## Smart Infrastructure Summit

**14th Annual Workshop for Australian Network of Structural Health Monitoring**
**UTS, November 2022**

# Industry 4.0 Technologies for Buildings and Infrastructure - Key Challenges and Opportunities


**Prof Tuan Ngo**

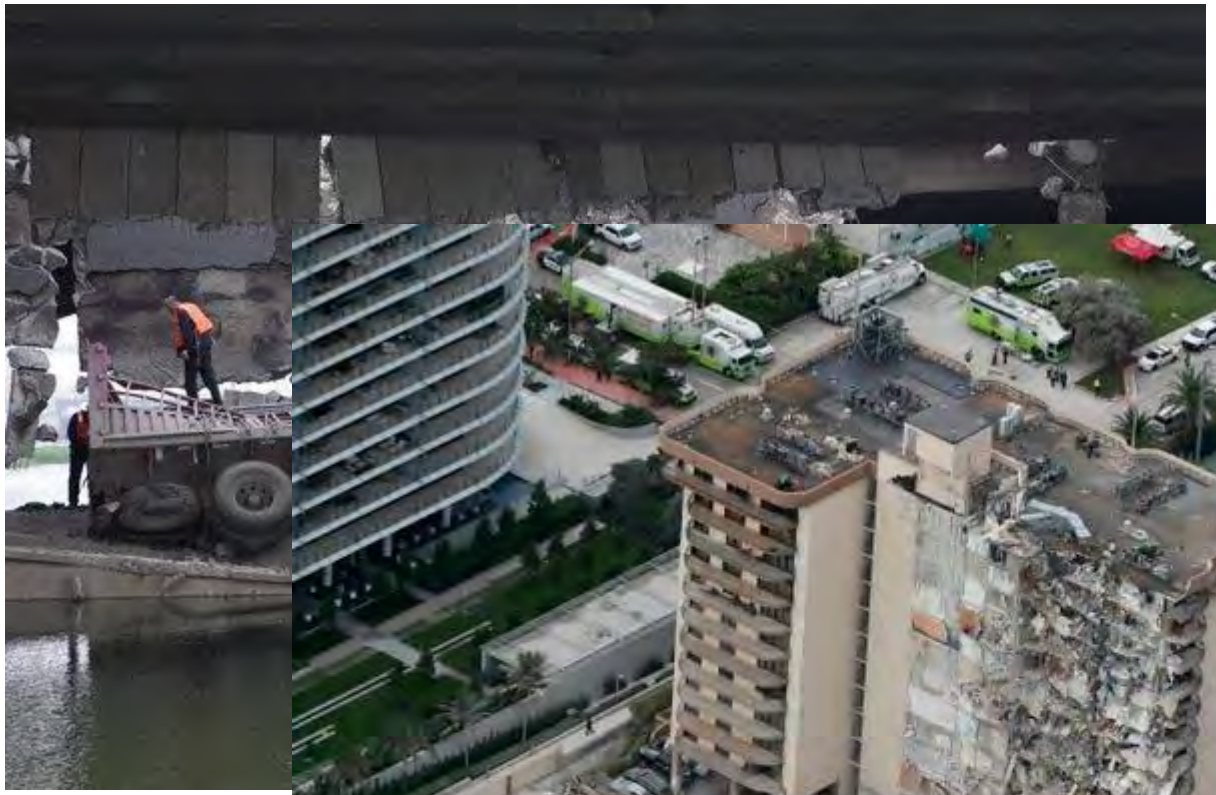
**The University of Melbourne**


**November 2022**

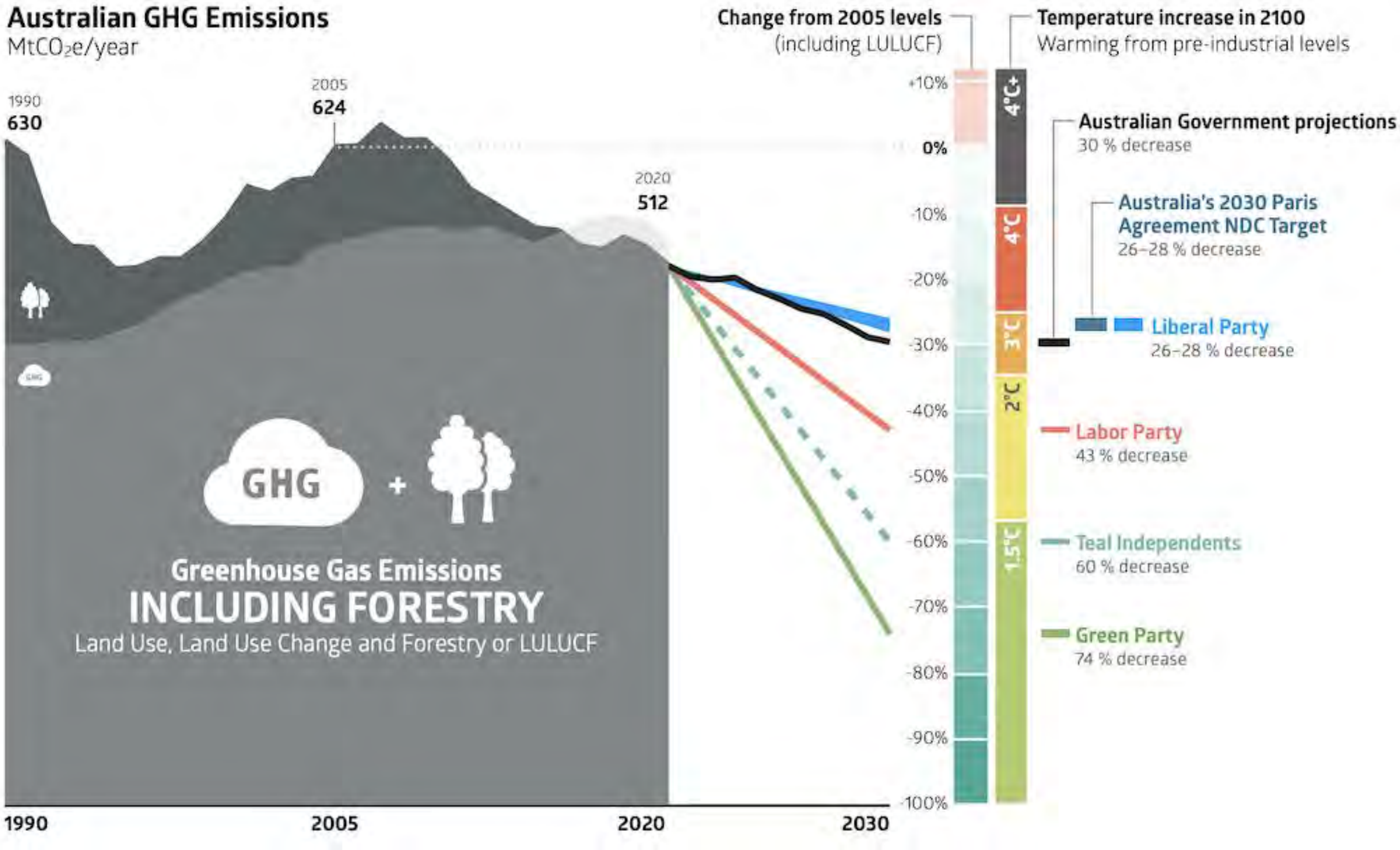
# A world of extreme events

# Man-made Disasters

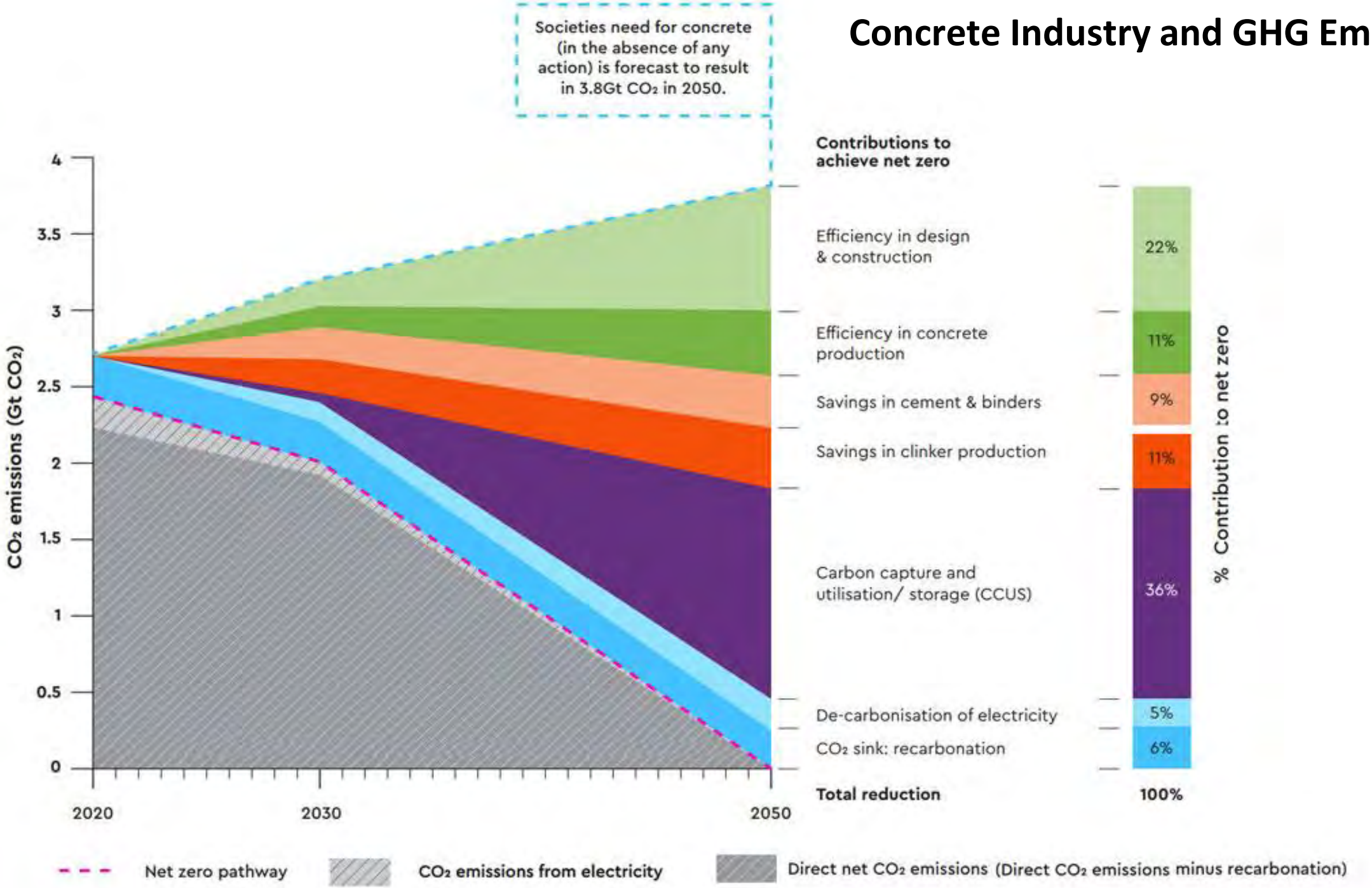
# Aging Buildings and Infrastructure





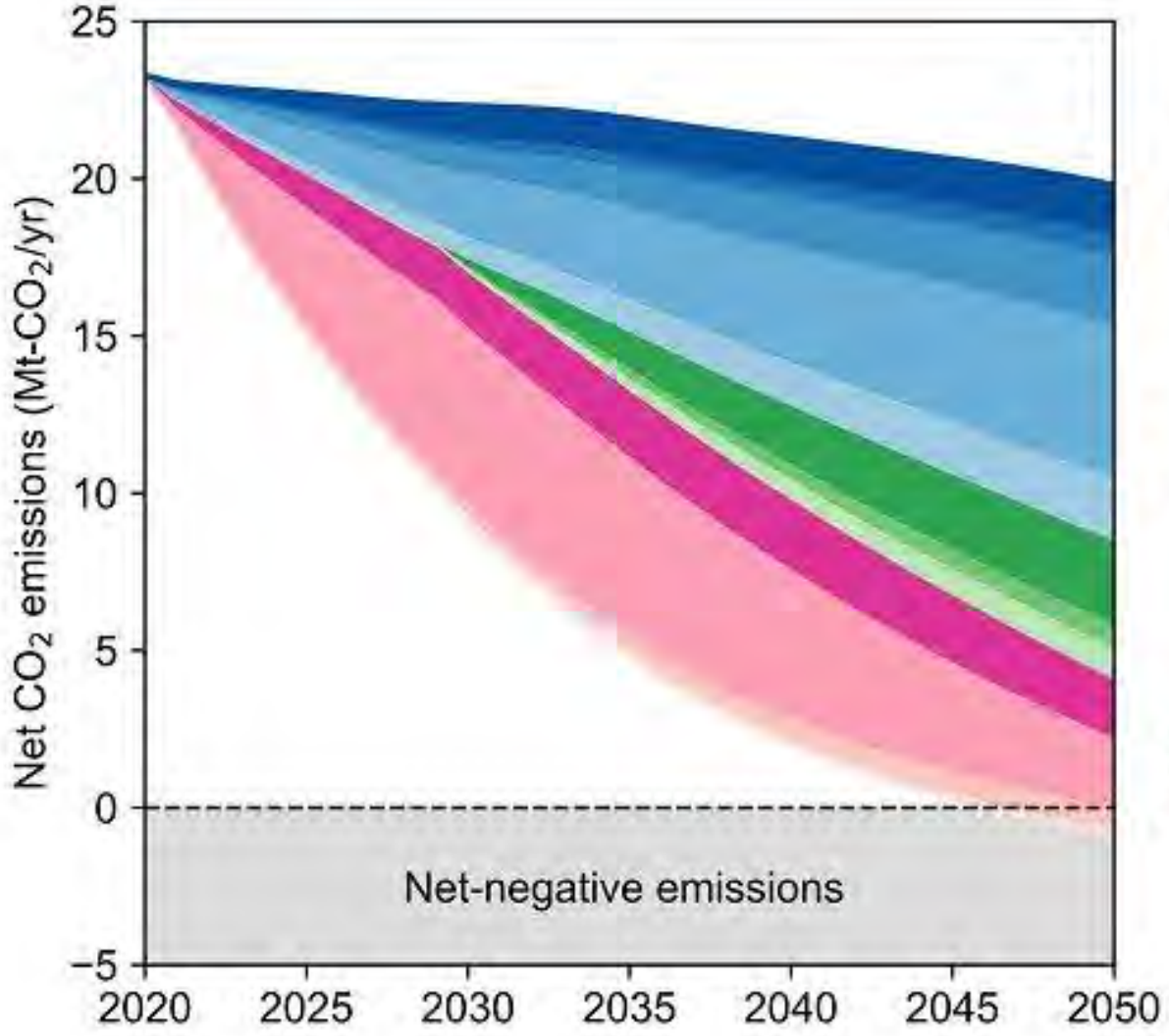

Australian GHG Emissions
MtCO2e/year
1990
630
2005
624
2020
512
GHG
+
Greenhouse Gas Emissions
INCLUDING FORESTRY
Land Use, Land Use Change and Forestry or LULUCF
1990
2005
2020
2030
Change from 2005 levels
(including LULUCF)
+10%
0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%
-90%
-100%
Temperature increase in 2100
Warming from pre-industrial levels
4°C+
4°C
3°C
2°C
1.5°C
Australian Government projections
30 % decrease
Australia's 2030 Paris Agreement NDC Target
26–28 % decrease
Liberal Party
26–28 % decrease
Labor Party
43 % decrease
Teal Independents
60 % decrease
Green Party
74 % decrease

# Concrete Industry and GHG Emission



# How to decarbonise Concrete?

## Japanese Roadmap Case Study





Role of supply- and demand-side strategies in net CO2 emissions associated with the cement and concrete cycle in Japan, 2020–2050.
Credit: *Nature Communications* (2022). DOI: 10.1038/s41467-022-31806-2

# The Start of the Fourth Industrial Revolution

**4th Industrial Revolution -** mobile, cloud, smart connected devices, cyber physical systems, smart factory, robots, mass customization, product as-service

**3rd Industrial Revolution –** electronics, telephones, PLCs, NC machines, PCs, CAM, CIM, spreadsheets, Lean manufacturing

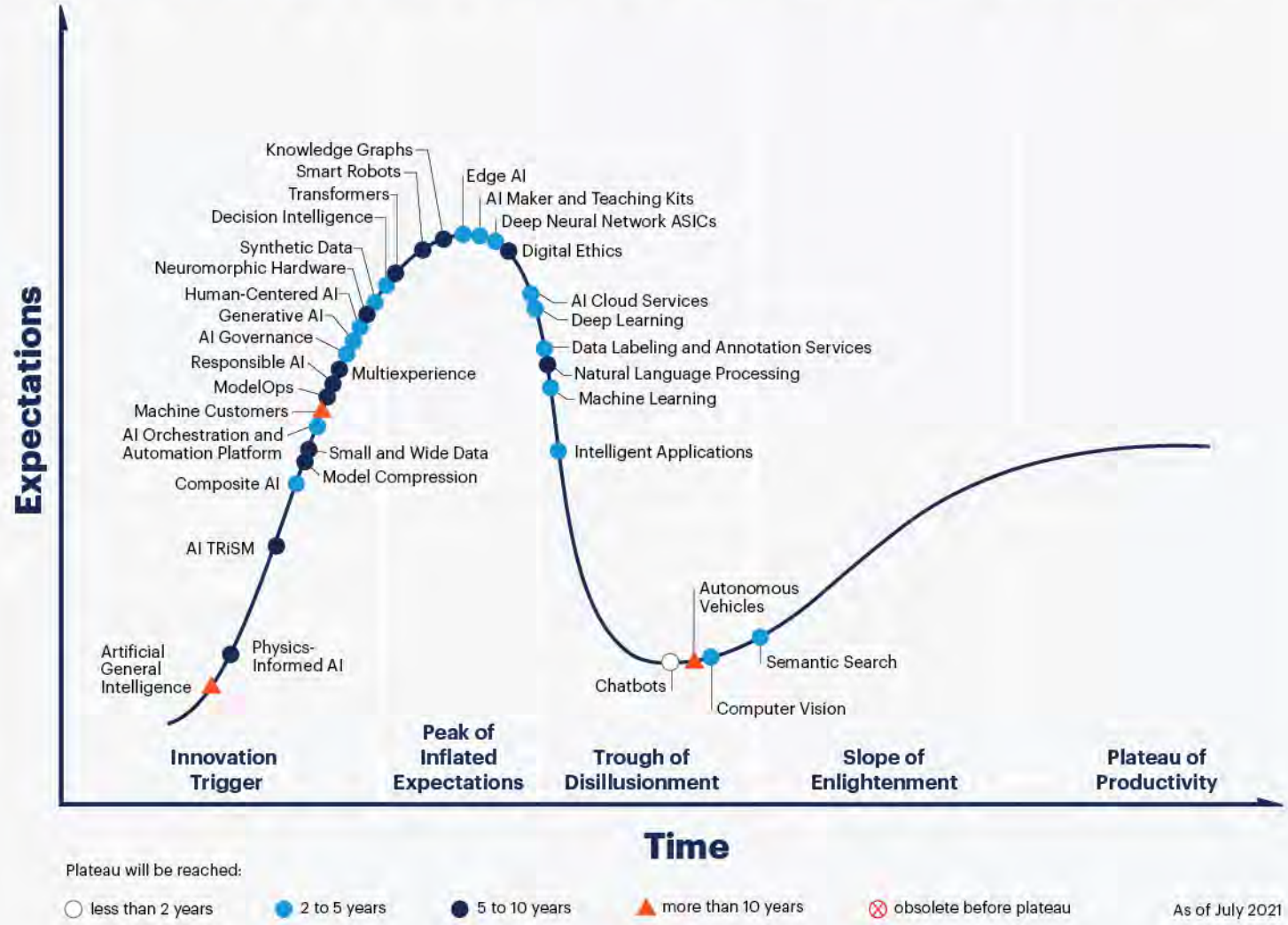
**2nd Industrial Revolution –** manufacturing assembly line and infrastructure of electricity, gas, water, telegraph, roads

