# A Systems-Theoretic Approach to Safety & Modern Methods of Construction

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Systems Engineering, Integration & Assurance, WSP UK
Health & Safety Executive (HSE)
University College London (UCL)

# My journey

MEng, 2010
MSc, 2012
PhD, 2015

University of Cambridge, 2015

WSP UK, 2018

HSE, 2021

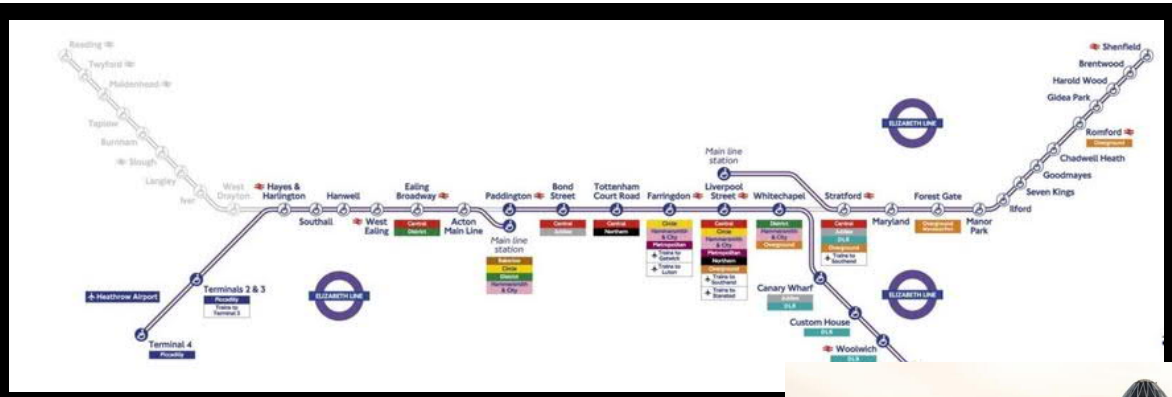
Imperial College London, 2016

Fellow of SaRS, Imperial College, Cranfield, 2019

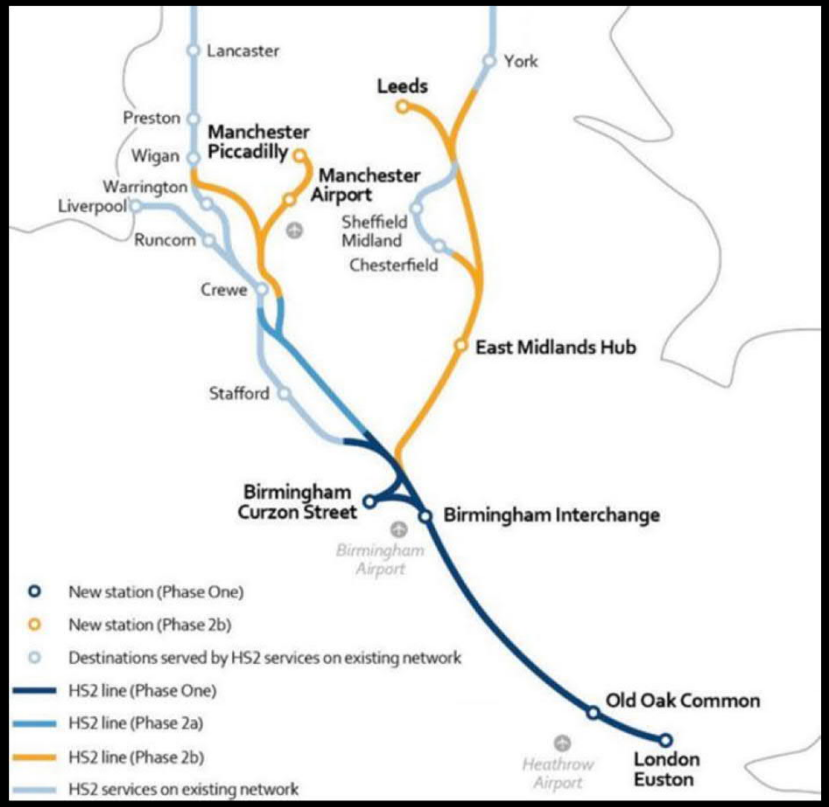
RAEng, 2020

# The Context

## Major Projects

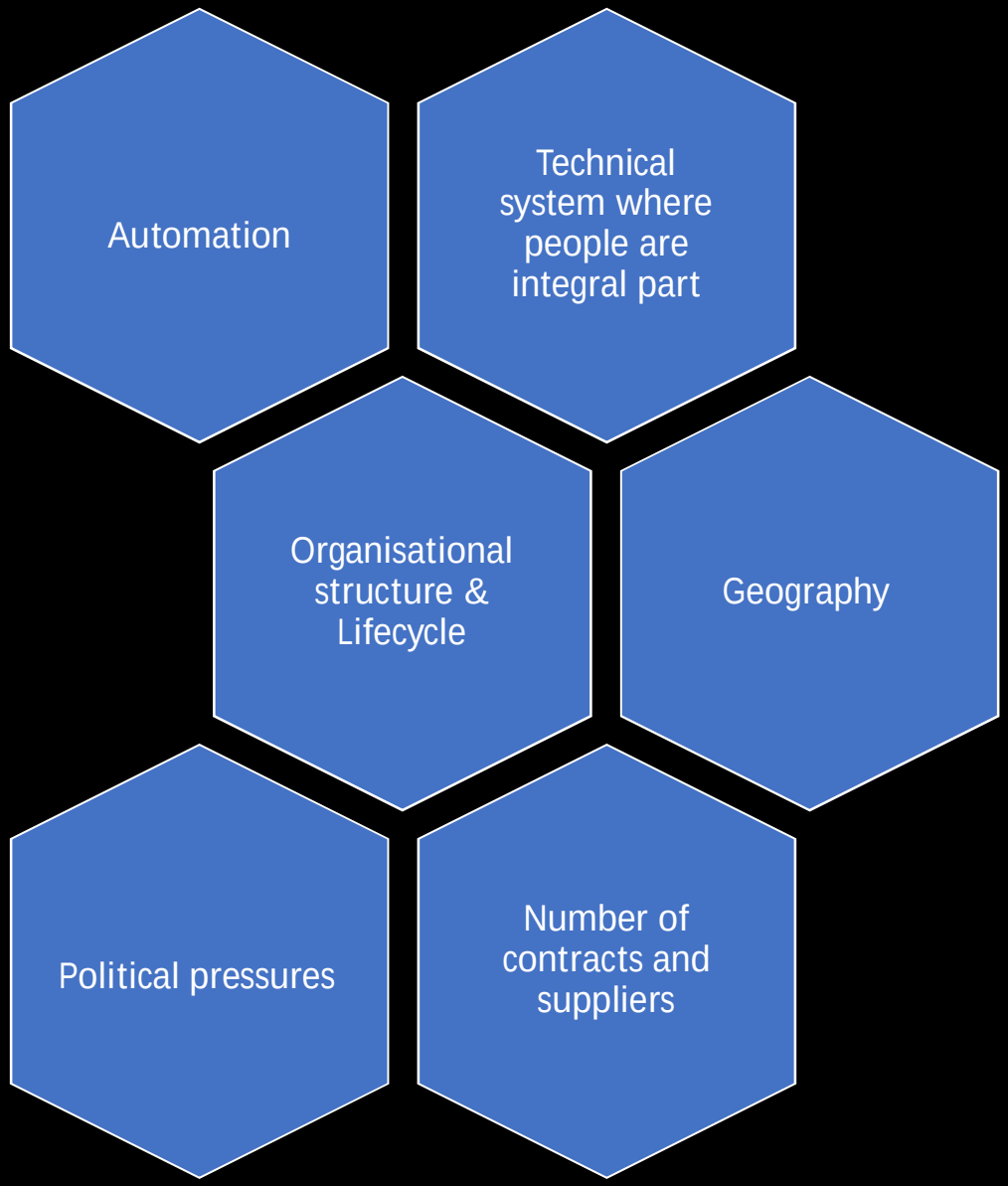

Reading
Twyford
Maidenhead
Taplow
Burnham
Slough
Langley
Iver
West Drayton
Hayes & Harlington
Hanwell
Southall
West Ealing
Ealing Broadway
Acton Main Line
Paddington
Main line station
Bond Street
Tottenham Court Road
Farringdon
Main line station
Liverpool Street
