# Prevention through Design Research:

## Updates and Progress

May 15th, 2024

**Sang Daniel Choi, PhD, MPH, MS, CSP, CPE, Professor**

**George Mason University**

NORA Construction Sector Council

COLLEGE OF PUBLIC HEALTH
George Mason University

# Outline

- ❖PtD Introduction
- ❖Global construction overview
- ❖Global comparisons of design for construction safety and health among the United Kingdom, Singapore, South Korea, and United States
- ❖PtD Checklists
- ❖Automated machines and Equipment (AAM&E) in the Industrial Applications
- ❖PtD - Research to Practice to Research (RtPtR) ***Goes Beyond the USA***
- ❖ Q & A

# Prevention through Design

To prevent or reduce occupational injuries, illnesses, and fatalities through the inclusion of prevention considerations in all designs that impact workers. The mission can be achieved by:

- ❑ **Eliminating hazards and controlling risks** to workers to an acceptable level "at the source" or as early as possible in the life cycle of items or workplaces.

- ❑ **Including design, redesign and retrofit of new and existing** work premises, structures, tools, facilities, equipment, machinery, products, substances, work processes and the organization of work.

- ❑ **Enhancing the work environment** through the inclusion of prevention methods in all designs that impact workers and others on the premises.

PtD
Prevention through Design


Source: NIOSH. Prevention through Design. https://www.cdc.gov/niosh/topics/ptd

# Prevention through Design (PtD)

## Hierarchy of Controls

*Evolving Theories & Models*
*Systems & Behavior Safety, Risk Management*
*Manuele (2014)*


**Wm J. Haddon (1973)**

***Energy Damage & 10 Countermeasure Strategies (Human Factor 15(4) 355-366)***

**Jack E. Peterson (1974)**

***Industrial Environment Its Evaluation and Control*** **(NIOSH's Publication 74-117)**

**W. G. Johnson (1975)**

***Management Orversight & Risk Tree***

***(JSHER 7(1) 4-15)***

**F. A. Manuele (2005 & 2014)**

***Risk Assessment and Hierarchy of Control (Professional Safety 50(5) 33-39***

***Socio-Technical Model (Advanced Safety Management – Chapter 14 p. 267-280)***

**ANSI/AIHA Z10-2005**

**ELIMINATION**

**Design it out!!**

**SUBSTITUTION**

**Use something else**

**ENGINEERING CONTROLS**

**Isolation and guarding**

**ADMINISTRATIVE CONTROLS**

**Training and work scheduling**

**PERSONAL PROTECTIVE EQUIPMENT**

**Last resort**

**Control Effectiveness**

**Business Value**

# Global Comparisons of Design for Construction Safety and Health among the United Kingdom, Singapore, South Korea, and United States

**Prof. Sang Choi, George Mason University, USA**

Rory O'Neill, Queen Mary University of London, UK

Yang Miang Goh, National University of Singapore, Singapore

Jeong Hun Won, Chungbuk National University, South Korea

James G. Borchardt, Construction Ergonomics LLC, USA

Scott Schneider, Former Director at LHSF, USA

Linnea Wikstrom, Director of BWI, Geneva, Switzerland

# Introduction/Overview

## Global Construction

- ❑Construction is one of the world's biggest and fastest growing industrial sectors. In 2022, the global construction industry was valued at $14.4 trillion which was 14.2% of the global GDP.
- ❑ From 2022 to 2032, global construction is expected to grow 6.2% annually due to: infrastructure development by governments; increases in green construction and industrialization.
- ❑ The U.S. was the leading market in the construction industry, accounting for 21.6% of the total in 2022 (The Business Research Company, PR Newswire, 2023)

- ➢ One of most dangerous industries with disproportionately high accident rate (NSC, 2022).
  -- 108,000 killed annually i.e. about 30% of all occupational fatal injuries (Gürcanli and Müngen, 2013; ILO, 2015).

**However, Construction Fatality Rates DIFFER Widely between countries!**

For example, UK's 2010 All Industry Fatality Rate was 1/3 the US All Industry Fatality Rate and UK's Construction Fatality Rate was ¼ US Construction Fatality Rate. European Union (EU) countries' fatality rate was almost as low as UK (Mendeloff and Staetsky, 2014; O'Sullivan, 2018).

