CSRA Research Summary

Prevention through Design (PtD) of Safe Work Operations: Phase I

Principal Investigator:

John Gambatese, PhD, PE(CA)
Professor, School of Civil and Construction Engineering
Oregon State University
101 Kearney Hall
1491 SW Campus Way
Corvallis, OR 97331
Tel.: 541-737-8913
john.gambatese@oregonstate.edu

Co-Principal Investigator:

Ziyu Jin, PhD
Assistant Professor, Department of Construction Management
Colorado State University
102 Guggenheim Hall
291 W. Laurel St.
Fort Collins, CO 80523-1584
Tel.: (970) 491-1442
ziyu.jin@colostate.edu

May 6, 2025

Executive Summary

Prevention through design (PtD) has shown promise in influencing the design of architectural, structural, and mechanical work processes to address worker safety and health during the early phases of a project. However, its integration into the design of work processes remains limited, despite the potential to reduce serious injuries and fatalities (SIFs). Through industry surveys, field observations, and focus group meetings, this study explored how design and construction professionals currently approach planning for work operations and site logistics, the potential benefits of applying PtD, and ways to apply PtD in these areas. Key findings highlighted the phases of critical decision-making for construction phasing, and identified the design review stage most commonly used for constructability reviews, suggesting optimal timing for integrating PtD. The study also identified several key factors influencing worker safety, which practitioners could prioritize when planning work operations and logistics. Potential PtD interventions include high-energy controls, the hierarchy of controls, design for safety principles and/or guidewords, and the cognitive demand/workload concept. Further research is needed to develop, test, and measure the effectiveness of PtD intervention application to the design of construction work processes for the purposes of preventing SIFs.

[Note: This document provides a summary description of the research study and findings. A journal paper that provides a comprehensive description and analysis of the research study and findings is planned for submittal and publication in an academic journal.]

Table of Contents

Prevention through Design (PtD) of Safe Work Operations: Phase I

1. Introduction

Design is a powerful ability. It affords us the opportunity to create an environment to our liking. In the construction industry, design facilitates the creation of built infrastructure that meets the needs and desires of our society. The design of buildings, roadways, bridges, and the many other parts of our physical infrastructure provides us with shelter, and enables us to work, produce food and goods to live, get from one location to another, and live a safe and healthy life. The influence that the design of our built infrastructure has on daily human life, including on those who construct the designs, places considerable importance on creating designs that are safe and enable healthy and prosperous lives. That is, good design demands attention. Conducted with care, design can be extremely beneficial; without critical thought and ethical guidance, design may unintentionally cause harm.

Designing our built infrastructure is a complex process that involves design professionals knowledgeable in various fields of study, most notably architecture and engineering. Architects and engineers create project designs that depict and describe the quality, physical shape, and location of the infrastructure to be built. Construction professionals then turn the design into reality. To do so, constructors review the design drawings and specifications and determine how to build the design, the order of the work activities, and the personnel, materials, and equipment required. Constructors start with the design "product" and create the "process" to be followed to build the design. In other words, constructors *design* the construction process for the project.

The prevention through design (PtD) concept recognizes the importance of good design to the safety and health of those who interact with the design. The National Institute for Occupational Safety and Health (NIOSH) defines PtD as "all of the efforts to anticipate and design out hazards to workers in facilities, work methods and operations, processes, equipment, tools, products, new technologies, and the organization of work"[1]. PtD is implemented whenever design occurs, eliminating or reducing the need to apply lower-level controls that are less reliable after the fact.

While efforts to advance PtD have made progress in influencing how buildings and infrastructure are designed, its role in shaping safer construction processes, such as work plans, site layouts, and logistics, has received far less attention. However, these processes have a direct impact on the conditions that workers face on jobsites. How tasks are sequenced, how spaces are organized on-site, and how materials are moved, are just as critical to ensure worker safety as the architectural and structural design itself.

This scoping study explored how PtD principles can be applied to designing safer construction processes, and documented the influence of PtD on the design of construction work processes.

2. Background and Rationale

In the construction sector, “construction operations” refers to “any activity that contributes to the delivery of a construction project” [2]. When planning construction projects, the primary emphasis is often on managing budgets and schedules [3], while worker safety receives less attention. From a safety perspective, designing construction operations involves considering various factors that affect worker well-being, including, but not limited to: construction site utilization and layout planning [4], [5], workforce selection including workers, supervisors [6], as well as subcontractors [7], the selection of temporary structures, equipment, and tools [6], [8], and the sequencing of construction tasks and workflows [9].