Whitechapel
Stratford
Maryland
Forest Gate
Manor Park
Ilford
Seven Kings
Goodmayes
Chadwell Heath
Romford
Gidea Park
Harold Wood
Brentwood
Shenfield
Heathrow Airport
Terminals 2 & 3
Terminal 4
Canary Wharf
Custom House
Woolwich
ELIZABETH LINE


FLUGHAFEN BERLIN BRANDENBURG WILLY BRANDT


Lancaster
York
Leeds
Preston
Manchester Piccadilly
Wigan
Manchester Airport
Warrington
Liverpool
Sheffield Midland
Runcorn
Chesterfield
Crewe
East Midlands Hub
Stafford
Birmingham Curzon Street
Birmingham Interchange
Birmingham Airport
New station (Phase One)
New station (Phase 2b)
Destinations served by HS2 services on existing network
HS2 line (Phase One)
HS2 line (Phase 2a)
HS2 line (Phase 2b)
HS2 services on existing network
Old Oak Common
Heathrow Airport
London Euston

LONDON 2012

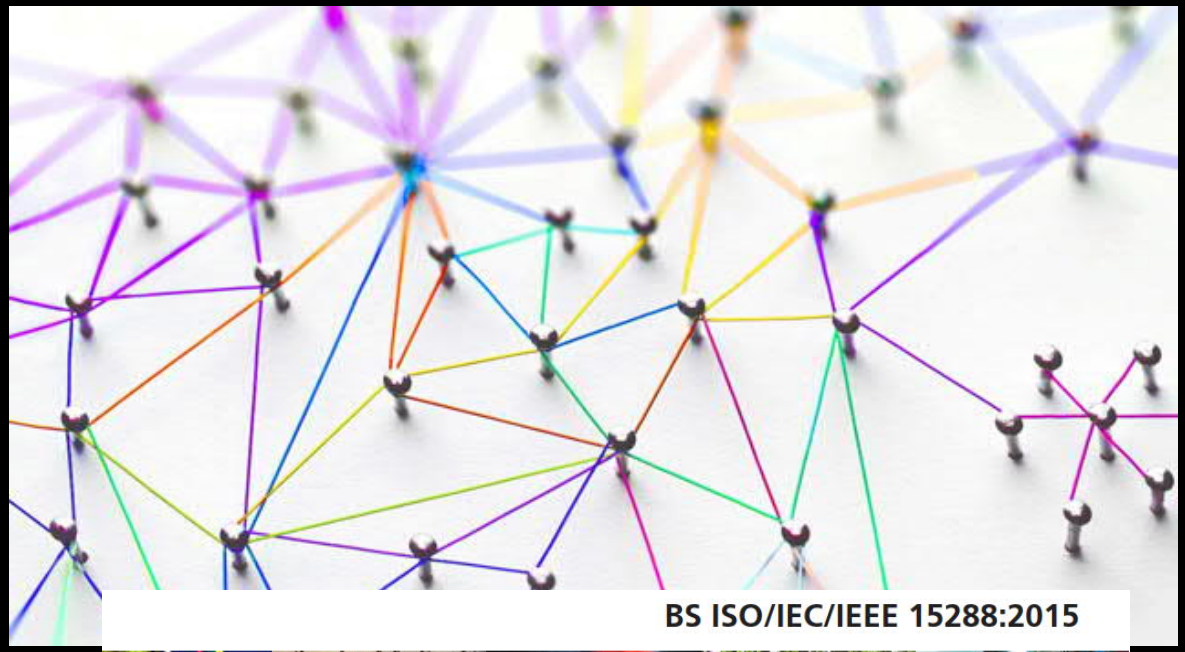
# ‘The Complexity Mosaic’