**1st Industrial Revolution –** water and steam powered mechanical manufacturing facilities

Productivity, Complexity

End of 18th century | Start of 20th century | Late 20th century | Today

# Hype Cycle for Artificial Intelligence, 2021




gartner.com

Source: Gartner



Gartner

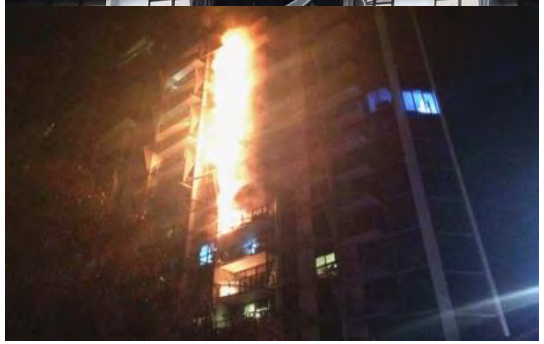
# Key Challenges for Construction Industry

***How can we build faster, cheaper, better quality, safer and more sustainable ?***

## 1. Project Delays & Cost Overrun

- **One in three projects experienced delay and cost overrun by up to 50%**
- **$28 billion lost over the last 15 years on cost overruns**

## 2. Material shortage, Non-conforming Products

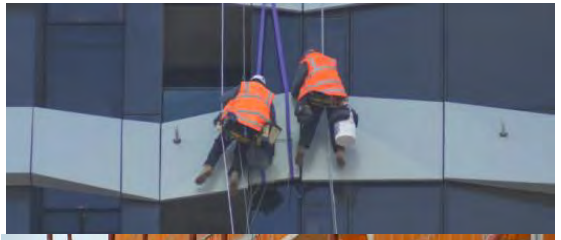


- **Steel and timber prices went up by 40%**
- **Supply chain disruption**
- **Flamable cladding issues**

## 3. Quality & Performance Issues

- **80% projects reported having quality issues**
- **Cost $2 billion a year for re-work**

## 4. Safety on Site & Skilled Labour Shortage



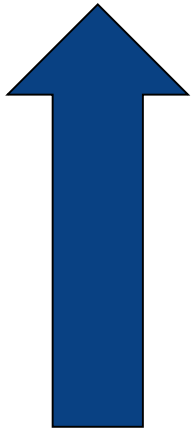
**Over 5 years 2008-2013**

- **182 workers killed**
- **63230 serious injuries**

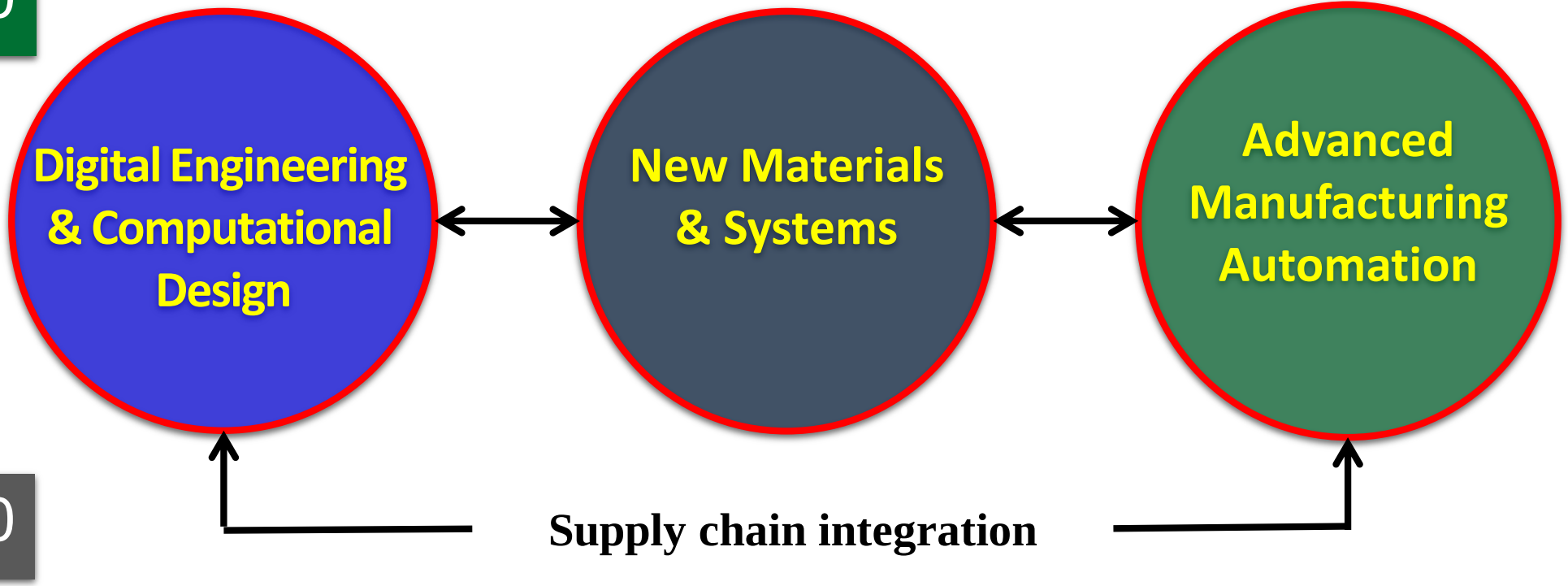
**20% tradespeople above 55 yr**

# We need a holistic approach

Construction 4.0

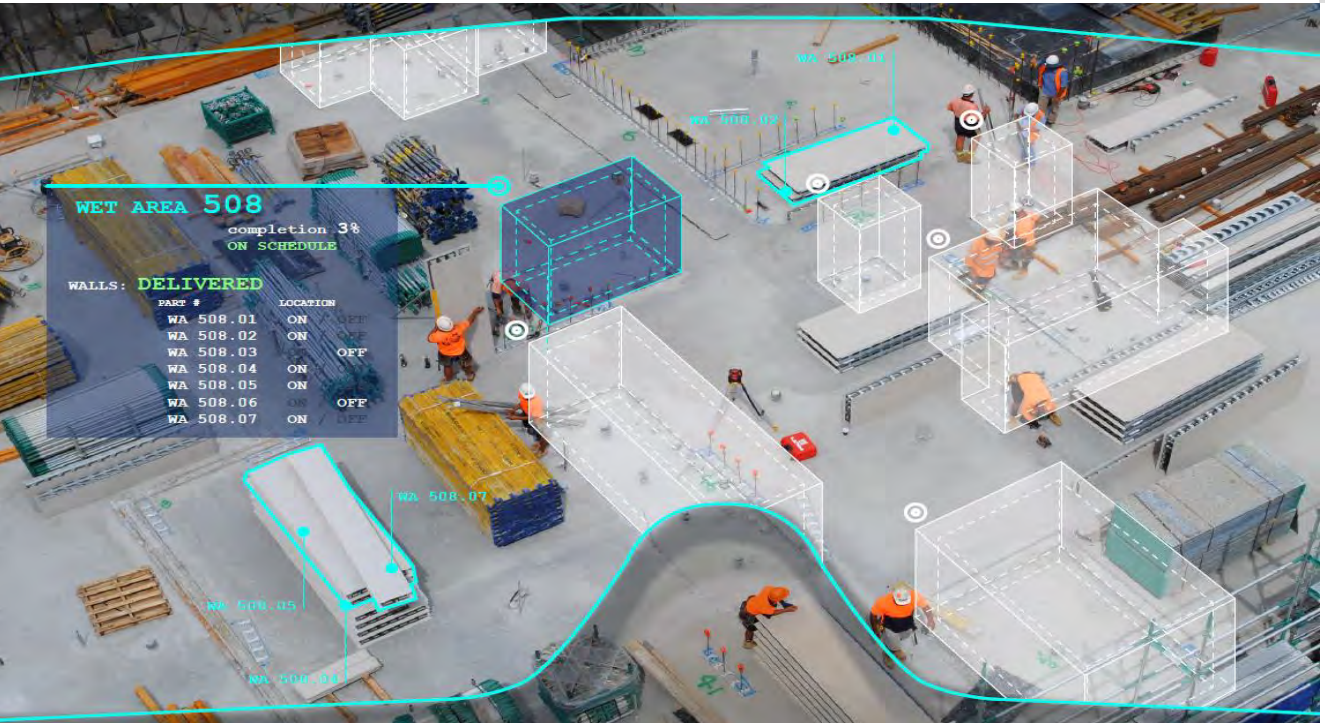


Construction 2.0



# Redefining construction for the 21st Century

building 4.0 crc




## VISION

The transformation of the construction industry through an open and deeply connected value chain, creating a more productive, customer-centric industry that positions Australia as a leader in the advanced manufacture of buildings.

# Building 4.0 CRC

Total R&D value: $130M

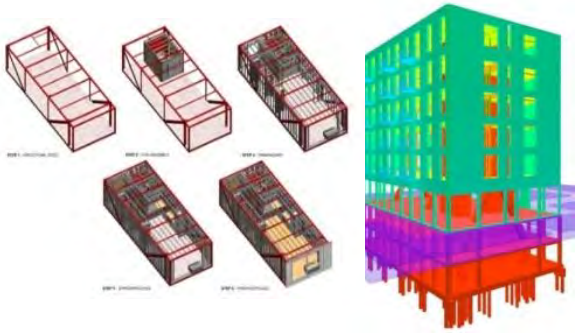
## Partners and Capability

- 5 Large Commercial
- 10 Medium Commercial
- 5 Small
- 4 Peak Bodies
- 3 Research Organisations
- 1 Skills and Training Organisation

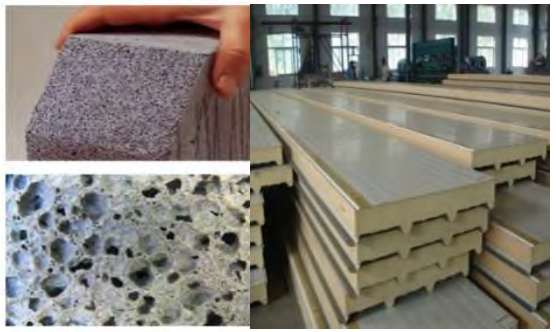
lendlease
MONASH University
THE UNIVERSITY OF MELBOURNE
DONOVANGROUP
BLUESCOPE
CSR
SUMITOMO FORESTRY
uTECTURE
BENTLEY HOMES
Coresteel BUILDINGS
A.G.Coombs
ultimatewindows
QUT
holmesglen
HYNE TIMBER
XLam
SHAPESHIFT DESIGN TECHNOLOGIES
salesforce
MODULAR
schiavello
aws
GELION POWERING THE FUTURE
YNOMIA
FLEETWOOD AUSTRALIA
MASTER BUILDERS VICTORIA
prefabAUS
green building council australia
STANDARDS Australia
TARONGA VENTURES
VBA VICTORIAN BUILDING AUTHORITY BUILDING CONFIDENCE
VICTORIA State Government | Jobs, Precincts and Regions

# Key Research Areas

## 1. Computation Design and Simulation

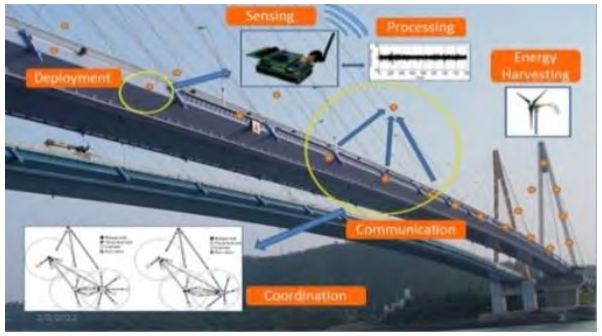


## 2. Novel Material Development & Testing



## 3. Innovative Construction & Infrastructure Systems

## 4. Smart Maintenance and Operation




**Improved Productivity & Safer Construction**

**Cost Effective, Energy Efficient, Less Waste**

**Better Quality & More Affordable Housing**

**Export Opportunities, Global Market**

**More Resilient, Lower Life Cycle Cost**

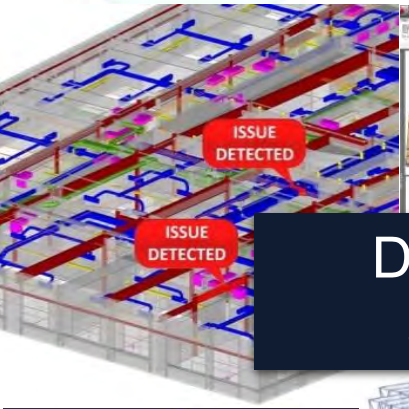
## Industry Outcomes

- 60% faster construction
- 50% reduction in life cycle costs
- 90% reduction in waste
- 50% reduction in GHG emission
- 70% reduction in labour & transport

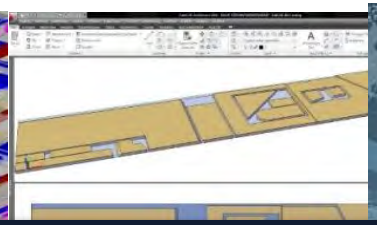
# Construction 2040

## What will it look like?

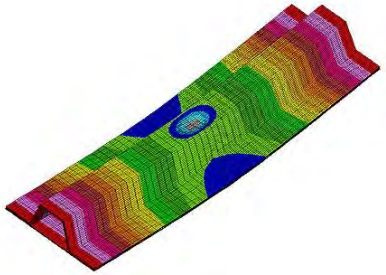
# Enabling technologies

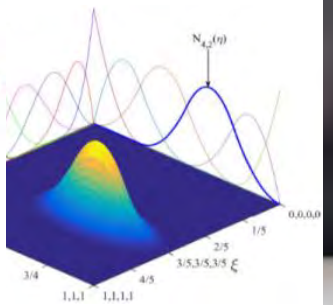


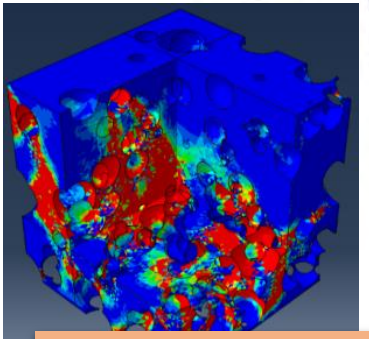

Digital Design automation

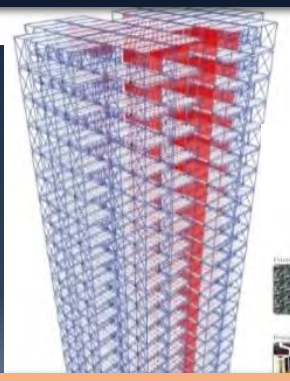


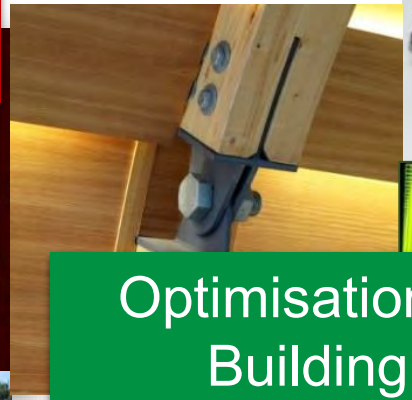
AI/ML for Design, Optimisation, Production & Operation

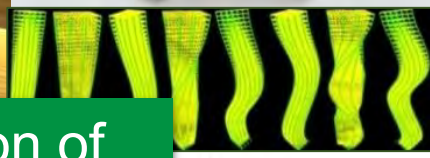






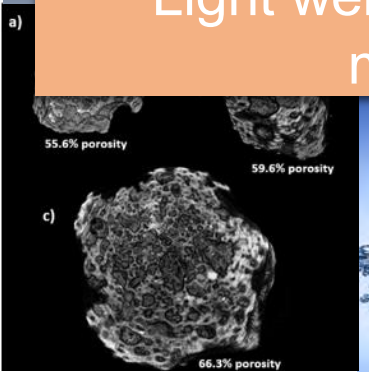






Optimisation of Building Performance

Light weight & Low GHG materials




3D printing, AM, Robotics

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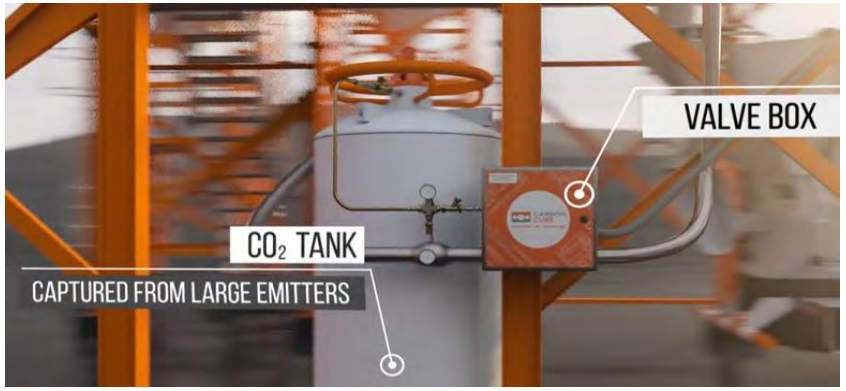
# Future Building Materials:
# Advanced Materials
# Sustainable Materials

