BCA ACADEMY

Design for Manufacturing and Assembly With Focus on PPVC

School of Graduate Development and Management

The Education and Research arm of the Building and Construction Authority

Please complete the electronic course evaluation form via the URL http://tiny.cc/yn0igy
or the appended QR code:



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OBSATCLES TO DfMA

Integrated Procurement

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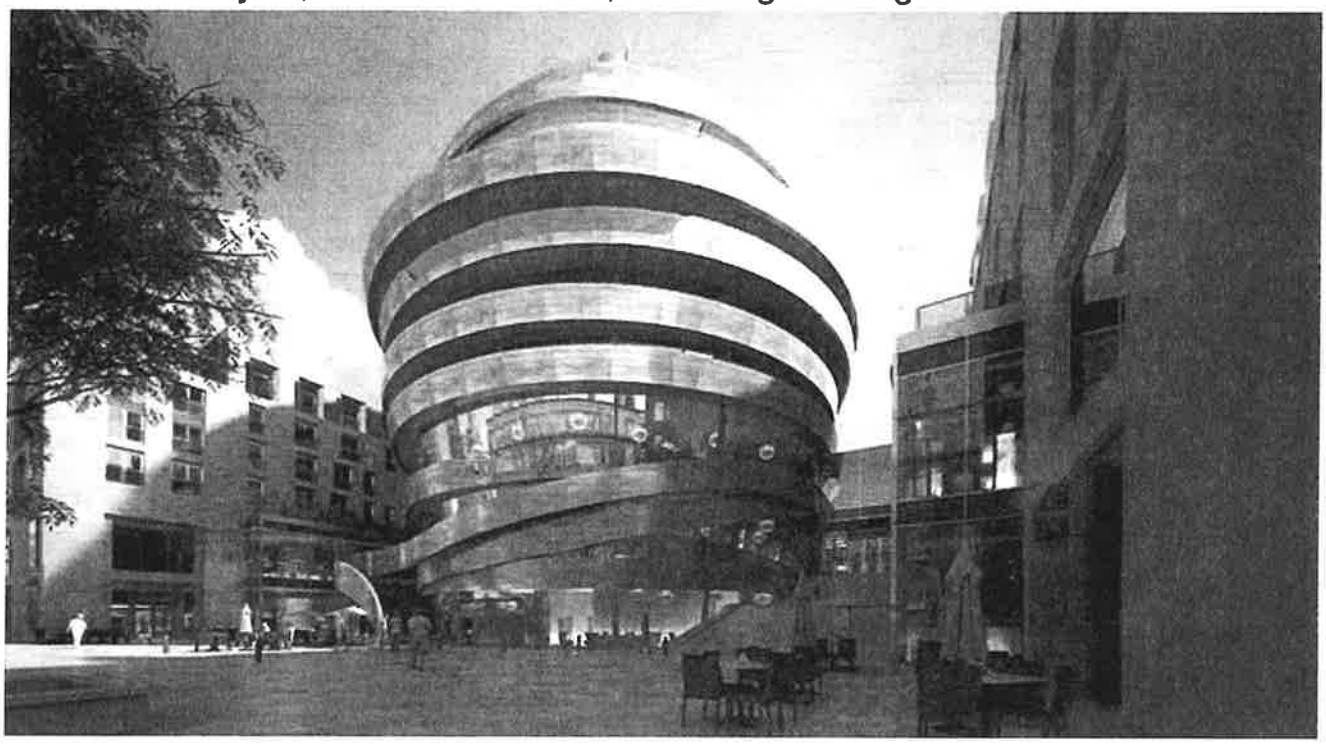
Example of Integrated Procurement Contract

- $1.5B Project, St James Centre, Edinburgh: Laing O'Rourke



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OBSATCLES TO DfMA

Topics for Discussion

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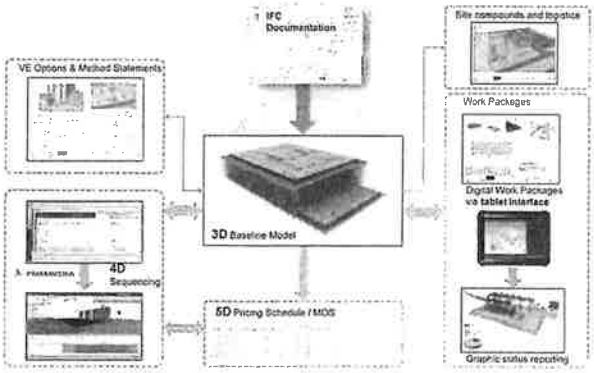
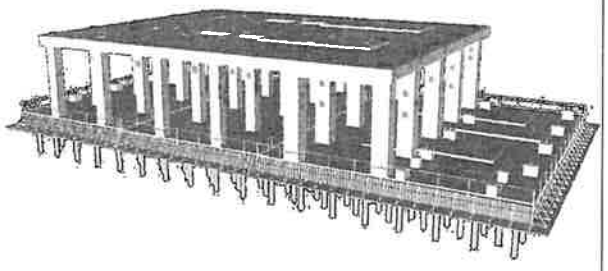
- Procurement Process
- **Risk Averse Financial Institutions**
- Industry Reluctance
- Negative Associations with "Pre-fabricated" Structures
- Timelag
- Lack of Regulation
- Differing Regulations in Different Countries





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OBSATCLES TO DfMA

Risk Averse Financial Institutions

Financial Institutions' Assets Need to be:

- Long-life (Durable)
- Low Maintenance
- Attractive to Tenants
- Codified in Building Regulations



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OBSATCLES TO DfMA

Risk Averse Financial Institutions

Financial Institutions' Assets Need to be:

- Long-life (Durable)
- Low Maintenance
- Attractive to Tenants
- Codified in Building Regulations

They Perceive Modular (DfMA) as:

- Untried – may not have a long-life
- Unquantified Maintenance
- Unattractive to Tenants
- Not Regulated in Building Codes



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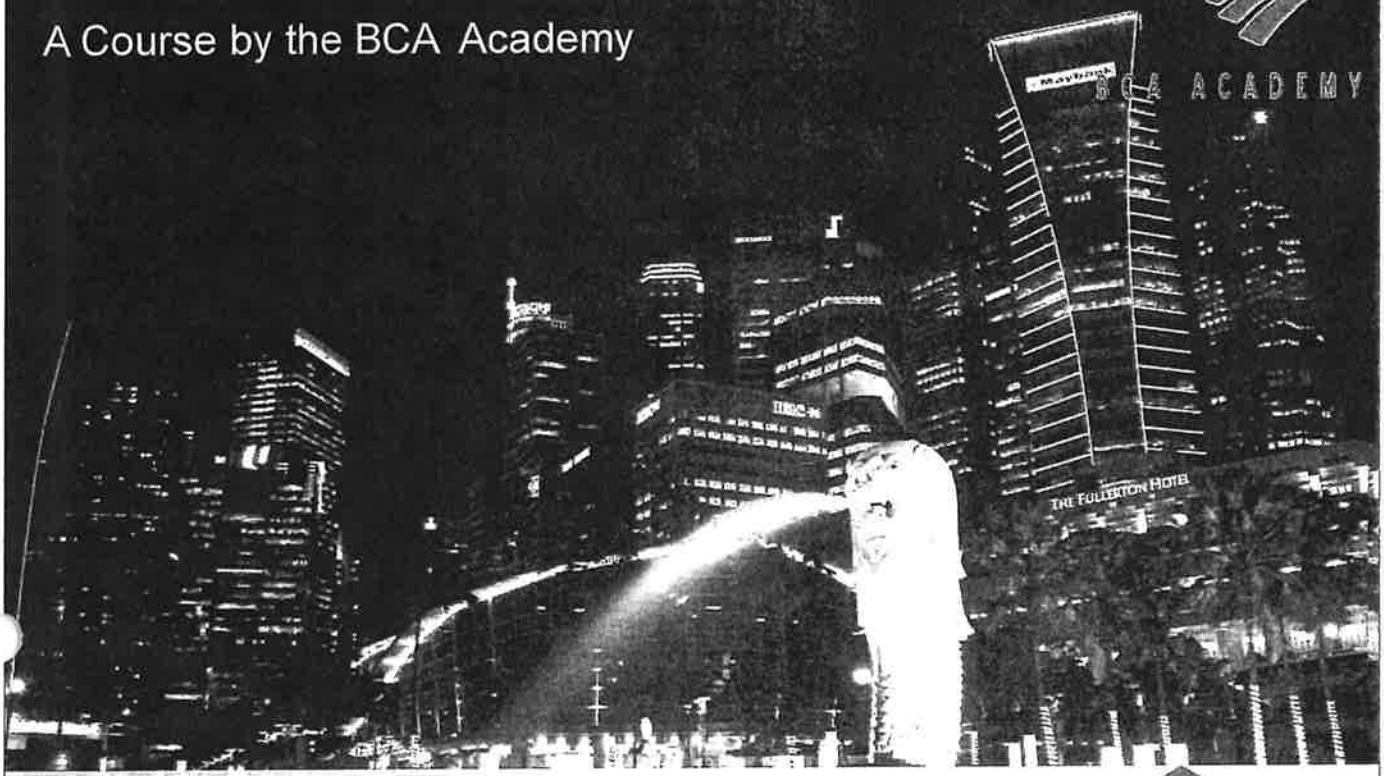
DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)