# Systems Engineering

Definition of SE:
'A transdisciplinary and integrative a pproach to enable the successful realisation, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.'

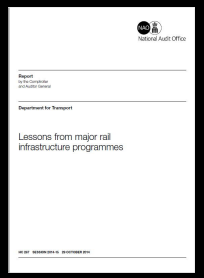
INCOSE



# Industry guidance calling for SE

2009: SI at Heathrow T5

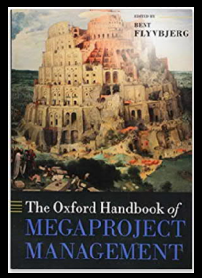

2014: NAO Lessons from major rail programmes



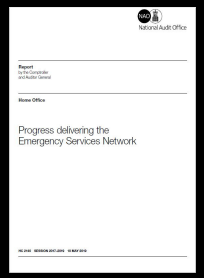

2016: IPA Project Initiation Routemap


2017: IPA Transforming Infrastructure Performance

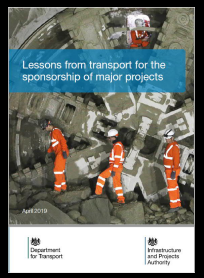

2017: SI at London 2012




2019: NAO Delivering the Emergency Services Network

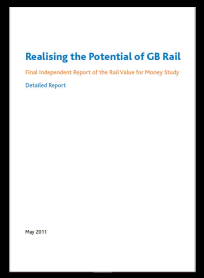



2019: DfT Lesson Learned from the sponsorship of major projects