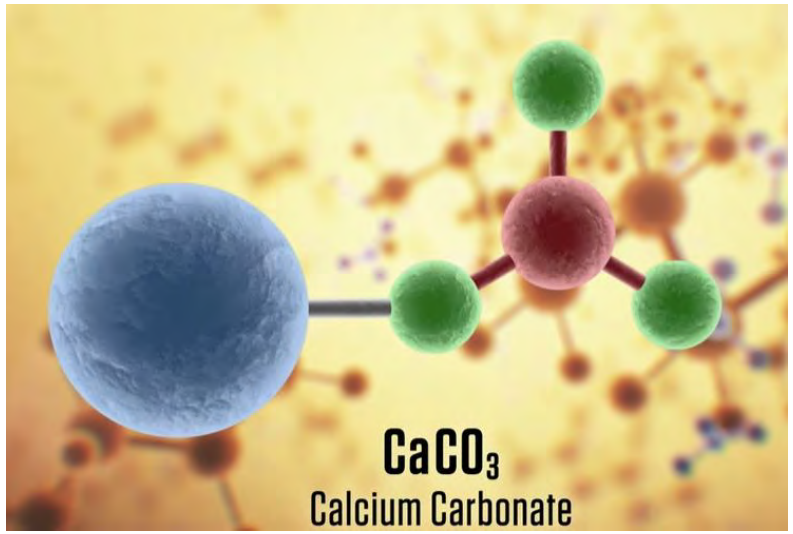
Amazon's HQ2 in Arlington, Virginia

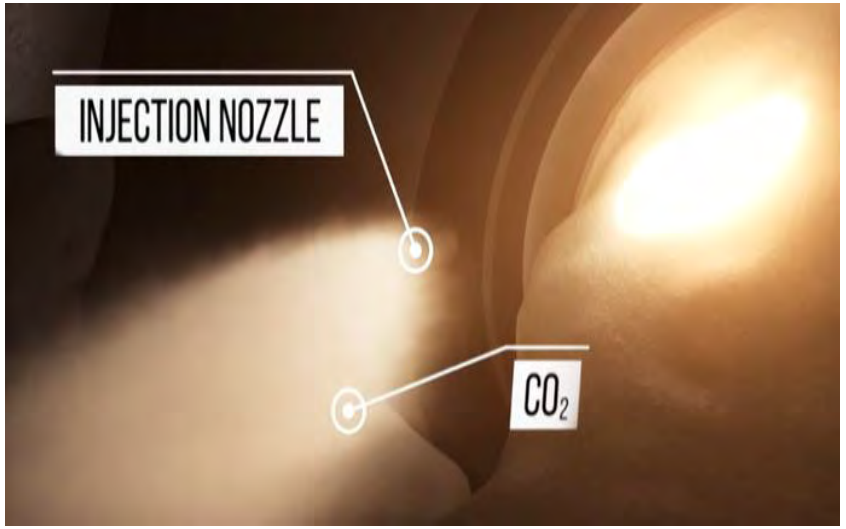
# Construction 2050 – The Future Material: Sustainable building materials

CARBONCURE





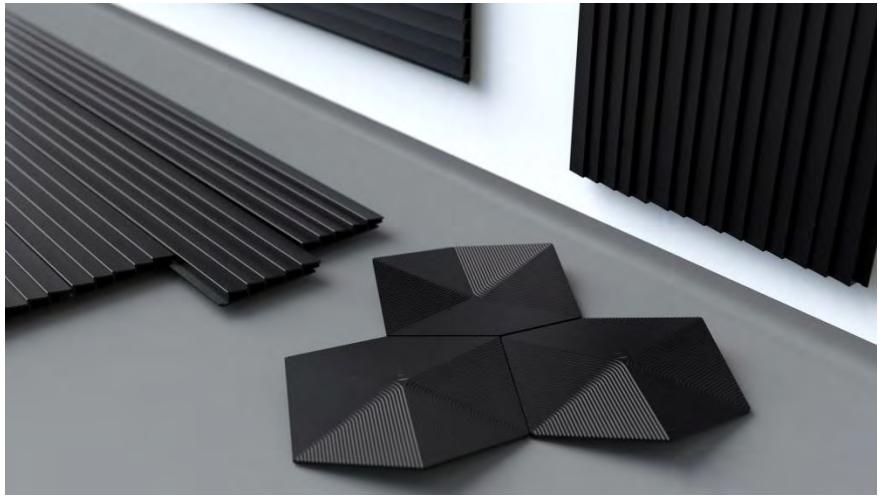


CarbonCure concrete reduces an average 15 kg/m$^3$ of $CO_2$

# Construction 2050 – The Future Material: Sustainable building materials – other examples

**Carbon-sequestering Carbicrete**

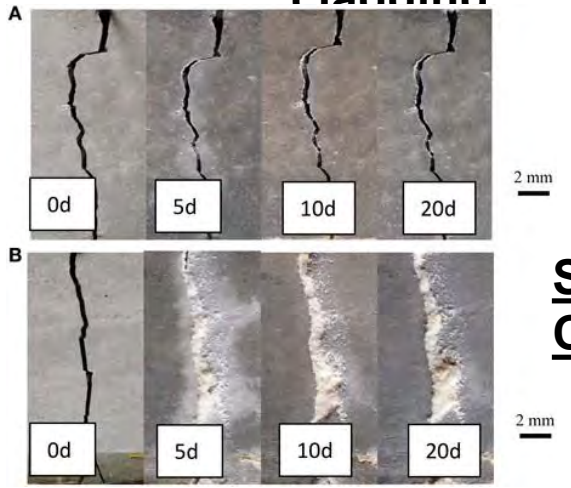
**K-Briq construction waste bricks**



**Biochar cladding**

**Carbon-modified concrete**

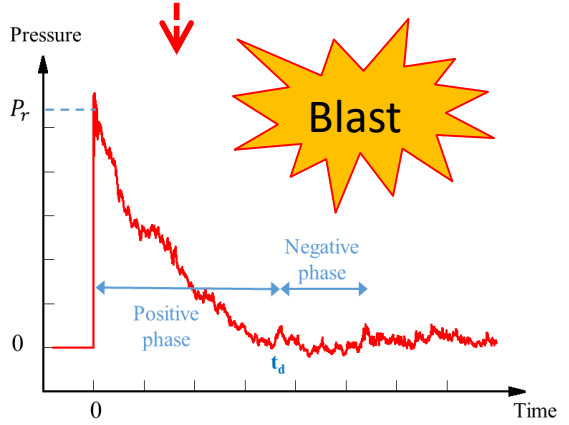
**Hemp rebar**




**Self-healing Concrete**

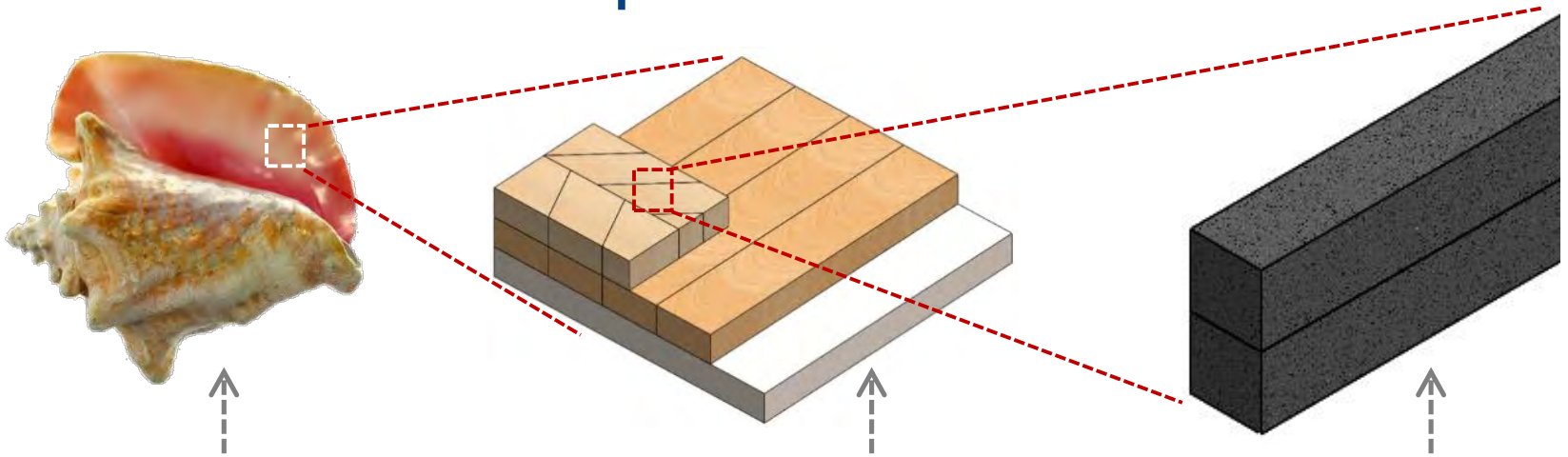
# Is timber a solution for sustainable buildings? How safe is timber multi-story buildings

# Bio-inspired Cross-Laminated Timber for Protective Structural Applications




- ✓ Improving hardness, fracture resistance
- ✓ Good energy-dissipating mechanisms
- ✓ Enclosing damages
- ✓ High stiffness to weight ratio
- ✓ Lightweight and cost-effective
- ✓ Environmentally friendly
- ✓ To dissipate more energy
- ✓ To reduce damage
- ✓ To prevent fatality

# Bio-inspired CLT



Conch shell

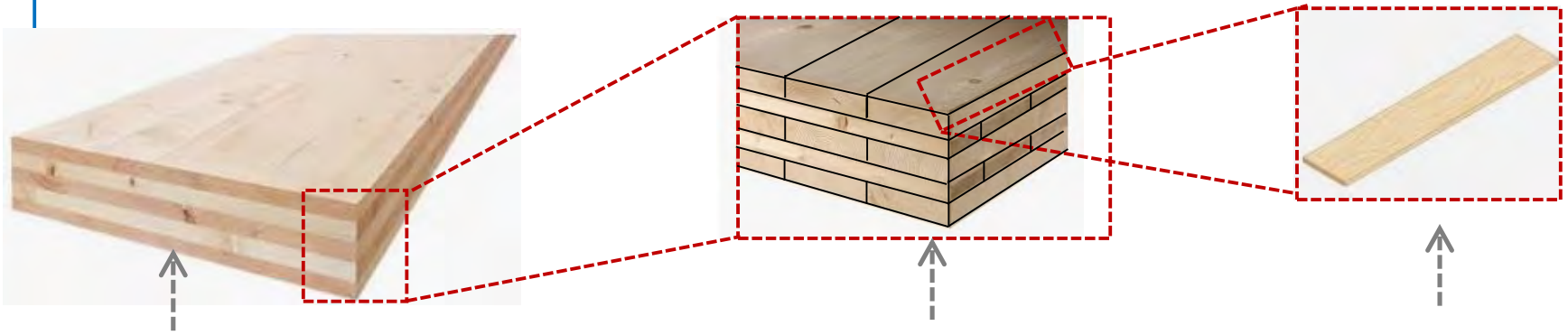
Three-order lamellar structure

Nano-sized conforming planks

mm

μm

nm

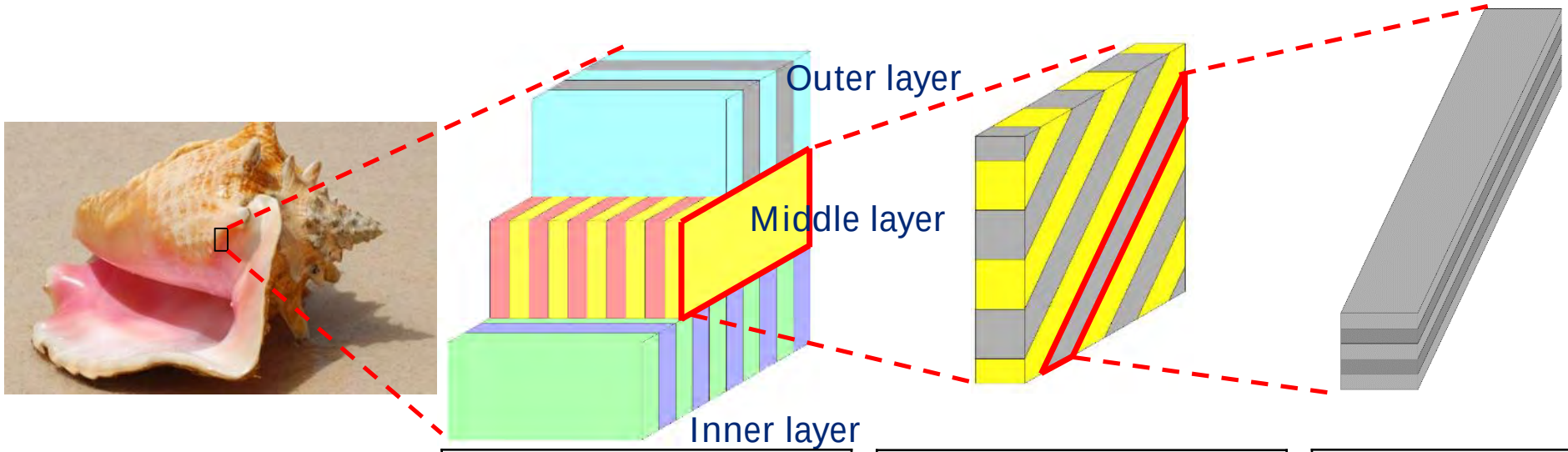


Cross laminated timber

Multiple layers

Timber planks

# 3rd order lamellar structure of conch shells

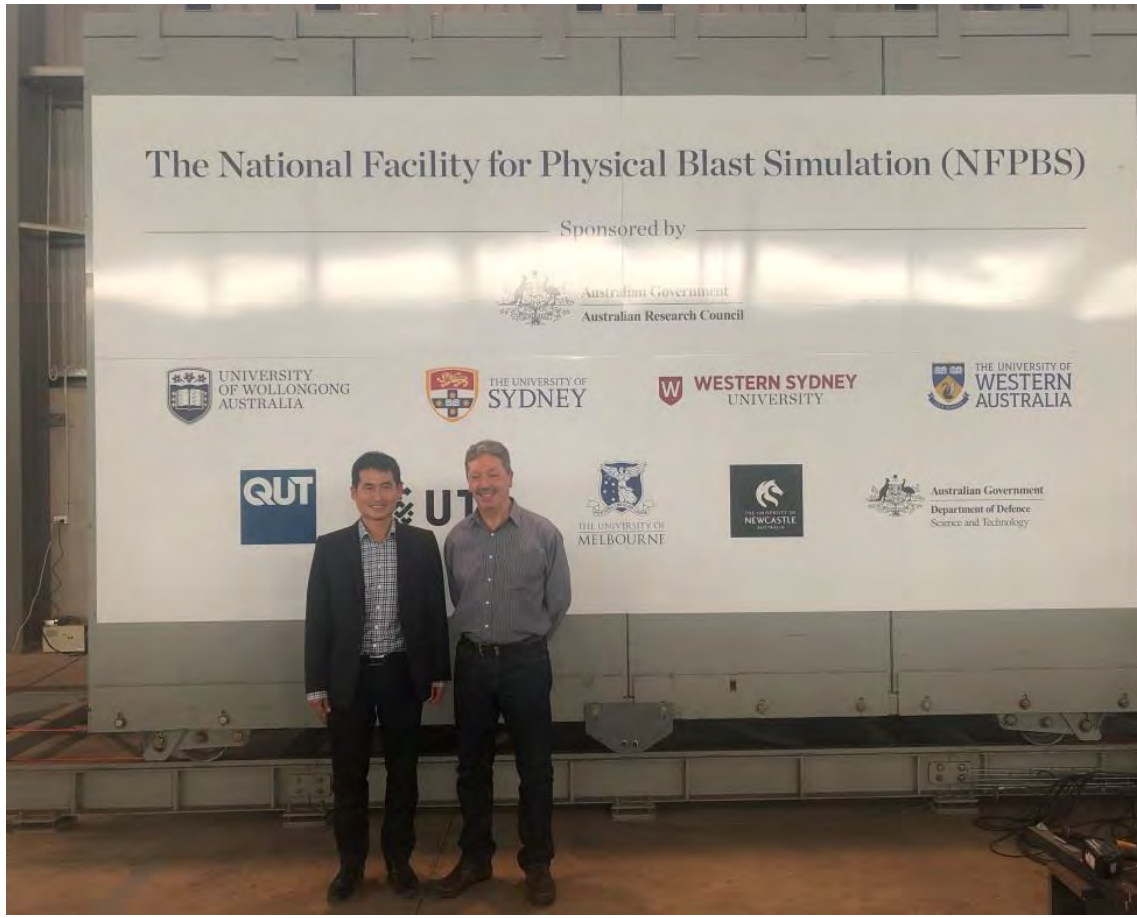



Crossed lamellar:

- Inner layer
- Middle layer
- Outer layer

| 1st order | 2nd order | 3rd order |
|---|---|---|
| **Parallel sheets in each layer** | **Alternative direction beams** | **Nano-twinned aragonite platelets** |
| Deflect crack along weak direction | Deflect crack along weak direction | Increase crack bridging & interlocking |
| Interlocking by the roughness of interfaces | Crack bridging | |

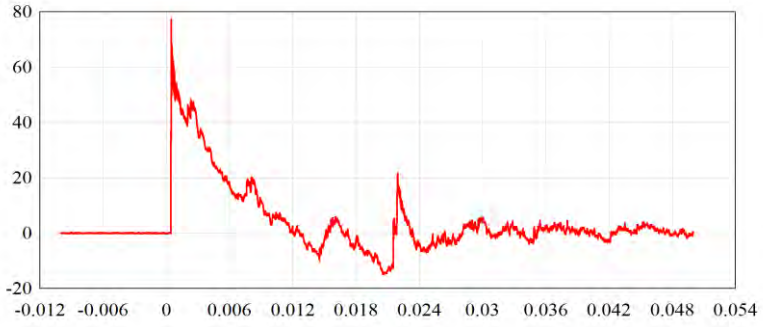
# Behaviour of CLT Timber Panels subjected to Extreme Blasts

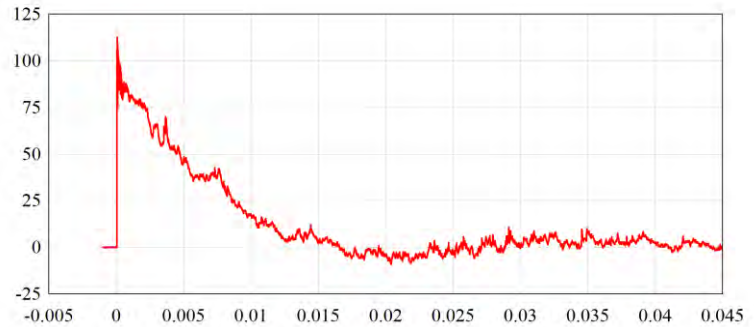
# Behaviour of CLT Timber Panels subjected to Extreme Blasts

# Reflected pressures

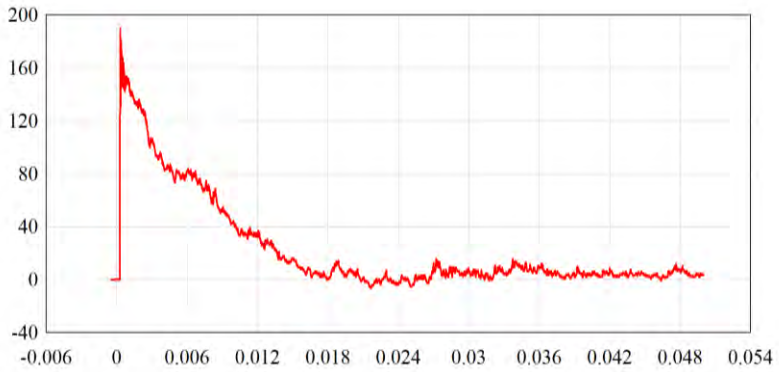
CLT panel (left) CLT5-145



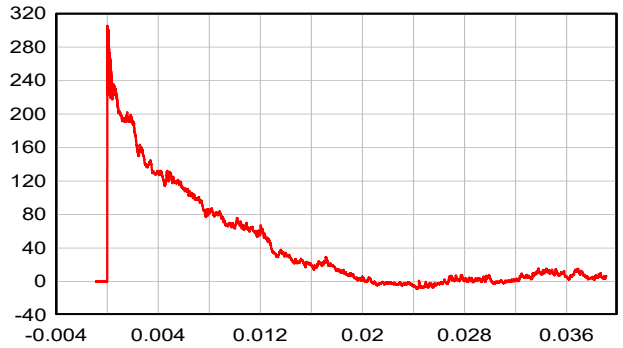

1st shot (~60kPa, 10ms)