In particular, when planning a construction site and layout, several worker safety-related factors must be considered. These factors can be broadly categorized into three groups: general safety considerations, interaction flows, and environmental factors. General safety considerations include fundamental aspects that influence site safety, such as access [4] and housekeeping [4], and risks related to heavy equipment, such as cranes and material hoists [5], [10]. Interaction flows [5] mainly concern the movement of resources and personnel, including materials (raw materials, work-in-process, and finished products), equipment (used to transfer resources between facilities/locations), jobsite personnel, and information (the exchange of oral communication or reports). Lastly, environmental factors include noise, chemical hazards, vibrations, and other harmful substances [4], [5]. However, there is limited research or guidance available that focuses on improving these plans with a particular emphasis on design for safety considerations.

A similar concern arises when choosing the optimal construction strategy, which involves making decisions about construction operations. The selection process requires careful consideration of risk, cost, benefits, and the potential outcomes of each option [6]. For example, when constructing reinforced concrete buildings, decision-making involves factors such as the forming technique, construction cycle, number of shored and reshored floors, experience level of construction personnel, supervision and quality control, as well as the type of construction equipment used [6]. While some decision-making frameworks have been developed, as noted in [6], their application in the field has been limited or not thoroughly examined. Additionally, the potential impact of construction strategy decisions made in the early phases on downstream worker safety has not been thoroughly investigated to date.

To address these gaps, several studies have focused on PtD applications in specific construction operations. For example, a study on the design and installation of solar systems [11], based on interviews and four case studies, highlights how PtD can be applied to such work. The study identified several design attributes that impact worker safety and the selected work processes, such as roof slope (e.g., flat, steep), roof material (e.g., metal, composite), roof accessories (e.g., skylights, chimneys), panel layout (e.g., clearance, location), fall protection systems (e.g., location or number of anchors), lifting methods (e.g., mechanical lifts, ladders), electrical systems (e.g., rapid shutdown, wire location), and installation sequences (e.g., vertical, horizontal). The study also proposed a PtD protocol as guidance for implementing PtD in residential solar projects. Though such studies provide valuable insights on how PtD can be applied to improve worker safety and health in specific construction operations, there is currently a lack of formal investigations on how PtD can be systematically integrated into decision-making processes for construction planning and logistics for broader, general purposes.

Given the limited research on integrating PtD into the construction work process, it is important to investigate how design and construction practitioners determine construction strategies when creating and using design documents. Understanding their decision-making process could help identify ways to incorporate PtD, develop PtD interventions, and enhance work plans and logistics to make construction operations safer and prevent SIFs.

To achieve this goal, the first step is to examine how design and construction practitioners currently approach work operations and logistics during the design/planning and construction phases. This examination could help document industry practices, including key considerations, priorities, available resources, tools, and the decision-making processes practitioners rely on. By gaining understanding of these existing processes, it is possible to identify opportunities to integrate PtD and improve safety in construction work.

3. Methodology

The study followed a three-step approach to explore how PtD principles can be applied to designing safer construction processes. The aim was to understand current practices, identify opportunities to integrate PtD, and finally provide recommendations for future research and practical application. The specific research questions that the study attempted to answer are listed as follows:

1. How do construction professionals commonly develop project work plans and logistics?
2. What factors and priorities do construction professionals consider when creating project work plans and logistics?
3. What resources and guidance do construction professionals commonly rely on, if any, for developing project work plans and logistics?
4. Are there current PtD-related concepts and practices that could potentially enhance work plans and logistics to benefit worker safety, and which should be studied further?

Step 1: Industry Survey

The first step in the study involved gathering insights directly from industry professional through a survey. The survey focused on understanding how work plans and logistics are typically developed. It explored what factors are prioritized, what resources and tools are commonly used, and where safety considerations currently fit into the process.