**Why is Construction Work in UK, EU and Asian Countries such as Singapore and South Korea Safer than in the US?**

**Let's Explore possible reasons e.g. the Effectiveness of Safety/Health Initiatives in United Kingdom (CDM); Singapore/Korea (DfS); United States (PtD)**

# Possible Reasons?

## U.K. Industry and S&H Initiatives

(Mitrefinch, 2021; Van Green, 2022; Phillips, 2022)

**U.K. vs U.S. construction workforce**

- ✓ **More Stable,**
- ✓ **More Experienced,**
- ✓ **Less Risk Taking,**
- ✓ **Tougher Fall Protection Rules,**
- ✓ **More Government-Funded Projects which are safer because more closely follows Regulation** (e.g. 2012 London's Olympic Park).

**UK's Health and Safety Act (HSW Act)** (Aires and Gamez, 2015)

- ✓ **Added Construction Design & Management Regulations (CDM, 2015),**
- ✓ **Obligates Designers & Architects to include Safety in ALL Project Phases,**
- ✓ **Establishes sensible Work Plan which Manages Risks from Start to Finish,**
- ✓ **Has "Right People for the Right Job at the Right Time",**
- ✓ **Coordinates All Worksites Work**
- ✓ **Provides Risk and Mitigation information,**
- ✓ **Communicates these Effectively to All workers involved.**

# Possible Reasons con't?

## Singapore, South Korea

## S&H Initiatives Examples

<u>Singapore's S&H Initiatives (WSHC, 2018)</u>

- ✓ "Guidelines on Design for Safety for Building and Structures" (2008)
- ✓ Design for Safety (DfS) Coordinator Course (2010)
- ✓ DfS Recognition Scheme (2011)
- ✓ Dfs Regulations (2015) – Enacted & Enforced by Singapore's Ministry of Manpower
  - -- Applies to all contracts exceeding S$10 million
  - -- Focused on developers and Designers

<u>South Korea's S&H Initiatives</u>

- ✓ Construction Technology Promotion Act (CTP Act) By Ministry of Land, Infrastructure Transport
- ✓ Occupational Safety and Health Act (OSH Act) By Ministry of Employment and Labor

# Comparative Analysis

## Construction Design & Management (CDM)

## Design for Safety (DfS)

## Prevention through Design (PtD)

---

## Criteria

Pertinent Areas and Goals

Application Phase

Design Change Requirements

Collaboration among Participants & Stakeholders

Expert Involvement

Alternative Designs & Reviews

Design Support Tools & Resources

# Summary of Comparative Analysis of CDM, DfS, and PtD.

| Criteria | U.K. (CDM) | Singapore (WSH/DfS) | South Korea (DfS) | U.S. (PtD) | NOTES |
|---|---|---|---|---|---|
| **Pertinent Area/Goals** | Specific requirement I:<br><br>When construction working day is more than 30 days and more than workers 20 at the same time.<br><br>Specific requirement II:<br><br>Annual construction workers exceed 500-person days in total. | To reduce risk at source.<br>Applicable when contract sum is greater than S$10 million | DfS concept:<br><br>Applicable in design stage to prevent workers' accident.<br><br>Applicable to public construction | Prevention through Design (PtD) concept:<br><br>Applicable principles during entire Life Cycle:<br><br>(concept, design, production, operation, dismantle /disposal) | CDM 2015: Health and Safety Executive (HSE) must be notified of the project by the client (Form 10 rev).<br><br>"A quick guide for clients on CDM 2015" (https://www.hse.gov.uk/ pubns/indg411.htm). |