2st shot (~90kPa, 12ms)




3st shot (~160kPa, 14ms)

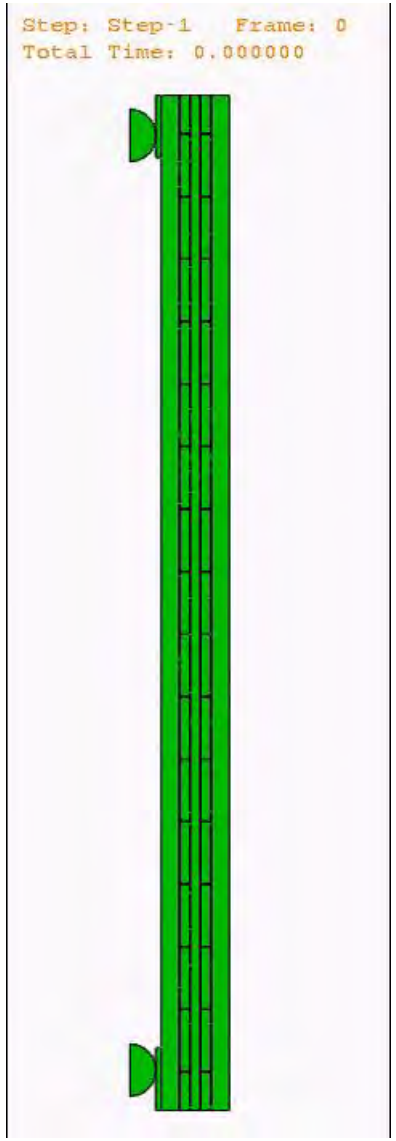


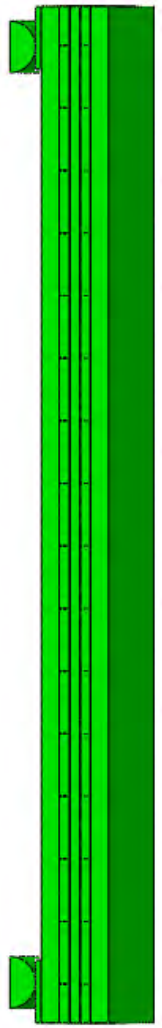

4st shot (~250kPa, 12ms)

# Reflected pressure: 260kPa, $t_d$ = 19ms

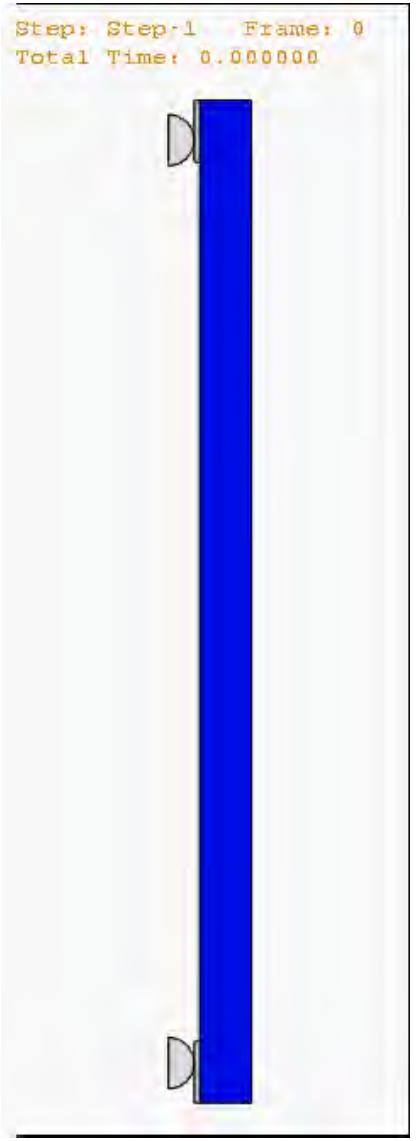

CLT5-145 & CLT5-130

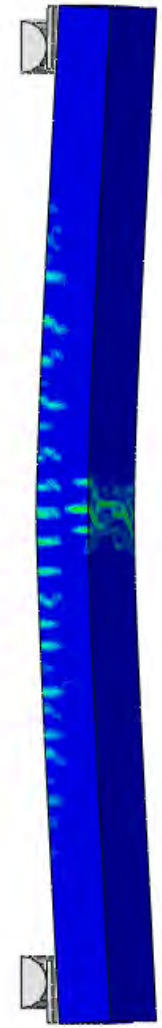

RC Panel 100mm THK.



260kPa 19ms After the test



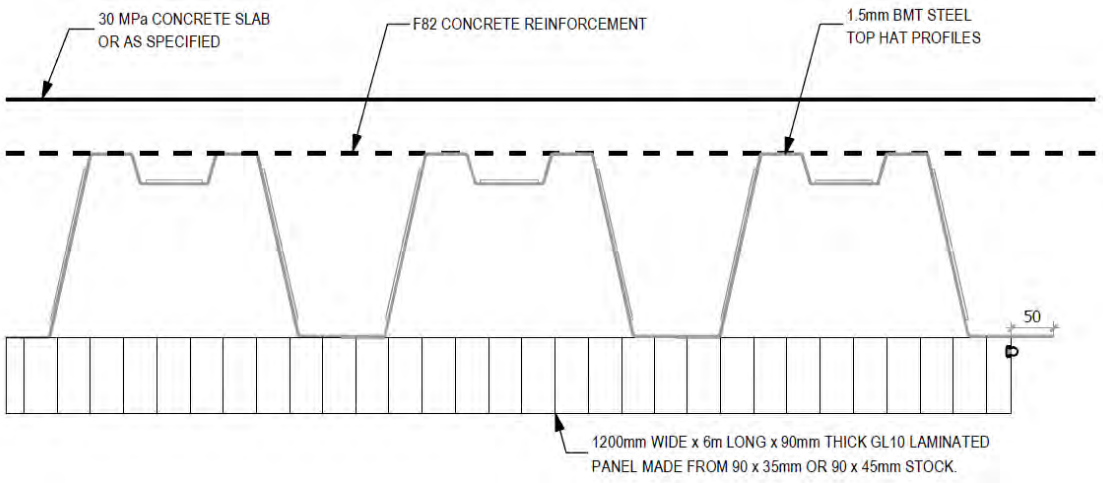
260kPa 19ms After the test

CLT5 - 130mm

Concrete 100mm thk.

# Hybrid Timber & Steel Floor Systems

- Viridi Strongfloor
- Structure combining timber steel and concrete
- Steel deck concrete slab on top, timber panels at the bottom
- Steel element protected from direct fire exposure
- Capable of 9 m span without back-propping
- Preliminary fire testing has resulted in an FRL of 90/90/90 for a 275 mm thick floor system



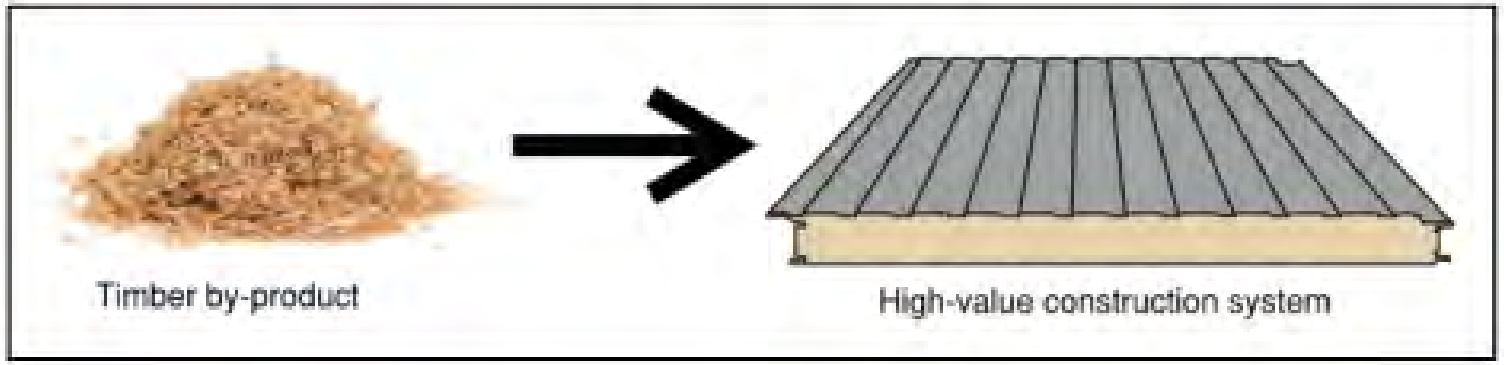

**Cross-section of proposed floor system - Figure from [12]**

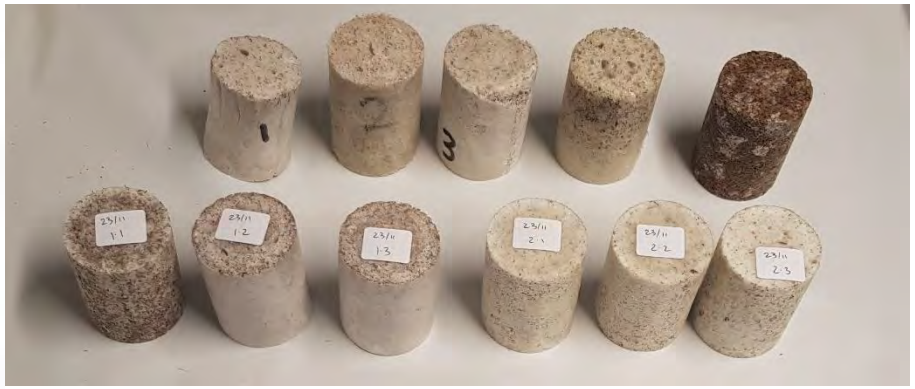
# Re-Use of Mass Timber - Challenges

- Significant challenges posed by screed/concrete
- Connection design for disassembly
- Re-processing limited by polyurethane and treatments

# Melbourne University Structural Testing and Research

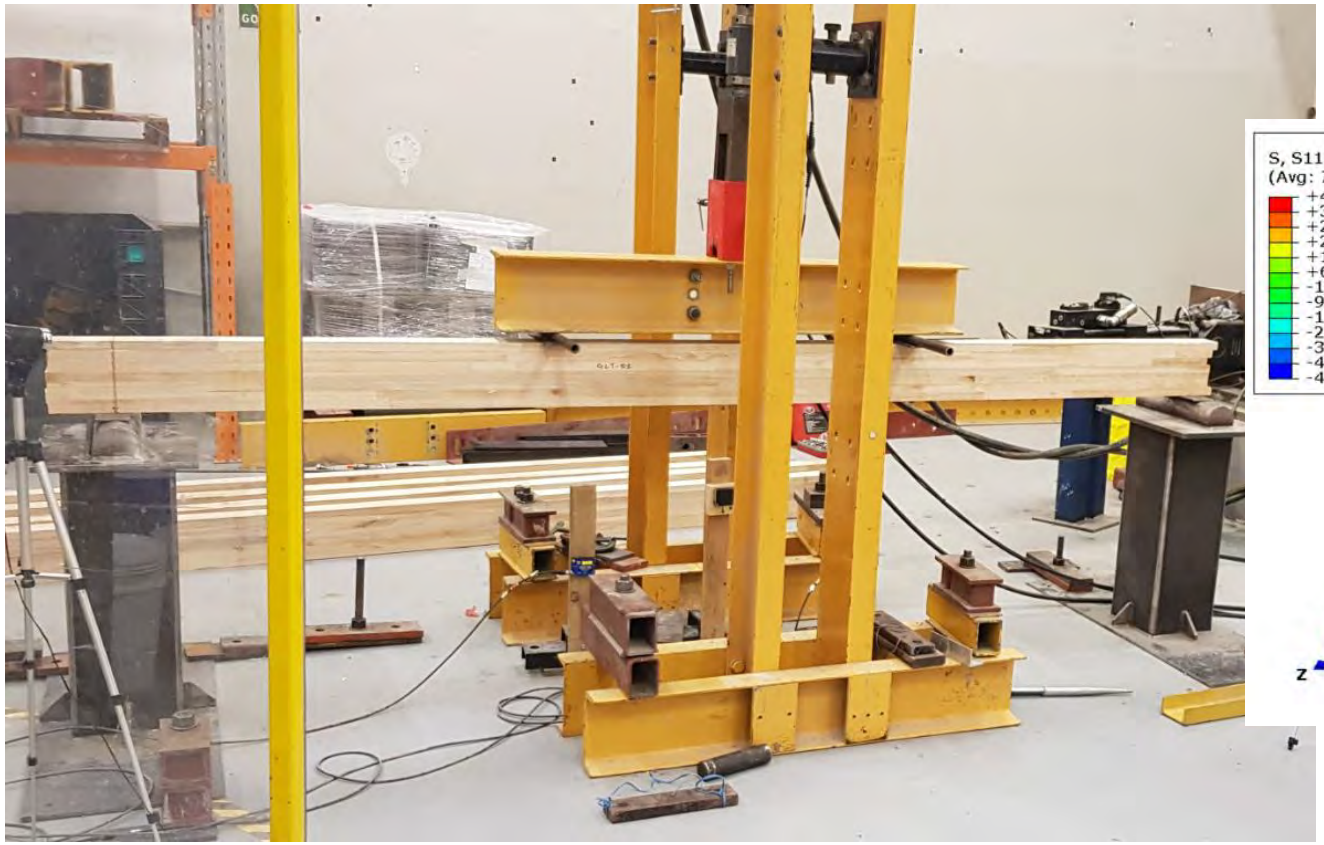
*Figure 1. Valorising a waste timber product to produce a key component in a valuable construction system*

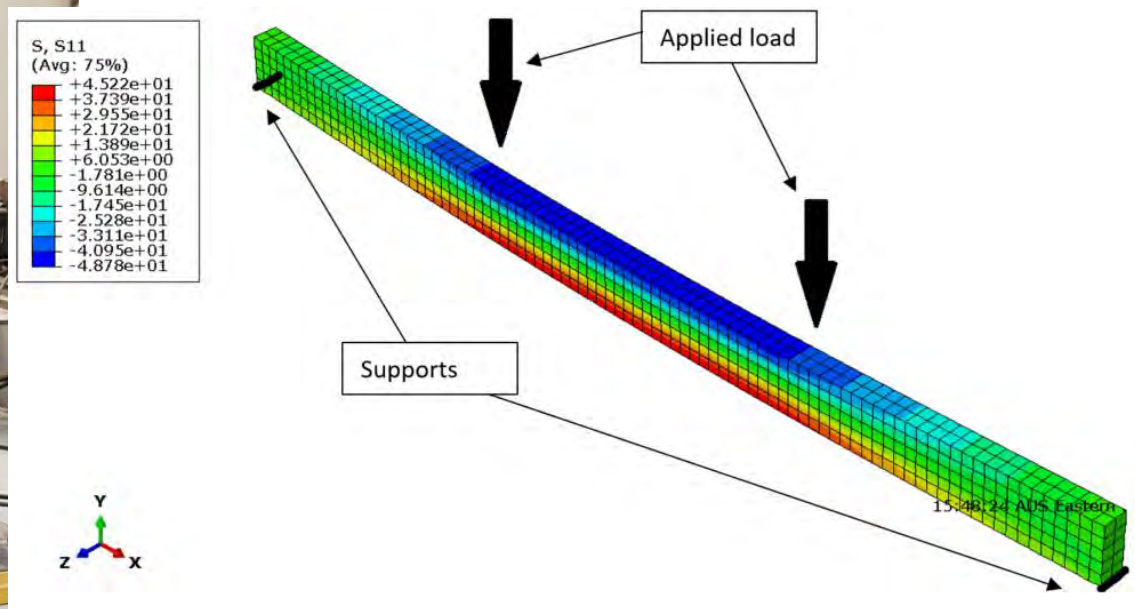


# Re-cycling of waste timber products
# National University Wood Challenge

# Hardwood glulam four-point bending tests





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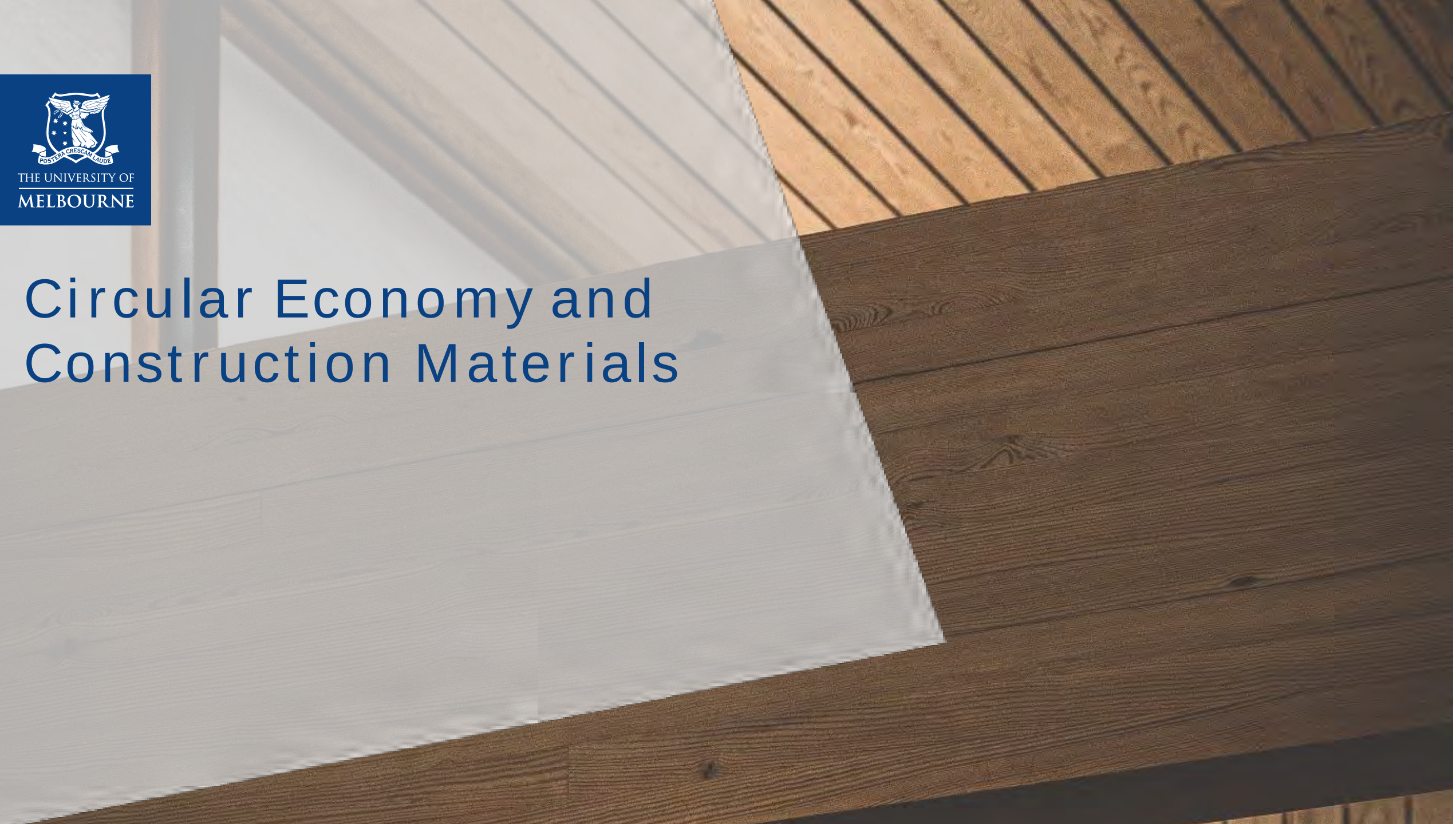
# Circular Economy and Construction Materials