The survey consisted of seven parts: 1) general information about the participant (e.g., work position, years of experience, role/responsibilities, etc.); 2) a specific project description (e.g., type of project, scope of the project); 3) work operations and logistics planning process of the selected project described in part 2 (e.g., people involved in the decision-making process in terms of construction work phasing, activities, and resources, the timing of such meetings, the physical attributes discussed during the meetings, and resources used); 4) influencing factors of work operations on worker safety (e.g., the impact of dimensional characteristics, location characteristics, and actions and interactions on worker safety, etc.); 5) questions related to the PtD concept (participants' familiarity with PtD, experience with PtD, current practices related to the design of the construction process, etc.); 6) involvement in the design phase and constructability reviews (e.g., when, by who, and how constructability reviews were conducted,

what factors were considered, and to what extent the factors are considered); 7) any additional comments participants may have about the topic.

The survey questionnaire was distributed by CSRA between June and August 2024 to its member companies and others on its contact list. A few recipients also helped by forwarding the invitations to others who might be interested in participating. A total of 41 respondents from the construction industry across the U.S. and Canada were sampled and included in the final analysis.

Step 2: Observations of Planning Processes

Following the industry survey, the second step moved to the field to observe how design and construction professionals plan work processes in real-world settings. By attending work planning meetings, the study captured a snapshot of how decisions are made, what worker safety considerations are discussed, to what extent they are addressed, and where PtD concepts could fit into the processes. These observations were designed to confirm and complement the findings from the online survey. Before conducting the observations, an observation checklist was developed to make sure consistent information was recorded across meeting and projects. Two projects were observed and included in this scoping study: one university research and education center project (Project A) and an expansion project of a natural gas pipeline system (Project B). Regarding the timeline, Project A was already in its construction phase, and the meetings attended included two daily hurdles meetings and two weekly project look-ahead meetings. For Project B, the project was still in its design phase (30% design completion), and the researchers attended two online design review meetings.

Step 3: Focus Group Meetings

During the course of the study, the research team held focus group meetings with the CSRA PtD research team to present and discuss the research progress and gather their feedback and input. In addition to the initial discussion of the study in November 2023, a meeting was held on May 10, 2024 to report on the progress of the survey design and observation meeting planning. Another meeting was held on October 16, 2024 to review the preliminary findings of the study and seek recommendations for the next phase.

4. Key Findings

Existing studies on PtD have primarily focused on its integration into architectural, structural, or other permanent elements of design. Limited attention has been given to how PtD could be applied to the design of construction work operations and site logistics. However, without careful consideration of such processes, site operations can significantly impact efficiency and may increase the likelihood of SIFs. This study aimed to develop fundamental knowledge and provide recommended paths for future studies on the integration of PtD into construction work operations and site logistics.

Key findings from the study reveal that decision-making about construction phasing mainly occurs in three stages: after being selected for the project but before mobilization to the site, after mobilizing to the site, and during the construction phase prior to each new work activity. Regarding the design phase, the 90% design review was the review most commonly

used for addressing constructability of the design. These timings may suggest optimal points for integrating PtD into work operations and logistics. While some key practices are used in work plan and logistics development, there are currently no standardized procedures for applying and implementing PtD in these tasks. However, survey participants highlighted that careful planning of work operations and logistics could help reduce accidents, as many past injury and fatality incidents were attributed to design flaws, lack of coordination, worker-related issues, environmental factors, or last-minute design changes, all of which closely tie to work operation processes or site logistics.

The study also identified the factors influencing worker safety and assessed their levels of impact. For example, work operations with the greatest influence on safety include work phasing, activity sequencing/process development, equipment siting and selection, and material availability/access. Additionally, the amount of energy associated with actions and interactions as well as the positional characteristics of the work, is generally considered as the most significant factor influencing worker safety in these two categories. The findings regarding factors with the greatest influence on worker safety could serve as starting points for practitioners when planning for work processes and logistics. By focusing on these critical factors, practitioners could prioritize their efforts and allocate resources more effectively to the areas with the greatest impact, ultimately reducing SIFs more efficiently.

The findings from this Phase I study also reveal several possible interventions during the design of the work processes and the project logistics planning to positively influence construction safety and eliminate SIFs. Introducing and applying the concept of high-energy controls during design and construction pre-planning is likely to benefit enhancing safety associated with the selected work processes and logistics. Other interventions identified as potentially beneficial include incorporating the hierarchy of controls concept, introducing design for safety principles and/or guidewords, and mitigating conditions that create considerable cognitive demand/workload. All of these potential interventions are envisioned to support going from the product design to the process design to improve safety during construction.

Further research is needed to identify which potential interventions should be explored further, how the interventions could be developed and tested for the design of work operations and site logistics, and how their effectiveness can be measured. Additionally, it is important to explore how and when PtD interventions should be implemented on a project to have the greatest impact on preventing SIFs.