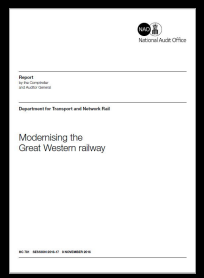



2020: NAO Lesson Learned from major programmes

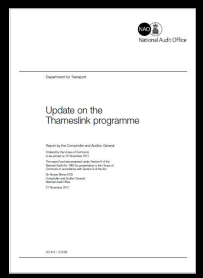

2009 → 2020




2011: DfT Realising the potential of GB Rail

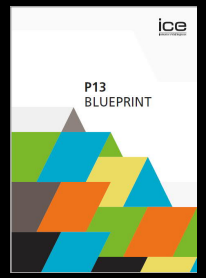



2016: NAO Modernising the Great Western

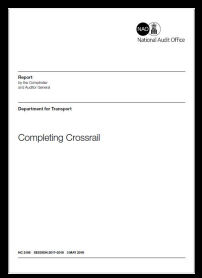



2017: NAO Update on the Thameslink Programme

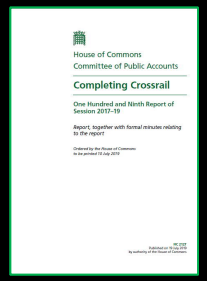

2017: DfT Transport Infrastructure Efficiency Strategy




2018: ICE P13 Blueprint



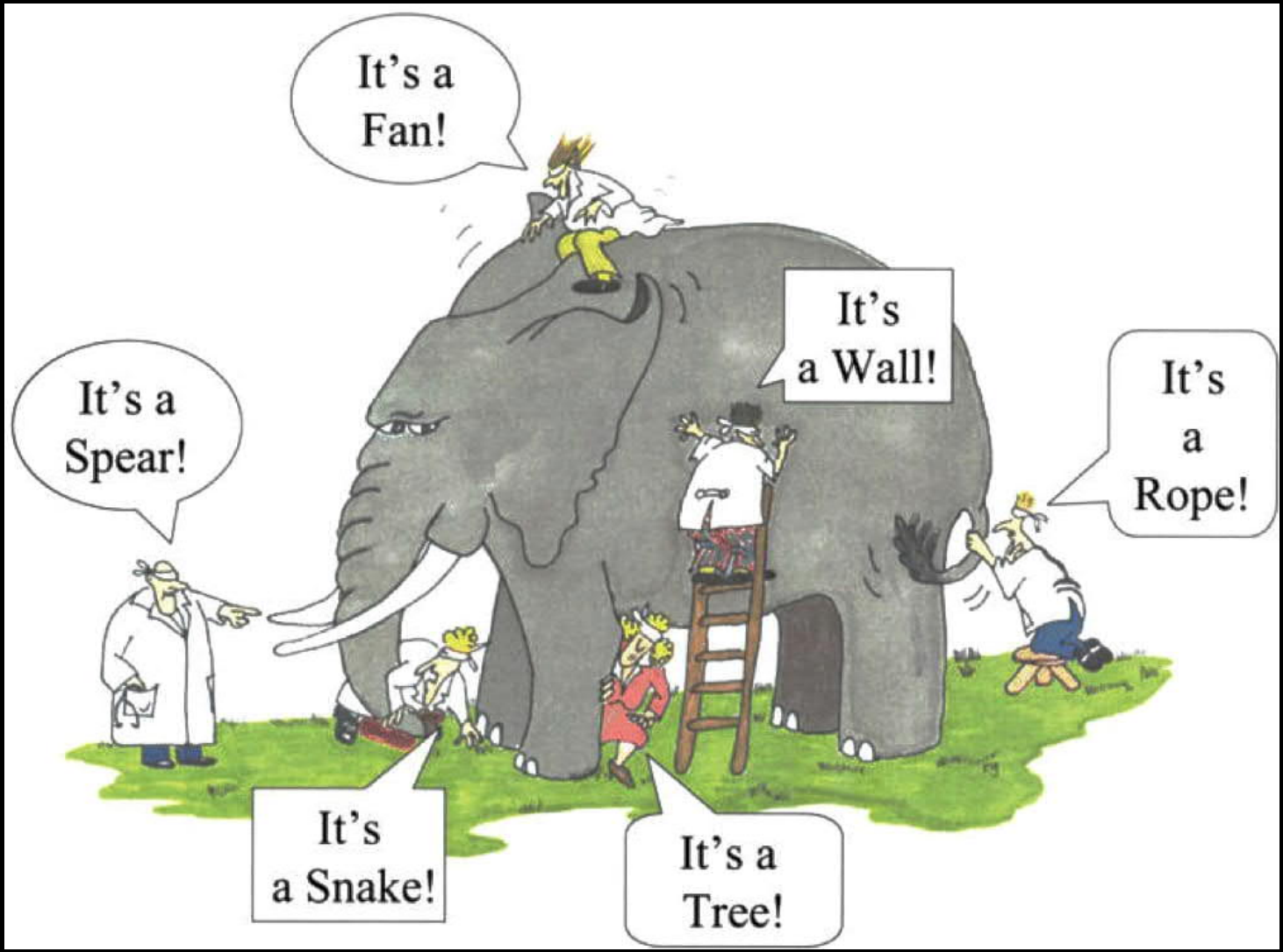

2019: NAO Completing Crossrail




2019: HoC Completing Crossrail

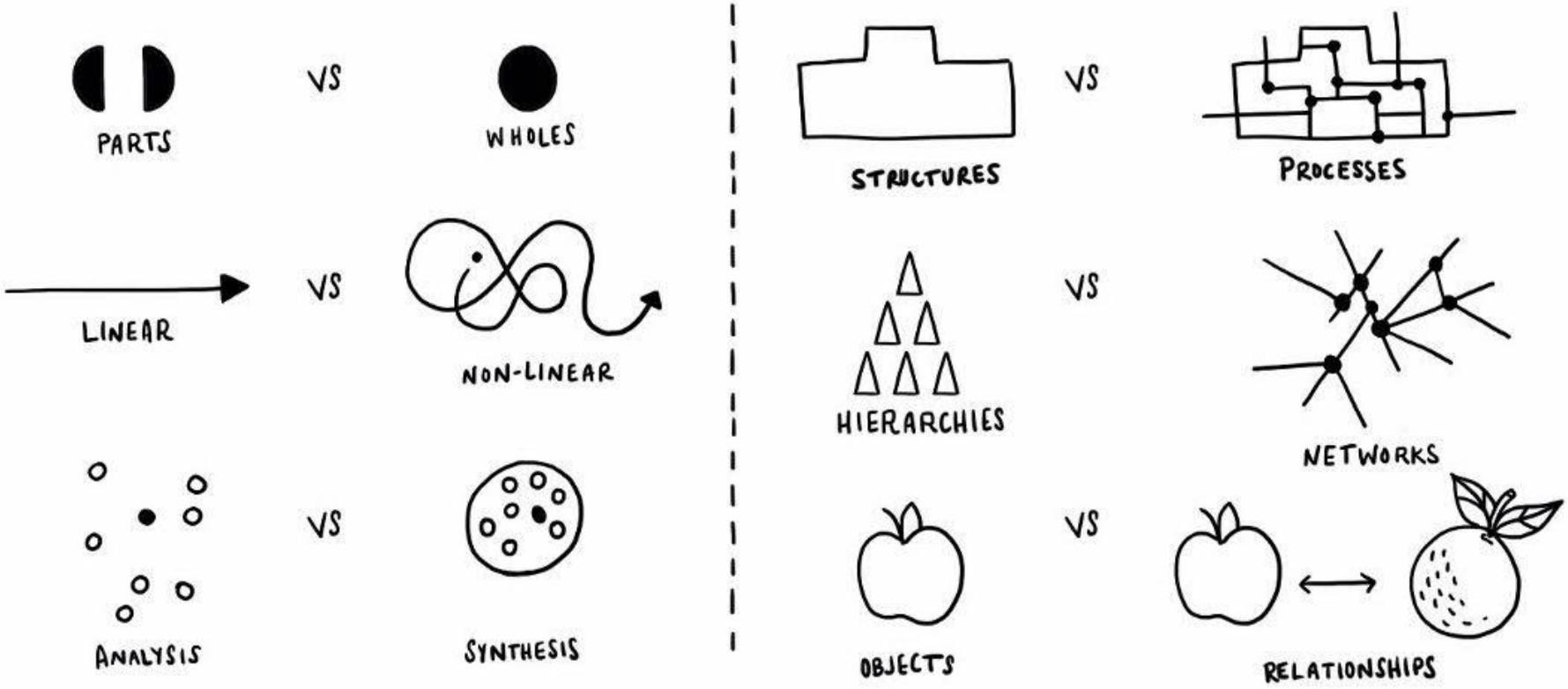
# The Paradigm Shift

Look at the whole not just the parts!