# Building and Construction opportunities

- What percent of building material is wasted? **10-15%**
- Of this how much goes to landfill? **54% with some countries such as Germany <10%**
- What percent of all extracted materials are in the built environment? **40%**

**World Bank 2020, data.un, One Planet SBC**

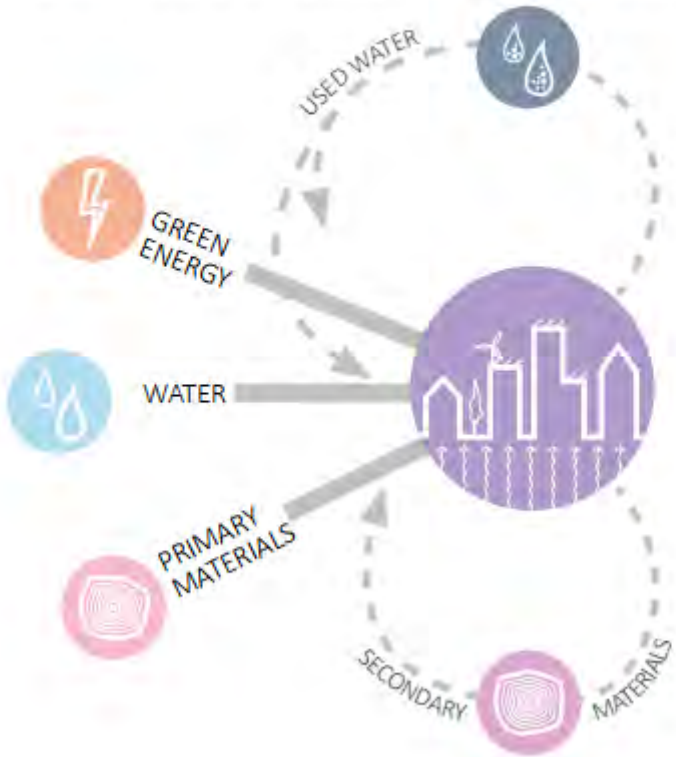
# Global State of Play for Circular Built Environment

## LINEAR CONSTRUCTION

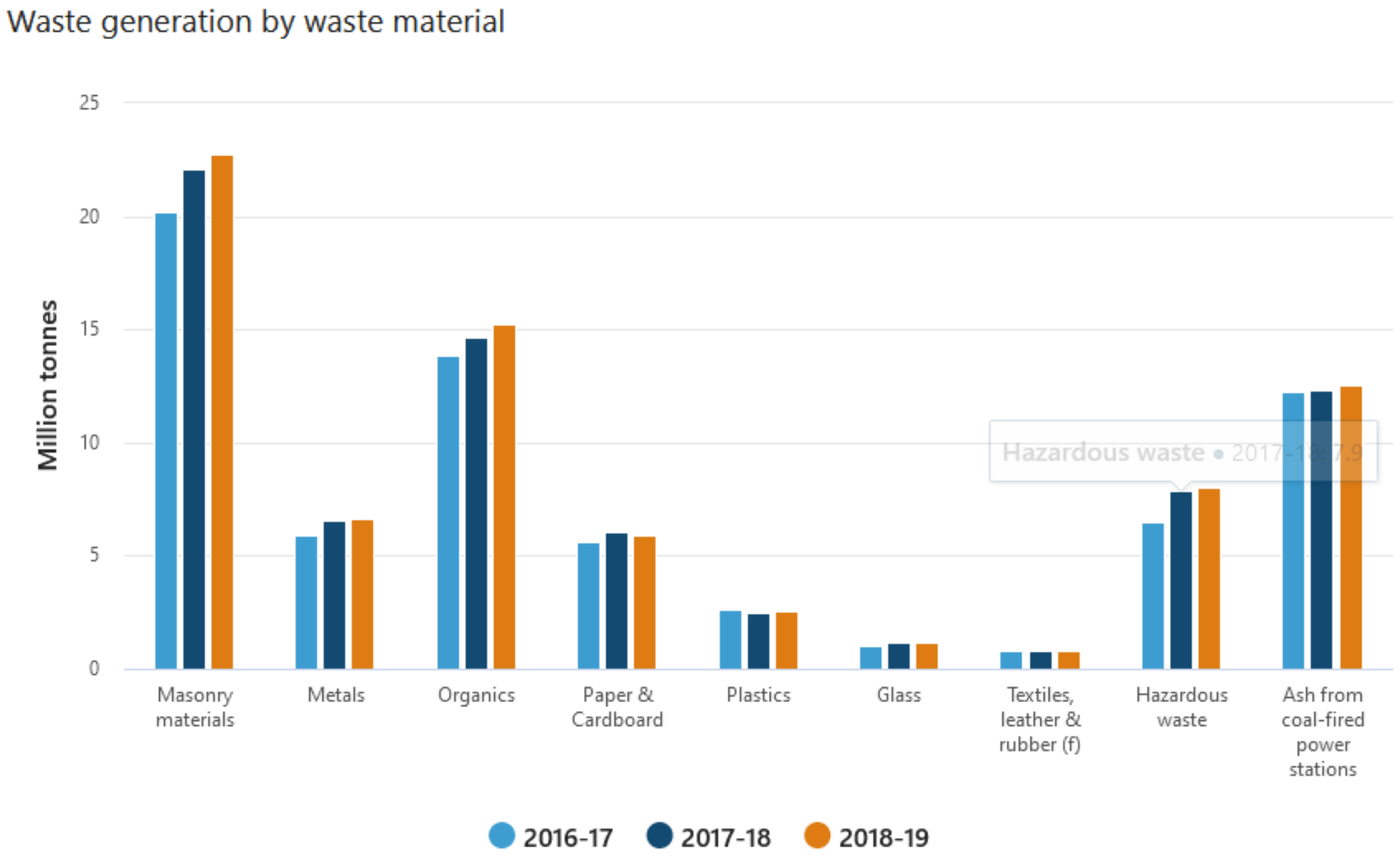
High consumption, low production, high pollution


## CIRCULAR CONSTRUCTION

Low consumption, high production, no pollution



# Australian Waste



# How can we begin to circularize construction?

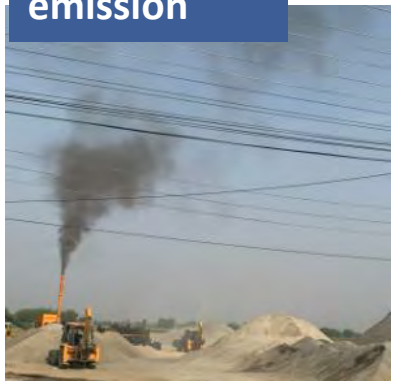

The Essential Building Blocks:
Materials and Systems

# Sustainable concrete with recycled glass

# Natural Sand Challenges

## Sand shortage

## CO2 emission



## Ecological damages


Natural sand

Replacement

?

# Waste Glass Landfilled & Stockpiled

Generated glass waste

Recovered

Rubbish bin

Breakage

mixed colour contaminated

Glass manufacture_48 %

Landfilled_24 %

Stockpiled_28%

# Glass Fines as Sand Replacement

## Benefits

Alleviate glass fines stockpiling

Reduce use of virgin sand

GREEN CONCRETE

Waste glass fines

Similar physical properties

Natural sand

## Barriers

- Updating of standards to allow the use: concern of contaminants

vicroads

EPA VICTORIA

- Alkali-silica reaction (ASR): “concrete cancer”

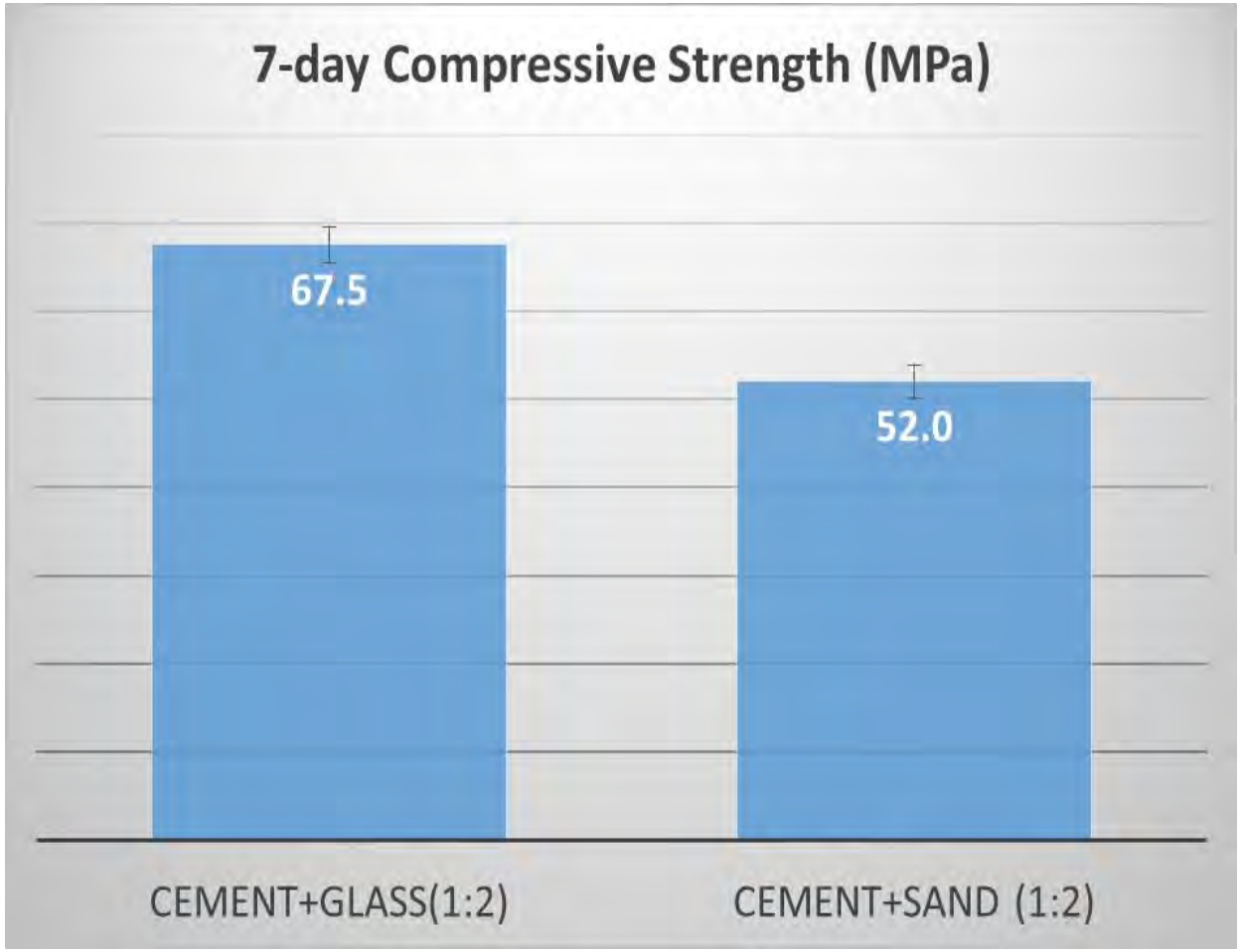
# Sustainable concrete with recycled glass

- **30% Stronger**
- **20% Cheaper**
- **Similar workability**

**Table 1. Particle sizes of as received glass fines**

| Diameter(mm) | Percentage (%) |
|---|---|
| 1.0- 2.0 | 32.9 |
| 0.7-1.0 | 20.4 |
| 0.4-0.7 | 16.9 |
| 0.2-0.4 | 14.6 |
| <0.2 | 15.2 |

| | Fine sand | Portland cement | Fly ash | glass |
|---|---|---|---|---|
| **Density (kg/m$^3$)** | 2820 | 3100 | 2540 | 2570 |




ASTM C109

# Contaminated Waste Glass Fines as Partial Sand Replacement in Concrete

## Overview

**Collaboration:**


THE UNIVERSITY OF MELBOURNE
LEVEL CROSSING REMOVAL PROJECT
NORTH WESTERN PROGRAM ALLIANCE
Hanson HEIDELBERGCEMENT Group
Sustainability Victoria
ALEX FRASER GROUP
BUILDING GREENER ROADS.
JOHN HOLLAND
VICTORIA State Government Department of Transport

**Updating VicRoads standards Section 703**:

- Certain level of contaminants
- Unknown impacts
- Were thoroughly washed in literature review

**Section 703:** General Concrete Paving – Previously glass fines was included but needs to be washed and free from contaminants, may use up to 30 wt. %

Unsustainable; uneconomical; less appealing!

# Project outcomes

- Contaminants' detection/quantification:  light particles and organic contaminant
- Safe and low-risk replacement: 10 wt. %
- Differences between laboratory and site → significance of industry scale
- Chemical leaching test → no environmental risk
- Section 703 has been now revised to "*unwashed fine glass aggregate up to a maximum of 10 % may be used as a replacement of the total mass of fine aggregate for concrete grades specified in this section*".

# Development 0f Rubberised Concrete Road Barriers

# Rubberised concrete

**Motivation and Background**: **Rubberised concrete**

- 63% of end-of-life waste tyres (140,000 tonnes) are landfilled and stockpiled in Australia
- Environmental Impacts:
  - Resistant to decay
  - Reduction in valuable space
  - Landfill gas mitigation
  - Breeding ground for pests
  - Highly flammable
- The major environmental pollution caused by waste tyres encourages researchers to find ways to recycle and reuse this waste material → Rubberised concrete

# Why Rubberised concrete for Safety Barriers?

**Current rigid road barrier design**

- Impose large deceleration forces
- Extensive damage to impacting vehicles during an accident
- Increases the likelihood of injury to occupants of a vehicle during a collision with a concrete safety barrier

# Rubberised Concrete for Impact Resistant Road Barriers

- ✓ Improved impact resistance
- ✓ Good energy absorption
- ✓ Reduced damage
- ✓ Sustainable constructions

