IES-NUS DfS Library of Construction & Maintenance Related Design Risks

A/Prof Goh Yang Miang
Safety and Resilience Research Unit (SaRRU)
Department of The Built Environment
College of Design and Engineering

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Outline

- Challenges in Implementing DfS
- Creating the IES-NUS DfS Library
- DfS Concepts
- Examples from DfS Library
- SafeSim Design – Free Training

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PROBLEMS

Construction Industry

- Construction is consistently one of the **top contributors** to workplace fatalities in Singapore and other countries
- **Common causes of accidents:**
  - Unsafe acts and/or condition
  - Lack of design and planning for safety
- Can be eliminated or controlled effectively with **early intervention**
- WSH (Design for Safety) Regs 2015 came into operation on 1 August 2016

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Research by SaRRU on the practice of DfS since 2016

2016

9 interviews collected; observations of DfS review meetings

2017

15 interviews conducted; observations of DfS review meetings

2019

35 interviews conducted; observations of DfS review meetings

2020

4 focus groups, 15 participants on previous findings conducted, poll on a seminar about DfS; observations of DfS review meetings

2020

242 survey responses collected on DfS climate; observations of DfS review meetings

Interviews analysed using thematic analysis, survey responses analysed with statistical factor analysis

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Common Problems

- Designers tend to focus on users' and maintenance workers' safety and health
- Tend to defer construction safety and health issues back to contractors
- Confusion between DfS review and Construction Risk Assessment
- Designers do not have construction knowledge to understand the impact of their design

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Potential interventions to improve DfS

Band 1 **Training and development**	• Continuing DfSP training and refresher courses • DfS training for non-DfSP project stakeholders • Samples and solutions
Band 2 **Industry actions**	• Incorporate Building Information Modelling (BIM) for DfS review • Creating a DfSP association and having renewal criteria to maintain DfSP certification • Recognition of good developers for DfS through awards
Band 3 **Regulatory actions**	• Submissions of the Risk Register to Ministry of Manpower (MOM) • Compulsory 3rd party audits for DfS

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IES-NUS Design for Safety (DfS) Library for Designers: Construction and Maintenance Design Risks

https://www.ies.org.sg/Publication/TechResource

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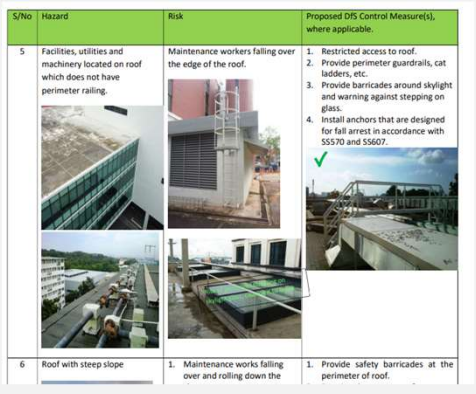
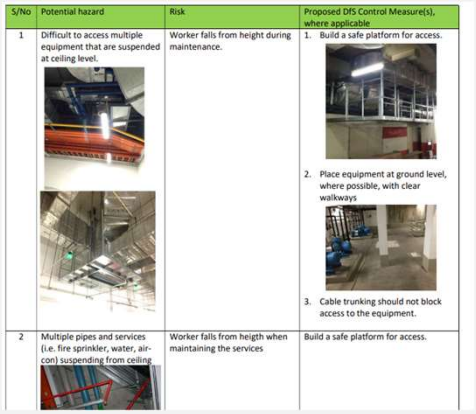
Existing DfS Libraries

Design for Safety (DfS) Library Examples of Hazards – Architectural Design



S/No	Hazard	Risk	Proposed DfS Control Measure(s), where applicable.
5	Facilities, utilities and machinery located on roof which does not have perimeter railing.	Maintenance workers falling over the edge of the roof.	1. Restricted access to roof. 2. Provide perimeter guardrails, cat ladders, etc. 3. Provide barricades around skylight and warning against stepping on glass. 4. Install anchors that are designed for fall arrest in accordance with SS570 and SS607.
6	Roof with steep slope	1. Maintenance works falling over and rolling down the	1. Provide safety barricades at the perimeter of roof.

Design for Safety (DfS) Library Examples of Hazards – Mechanical & Electrical Design



S/No	Potential hazard	Risk	Proposed DfS Control Measure(s), where applicable
1	Difficult to access multiple equipment that are suspended at ceiling level.	Worker falls from height during maintenance.	1. Build a safe platform for access. 2. Place equipment at ground level, where possible, with clear walkways 3. Cable trunking should not block access to the equipment.
2	Multiple pipes and services (i.e. fire sprinkler, water, air-con) suspending from ceiling	Worker falls from heigth when maintaining the services	Build a safe platform for access.

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The IES-NUS DfS Library for Designers: Construction and Maintenance Design Risk

- Review existing DfS registers shared by practitioners
- Select construction (and some maintenance) examples
- Develop figures based on pictures supplied by practitioners
- Critique by practitioners and regulators

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Design for Safety (DfS)

Design for Safety (DfS) is the **process** where **stakeholders of a construction project**[1] come together at the **earliest opportunity** during **different stages of a project**[2] to **identify and eliminate or reduce foreseeable design risks** throughout the **life cycle**[3] of a structure through good design.