A Course by the BCA Academy



The Presenters & The Course

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COURSE SUMMARY

The Presenters

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Angus McFarlane
Leader Structural Engineering, EnExG
Chair Modular Construction Codes Board

EnEx G
Engineering Excellence Group

LAING O'ROURKE



Prof James Murray-Parkes
Head of Science & Engineering
Vice-chair Modular Construction Codes Board

MULTIPLEX
Engineering Innovations Group

Brookfield

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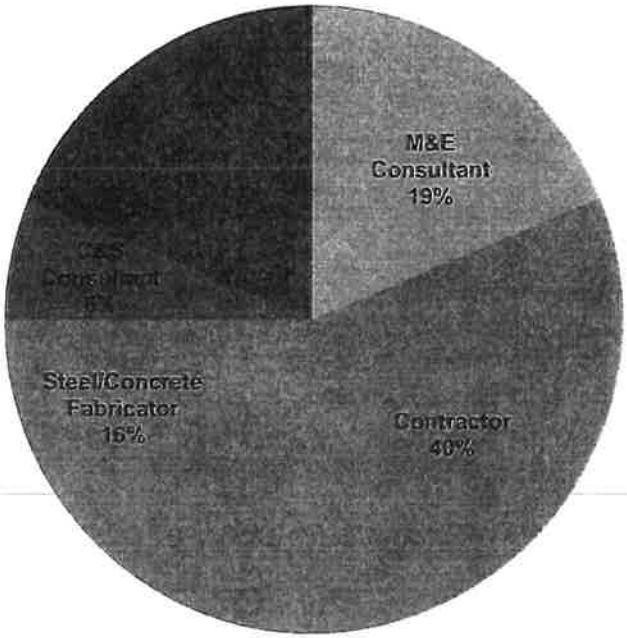
COURSE SUMMARY

Company Profile of Participants



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BCA ACADEMY

COURSE SUMMARY

Day 1

Time	Contents
09:00-09:15	The Presenters ▪ An introduction to the presenters
09:15-10:00	What is DfMA? ▪ Angus describes key aspects of DfMA
10:00-10:45	Why DfMA? ▪ James presents the need for DfMA
10:45-11:05	Tea/Coffee Break
11:05-11:50	Obstacles to DfMA ▪ Angus discusses obstacles to implementing DfMA
11:50-12:35	Model Code for the Design of Modular Structures ▪ James summarises the work of the Modular Construction Codes Board
12:35-13:35	Lunch
13:35-14:05	The Route to DfMA ▪ Angus discusses methods for implementing DfMA
14:05-14:35	Details of DfMA ▪ Angus presents details of design, manufacture & assembly
14:35-14:55	Tea/Coffee Break
14:55-15:25	Off-site Production ▪ Angus presents the DfMA continuum & off-site production methods/materials
15:25-17:00	DfMA in Action ▪ James presents case studies of two recent DfMA projects including discussion with participants: ▪ Perth Stadium & Mona Hotel
17:00-17:30	Discussion & End of Day

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COURSE SUMMARY
Day 2

Time	Contents
09:00-09:15	Recap ▪ The presentation team summarise the previous day's work
09:15-10:00	Progressive Collapse ▪ Angus discusses progressive collapse with an emphasis on modular structures
10:00-10:45	Connections (TICC-TOCC) ▪ James discuses innovative connections & they why they are key to design & performance
10:45-11:05	Tea/Coffee Break
11:05-11:50	A Physicist's Approach to the Design of Structures ▪ James presents the Elliptical Energy Pathway Theorem
11:50-12:20	Transportation Loading & Installation ▪ Angus discusses transportation & installation loading on modules
12:20-13:20	Lunch **WTU funded participants to stay back for a 20 mins assessment before going for lunch**
13:20-14:05	Digital Engineering ▪ Angus discusses BIM, Augmented Reality, & Virtual Reality
14:05-14:50	DfMA in Action ▪ James presents a DfMA case study on A108 – Australia's tallest building
14:50-15:10	Tea/Coffee Break
15:10-15:55	FreeFAB 3D Printing ▪ James Gardiner describes real-world implementation of 3D printing
15:55-16:15	Measurement of DfMA ▪ Angus describes a DfMA calculator
16:15-17:00	DfMA in Action ▪ James presents a case study of a recent DfMA project Paramatta Stadium
17:00-17:30	Panel Discussion & Close

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DfMA: COURSE SUMMARY
About the Presenters

EnEx G
Engineering Excellence Group

Angus McFarlane

- A Chartered Engineer with over 35 years' experience, mainly in high-rise buildings & major civil engineering projects


Angus McFarlane

Key Attributes

- Comprehensive experience in multi-billion dollar projects involving major international consultants & contractors
- Proficient in Australian, Eurocode, UK & US design codes & construction methodology
- Innovative – has made many major contributions to the buildability & cost-effectiveness of projects
- Committed implementer of DfMA (Design for Manufacturing & Assembly) in major projects

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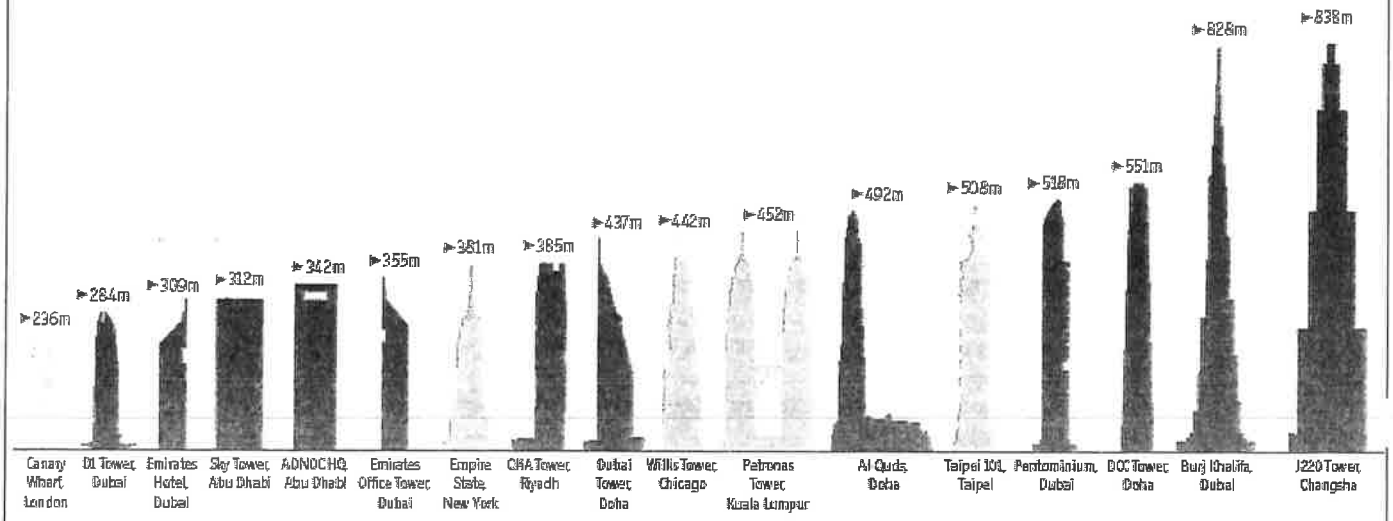
DfMA: COURSE SUMMARY