- ✓ To dissipate more energy
- ✓ To reduce damage
- ✓ To prevent fatality

# Impact Performance 0f Rubberised Concrete Road Barriers

**How can we make better barriers?**

Traditional Concrete

vs

Rubberised concrete

Less sustainable

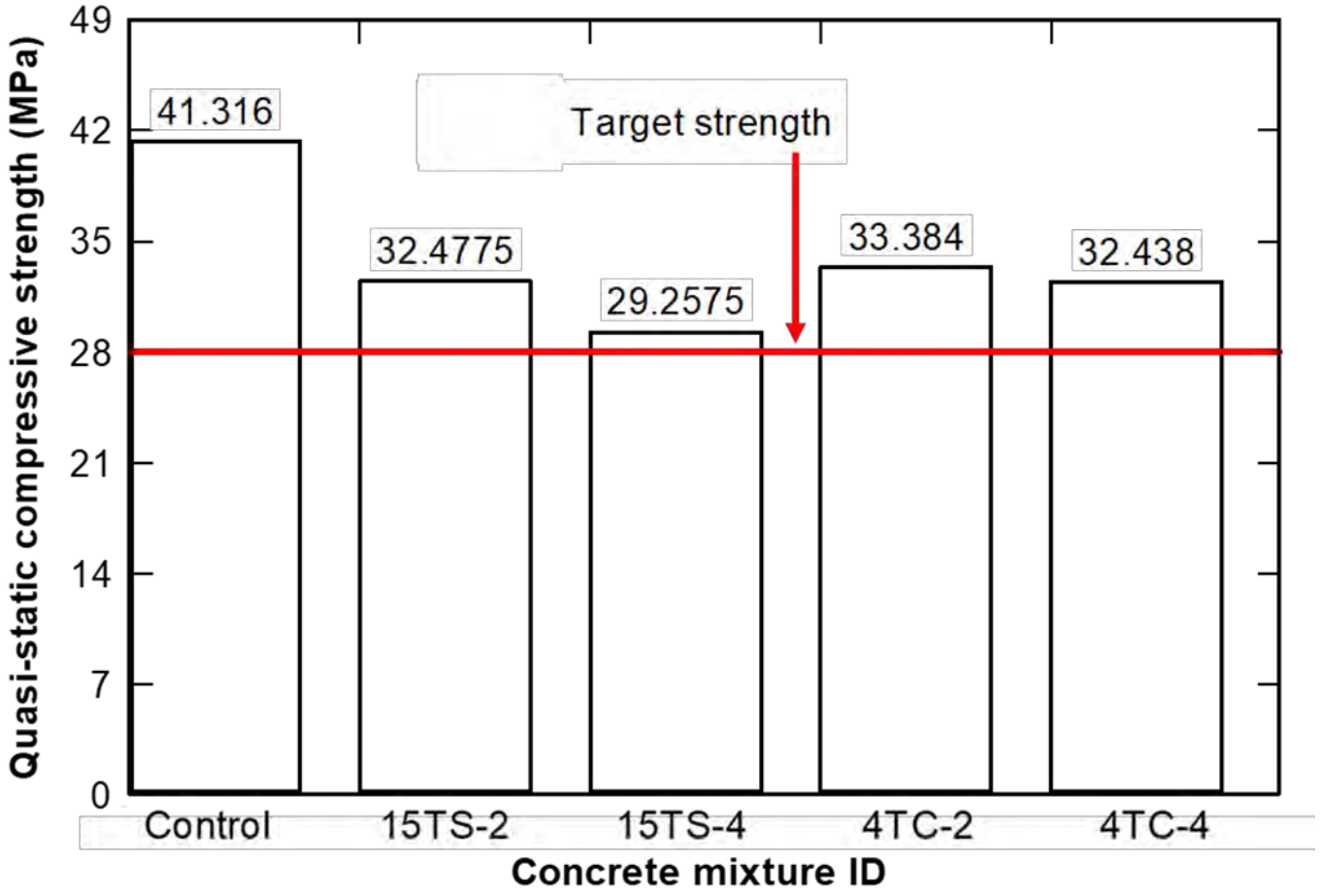
vs

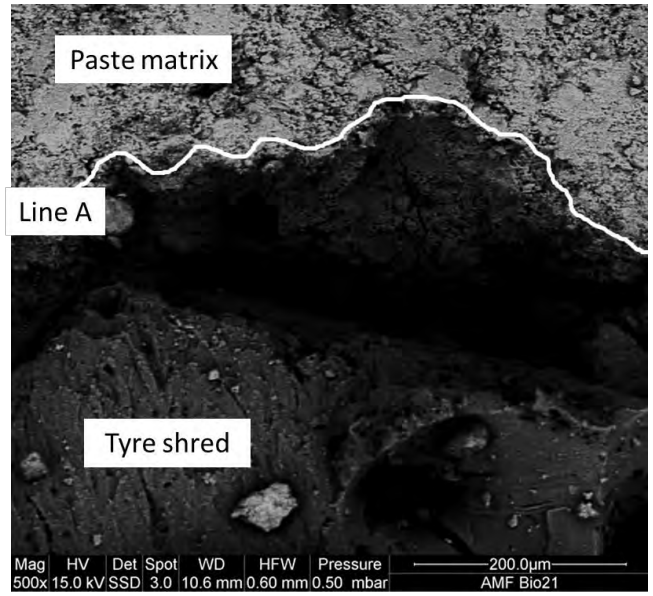
+

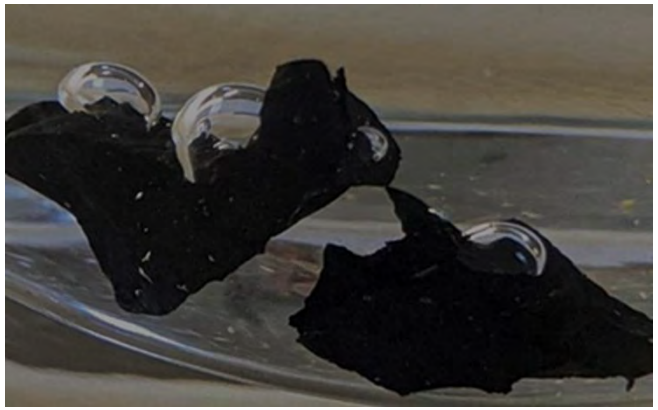
Increased sustainability

# Quasi-static Properties of Rubberised Concrete

**Compressive strength**



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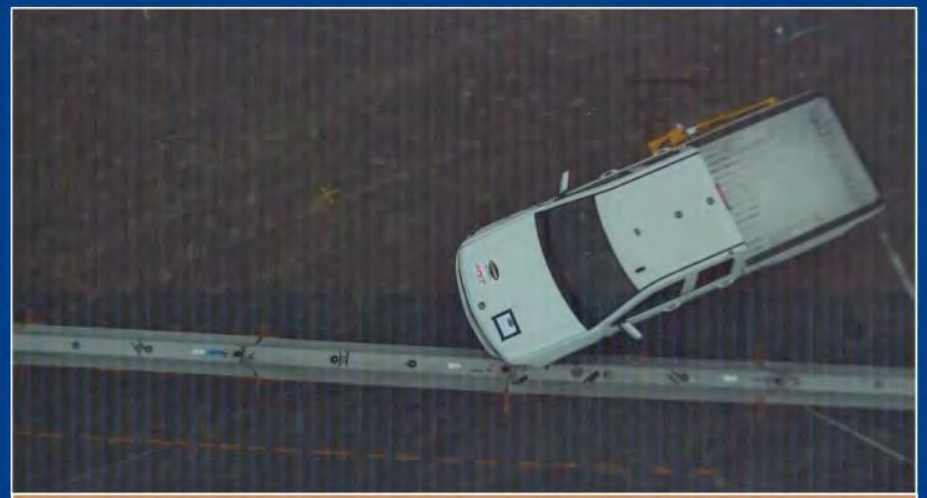
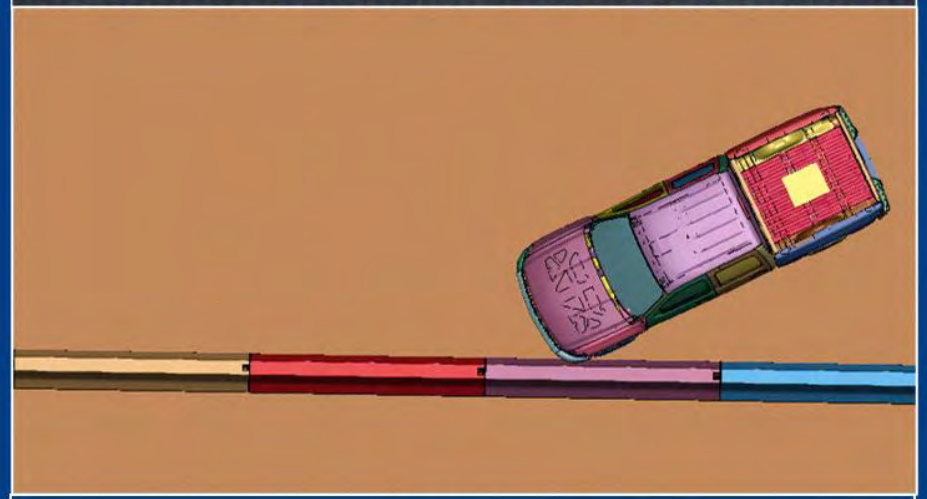




Top View

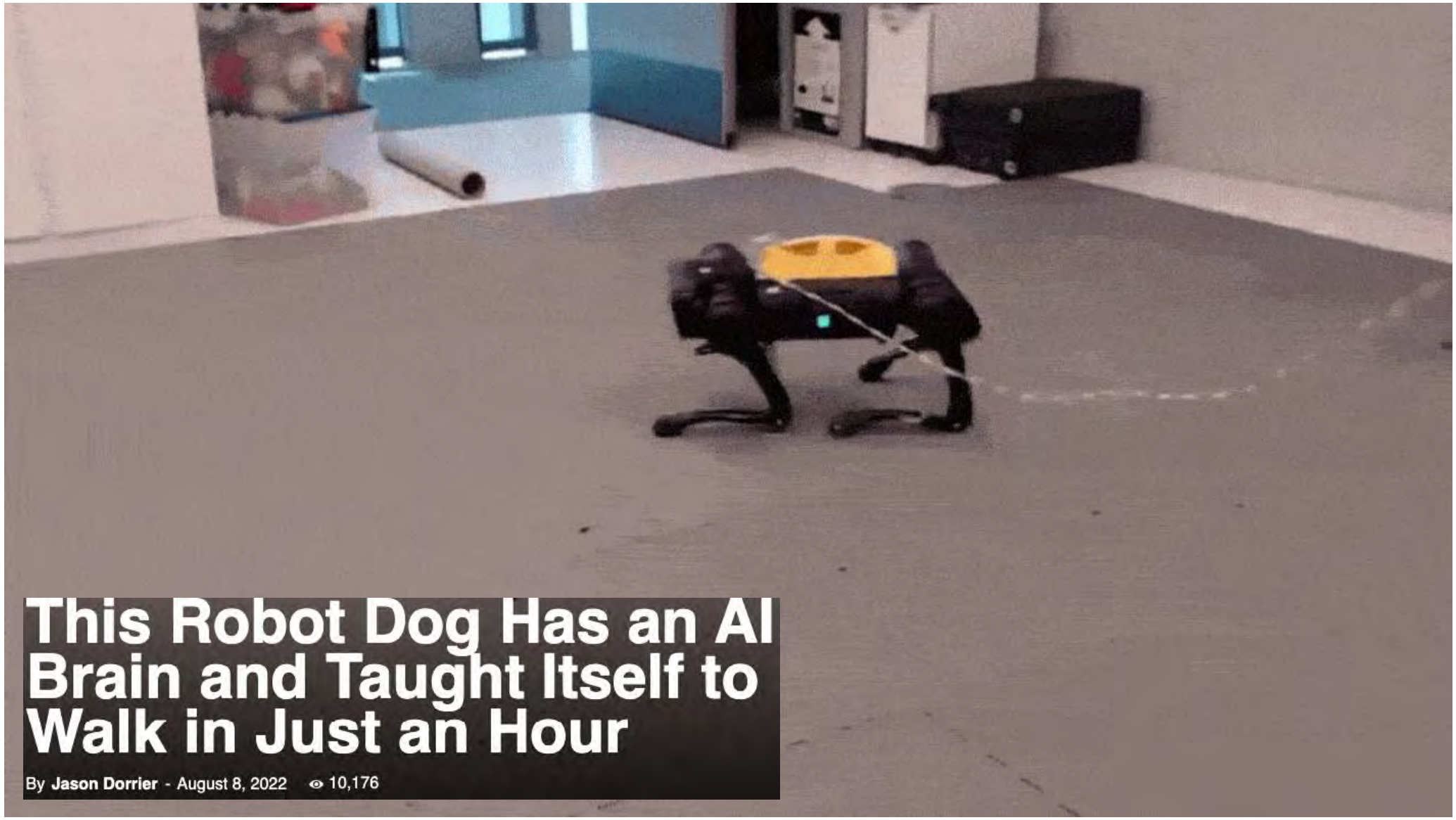
Front View

# Artificial Intelligence in Construction

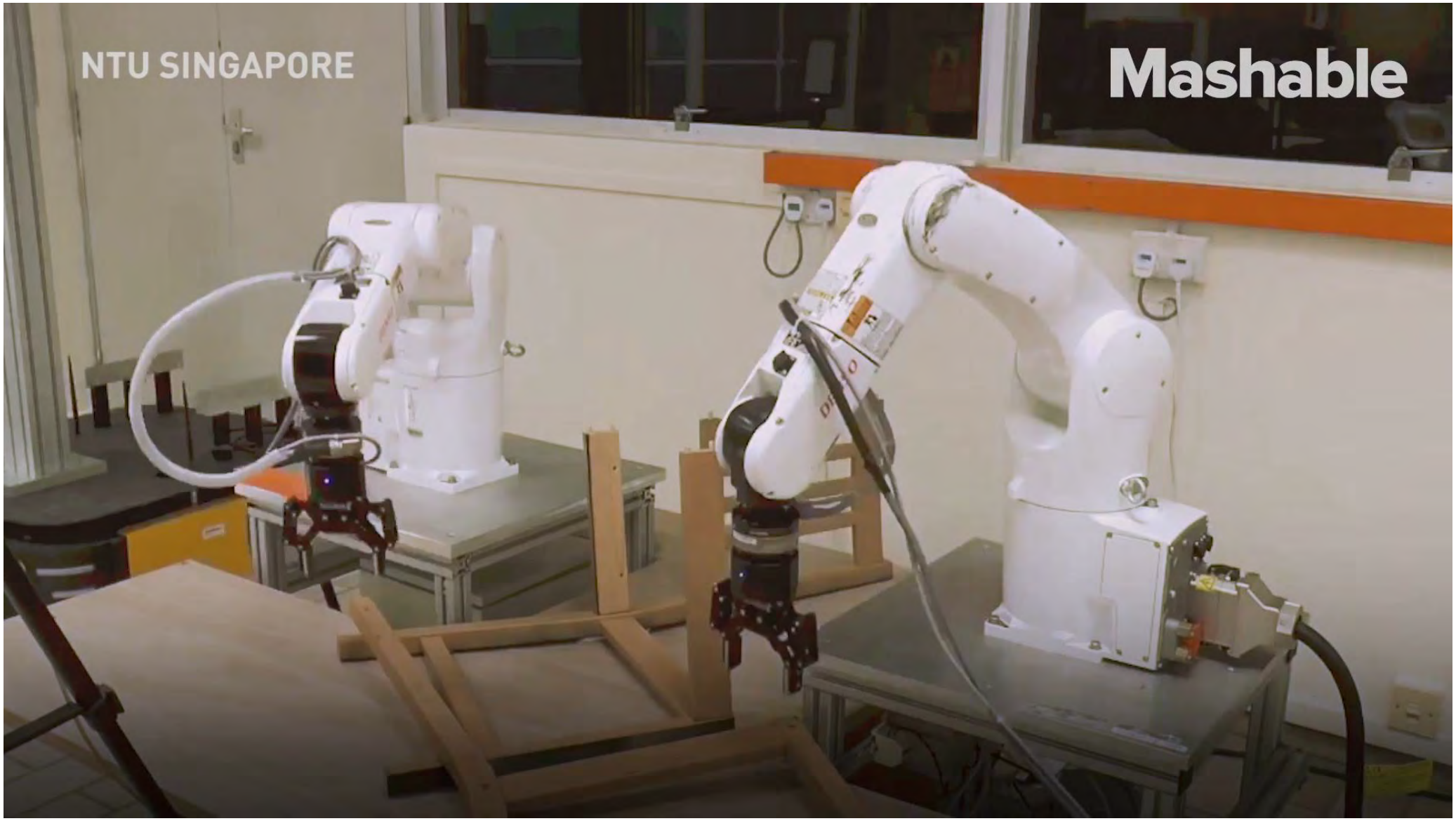
# An AI-Generated Artwork Won First Place at a State Fair Fine Arts Competition, and Artists Are Pissed

Jason Allen's AI-generated work "Théâtre D'opéra Spatial" took first place in the digital category at the Colorado State Fair.

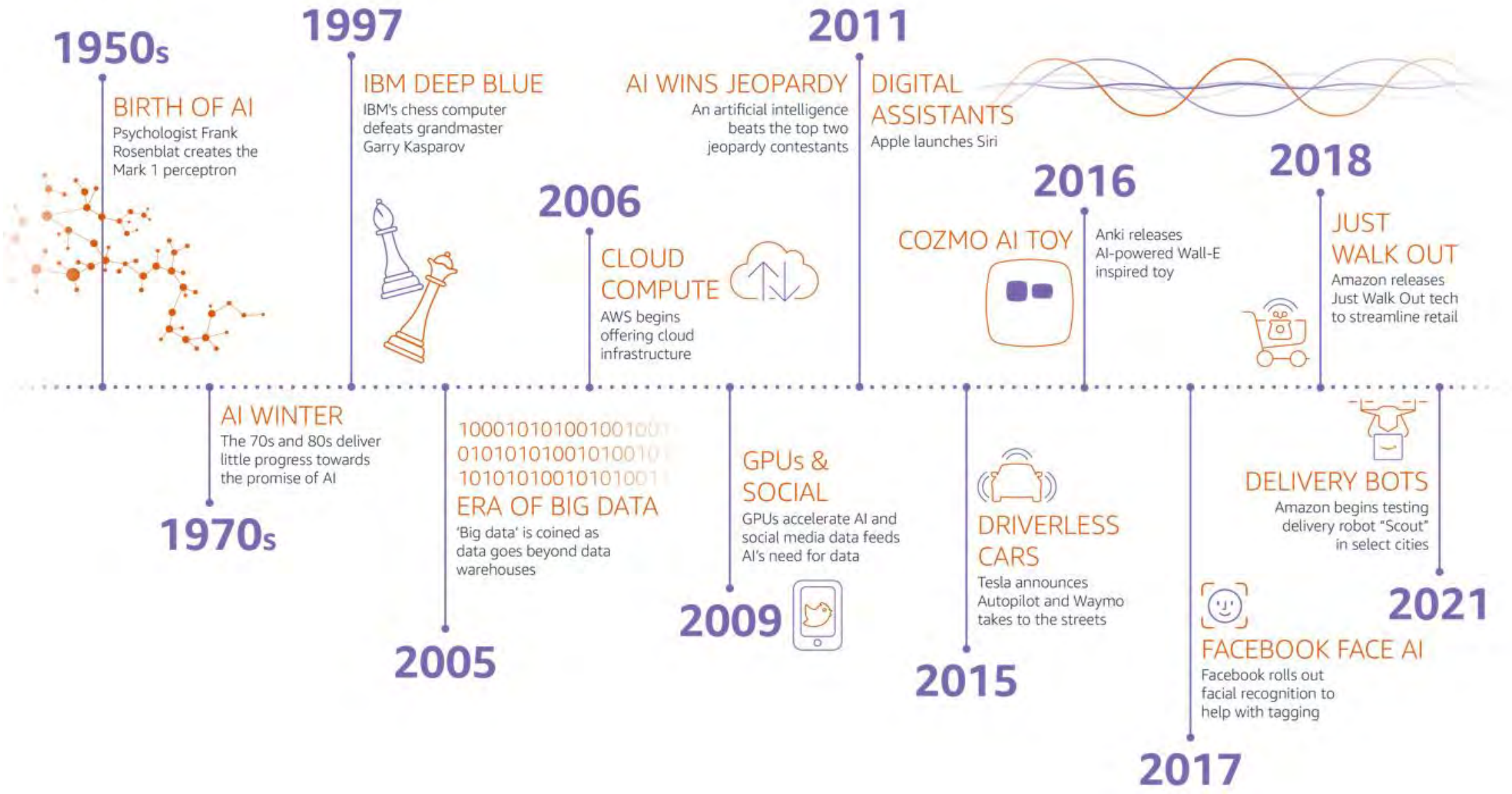
# A Self-Teaching Robot Dog



# Autonomous Assembly

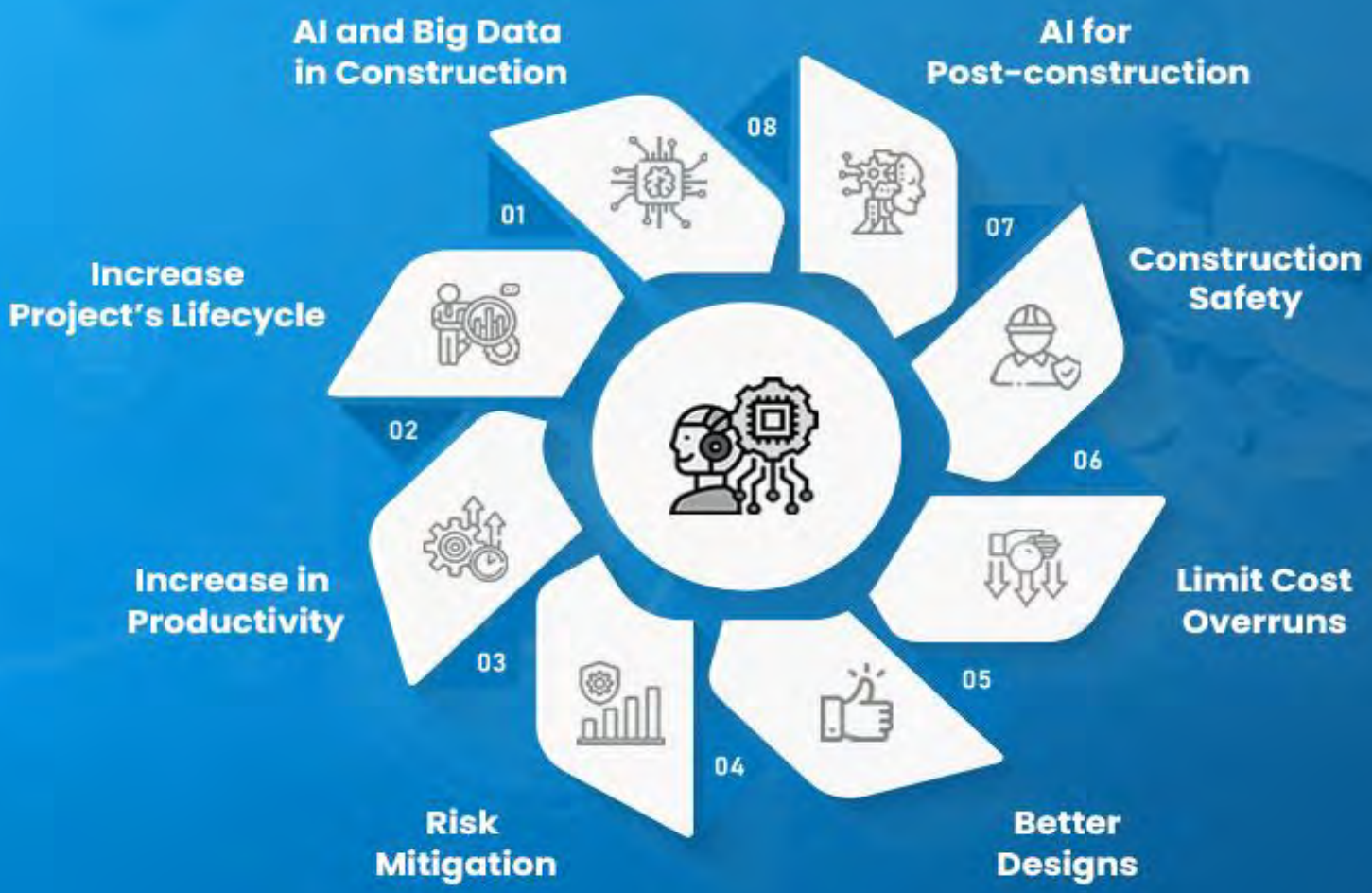


# The Evolution of Artificial Intelligence




https://aws.amazon.com

# Applications of AI and Machine Learning in Construction

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# Construction Apps for the Future

**Smart, high performance materials**: Lightweight, high strength, durable

**Digital design**: CAD, BIM, Generative Design, Customised Modular Design

**Digital fabrication**: Production line, Robotics, Additive Manufacturing

**Digital Construction**:

- Project management: Visualise drawings and 3D models on site; Update and check project schedule online; etc
- Productivity management: Track workers' deployment in the real-time; Track the installation of components and detect errors in the real-time.
- Safety management: Track and report safety incident on site in the real-time; Detect and alert workers on unsafety behaviour
- Materials management: Identify, track and locate materials in the supply chain
- Contract management: Update and track contract compliance; Optimise procurement and delivery

**Operations and Maintenance**: Real-time monitoring building systems; Adaptive operation systems; Condition-based maintenance

AI

Block chain

Smart Contract

?