Key Concepts

I. **Reducing risk at source**
II. **Collaborative and systematic risk assessment**
III. **Lifecycle approach**

[1] *E.g., developer, designers, contractors*
[2] *From planning and design phases onwards*
[3] *E.g. construction, use/operation, demolition*

Adapted from https://www.tal.sg/wshc/Topics/Design-for-Safety/About-Design-for-Safety

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Definition of
Design Risk (DR)

any permanent or temporary structure, and a reference to a structure includes any part of the structure and any product or mechanical or electrical system intended for the structure

"in relation to a **structure**, means **anything present or absent** in the **design** of the structure that **increases the likelihood** that an **affected person** will **suffer bodily injury** when constructing, working at or demolishing the structure"

(a) Construction worker
(b) Maintenance worker or cleaner
(c) People affected by the work

Workplace Safety and Health (Design for Safety) Regulations 2015.
https://sso.agc.gov.sg/SL/WSHA2006-S428-2015.

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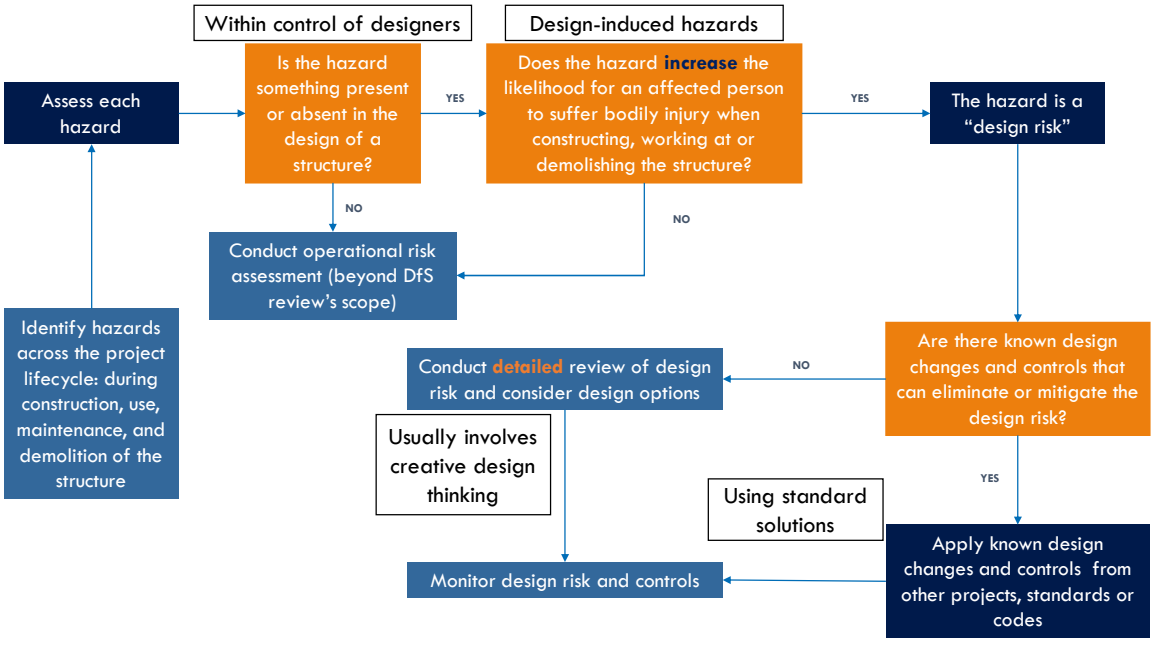

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Would you review this hazard as part of DfS?

A prefabricated link bridge to be installed between two towers using welding; temporary corbels are provided.
Due to the position of the joints, the welding is expected to take significant time.

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Category A: Precast and Prefabrication Elements	
S/N:	A-4
Design Consideration:	Prefabricated link bridge
Context:	A prefabricated link bridge is to be installed between two towers using welding (see Figure 4); temporary corbels are provided. Due to the position of the joints, the welding is expected to take significant time.
Design Risk:	The presence of the joints between the link bridge and the towers requires workers to work at height when welding the joints, and the extended exposure increases the likelihood of workers falling from height.
Possible Incident:	Workers fall from height due to the need to work at height for an extended period.
Possible Design-Related Control(s) or Change(s):	**Substitution** Design the connection between the bridge and the towers to use bolting instead of welding.
Action By:	Architect, C&S Engineer