# Summary of Comparative Analysis of CDM, DfS, and PtD (cont'd)

| Criteria | U.K. (CDM) | Singapore (WSH/DfS) | South Korea (DfS) | U.S. (PtD) | NOTES |
|---|---|---|---|---|---|
| **Application Phase** | Phase I:<br>Identification of the major hazards during the design phase.<br><br>Phase II:<br>Reflection of the risk at design phase by safety experts.<br><br>Phase III:<br>Consideration of the unremoved risk at the design phase during the pre-construction phase. | Earliest opportunity from the planning and design phases onwards. | Conduct the review in the whole design process. The report is made by at the end of design stage. | Phase I:<br>Conduct the review<br>from the beginning of the concept or design phase.<br><br>Phase II:<br>Conduct the review<br>from design phase is<br>30%, 60% and 90% complete. | PtD is applicable to the entire life cycle of product or project.<br><br>CDM focus on preparations and hazard/risk assessments/removal at or during design phase. |

# Summary of Comparative Analysis of CDM, DfS, and PtD (cont'd)

| Criteria | U.K. (CDM) | Singapore (WSH/DfS) | South Korea (DfS) | U.S. (PtD) | NOTES |
|---|---|---|---|---|---|
| **Design Change Requirements** | Mandatory/compulsory modification as per CDM requirements. | Developers and designers must eliminate foreseeable design risks. If it is not reasonably practicable to eliminate the design risks, developers and designers have to work collaboratively to reduce the design risks to as low as reasonably practicable | Only applicable in the design stage. The design change in the construction process do not apply DfS. | Recommendation or guidance for consideration. | PtD is a guidance vs. CDM is compulsory for design changes. |

# Summary of Comparative Analysis of CDM, DfS, and PtD (cont'd)

| Criteria | U.K. (CDM) | Singapore (WSH/DfS) | South Korea (DfS) | U.S. (PtD) | NOTES |
|---|---|---|---|---|---|
| **Collaboration among Participants/ Stakeholders** | Mandatory sharing the information among the participants (managed by: principal designer and/or principal contractor) | Mandatory sharing of information and collaboration through DfS review meetings and DfS register (managed by developer, who can delegate the duty to a DfS Professional) | The owner and designer should participate in DfS. | All stakeholders or participants are recommended to participate in the entire life cycle | PtD concept strongly encourage the participants of all the stakeholders, but not mandatory unlike CDM |
| **Expert Involvement** | Principal designer is assigned as facilitator, considering using specialist who is familiar with the necessary precautions, etc. | Developer or DfS Professional is to facilitate the DfS review process and manage the DfS register; relevant Designers and Contractors must be involved. | It is recommended to involve safety experts. | Little or none unless otherwise voluntarily. | PtD is voluntarily vs. CDM/client assigns "Principal Designer" |

# Summary of Comparative Analysis of CDM, DfS, and PtD (cont'd)

| Criteria | U.K. (CDM) | Singapore (WSH/DfS) | South Korea (DfS) | U.S. (PtD) | NOTES |
|---|---|---|---|---|---|
| **Alternative Design-Reviews** | Change of the design through regular review at the design and/or construction phases | Change of the design through regular review throughout the project, in particular the planning and design phases. | The owner has a duty for managing DfS. The approval of alternative design is depend on the owner. | Contractor should participate risk analysis when working design is 30% complete of the project | PtD is "design out" approach, vs. CDM requires regular reviews thru risk assessments. |
| **Design-Support Tools/ Resources** | Accessible resources and toolkits: Checklists for clients, principal designers, contractors, principal contractor, and general safety plans and requirements. | Accessible resources and toolkits: Checklists and guidelines for developers and designers; library of solutions provided by industry association; approved training conducted by industry associations | The DfS manual provided the sample and form. KALIS operates the DfS system for supplying the information of the review process. (https://www.csi.go.kr) | Available resources and tools: design review checklists, risk assessment pro forma, various database of safe designs, design risk calculators. | PtD design has ample resources and guidance provided by NIOSH. (www.cdc.gov/niosh/topics/ptd/pubs.html)<br><br>CDM related resources and toolkits are available by HSE and various consultants. |