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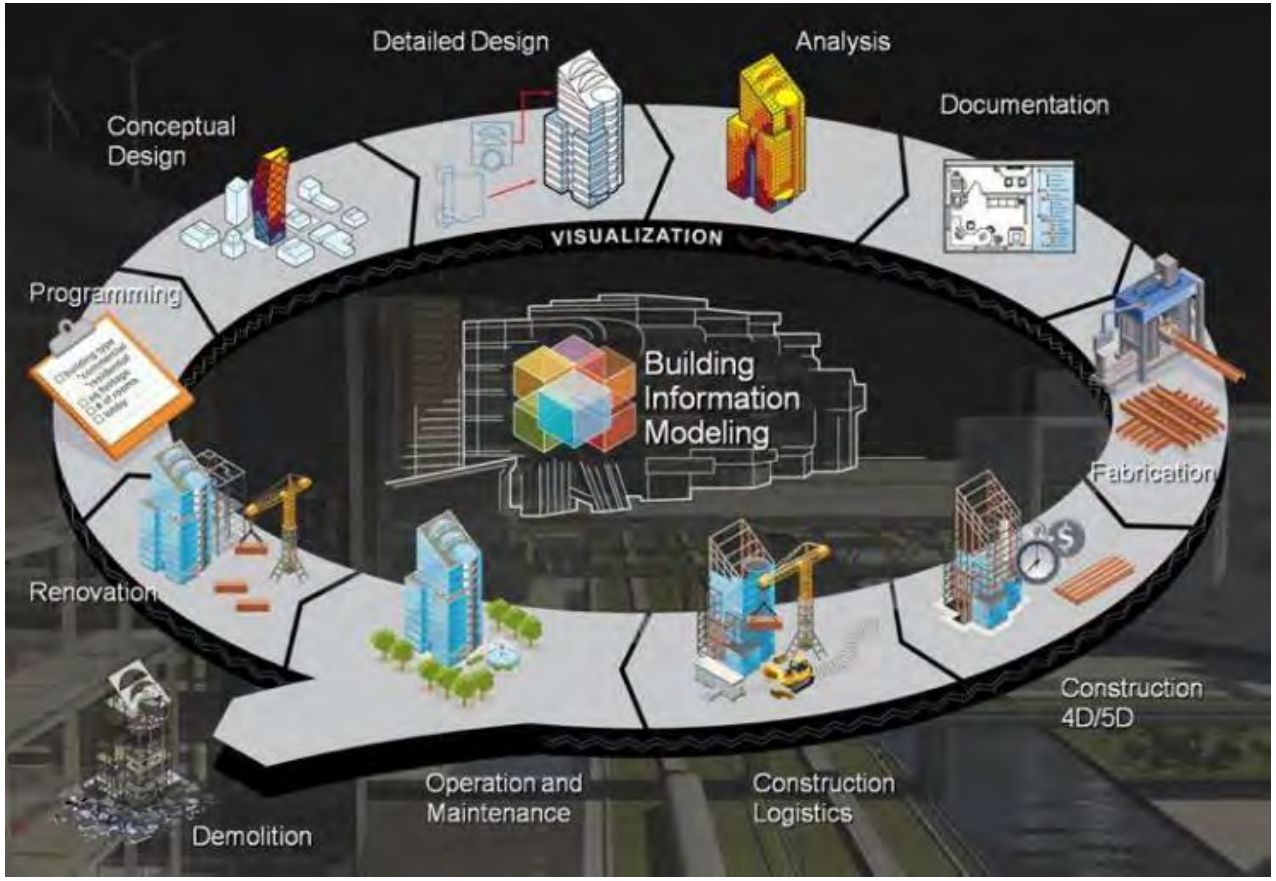
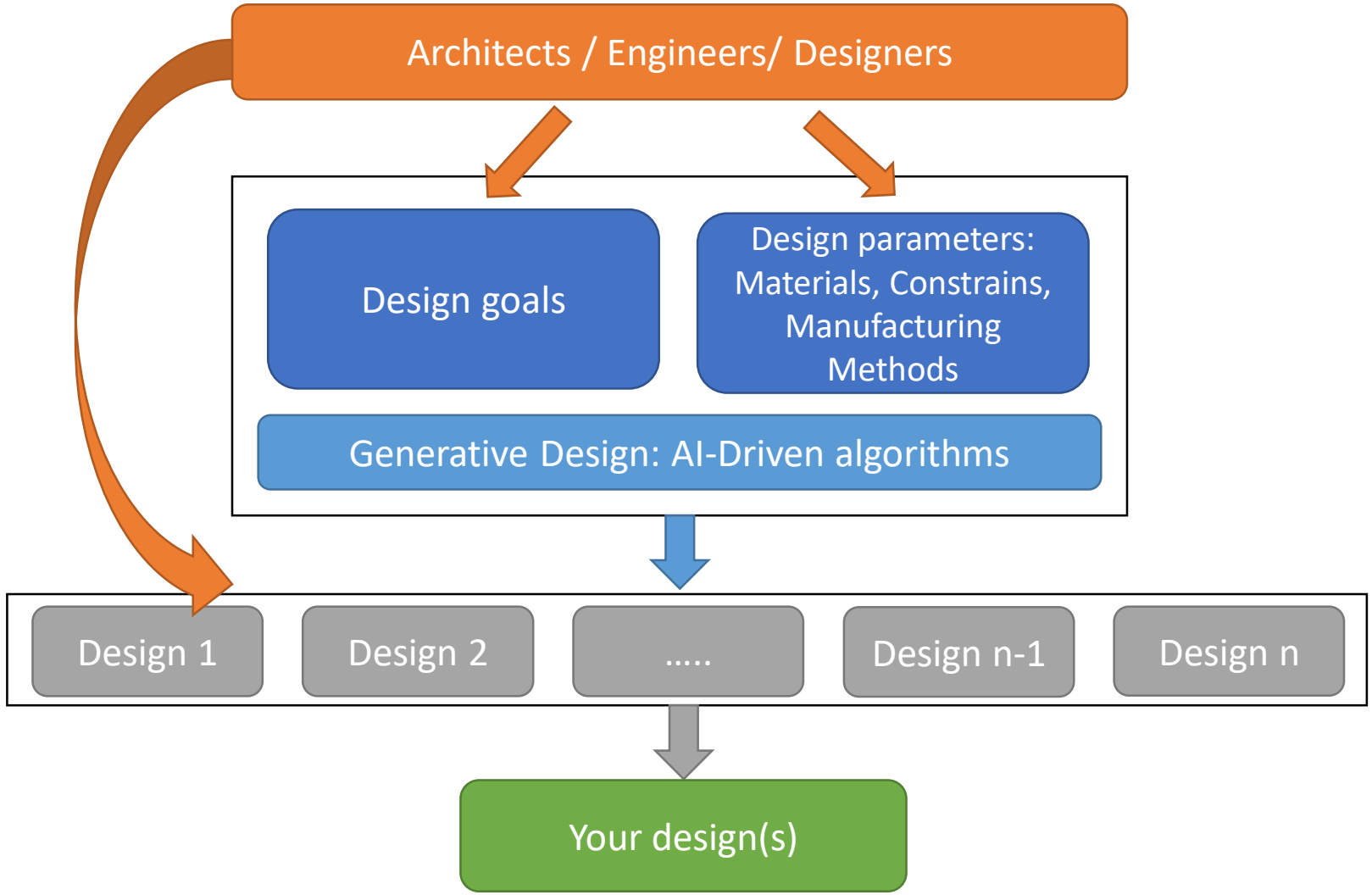
# AI in Planning and Design



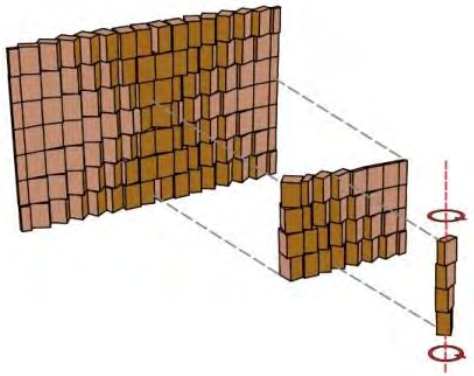

AI-based Building Information Modelling (BIM) and AI-based Generative Design

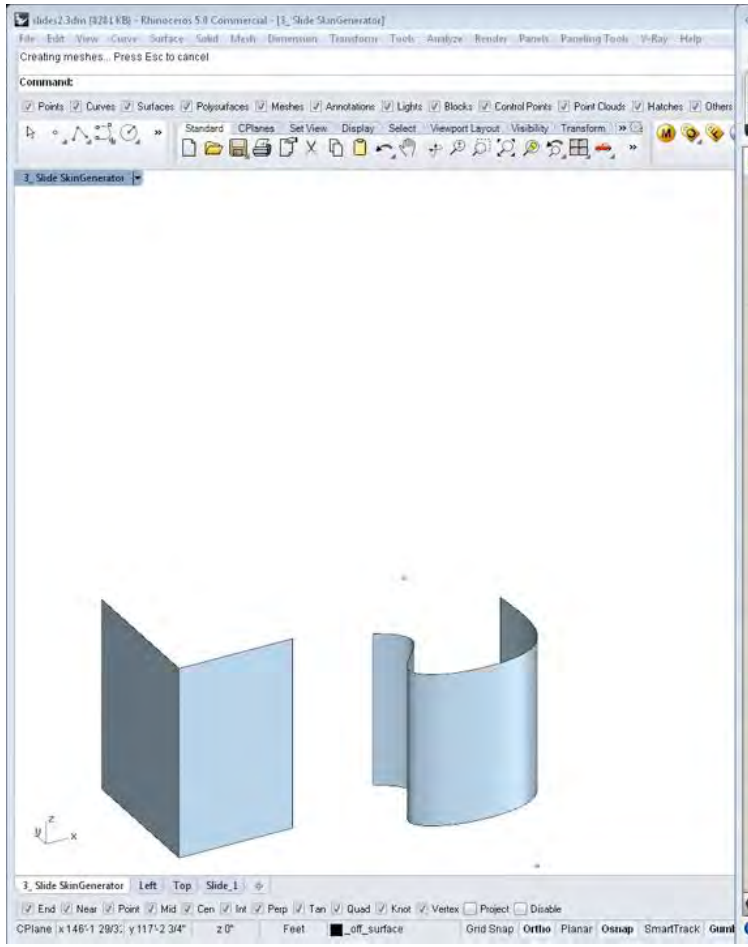
# Future of Design

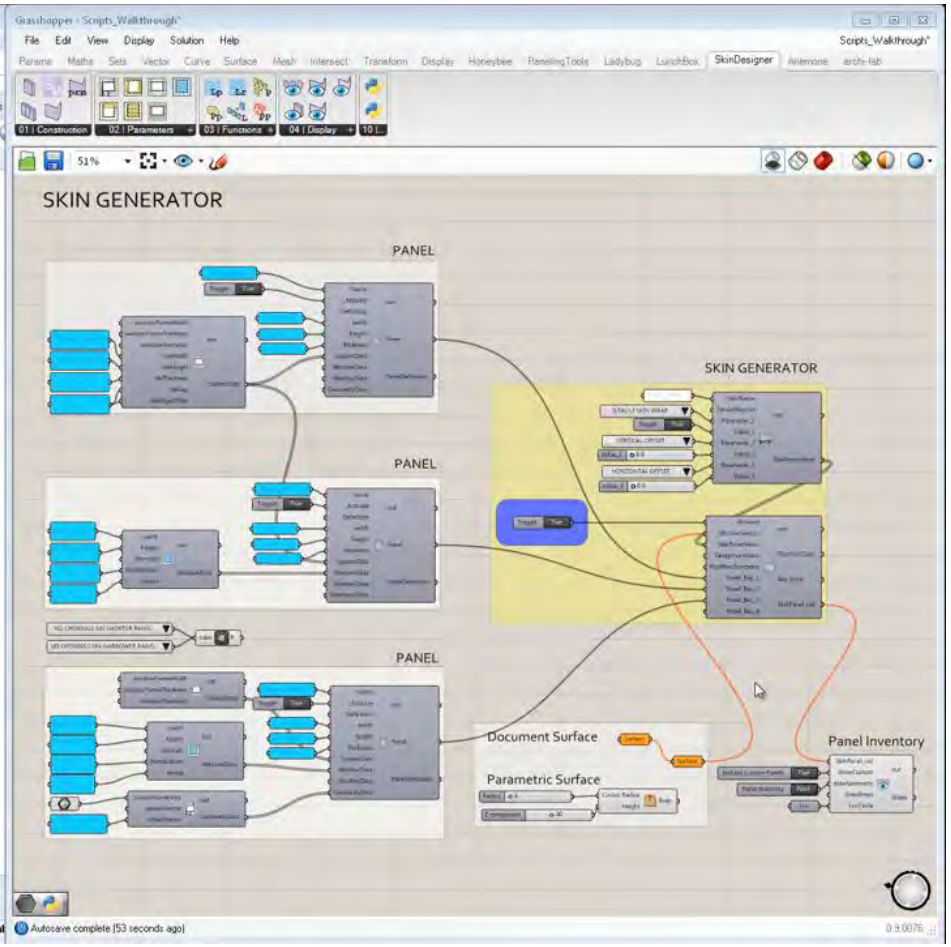
## Generative design + AI/ML



# Computational / Parametric Design





What do you want to have in your house?

*Bathroom,Bedroom,Bed Ex.,Closet,Dining,Foyer,Hall,Kitchen,Living,Master B.,Tv Room,Washing,Waking Cl