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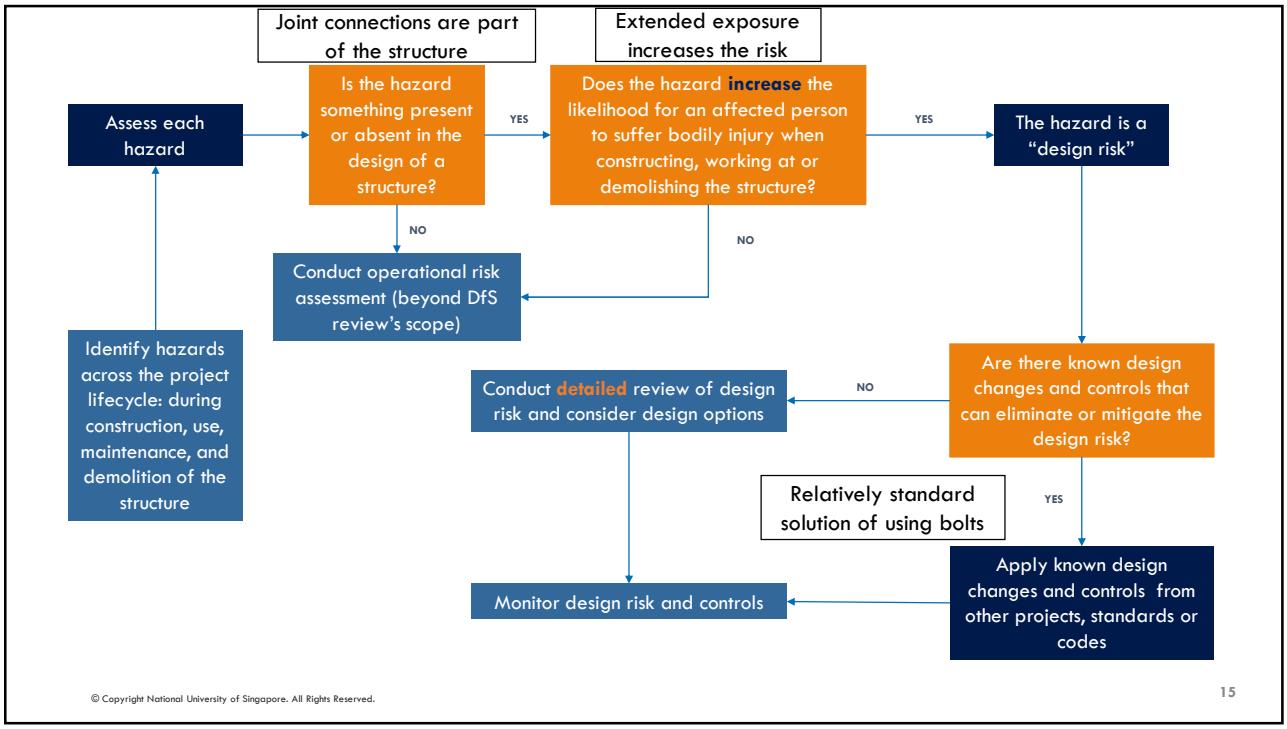
Joint connections are part of the structure
Extended exposure increases the risk
Assess each hazard
Is the hazard something present or absent in the design of a structure?
YES
Does the hazard increase the likelihood for an affected person to suffer bodily injury when constructing, working at or demolishing the structure?
YES
The hazard is a "design risk"
NO
NO
Conduct operational risk assessment (beyond DfS review's scope)
Identify hazards across the project lifecycle: during construction, use, maintenance, and demolition of the structure
Are there known design changes and controls that can eliminate or mitigate the design risk?
NO
Conduct detailed review of design risk and consider design options