5. References

[1] NIOSH, “Prevention through Design,” Prevention Through Design. Accessed: Dec. 25, 2024. [Online]. Available: https://www.cdc.gov/niosh/ptd/about/index.html

[2] Chartered Institute of Building (CIOB), “Construction operations definition.” Accessed: Jan. 13, 2024. [Online]. Available: https://www.designingbuildings.co.uk/wiki/Construction_operations_definition

[3] C. Hendrickson and T. An, *Project management for construction: Fundamental concepts for owners, engineers, architects and builders*. Prentice Hall, 1998.

[4] H. M. Sanad, M. A. Ammar, and M. E. Ibrahim, “Optimal Construction Site Layout Considering Safety and Environmental Aspects,” *Journal of Construction Engineering and Management*, vol. 134, no. 7, pp. 536–544, Jul. 2008, doi: 10.1061/(ASCE)0733-9364(2008)134:7(536).
[5] X. Ning, J. Qi, C. Wu, and W. Wang, “A tri-objective ant colony optimization based model for planning safe construction site layout,” *Automation in Construction*, vol. 89, pp. 1–12, 2018.
[6] B. M. Ayyub and A. Haldar, “Decisions in Construction Operations,” *Journal of Construction Engineering and Management*, vol. 111, no. 4, pp. 343–357, Dec. 1985, doi: 10.1061/(ASCE)0733-9364(1985)111:4(343).
[7] S. Love, “Subcontractor partnering: I’ll believe it when I see it,” *Journal of Management in Engineering*, vol. 13, no. 5, pp. 29–31, 1997.
[8] B. D. Lowe, J. Albers, M. Hayden, M. Lampl, S. Naber, and S. Wurzelbacher, “Review of Construction Employer Case Studies of Safety and Health Equipment Interventions,” *Journal of Construction Engineering and Management*, vol. 146, no. 4, p. 04020012, Apr. 2020, doi: 10.1061/(ASCE)CO.1943-7862.0001782.
[9] M. G. I. Shaaban, M. A. Kenawi, A.-A. A. Senoon, and M. A. A. El-Naiem, “Effects of excavation and construction sequence on behavior of existing pile groups,” *Innov. Infrastruct. Solut.*, vol. 8, no. 8, p. 223, Aug. 2023, doi: 10.1007/s41062-023-01193-8.
[10] K. El-Rayes and A. Khalafallah, “Trade-off between Safety and Cost in Planning Construction Site Layouts,” *Journal of Construction Engineering and Management*, vol. 131, no. 11, pp. 1186–1195, Nov. 2005, doi: 10.1061/(ASCE)0733-9364(2005)131:11(1186).
[11] C. Ho, H. W. Lee, and J. A. Gambatese, “Application of Prevention through Design (PtD) to improve the safety of solar installations on small buildings,” *Safety Science*, vol. 125, p. 104633, May 2020, doi: 10.1016/j.ssci.2020.104633.
[12] E.D. Oguz Erkal and M. Hallowell, “Moving Beyond TRIR: Measuring & Monitoring Safety Performance With High-Energy Control Assessments,” *Professional Safety*, vol. 68, no. 05, pp. 26–35, 2023.
[13] National Institute for Occupational Safety and Health (NIOSH), “Hierarchy of Controls.” [Online]. Available: https://www.cdc.gov/niosh/hierarchy-of-controls/about/index.html
[14] Workcover, "CHAIR: Safety in Design Tool," New South Wales. [Online]. Available: https://safedesignaustralia.com.au/wp-content/uploads/2018/10/CHAIR_Safety_in_Design_Tool_WorkCoverNSW.pdf.
[15] J.A. Gambatese, *Prevention through Design (PtD) in the Project Delivery Process*, Aug. 2019. [Online]. Available: https://designforconstructionsafety.org/wp-content/uploads/2019/09/ptd-in-the-project-delivery-process.pdf.
[16] Alotaibi Abdulaziz and Gambatese John, “Impact of Task Demand and Physical Energy on Mental Workload Experienced by Construction Workforce: Insights of Construction Professionals,” *Practice Periodical on Structural Design and Construction*, vol. 29, no. 2, p. 04024006, May 2024, doi: 10.1061/PPSCFX.SCENG-1422.