# Project #4

Computational Design and Optimisation

Tools for Prefabricated Building Systems



00:00:16

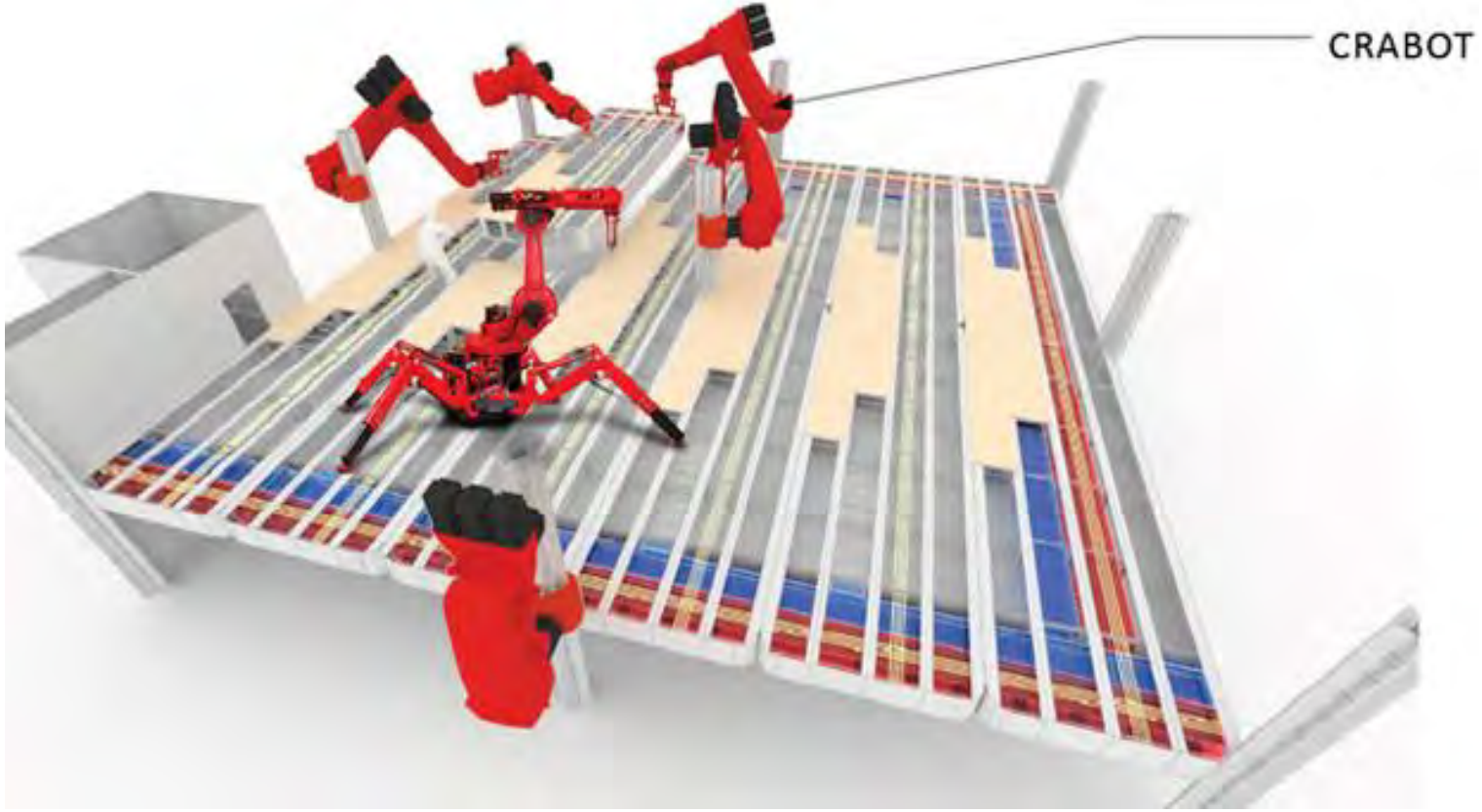
# Autonomous Construction

**Bricklaying Robot**

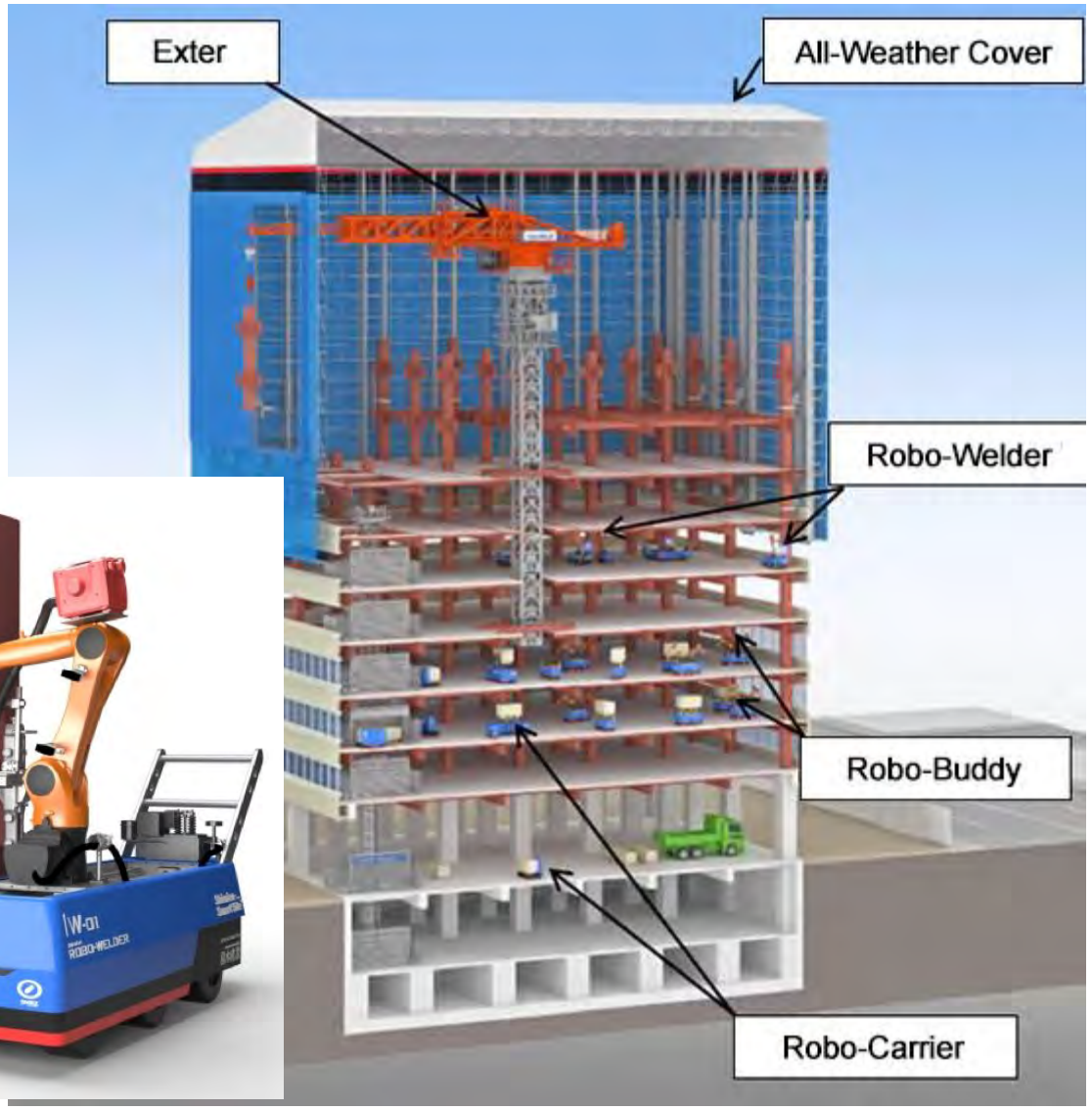
**Autonomous Drones for Construction**

# Autonomous Construction

- **Google**: Grabots or autonomous cranes
- Propose for new Google HQ in Silicon Valley
- **The building is modular, prefabricated**
- Grabots will assemble walls and floors systems.



Robot-Welder

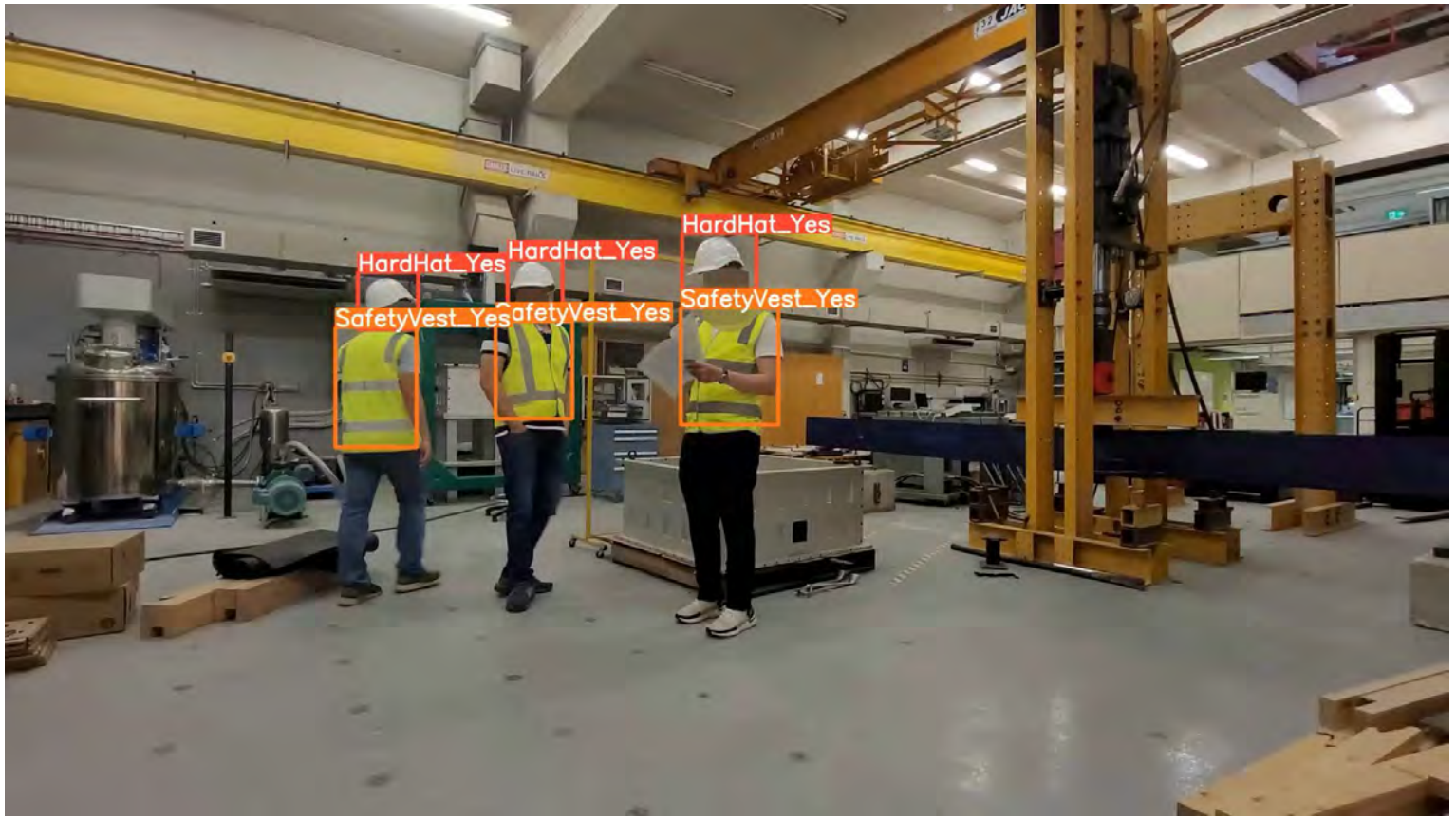
# Construction Safety Apps

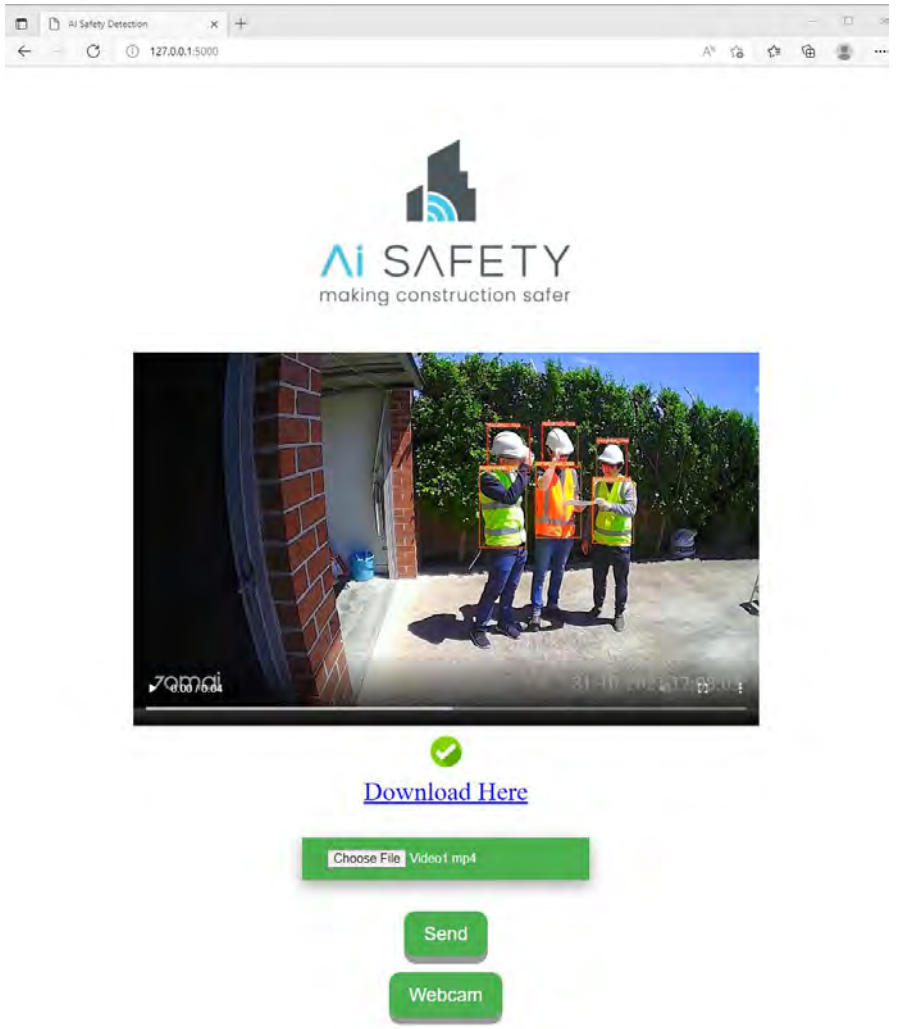


Construction workers are killed on the job **five times more often** than other industries

# Construction: Safety

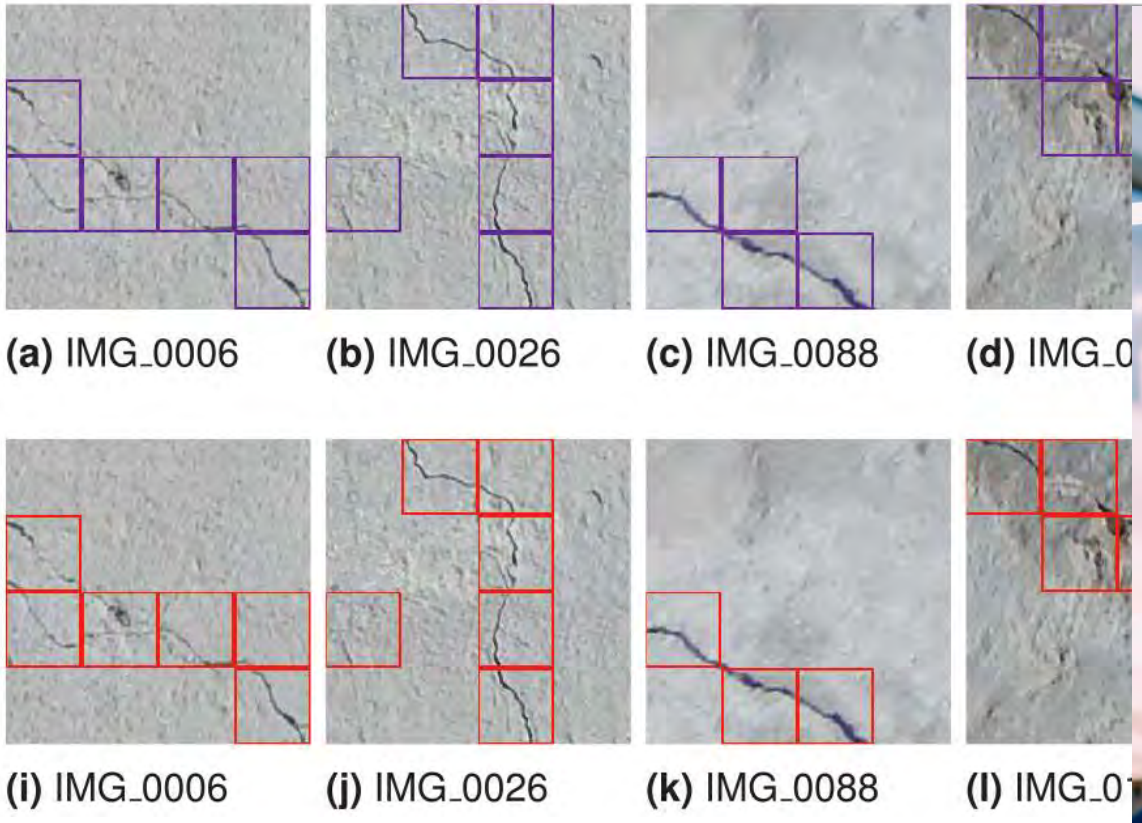
AI can help to detect unsafety behaviours on construction sites.



# Virtual Inspection – Damage Detection

AI can help to detect structural damages.




# Construction: Monitoring Productivity

AI is used to detect and track vehicles on construction sites.

# AI for Building Management


A smart platform, Neuron, from ARUP

# Challenges of AI in Construction Industry

Cultural issues in Construction

Talent Shortage


Computing Power and Internet Connectivity

Poor data quality

High Initial costs


Ethics and Governance

Security

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# Thank you

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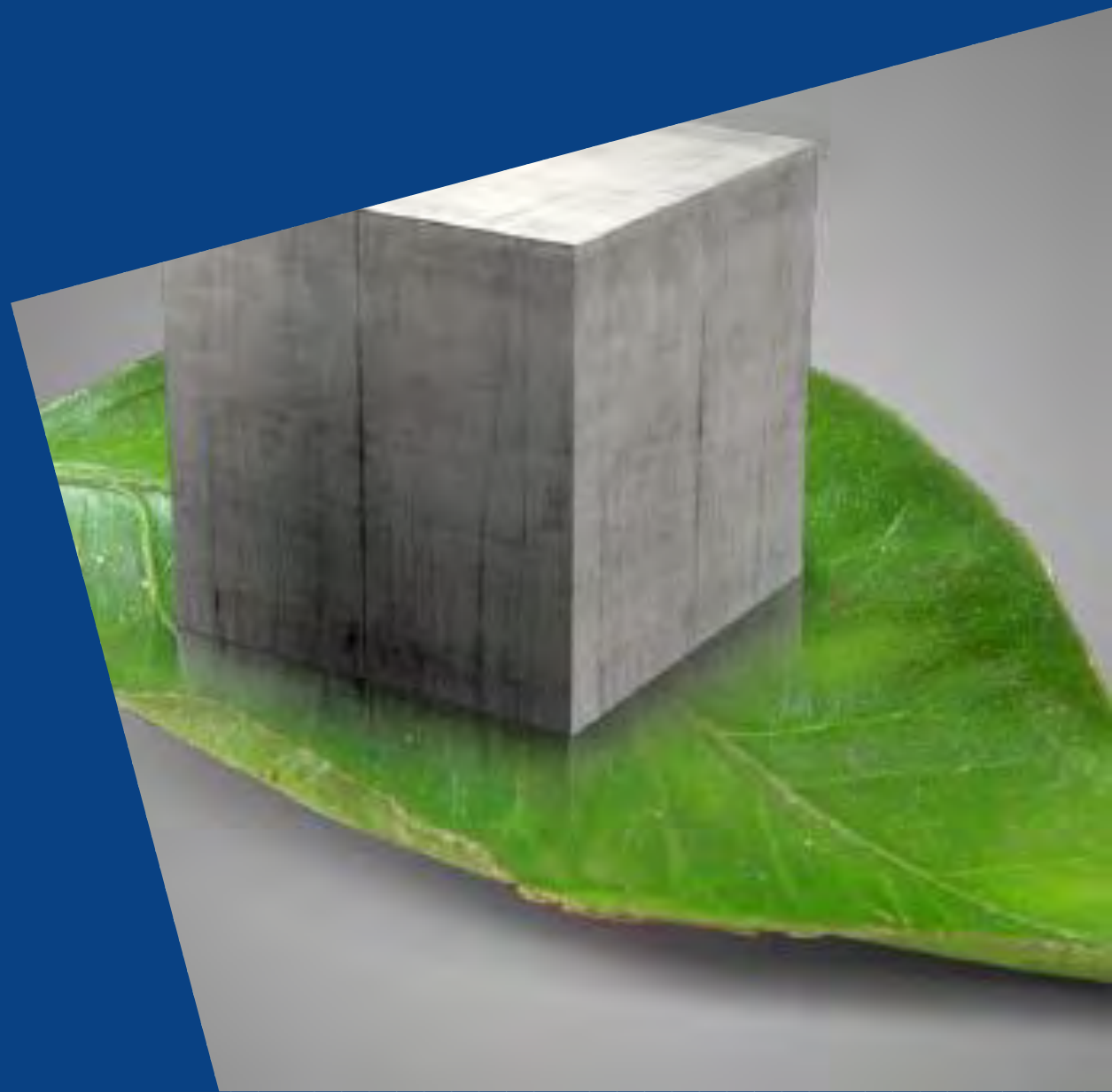
**The University of Melbourne**



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