Relatively standard solution of using bolts
YES
Apply known design changes and controls from other projects, standards or codes
Monitor design risk and controls
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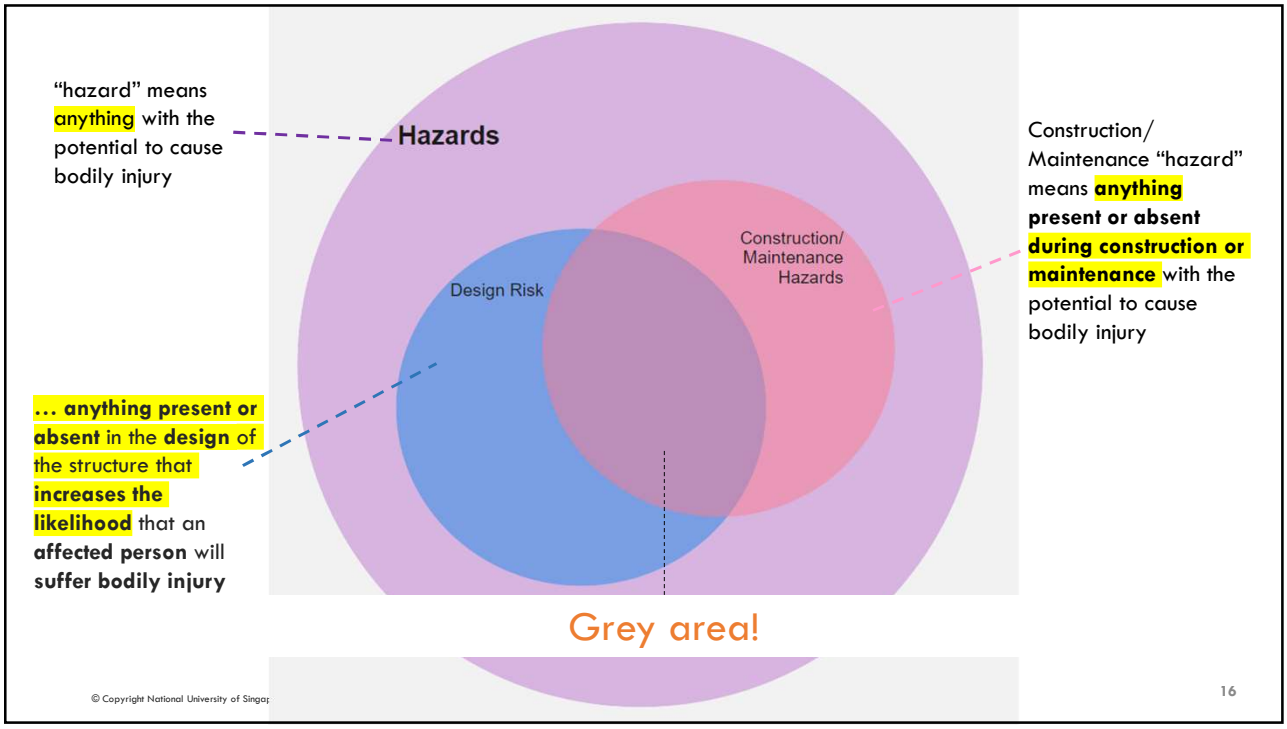
"hazard" means anything with the potential to cause bodily injury
Hazards
Construction/ Maintenance "hazard" means anything present or absent during construction or maintenance with the potential to cause bodily injury
Design Risk
Construction/ Maintenance Hazards
… anything present or absent in the design of the structure that increases the likelihood that an affected person will suffer bodily injury
Grey area!
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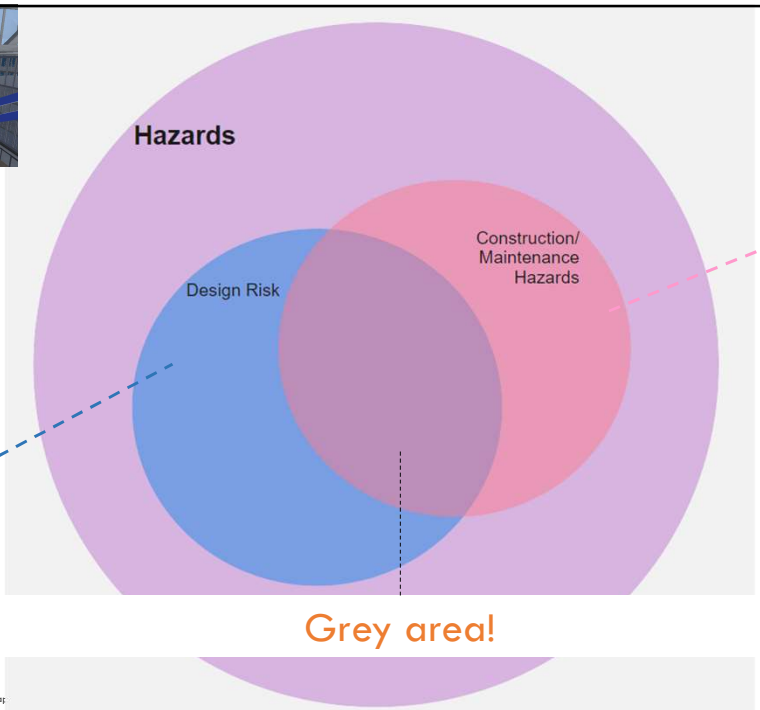

