not heard of PtD, they find the concept compelling and do not anticipate significant barriers to its implementation. Key empirical findings indicate that (1) an explicit PtD process is required for implementation; (2) proactive owner leadership and involvement are necessary to initiate PtD on a project; (3) owner leadership is required both to set high expectations for worker safety and health and to ensure general contractor and trade contractor personnel participation in the design review process; and (4) supporting tools, such as design checklists, four dimensional (4D) computer-aided design (CAD) systems, and risk identification and assessment documents, facilitate the PtD process. These findings can be used by owners to most effectively implement a PtD program on one or more of their projects.

Tymvios, N. and J. A. Gambatese (2016). "Direction for Generating Interest for Design for Construction Worker Safety - A Delphi Study." *Journal of Construction Engineering and Management* 142(8).

Decisions made prior to construction impact the safety of construction workers. Past research has shown that there is a link between design decisions and fatalities. Prevention through Design (PtD) is a concept that attempts to identify and mitigate hazards early in the design process with the goal of eliminating the risks of injury to workers and/or damage to facilities during construction. PtD is a required practice in some countries, primarily because of legislation. In the United States, however, PtD is not well known by design professionals and there is opposition to its practice. The objective of this paper is to present the results of a Delphi study, in which the Delphi panel was tasked to identify: (1) the construction industry group with the most influence to generate interest in PtD in the United States, (2) the method with which that interest can be achieved, and (3) the industry group that should be targeted with that method. The Delphi panel came to a consensus that owners have the greatest influence to generate interest, and they should be the group to be targeted using the business case method. © 2016 American Society of Civil Engineers.

Tymvios, N. and J. A. Gambatese (2016). "Perceptions about design for construction worker safety: Viewpoints from contractors, designers, and university facility owners." *Journal of Construction Engineering and Management* 142(2).

Decisions made before construction can affect safety on the construction site, either positively or negatively. This was observed from past research that identified the link between design decisions and fatalities. The concept of implementing design decisions that positively affect safety falls under the general concept of prevention through design (PtD), which attempts to identify and mitigate hazards early in the design process to eliminate the risks of injury or damage during construction. Prevention through design is practiced in other countries, primarily through legislation. The objective of this paper is to present the results of a survey that was conducted to identify construction industry stakeholders' views on the concept of PtD and gauge the possibility for implementing PtD in the U.S. construction industry through either legislation or other means. Four distinct groups were surveyed: engineers, architects, contractors, and owners. Within this study, PtD was described and introduced to survey participants as design for construction worker safety (DCWS) to differentiate PtD efforts in construction from efforts in other industries. The survey consisted of questions that asked about the industry's knowledge of PtD and the extent of PtD practice in the United States, participants' opinions on designer and owner safety knowledge and perceptions, and obstacles and enablers for designer participation in construction safety. The responses from the various groups were compared to identify the groups that are more receptive to the idea of designer participation in construction worker safety. The results showed that architects were the least receptive to the idea, whereas the other groups were more likely to be supportive, with some hesitations. Architects and engineers identified the existence of economic, legal, and contractual obstacles for designers to practice DCWS, whereas contractors only identified economic obstacles. No enablers were identified by any group. The research contributes additional information that can be used by construction industry practitioners and organizations desiring to expand and optimize PtD implementation in the United States. The research results can be used by project

teams to plan for PtD education and training efforts on projects and by construction industry organizations to develop PtD diffusion strategies. © 2015 American Society of Civil Engineers.

Weidman, J., et al. (2015). "Intervention to Improve Purchasing Decision-Maker Perceptions of Ventilated Tools." *Journal of Construction Engineering and Management* 141(6): 04015007.