It's a Fan!
It's a Wall!
It's a Spear!
It's a Rope!
It's a Snake!
It's a Tree!


Engineering a Safer World
Systems Thinking Applied to Safety
Nancy G. Leveson
ENGINEERING SYSTEMS

# TOOLS OF A SYSTEM THINKER




DISRUPT DESIGN

# The Construction Industry

## The Milestone

# ‘The Grenfell Tragedy’

Grenfell Tower fire, 72 deaths

North Kensington, London

June 2017

# The Report

‘We must also begin thinking about buildings as a system so that we can consider the different layers of protection that may be required to make that building safe on a case-by-case basis.’


# Key issues underpinning the system failure

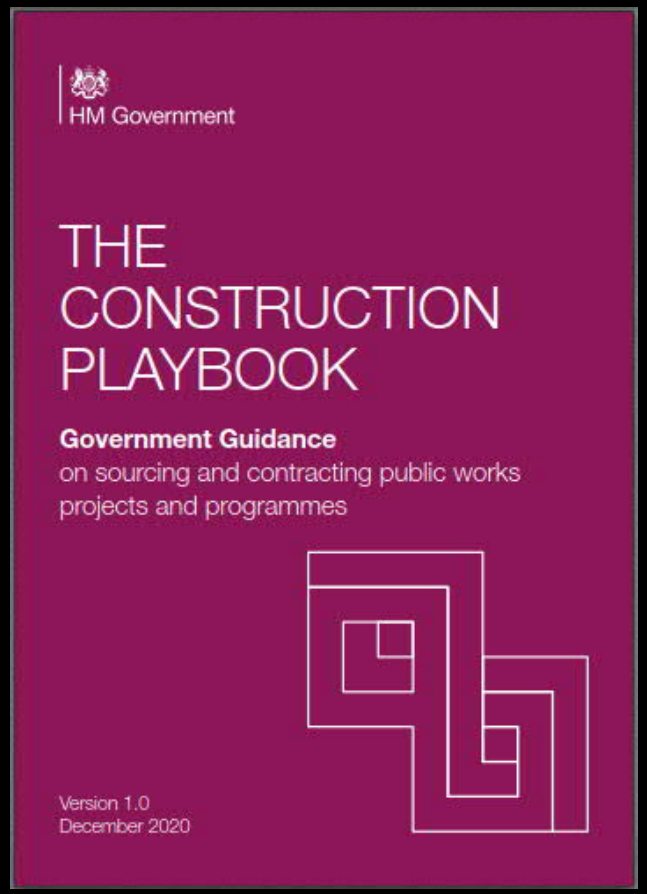
- Ignorance – regulations and guidance are not always read by those who need to, and when they do the guidance is misunderstood and misinterpreted.
- Indifference – the primary motivation is to do things as quickly and cheaply as possible rather than to deliver quality homes which are safe for people to live in.
- Lack of clarity on roles and responsibilities – there is ambiguity over where responsibility lies.
- Inadequate regulatory oversight and enforcement tools – the size or complexity of a project does not seem to inform the way in which it is overseen by the regulator.

# New Solutions

## Lessons Learned

# Modern Methods of Construction

‘Greater use of offsite manufacturing can deliver efficiencies and higher quality and safer solutions with lower GHG* emissions quicker than traditional construction methods.’




*Greenhouse Gas emissions

# Key Safety Advancements

- H&S issues minimised due to the lightweight nature of the product and the speed of erection.
- The process removes a lot of trades from site. One of the biggest H&S risks on sites is working at height – moving that into a factory environment makes it a lot safer.
- Better safety onsite as well because we use cranes to erect it, so we have fewer falls from height, fewer manual handling issues, and fewer trips and slips as a consequence of having fewer materials onsite.

# Some Concerns

- Flammable materials – in modular timber frames fire is a concern.
- How do volumetric structures perform in terms of robustness, design life and durability, especially in case of natural disasters?
- Adaptability – off-site volumetric modular spaces may be harder to alter, extend or reconfigure and there may be risks in relation to fire safety or structural stability when alterations are made.
- Design of interfaces between volumetric units, and between off-site and non-off-site elements.
- Transportation, storage, effect of lifting and placement and protection of volumetric elements being assembled on site.
- Regulatory framework needs to become ‘future-ready’.

# Residential and Offices

# Supermarkets



# A Case Study

## The Grange University Hospital

# Hospitals

LAING O'ROURKE

WHO WE ARE WHAT WE DO INSIGHTS CAREERS

Investors News Contact us

What We Do / Projects / The Grange University Hospital

The Grange University Hospital is Aneurin Bevan University Health Board's new £350 million, 450-bed, specialist critical care facility in Cwmbran, Wales. The hospital opened four months ahead of schedule in November 2020. This achievement – a first for a hospital of this size – was the result of the project team committing to a BIM Level 2 digital approach from the outset and maximising off-site construction.

Working alongside contractor Laing O'Rourke, architects BDP and mechanical and electrical consultant AECOM; WSP provided structural, civil, drainage and other engineering services to the project through our local office in Cardiff. The whole project team committed to a digital approach using BIM to design for manufacture and assembly.