# PtD-checklists

**Interim Fall Prevention Checklist for Architects and Design Engineers**

**Interim Struck-by Checklist for Design Engineers and Architects/Resident Engineers - Roadway Workzones**

**Interim Struck-by Checklist for Architects and Design Engineers - Building Construction**

# Interim Fall Prevention Checklist for Architects and Design Engineers

**<u>Design Engineer Codes</u>: CI = Civil; ME = Mechanical; ST = Structural; SA = Safety**

| Component | Design Risk | PtD Controls | Architect | Engineer |
|---|---|---|---|---|
| Roof Openings (skylights, roof hatches, solar tubes, exhaust fans, etc.) | Falling through the roof openings during installation, maintenance, or emergency operations due to no or inadequate fall protection systems. | • Design permanent guardrails around openings | X | CI/ ST |
| | | • Specify skylights to have guardrails, load bearing mesh, or certified glass covers | X | ST |
| | | • Design group roof openings together to create one larger opening and guardrail rather than many smaller openings | X | ST |
| | | • Locate roof access away from leading edges | X | ME |
| | | • Provide adequate space around roof hatch to allow personnel movement | X | ST |
| Roof access | Falling from unsafe roof access points (Unprotected ladders, unsafe roof hatch openings). | • Design safe access directly to all roof levels or from level to level (protected ladder, ships ladder, stairs) | X | CI, ST |
| | | • Design/provide safety grab bar for hatch access | X | CI, SA |
| Roof Edges (elevated levels/changes in elevations) | Falling off the open edges during construction if they are not adequately guarded or protected. | • Design minimum 42” height parapets or railings at all roof edges | X | CI |
| | | • Design/specify embedded anchor points:<br>- Located to enable the end user to perform regular maintenance tasks safely | X | CI/ ST |

# Interim Struck-by Checklist for Design Engineers and Architects/Resident Engineers - Roadway Workzones

Design Engineer Codes: CI = Civil, TR = Traffic; ME = Mechanical; ST = Structural; PR = Project

| Component | Design Risk | PtD Controls | Action by |
|---|---|---|---|
| Vehicle and heavy equipment traffic | Construction vehicle movement and activities can lead to struck-by hazards for workers. | • Design access/egress so as to minimize construction and motorist traffic conflicts<br>• Design the order of work completion to minimize backing and minimize pedestrian worker and equipment conflicts | ☒ Architect (Resident Engineer)<br>☒ Design Engineer (TR, PR) |
| Motorist traffic | Highway and roadway motorist traffic can enter construction zones and strike construction workers. | • Specify physical barriers to protect workers in construction zones from passing motor vehicle traffic<br>• Design temporary traffic control setup to facilitate reducing speed of motor vehicle traffic<br>• Incorporate truck-mounted attenuators into traffic control plans to provide additional protection for motorists.<br>• Specify adequate lighting is provided during night operations. Install in a manner that minimizes glare and potential blinding of oncoming motorists | ☒ Architect (Resident Engineer)<br>☒ Design Engineer (TR, ME,PR) |
| Pedestrian Worker Traffic | Confined, congested, or unstable areas for walking adjacent to motor vehicle traffic and to operating construction equipment and vehicles increases risk of workers being struck-by passing motorist vehicles/ operating construction vehicles & equipment. | • Specify physical barriers to separate and protect workers from motorist traffic, construction vehicles, and heavy equipment<br>• Schedule different work activities at different time to reduce work crew exposure to passing construction vehicles and equipment<br>• Design separate work zone entry and exit points for pedestrians and vehicles<br>• Identify on site plans firm, level, well-drained pedestrian walkways that take a direct route | ☒ Architect (Resident Engineer)<br>☒ Design Engineer (TR, ST, PR) |

# Interim Struck-by Checklist for Architects and Design Engineers - Building

<u>Design Engineer Codes</u>: CI = Civil; ME = Mechanical; ST = Structural; SA = Safety