Angus's High-rise & Supertall Projects, Middle East



Tall Building Design Experience, Source: Hyder (1996-2012)

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STRUCTURAL REVIEWS

ADNOC HQ, Abu Dhabi (2010)

Independent Structural Review

Project

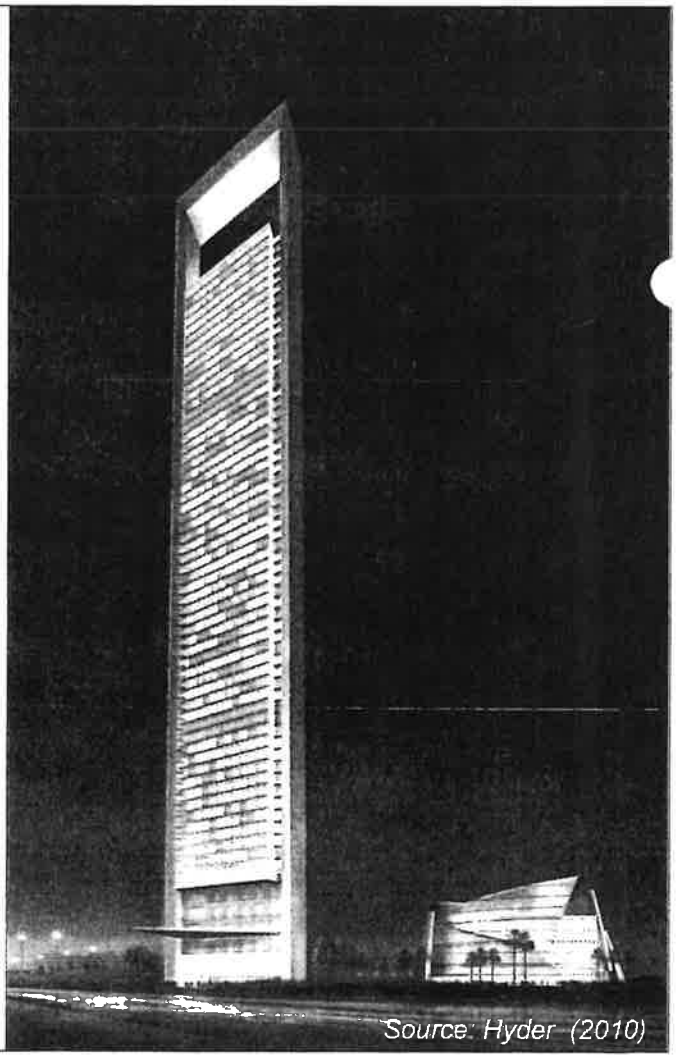
- Client: Six Construct
- Height: 342 m

Focus of Review

- Construction methodology
- Seismic design
- Axial shortening
- Progressive collapse

Outcome from Review

- 15% saving in construction cost compared with original design



Source: Hyder (2010)

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STRUCTURAL REVIEWS

Sky City One, Changsha (2012)

Internal Design Review

Project

- Client: Hyder Main Board
- Height: 838 m
- High-strength tubular steel frame
- Composite floor cassettes
- Steel exoskeleton

Focus of Review

- High-strength steel
  - Specification
  - Ductility
  - Fatigue
- Earthquake hazard
- Progressive Collapse
- Fire resistance

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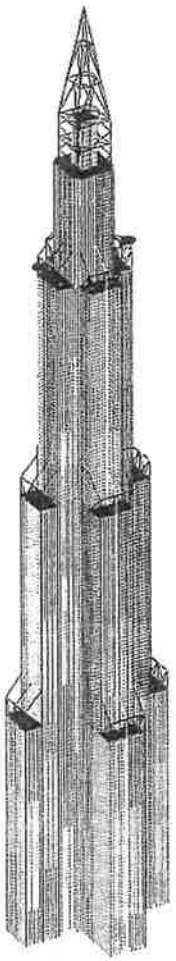

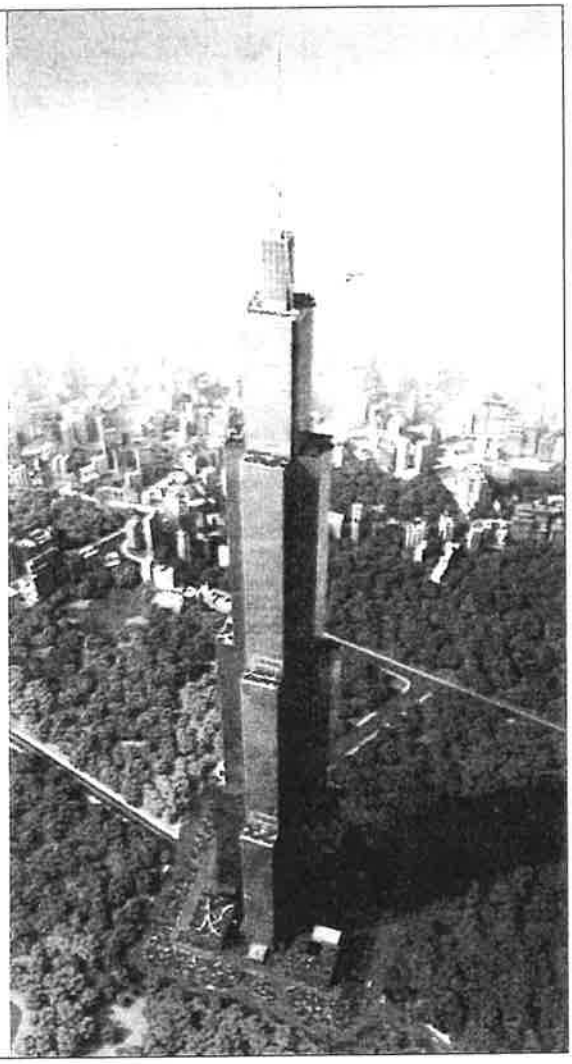

Source: Hyder (2012)

STRUCTURAL REVIEWS

Australia 108, Melbourne (2016)

EnEx G

Engineering Excellence Group

Project

- Client: Multiplex EiG
- Height: 319 m
- Tallest residences in Southern Hemisphere

Focus of Review

- Building Accelerations
- Axial Shortening
- Progressive Collapse



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STRUCTURAL REVIEWS

West Side Place, Melbourne (2016)

Project

- Client: Far East Consortium
- 4 buildings
- Height: 270 m max

Focus of Review

- Building Accelerations
- Axial Shortening
- Progressive Collapse

EnEx G
Engineering Excellence Group



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DfMA: COURSE SUMMARY

About the Presenters

MULTIPLEX
Engineering Innovations Group

Prof. James Murray-Parkes

- A highly experience Science & Engineering professional having participated in the design and/or concept of more than 750 major projects



James Murray-Parkes

Key Attributes

- Highly experienced high-load, structural connection designer
- Natural born innovator, applies first principles of physics to most of said innovations
- Innovation has made James a prolific test engineer and he now has his very own connections test lab, the Safe Structures Laboratory in Victoria, Australia
- Committed to the application of DfMA (Design for Manufacturing & Assembly) in most major projects he designs and/or concepts
- Ability to go "Beyond Design" and follow his innovations through to the build stage.