Activity:
Working at height

Design consideration/
element:
Connection between
bridge and building

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Contractor's RA vs DfS Review

Contractor's Risk Assessment	DfS Review
Hazards identified based on work activities and locations	Hazards identified based on design elements and considerations
Controls are typically focused on lower rungs of the Hierarchy of Control (engineering control, administrative control, and personal protective equipment (PPE)) and Safe Work Procedures (SWP)	Controls are typically focused on higher rungs of the Hierarchy of Control (elimination, substitution, and engineering control)
Addresses the operations during the construction stage	Addresses the full life cycle of the structure, including construction stage
Focuses on what contractors can do to improve workplace safety and health	Focuses on what the designers can do to improve workplace safety and health

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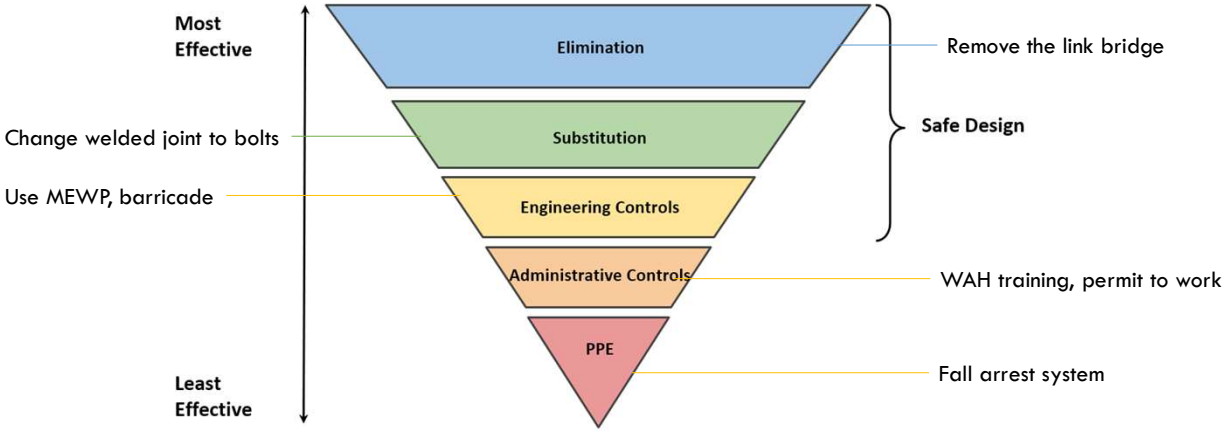
Hierarchy of Controls



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IES-NUS DfS Library: Examples

- Precast and Prefabrication Elements x 4
- Temporary Works x 6
- Roof and Skylight x 5
- Façade x 1
- Floor Openings x 2
- Detention Tank x 2

- Total = 20

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Precast and Prefabrication Elements

Category A: Precast and Prefabrication Elements	
S/N:	A-1
Design Consideration:	Large and heavy prefabricated beams and columns that need to be lifted in place
Context:	The structure under construction is in the vicinity of sensitive structures (MRT/LRT viaduct). The site also has constraints that require the crane to be sited far from the structure where the prefabricated beam and columns must be installed. Thus, even the larger cranes need to operate at 95%-110% of the safe working load (SWL).
Design Risk:	The presence of large and heavy precast beams and columns in the design that need to be lifted and installed in the vicinity of sensitive structures and the lifting radius is large. These design risks increase the likelihood of crane overload during construction.
Possible Incident:	Workers struck by falling objects caused by inadequate crane load capacity.
Possible Design-Related Control(s) or Change(s):	**Substitution** 1. Use U-shaped precast beams with cast-in-situ infill concrete to reduce the crane load (see Figure 1). 2. Use precast shell columns with cast-in-situ infill concrete to reduce the crane load (see Figure 2). 3. Considering the proximity to the sensitive structures, change selected precast elements to cast-in-situ to mitigate crane overload issues.
	Note: Precast elements have obvious benefits in terms of speed and safety, but in this case, a partially cast-in-situ solution is selected because of the high risk of crane collapse.
Action By:	C&S Engineer, Architect

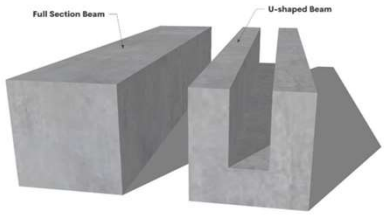

Figure 1 Use u-shaped precast beams instead of full section beam

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Façade

Category D: Façade	
S/N:	D-1
Design Consideration:	Installation of façade with protruding aluminium vertical fin at height (>3m)
Context:	The façade of the building requires vertical aluminium fins to be manually installed on site.
Design Risk:	The presence of a façade with long protruding aluminium vertical fins that need to be installed manually by workers on the gondola increases the likelihood of workers falling from height and falling objects during construction (see Figure 20).
Possible Incident:	Fall from height when working on the gondola or struck by falling vertical fin.
Possible Design-Related Control(s) or Change(s):	**Elimination** Remove the fin design, if possible. **Substitution** 1. Design the fins to be part of the precast wall (see Figure 21). 2. Reduce the number and size of fins, if possible.
Action By:	Architect, C&S Engineer

Figure 20 Long protruding vertical fins that need to be installed manually by workers on a gondola

Figure 21 Vertical fins are prefabricated as part of the precast wall

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Floor Openings

Category F: Floor Openings	
S/N:	F-1
Design Consideration:	Permanent floor openings for M&E services
Context:	Many floor openings (where construction workers can fall through) are protected with temporary covers such as planks and timber boards (see Figure 22) or uncovered.
Design Risk:	The presence of many floor openings increases the likelihood of workers falling from height and being struck by falling object.
Possible Incident:	The temporary cover used during construction may give way under the worker's weight or dislodge, resulting in the worker falling through. In addition, the unsafe covering can give a false sense of security to workers. If the openings are not covered, workers might fall into them accidentally.
Possible Design-Related Control(s) or Change(s):	**Engineering Control** 1. Design for load-bearing mesh or pipe sleeves (if the services are smaller) to be cast in as part of the opening to protect workers once the opening is created (see Figure 23). However, the mesh will need to be cut away as services come through. 2. An alternative is to bolt the mesh to the floor during construction. Then, remove the mesh when the services come through, but the opening is not guarded once the meshed is removed.
Action By:	C&S Engineer, Contractor

Figure 22 Floor openings with temporary covers such as planks and timber boards

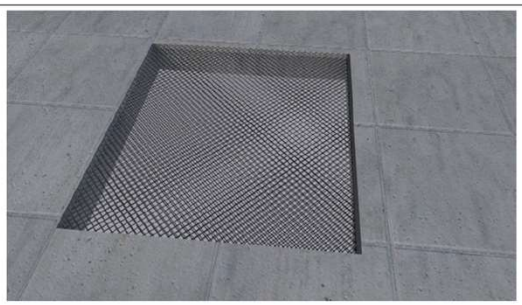

Figure 23 Cast load-bearing mesh as part of the opening

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DfS Library is Not Perfect!