| Component | Design Risk | PtD Controls | Action by |
|---|---|---|---|
| Piping and ductwork (erection) | Large pipe or ductwork sections, which lack adequate connection points for lifting and lack restraint from rolling can lead to struck-by hazards for workers. | • Design large pipe or ductwork sections to be oval or have one flatten portion to prevent rolling<br>• Keep all materials off ground, use racks, pallets, carts<br>• Ensure materials are secured, use chocks, cleats or other devices | ☒ Architect<br>☒ Design Engineer (ME) |
| Pipes/beams or overhead objects | Unmarked low beams or pipes at site can create struck-by hazards for workers. | • Route piping or overhead object to avoid “head knockers” (6’-6” min. above grade)<br>• Visibly mark beams/pipes or overhead objects | ☒ Architect<br>☒ Design Engineer (ME) |
| Precast, prefabrication and steel beams and other structural elements | Large and heavy precast, prefabrication and steel beams structures pose struck-by hazards or a wide lifting radius. | • Design U-shaped precast beams with cast-in-situ infill concrete to reduce the crane load<br>• Design precast shell columns with cast-in-situ infill concrete to reduce the crane load<br>• Specify proper crane loading and movement radius for the structure being lifted<br>• Identify “lift zones” on the site preplanning | ☒ Architect<br>☒ Design Engineer (ST, CI, SA) |
| Building exterior | Loose materials and equipment can lead to stuck by and other safety hazards for workers. | • Specify impact resistant windows, doors and shields in other openings at occupied spaces in high wind areas<br>• Identify bins for materials or debris | ☒ Architect<br>☒ Design Engineer |

# PtD

## Automated Machines and Equipment (AAM&E) in the Industrial Applications

# Human-centered Design and Evaluation Methodologies of Autonomous and Automated Machines and Equipment (AAM&E) in the Industrial Applications

## Background:

- ❑ Automated or autonomous machines are increasingly being implemented in the industrial work environment, and has great potential to alleviate workers' safety and health risks in the hazardous workplaces (Burgess-Limerick, 2020; Edet & Mann, 2022; Horberry & Lynas, 2012; Rogers et al., 2019).

- ❑ A global talent crisis and an imminent skilled labor shortage are affecting both developed and developing economies. Moving toward autonomous or automated machines solutions may help ease the skilled operators' shortages in the various industry (Choi & Borchardt, 2022; Jurgens, 2021).

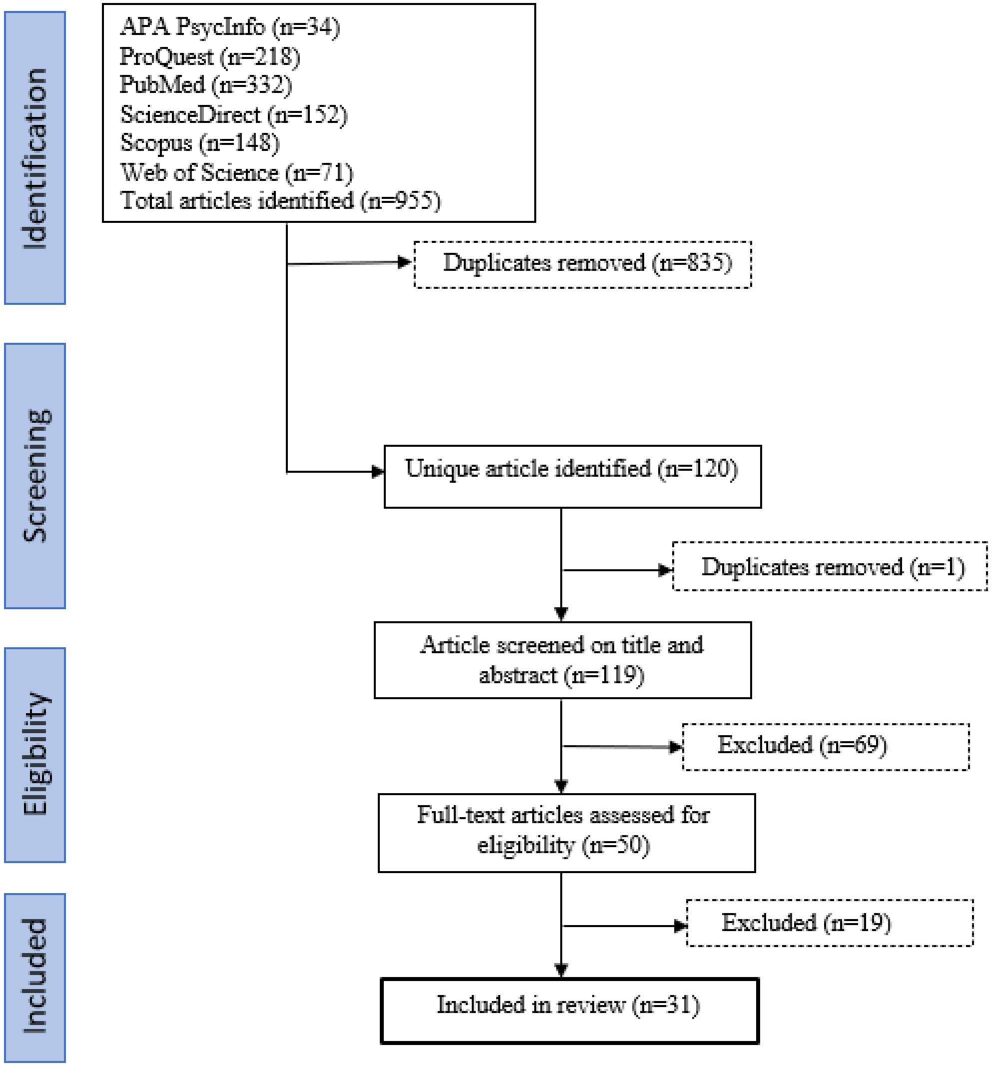
## Purpose:

- ➢ To review and synthesize human-centered design and evaluation methodologies for autonomous and automated equipment or machines in occupational and industrial settings, and propose methodological framework and future direction/guidance for addressing/improving limitations and weaknesses of the current AAM&E design and evaluation methodologies.

# Human-centered Design and Evaluation Methodologies of Autonomous and Automated Machines and Equipment (AAM&E) in the Industrial Applications

**Methods and Procedures:**

This review was based on the result of general keywords search of six databases: APA Psycinfo, PubMed, Web of Science, ScienceDirect, ProQuest, and Scopus. Initial searches of the databases produced a total of 955 results. After articles screened on title and abstracts, 69 paper were excluded.



## Human-centered Design and Evaluation Methodologies of Autonomous and Automated Machines and Equipment (AAM&E) in the Industrial Applications

- The full texts of the remaining 50 unique studies were reviewed for appropriateness, which resulted in an additional 19 studies being excluded, and resulted in a total of 31 studies.

- Of these papers, 22 reports on studies related to design methodology, and only 9 studies were on evaluation methodology of AAM&E in occupational and industrial settings.

- Reviewed and summarized the design and evaluation (and assessment) methodologies for autonomous and automated equipment or machines in various occupational and industrial settings (e.g., agriculture, mining, construction), while addressing and improving the limitations and weaknesses of the existing AAM&E design and evaluation methodologies.

# International Congress on Occupational Health (ICOH) 2024

## Prevention through Design (PtD) and Research to Practice to Research (RtPtR) in the aging U.S. construction workforce: Bridging the gap between academia and practitioners

# PtD - Research to Practice to Research (RtPtR)
# ***Goes Beyond the USA***

## Semi-Keynote/Plenary Speaker

| | | | | | |
|---|---|---|---|---|---|
| Friday, May 03, 2024 | 11:45 | Ministres | SPL 29 | Sang Daniel Choi<br>United States of America | PREVENTION THROUGH DESIGN (PtD) AND RESEARCH TO PRACTICE TO RESEARCH (RtPtR) IN THE AGING U.S. CONSTRUCTION WORKFORCE: BRIDGING THE GAP BETWEEN ACADEMIA AND PRACTITIONERS |

الرعاية السامية لصاحب الجلالة الملك محمد السادس
34th International Congress on Occupational Health
ICOH
Marrakesh 2024
Prevention through Design (PtD)
and Research to Practice to Research (RtPtR)
aging U.S. construction workforce: Bridging
between academia and practitioners
Sang Daniel Choi, PhD, MPH, MS, CSP, CPE, Professor
George Mason University, USA
James G. Borchardt, CPE, CSP
Construction Ergonomics LLC , USA
INSTITUTIONAL PARTNERS
CGEM
HOSTED BY
PLATINUM PARTNER
SILVER PARTNERS
CNSS
ICOH 2024
34th International Congress on Occupational Health