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MULTIPLEX – TIC TOCC

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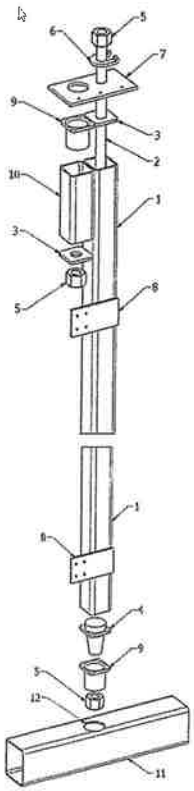

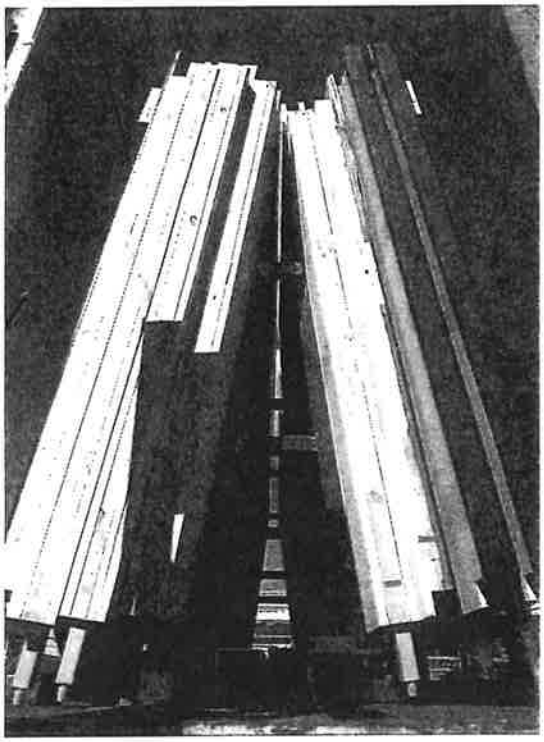

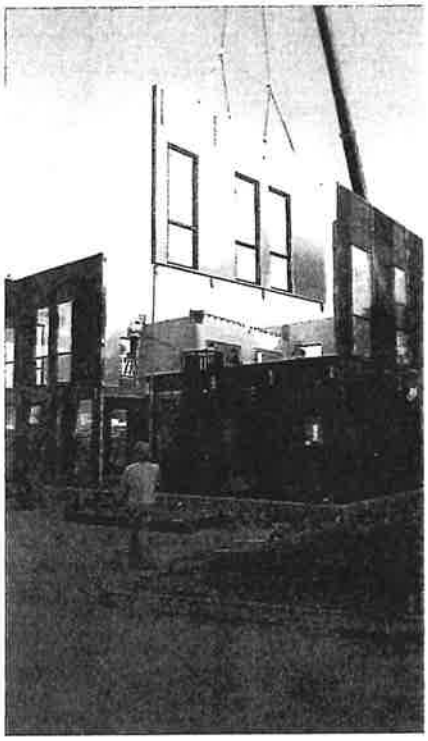

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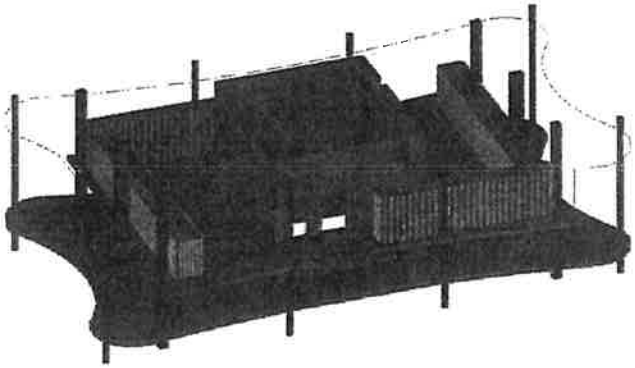
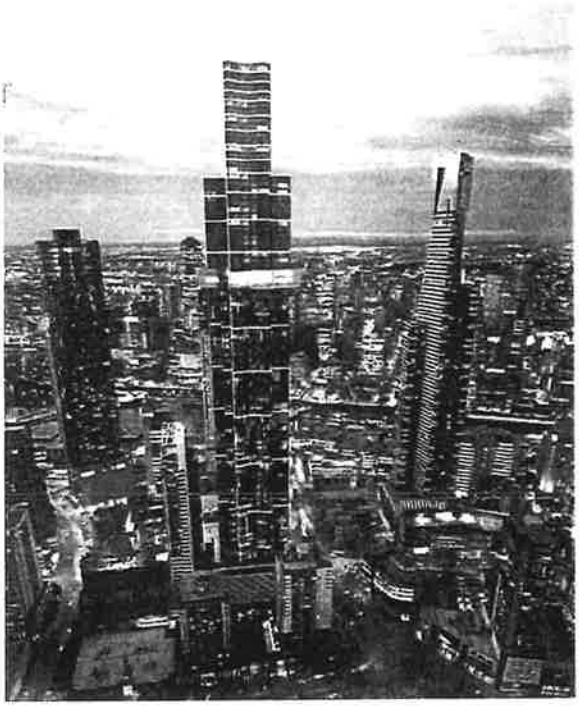
MULTIPLEX – A108

Engineering Innovations Group







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MULTIPLEX – Scotia Bolt

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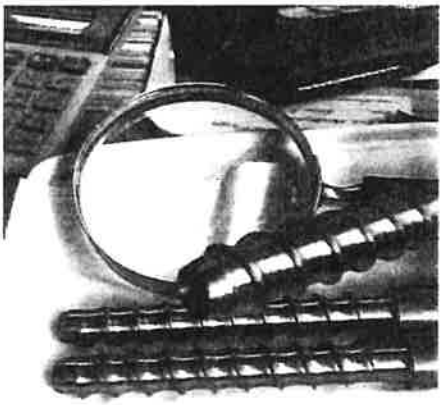

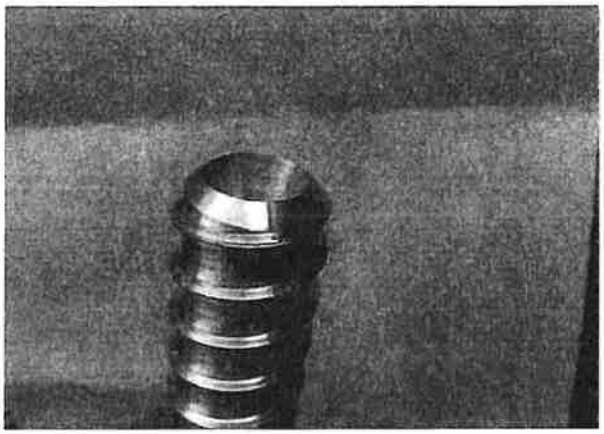

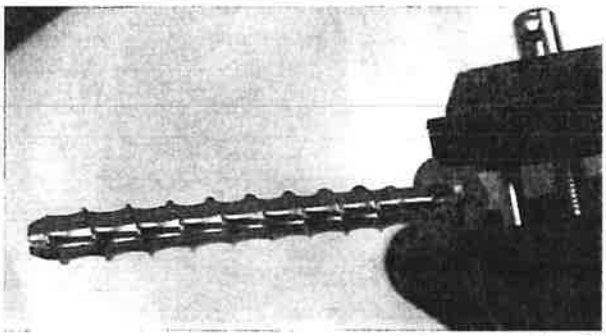

Top:
Poor market products have inspired new prototypes

Top Right:
New hollow tip revolutionising concrete spoil interference

Right:
Final test specimen featuring new high performance designs

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MULTIPLEX – Perth Stadium

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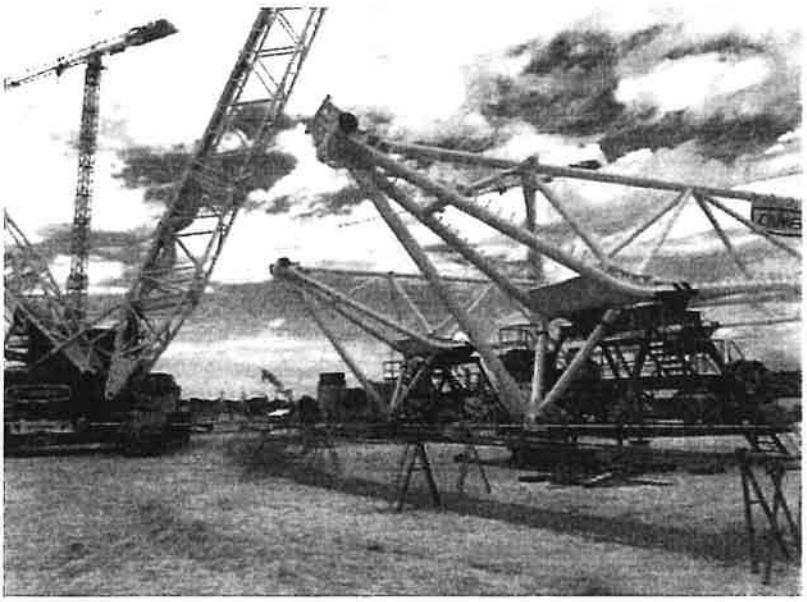