- Examples are meant to encourage designers to think of ways to improve construction and maintenance safety and health
- DfS review team can use the examples to spark discussions
- Examples are still relatively limited → Contributions are encouraged!

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Training to Complement DfS Library

- DfS training for designers
- Barriers
  - Busy!
  - Boring training
  - One-way communication – designers have their own thinking

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Using digital game-based learning (DGBL) to teach designers about DfS:
how to identify the design risk, how to mitigate them through design controls/changes

Advantages of DGBL

- **Increase learners' interest and understanding of the topic**
- **Opportunities to make mistakes in the virtual world**
- **Help learners understand how their actions affect the outcome**

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Introduction to SafeSim Design (SSD)

- Extension of SafeSim Risk (SSR)
  - implications of unsafe design throughout the project lifecycle
  - educate designers on the difference between design risks and construction hazards
  - how to conduct risk evaluation, and
  - how to design out issues through various design-related controls/ changes
- Content are based on the **IES-NUS DfS Library**

- **Four** stages of varying difficulties
  1. *different design limitations*
  2. *address different learning outcomes*
- **Two** phases at each stage
  - *Exploration Phase*
  - *Corrective Phase*

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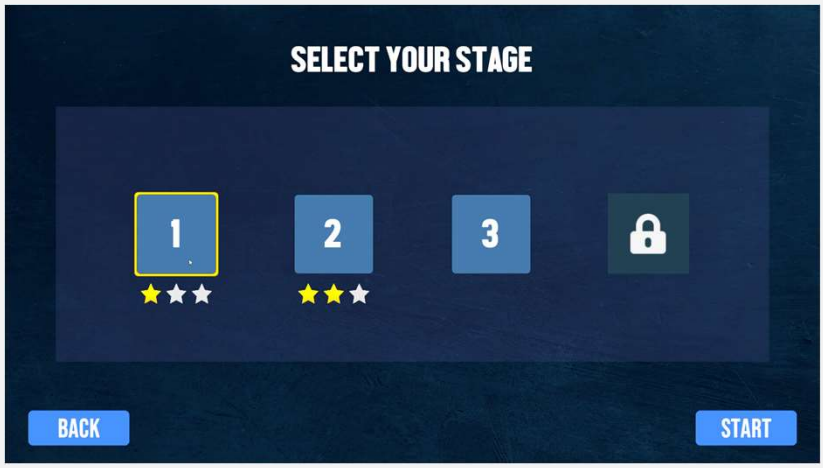
Overview of SafeSim Design



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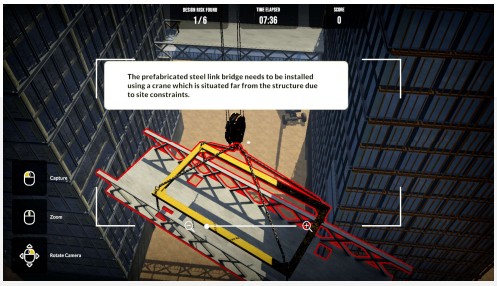
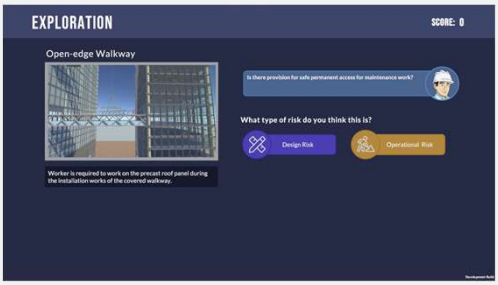
01. Guidance Tool

- Introduced to Mr Chief Designer (Mr CD)
- Non-playable character to guide players throughout the game
- Provide context
- Help with the introduction of the game controls and user interface

02. Exploration Phase

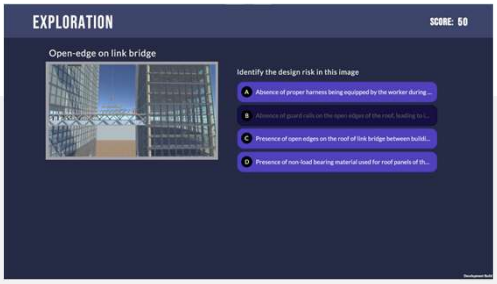
- **Capturing design risks**
  - Using the camera tool
  - Classify identified hazard as design risk or operational risk
  - Helps designers visualise the impact of their design