# References (select)


- Aires, M. D. M., & Gámez, M. C. R. (2015). The impact of occupational health and safety regulations on prevention through design in construction projects: Perspectives from Spain and the United Kingdom. Work, 53(1).
- American Society of Safety Engineers (2017). Occupational Safety and Health Management Systems. ANSI/ASSE Z-10-2012. Park Ridge, IL.
- Brown S., Harris W., Brooks R.D., Dong X.S. (2021, February). CPWR Data Bulletin. https://www.cpwr.com/wp-content/uploads/DataBulletin-February-2021.pdf.
- Construction Design and Management [CDM] 2015 (2019). Client Contractor Checklist, June 2019.
- Edet, U., & Mann D. D. (2022). Evaluation of Warning Methods for Remotely Supervised Autonomous Agricultural Machines. Journal of Agricultural Safety and Health, 28(1), 1-17.
- Health and Safety Executive [HSE] (2020). Health and safety in roof work (5th Edition). TSO@Blackwell. United Kingdom for the Stationary Office.
- Din, Z., & Gibson, G. E. (2019). Prevention through Design Accreditation Requirements in Engineering, Architecture, and Construction Education. Technical Report. November 2019.
- Driscoll TR, Harrison JE, Bradley C, Newson RS. (2008). The role of design issues in work-related fatal injury in Australia. Journal of Safety Resources. 2008;39(2):209-14.
- Goh et al.. (2021). IES-NUS Design for Safety (DfS) Library for Designers: Construction and Maintenance Design Risks. Health and Safety Executive [HSE]. What do I need to do? Construction (Design and Management) Regulations 2015).
- Gürcanli GE, and Müngen U. (2013). Analysis of construction accidents in Turkey and responsible parties. Ind Health. 2013;51(6):581-95. doi: 10.2486/indhealth.2012-0139. Epub. PMID: 24077446; PMCID: PMC4202747.
- Mendeloff, J. & Staetsky, L. (2014). Occupational fatality risks in the United States and the United Kingdom. Am J Ind Med., 57(1):4-14. doi: 10.1002/ajim.22258. Epub 2013 Sep 30. PMID: 24114988.
- Lim, M. S., & Goh, Y. M. (2023). Development and validation of the Design-for-Safety (DfS) climate measurement tool. Journal of Risk Research, 26(12), 1331–1352.
- Mitrefinch (2021).The Decline of Trade Unions in the UK. https://www.mitrefinch.co.uk/blog/employee-engagement/trade-unions-uk/.
- National Workzone Safety: Information Clearinghouse (2023). Public Awareness – 2023 National Work Zone Awareness Week. https://workzonesafety.org/public-awareness/work-zone-awareness-week/
- O'Sullivan, J. (2018). American workplaces are 900% more deadly than British ones. https://www.ishn.com/articles/108262-american-workplaces-are-900-more-deadly-than-british-ones
- Schneider, S. (2014). US vs. UK: Who is Safer and Why? https://www.lhsfna.org/us-vs-uk-who-is-safer-and-why/
- Schulte, Paul A., Richard Rinehart, Andrea Okun, Charles L. Geraci, Donna S. Heidel. (2008). National Prevention through Design (PtD) Initiative, Journal of Safety Research, Volume 39, Issue 2. Prevention through Design, 2008, Pages 115-121.
- The Business Research Company, PR Newswire (2023) Global Construction Industry Forecast - Market Size, Growth Rate And Leading Region, By The Global Market Model. https://www.prnewswire.com/
- The Institution of Engineers, Singapore (n.d.). https://www.ies.org.sg/Publication/Technical-Resources
- South Korea Occupational Safety and Health [SK – OSHA] (2017). Retrieved from: https://elaw.klri.re.kr/eng_service/lawView.do?hseq=43289&lang=ENG

# Acknowledgements

# Questions and Answers


schoi70@gmu.edu