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MULTIPLEX – Hinge Connection

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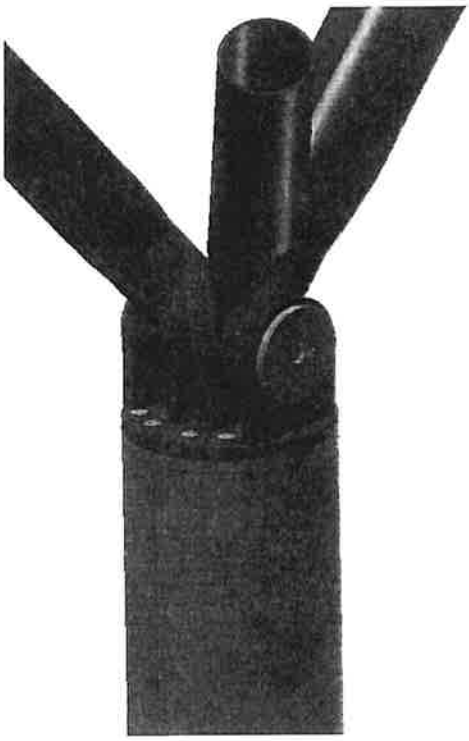

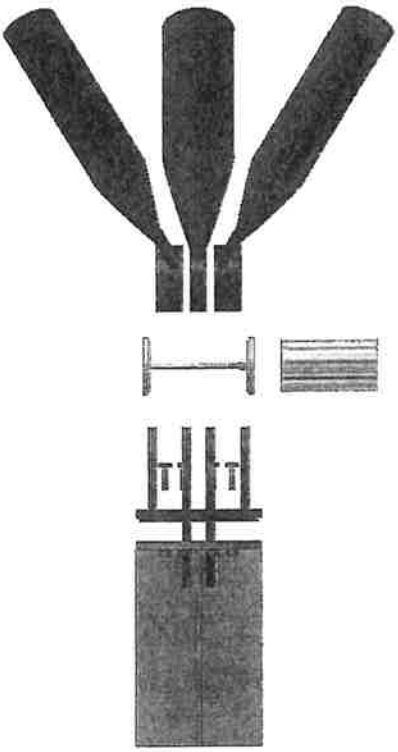

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MULTIPLEX – Hinge Connection

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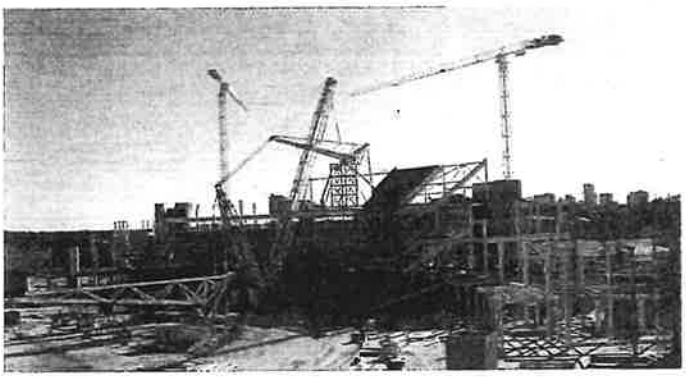

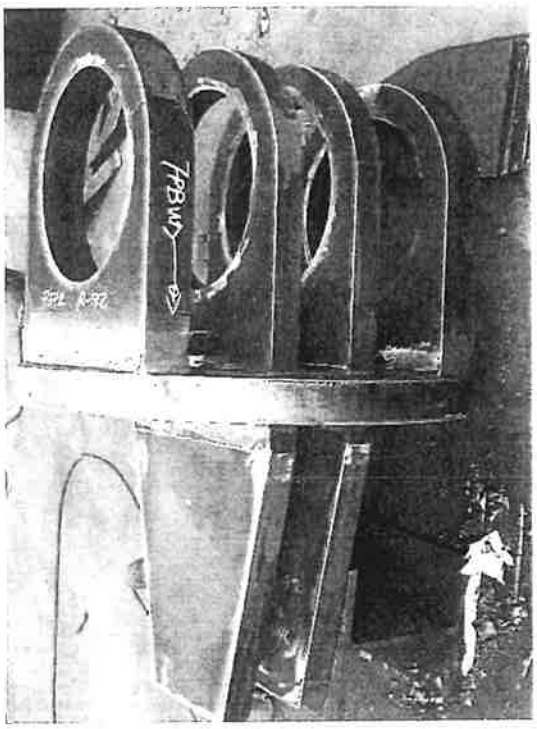



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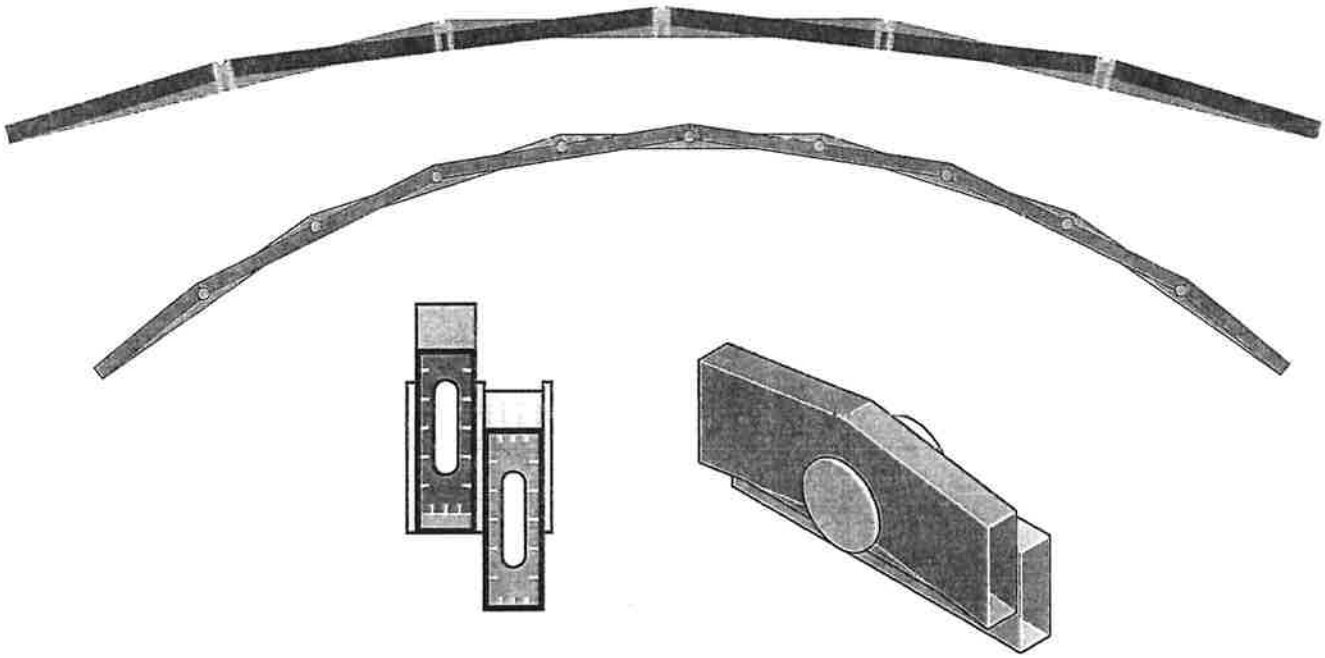
MULTIPLEX