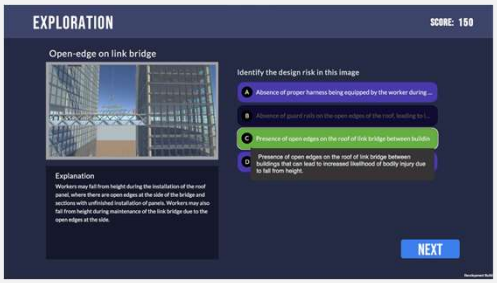




02. Exploration Phase

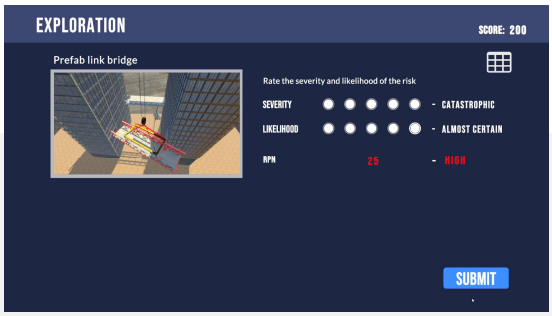
- **Answering MCQ**
  - Immediate feedback
- **Explanations and Rationale**
  - To reinforce the concepts of DfS
- Help designers understand concept of design risk – Hierarchy of Control

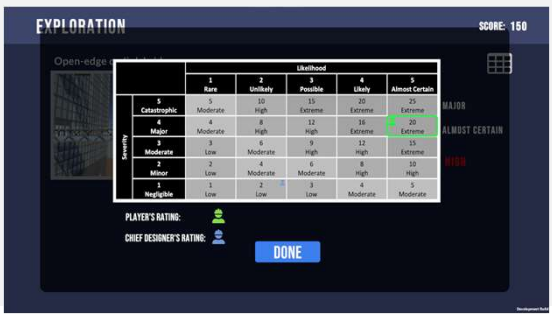




02. Exploration Phase

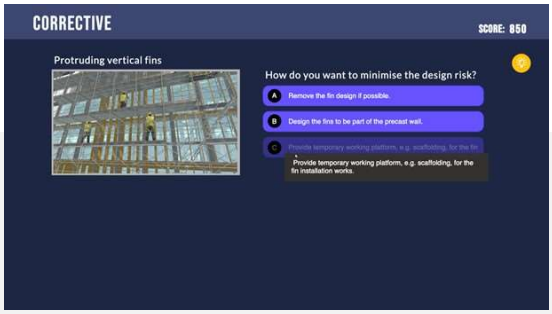
- **Rate** identified risk based on **severity and likelihood**
  - Based on RM Code of Practice
  - Practise thinking about likelihood and severity

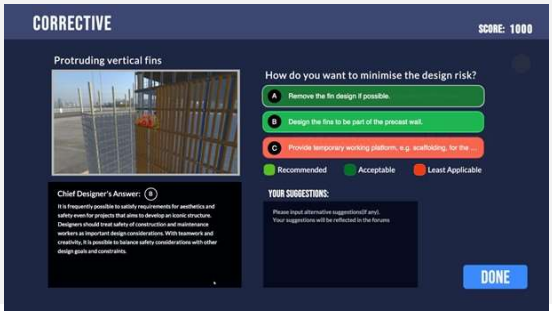




03. Corrective Phase

- Choose **most suitable** measure
  - No right or wrong answer
- Option to provide **alternative solutions**
- Answers will be posted to the forum for further discussions
- Encourage DfS thinking





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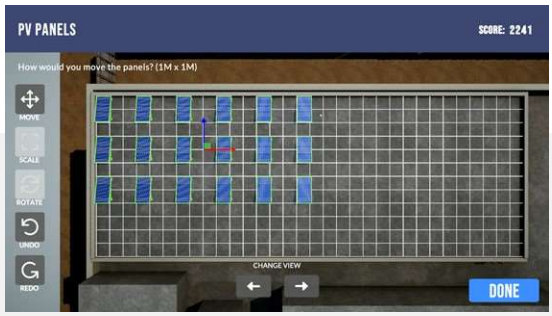
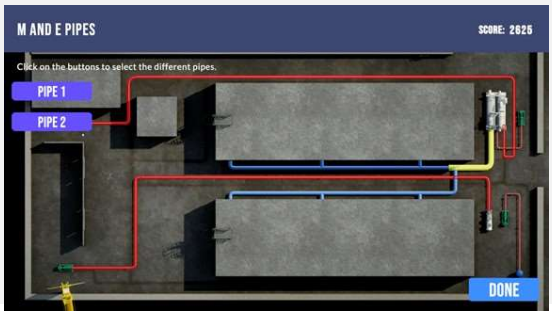
03. Corrective Phase

- **Bonus rounds (> Stage 2)**
  - Earn more points
  - Moving the elements, Manipulation, etc.
- Consider alternatives





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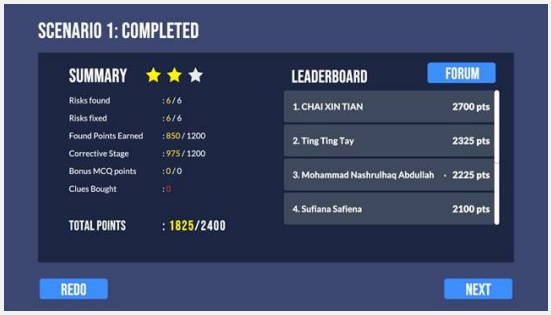
04. Summary Page