" We've delivered the largest project in Wales ahead of programme, under budget and to a high standard. We couldn't have achieved this without the dedication shown by the WSP teams. "

David Leverton,
Technical Leader, Laing O'Rourke

*Building Information Modelling
Level 2 is distinguished by collaborative working, and requires "an information exchange process which is specific to that project and coordinated between various systems and project participants"

Overall, the project achieved 50-55% off-site construction. Compared to a traditional approach, this saved 42 weeks of the programme – reducing it by 23% – and increased productivity by 45%. It also saved 237,099 hours of on-site labour, reducing the health and safety risks associated with working on site. Bringing complete manufactured elements such as bathroom pods to site instead of individual materials reduced vehicle movements by 30%, reducing disruption and emissions.

| OFF-SITE CONSTRUCTION | PRODUCTIVITY INCREASE | PROGRAMME SAVING |
|---|---|---|
| 50-55% | 45% | 23% |

To achieve this remarkable result, the whole design team worked entirely in 3D – beginning earlier than usual to thoroughly test the process. Our designers modelled the structural elements of the building in a protocol that could be transferred seamlessly to the factory. In a standard approach, they would then have received them back in 2D for checking. But this project took things further, with the reviewing and checking done in 3D. This made communication easier and reduced the risk of mistakes. For example, simple colour coding made it easier to check that the right rebar was in the right place.

> " The process for checking the design in 3D hadn't been done before so we put together a best-practice way of working that everyone could follow. The approach saved us time, it saved the factory time, the elements got to site quicker and ultimately the hospital was built quicker. "

**Matt Lewis, BIM and Digital Lead, WSP**

The thousands of elements constructed off-site included 243 bathroom pods, 1,200 precast shear walls, 661 corridor service modules and 774 precast panels that form the envelope of more than half the hospital. Manufacturing these panels, which combine façade elements with structural backing, off site and fitting windows at the same time meant there was no need for scaffolding on the site.

Slabs were designed with a 75mm rebar biscuit on the bottom so they could be dropped by crane straight onto trestles, and workers could then walk on them safely to install rebar. The precast biscuit also came with edge trims and handrail sockets so these could be installed easily to keep people safe.

The 3D model had other benefits too. With all the design data available to them through the model, the Health Board can see everything it needs to know to plan future maintenance effectively. The model also enabled virtual reality to be used for design reviews and to give staff a virtual tour of the building.

## Benefits of off-site construction

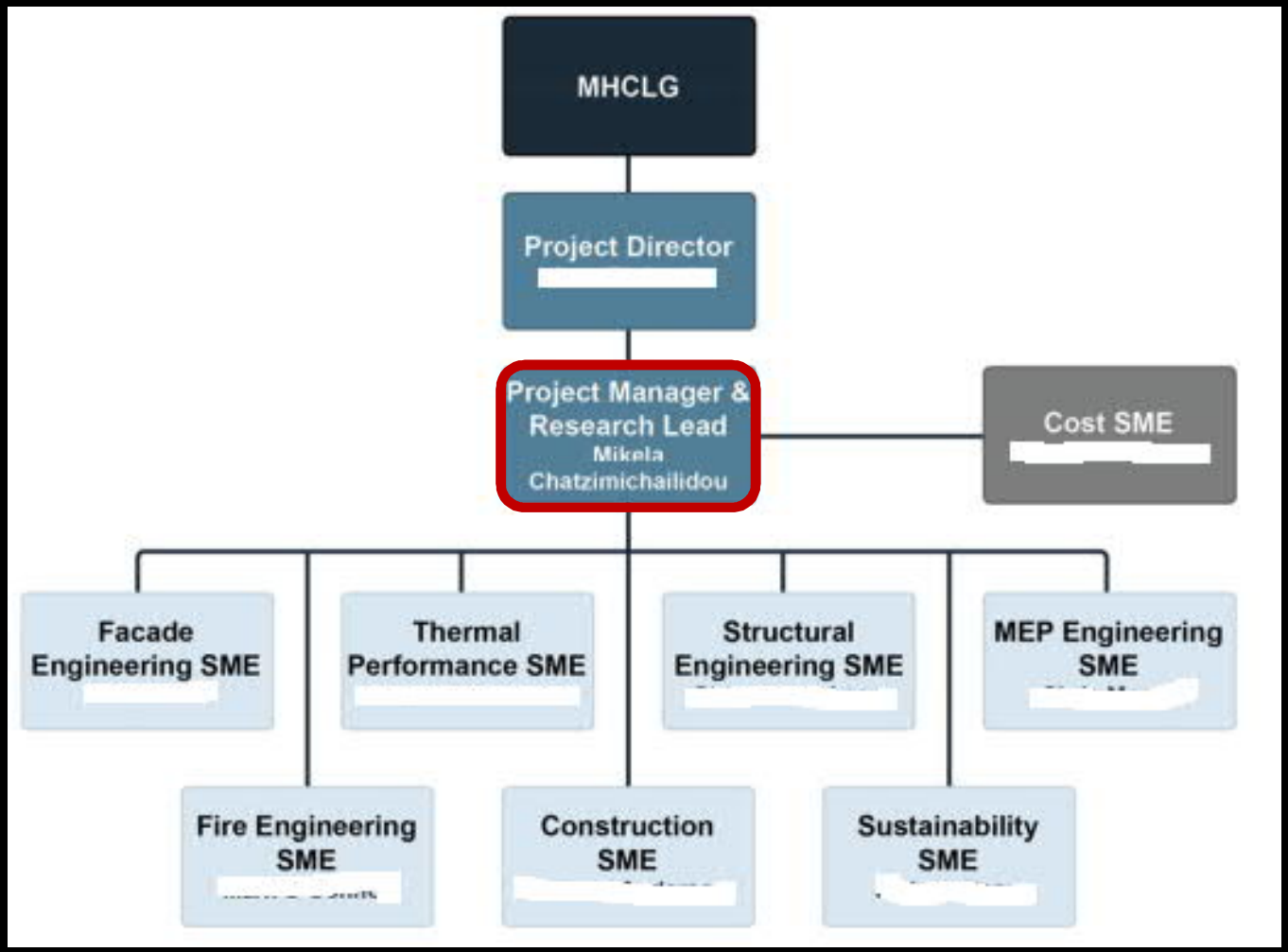
Manufacturing building elements in a controlled factory environment, instead of constructing them on a site at the mercy of the elements, has a number of advantages:

- Improved quality
- Increased speed
- Reduced waste
- Reduced health and safety risk

With design and fabrication teams all working efficiently in intelligent 3D formats, the ward area was handed over to the client in April 2020 in time to provide extra capacity during the Covid-19 pandemic. The whole hospital was officially handed over, with zero defects, and opened to patients in November 2020.

# Future Steps

## More Case Studies




Ministry of Housing, Communities & Local Government

HSE
Health & Safety Executive

# ‘One Team’ Approach

## INDUSTRY JOINT INITIATIVES

- Buildoffsite Property Assurance Scheme
- Construction Innovation Hub
- Buildoffsite
- Construction Leadership Council
- Construction Industry Training Board
- MMC Working Group

## ACADEMIA

- Imperial College London - Civil & Environmental Engineering
- UCL - Bartlett School of Construction & Project Management
- Cambridge Univerisity - Laing O'Rourke Centre for Construction Engineering and Technology
- Loughborough University - School of Civil Engineering
- Sheffield Advanced Manufacturing Research Centre (AMRC)
- Oxford Brookes University

## PUBLIC BODIES & PROFESSIONAL INSTITUTIONS

- Building Regulations Advisory Committee
- Local Authority Building Control
- Infrastructure and Projects Authority
- Health and Safety Executive
- Homes England
- National House Building Council
- Planning Officers Society
- Royal Academy of Engineering
- Institution of Civil Engineers
- Royal Institute of Chartered Surveyors (RICS)
- Building Research Establishment
- Association of British Insurers
- Association of Residential Managing Agents
- British Institute of Facilities Management
- Local Government Association
- National Fire Chiefs Council
- Fire Industry Association
- National Housing Federation
- Lloyds Register Foundation

## PRIVATE SECTOR ORGANISATIONS (INCLUDING CONTRACTORS & MANUFACTURERS)

- Reds10
- M-AR Off-Site
- Laing O'Rourke & Explore Manufacturing
- Crown House Technologies
- Balfour Beatty
- Premier Modular Limited
- MACE
- British Gypsum/Saint Gobain
- L&Q
- Legal & General
- Berkeley Homes
- Far East Consortium
- Ilke Homes
- Grainger PLC
- Pocket Living
- Caledonian Modular Systems
- Sovereign