Engineering Innovations Group

Brookfield MULTIPLEX

MULTISPAN



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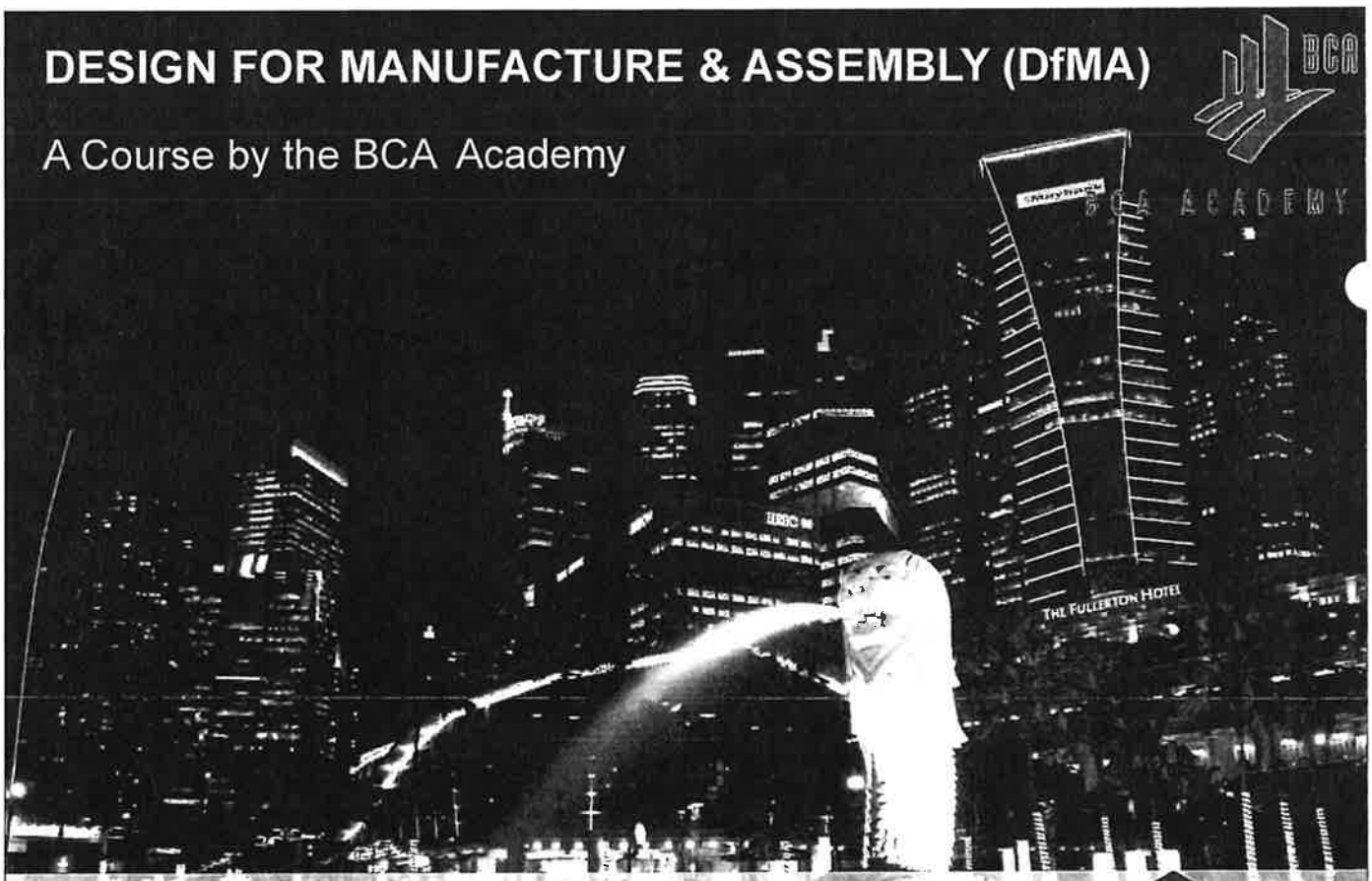
DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)

A Course by the BCA Academy



The Presenters & The Course. Q&A?

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DESIGN FOR MANUFACTURE & ASSEMBLY DfMA

A Course by the BCA Academy



What is DfMA?

Angus McFarlane BSc (Hons), MSc, CEng, FIStructE, FICE, FIEAust CPEng NER

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WHAT IS DfMA?

Topics for Discussion

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- DfMA is not New
- Where is DfMA used?
- The DfMA Envelope
- DfMA in the Construction Industry
- Components, Flat-pack & Volumetric Construction (PPVC)
- Conclusions

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WHAT IS DfMA?

DfMA is Design for Manufacture & Assembly

DfMA is a Design Process

- Product is DESIGNED for ease of MANUFACTURE
- Product is also DESIGNED for ease of ASSEMBLY



Product A

- No. of Parts = 2
- No. of Fasteners = 8



Product C

- No. of Parts = 1
- No. of Fasteners = 2

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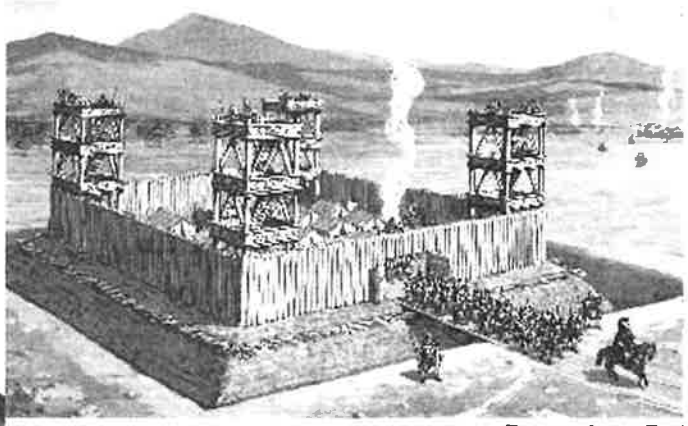
WHAT IS DfMA?

DfMA is not New

Used by Ancient Romans

- Roman Armies built a small town every night in 6 hours
- Also used for permanent buildings, e.g., Pantheon



Roman Army Fort



Pantheon, Rome

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WHAT IS DfMA?

DfMA is not New

Used over 100 Years Ago

1860's

- There were early pioneers, e.g., in 1860 Elihu Root devised industrialised assembly system for Samuel Colt



Colt Army Models 1861



Model T Ford Assembly Line

1920's

- Henry Ford pioneered mass-production of cars in 1920's

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WHAT IS DfMA?

Topics for Discussion

- DfMA is not New
- **Where is DfMA used?**
- The DfMA Envelope
- DfMA in the Construction Industry
- Components, Flat-pack & Volumetric Construction (PPVC)
- Conclusions

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WHAT IS DfMA?