- **Breakdown of scores**
- **Leader board**
  - Check ranking against peers
  - Motivate players to do better
- **Ability to redo**
  - Allowing players to do self-directed learning
- **Post questions/answer in the forum**
  - Able to critique alternative solutions
- Encourage collaborative learning



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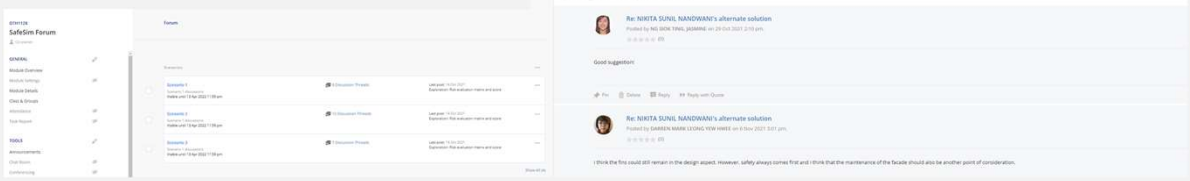
05. Forum Page

- Allow players to view other players' alternative solutions
- Able to reply and rate post



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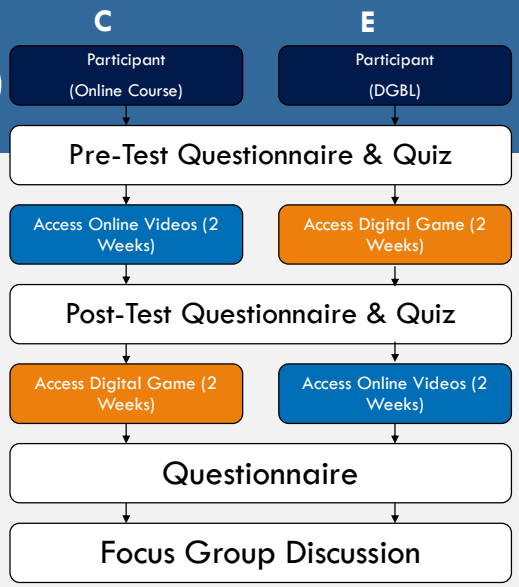
Research (aka Free Training)

- **120 participants,** above 21 years old
- Assigned to one of the groups (i.e., control **OR** experimental)
- **~6 x 1 hour online sessions**
  Quiz/Questionnaire:15 minutes each
- **Focus Group:** 45 minutes – 1 hour
- Total: 7 hours
- PDU points pending



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Fundamentals of Design for Safety

A/P Goh Yang Miang
bdgbox27@nus.edu.sg
Safety and Resilience Research Unit, Department of Building, NUS

This study is funded by SkillsFuture Singapore under Workforce Development Applied Research Fund (WDARF) Grant.

Invitation to join this study

NUS Safety and Resilience Research Unit (SaRRU) invites you to join us in learning DfS through a digital game-based approach.

If you are interested, please contact us at

bdgbox27@nus.edu.sg

(Attn: Ms Sufiana Safiena)

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IES-NUS Design for Safety (DfS) Library for Designers: Construction and Maintenance Design Risks

https://www.ies.org.sg/Publication/TechResource

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Research articles

Journal Papers

- Guo, B. H. W., Weston, R., Jianphinitnan, P., Liu, W., Scheepbouwer, E., van der Walt, D., & Goh, Y. M. (2021). A regulatory perspective on safety in design practices in New Zealand. *Safety Science*, *141*, 105352. https://doi.org/10.1016/j.ssci.2021.105352
- Toh, Y. Z., Goh, Y. M., & Guo, B. H. W. (2017). Knowledge, Attitude, and Practice of Design for Safety: Multiple Stakeholders in the Singapore Construction Industry. *Journal of Construction Engineering and Management*, *143*(5), 04016131-1-04016131–11. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001279
- Goh, Y. M., & Chua, S. (2016). Knowledge, attitude and practices for design for safety: A study on civil & structural engineers. *Accident Analysis and Prevention*, *93*(November), 260–266. https://doi.org/10.1016/j.aap.2015.09.023
- Asmone, A. S., Goh, Y. M., Lim, M. S. H. (2021). *Prioritization of industry level interventions to improve implementation of Design for Safety Regulations.* Manuscript submitted for publication.
- Goh, Y. M., Lim, M. S. H. (2022) *Surface and Deep Compliance in the practice of DfS Review*. Manuscript in preparation
- Goh, Y. M., Lim, M. S. H. (2022) *DfS climate: Measurement and applied implications*. Manuscript in preparation

Conference Papers

- Lim, M. S. H., Goh, Y. M., & Fang, D. (2019). Participation in Design for Safety : A Literature Review. *CIB World Building Congress, Hong Kong SAR, China 17 – 21 June 2019, June*, 1–11.
- Lim, M., Asmone, A., & Goh, Y. M. (2020, September 10). Design for Safety Review in Early Stages of Mandatory Implementation. *CIB W099 & TG59 Annual Conference 2020*.

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