A theory-based intervention strategy to improve purchasing decision-maker perceptions of ventilated tools was developed, implemented, and tested. The intervention was designed to target key constructs of the prevention through design adoption readiness model (PtD ARM), a previously published conceptual model. A Web-based intervention was developed that included information about the health effects of construction dust, a testimonial by a firm owner, and a video demonstrating side-by-side use of both ventilated and nonventilated tools, which provided visual evidence of dust generation and productivity performance. In a pretest/posttest with a control group and an experimental design, purchasing decision makers (n=49)

Weidman, J., et al. (2016). "Effective Intervention Strategy to Improve Worker Readiness to Adopt Ventilated Tools." *Journal of Construction Engineering and Management* 142(8).

An effective theory-based intervention strategy is developed to improve worker adoption of a ventilated dust-control tool that reduces dust exposure by 95%. The Prevention through Design Adoption Readiness Model (PtD ARM) was employed to develop educational materials, hands-on training, and worksite cues-to-action. Educational materials were targeted to improve worker knowledge of the health risks associated with construction dusts. Hands-on training was developed with the objective of improving worker self-efficacy regarding the new equipment. Additionally cues-to-action were given to the workers. These cues were hard-hat stickers and t-shirts with reminder slogans. In a pretest/posttest experimental design with control group (n=40), questionnaire data were analyzed using independent t-tests of the gain-scores, and significant changes ($p < 0.05$) were seen in worker self-efficacy, trust-in-technology, and overall readiness to adopt the tool. Theory-based intervention strategies were found to be effective in improving worker willingness to use ventilated tools. The most impactful intervention methods include training regarding risks to worker health, hands-on training with ventilated tools, and cues-to-action reminders to use the tools. © 2016 American Society of Civil Engineers.

Weinstein, M., et al. (2005). "Can design improve construction safety?: Assessing the impact of a collaborative safety-in-design process." *Journal of Construction Engineering and Management* 131(10): 1125-1134.

The impact of an extensive safety-in-design process implemented during the design and construction of a semiconductor manufacturing facility is studied. Twenty-six potential design changes on the project are identified, and the importance of timing, trade contractor involvement, and the type of design change is assessed. The issues of whether adopted design changes would have occurred in the absence of the safety-in-design initiative and whether the accepted design changes ultimately affected construction site safety on the project are also addressed

Young-Corbett, D. E. (2014). "Prevention through Design: Health Hazards in Asphalt Roofing." *Journal of Construction Engineering and Management* 140(9): 06014007.

The optimal method of preventing occupational illnesses, injuries, and fatalities is to design out the hazards and risks, thereby eliminating the need to control them during work operations. In 2007, the National Institute for Occupational Safety and Health launched a national Prevention through Design (PtD) initiative calling on all major industrial sectors to emphasize hazard mitigation at the design stage. PtD applies to the design of all tools, equipment, materials, and work processes that are employed during the construction process. This article reviews the asphalt roofing health hazards and currently available design solutions for their control and identifies gaps and priorities for further research. PtD solutions such as tanker systems, insulated hot luggers, mechanical asphalt spreaders, fume-suppressing asphalt, and local exhaust ventilation systems are discussed in terms of effectiveness and availability.

Zhang, P., et al. (2015). "Work-Health and Safety-Risk Perceptions of Construction-Industry Stakeholders Using Photograph-Based Q Methodology." *Journal of Construction Engineering and Management* 141(5): 04014093.

Work health and safety (WHS) on construction sites can be influenced by decisions made upstream from the construction stage. The effectiveness of WHS risk management relies on decision makers' ability to decide appropriate strategies to mitigate/control risks. However, it is unclear whether upstream decision makers share similar WHS risk perceptions with those who undertake the construction work. This study used Q methodology to explore WHS risk perceptions of architects, engineers, construction managers, and WHS professionals. Photographs depicting different technologies/methods were used to capture professionals' WHS risk judgments. Data were analyzed to identify the within-group and between-group similarity/difference in professionals' WHS risk perceptions. The data-analysis result indicates the coexistence of within-group difference and similarity, as well as between-group difference and similarity in WHS risk perceptions. The research contributes to the body of knowledge by showing that WHS risk is subjective in nature and that social, psychological, and technical factors interact to shape subjective risk judgments. The research finding challenges traditional risk-management thinking, which assumes risk is objective and easily quantifiable.