DfMA is used extensively in Aerospace Industry

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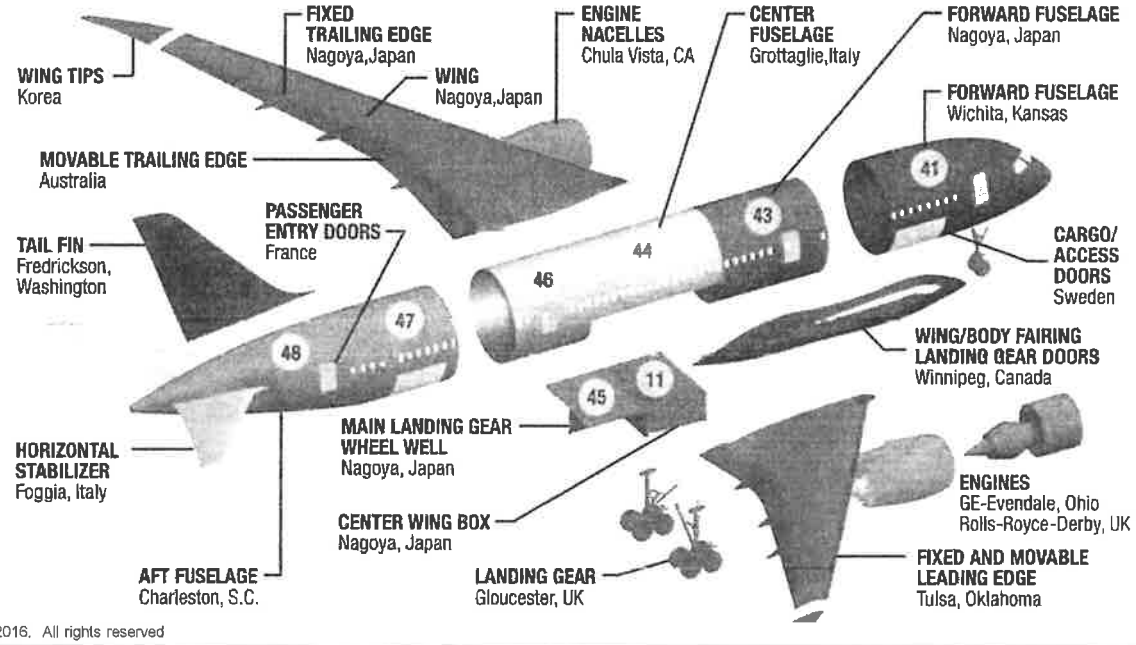
THE COMPANIES

U.S.	CANADA	AUSTRALIA	JAPAN	KOREA	EUROPE
Boeing	Boeing	Boeing	Kawasaki	KAL-ASD	Messier-Dowty
Spirit	Messier-Dowty		Mitsubishi		Rolls-Royce
Vought			Fuji		Latecoere
GE					Alenia
Goodrich					Saab



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WHAT IS DfMA?

DfMA is used extensively in Automobile Industry

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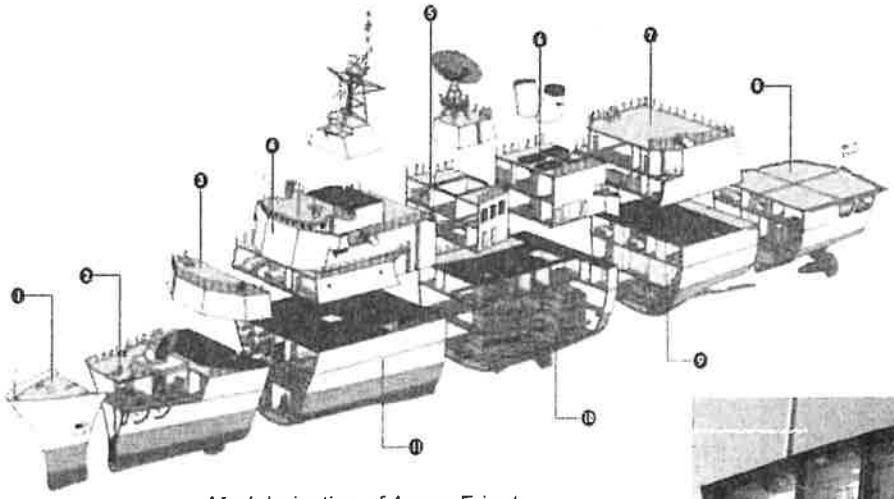
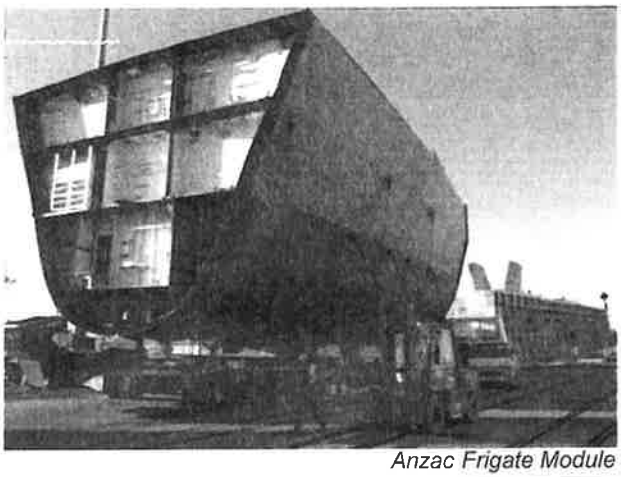
WHAT IS DfMA?

DfMA is increasingly used in Shipbuilding



Modularisation of Anzac Frigate



Anzac Frigate Module

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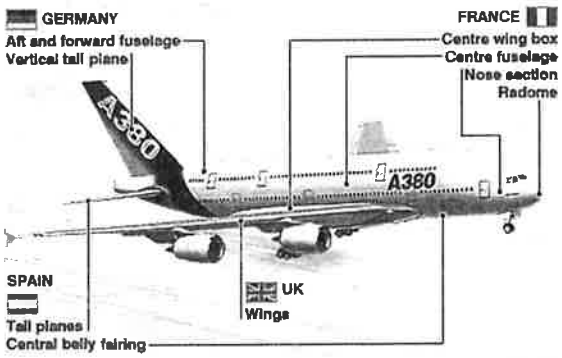
WHAT IS DfMA?

Summary of Where DfMA is Used

DfMA is used extensively in:

- Aerospace industry



Where Main Parts of A380 are Made

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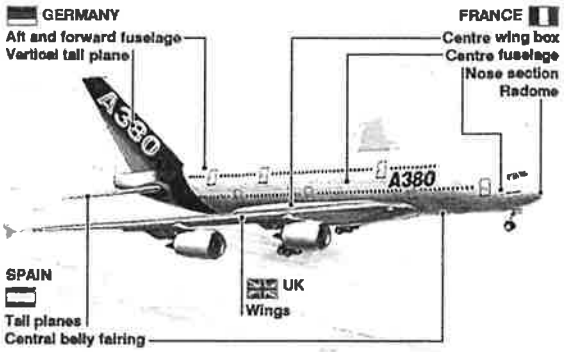
WHAT IS DfMA?

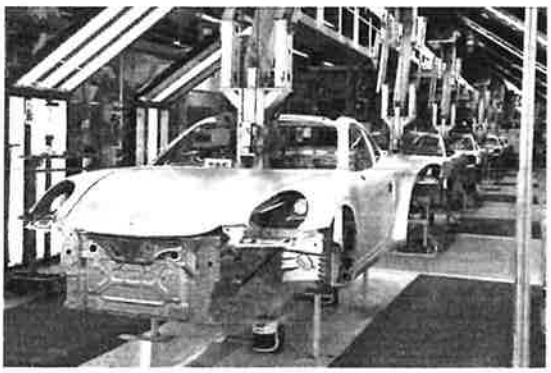
Summary of Where DfMA is Used

DfMA is used extensively in:

- Aerospace industry
- Automobile industry



Where Main Parts of A380 are Made



Porche Assembly Line

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WHAT IS DfMA?

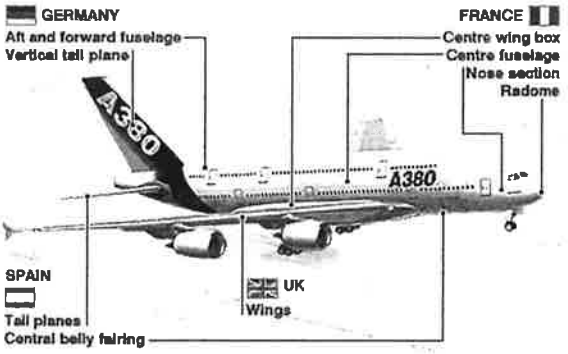
Summary of Where DfMA is Used

DfMA is used extensively in:

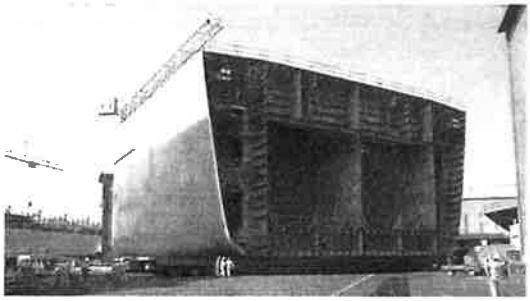
- Aerospace industry
- Automobile industry

DfMA is used increasingly in:

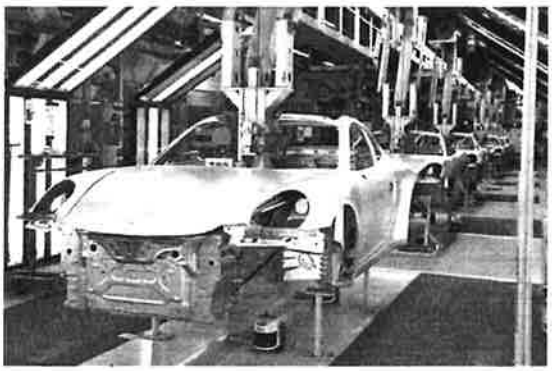
- Shipbuilding industry



Where Main Parts of A380 are Made



Ship Module



Porche Assembly Line

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WHAT IS DfMA?