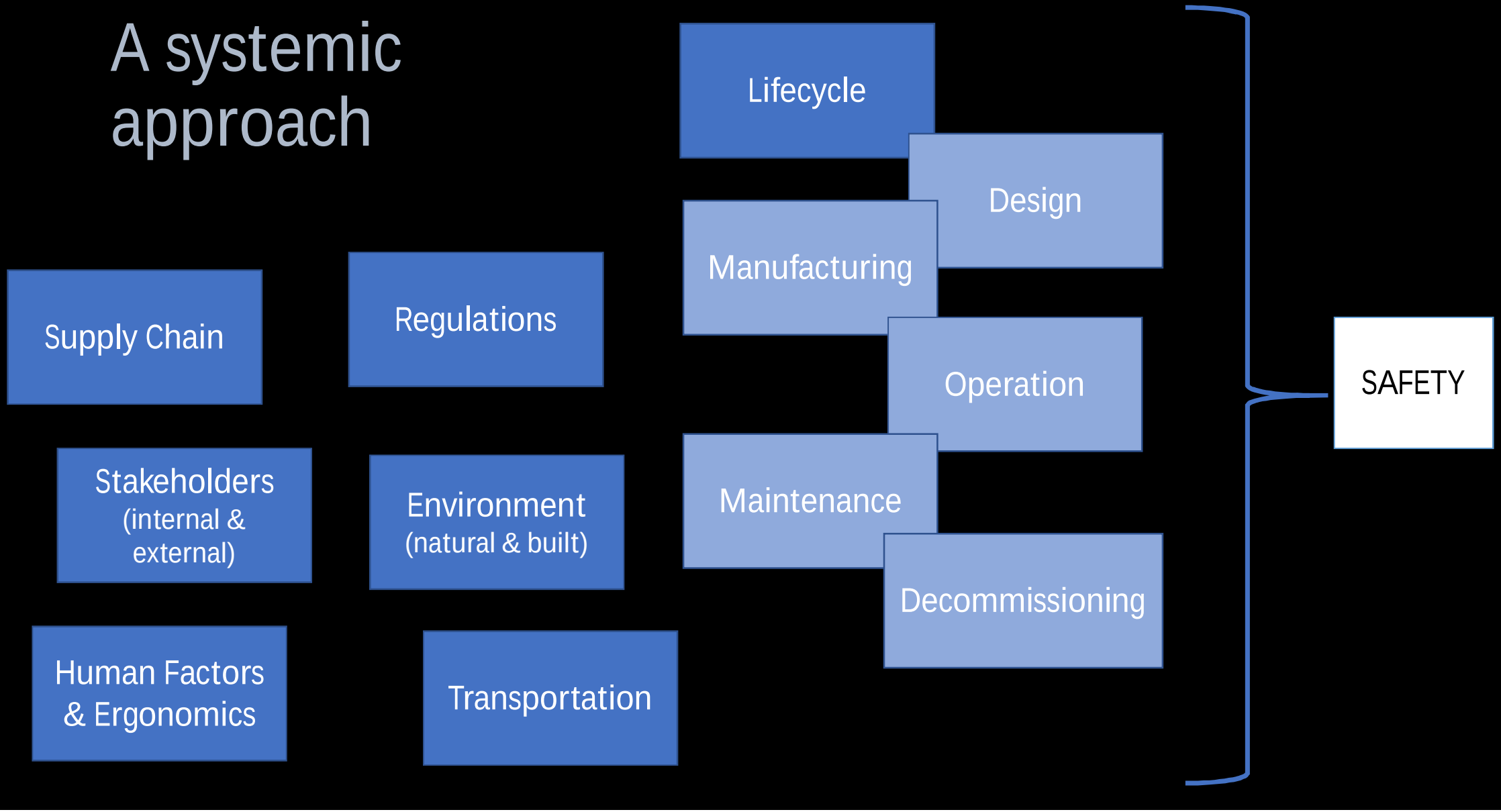
# Further read

1. Digitally enabled modular bridges [WSP, Network Rail A-Team Alert]
2. Offsite brings weight to the case for rail overbuild [WSP]
3. Delivering greater efficiency, less carbon and increased safety [WSP]
4. Could rail achieve more with offsite? [WSP]
5. Industrial Strategy: government and industry in partnership
6. Department of Business, Energy & Industrial Strategy
7. Station Design Principles for Network Rail
8. Modular construction: From projects to products
9. DfMA & LoR
10. The Construction Playbook
11. SMRs
12. Offsite and Modular Building Market Research

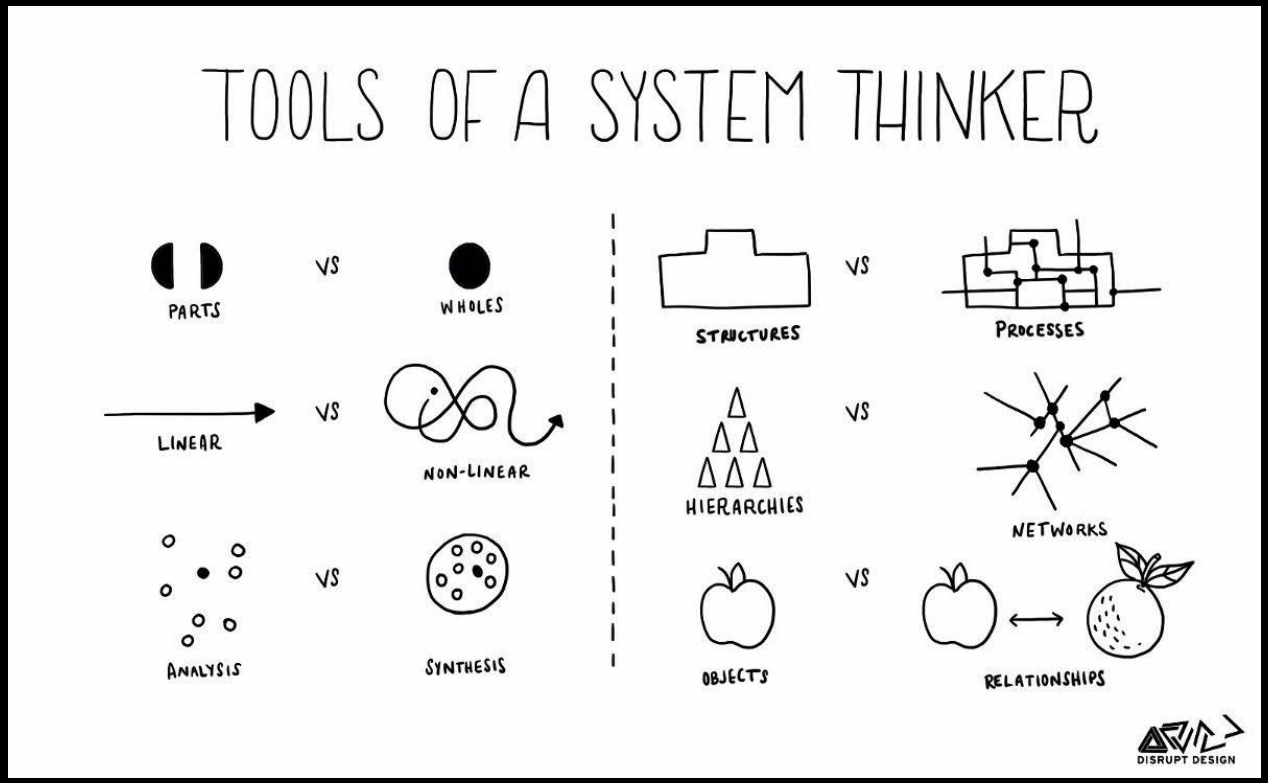
# Conclusion

Safety is a systems issue

# A systemic approach



# THANK YOU
# Q&A

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