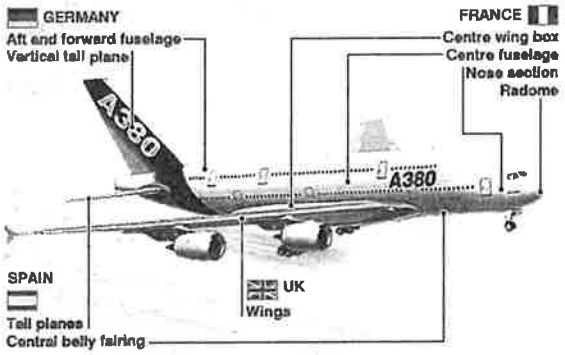
Summary of Where DfMA is Used

DfMA is used extensively in:

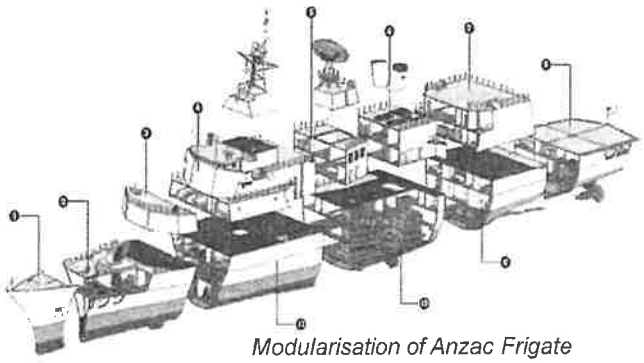
- Aerospace industry
- Automobile industry

DfMA is used increasingly in:

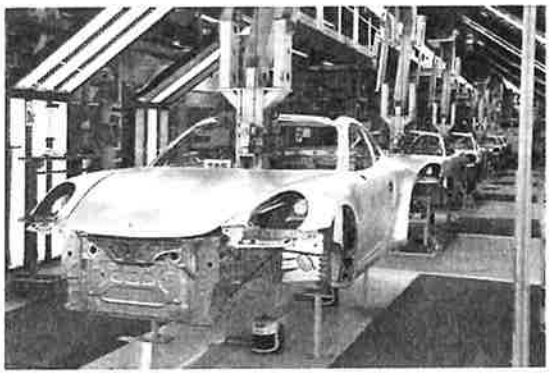
- Shipbuilding industry



Where Main Parts of A380 are Made



Modularisation of Anzac Frigate



Porche Assembly Line

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WHAT IS DfMA?

Summary of Where DfMA is Used

DfMA is used extensively in:

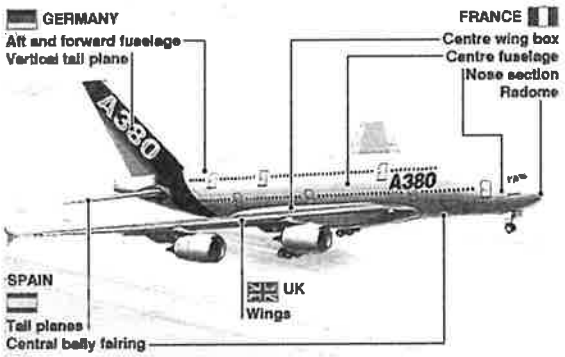
- Aerospace industry
- Automobile industry

DfMA is used increasingly in:

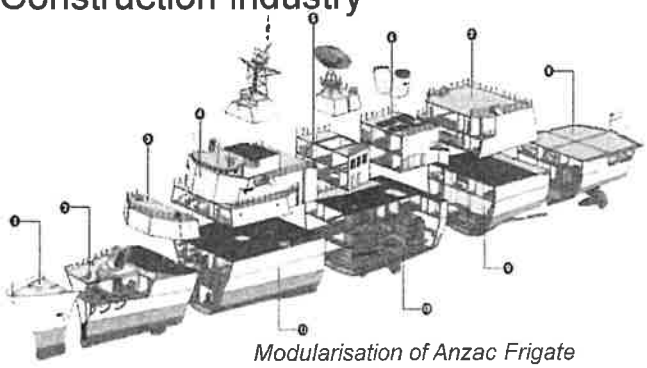
- Shipbuilding industry

DfMA is gradually being used in:

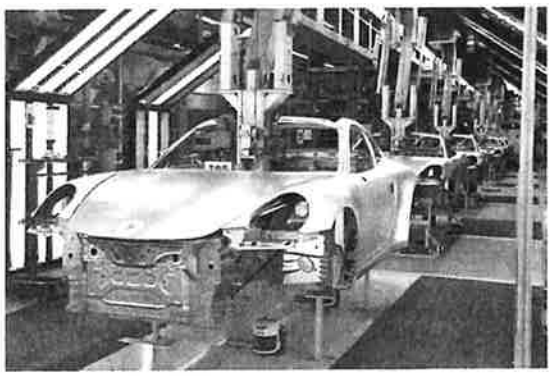
- Construction industry



Where Main Parts of A380 are Made



Modularisation of Anzac Frigate



Porche Assembly Line

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WHAT IS DfMA?
Topics for Discussion

- DfMA is not New
- Where is DfMA used?
- The DfMA Envelope
- **DfMA in the Construction Industry**
- Components, Flat-pack & Volumetric Construction (PPVC)
- Conclusions

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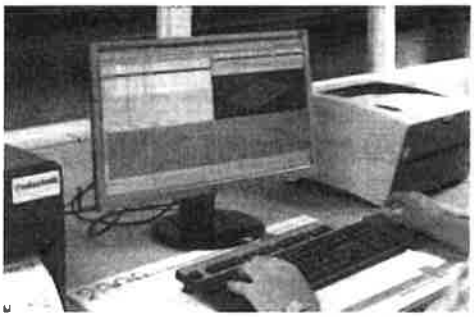
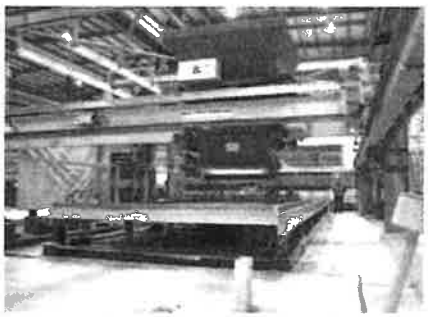
WHAT IS DfMA?
DfMA is Gradually being used in Construction



Explore (LOR) Automated Precast Factory, Steetley, UK



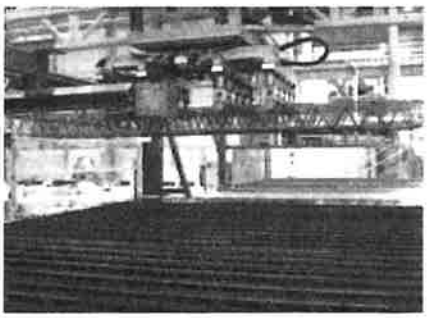
Control Centre



Concrete Spreader + Compaction Station



Bar Bending Robot



Lattice Placement Robot

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WHAT IS DfMA?

DfMA is Gradually being used in Construction



Explore (LOR) Automated Precast Factory, Steetley, UK

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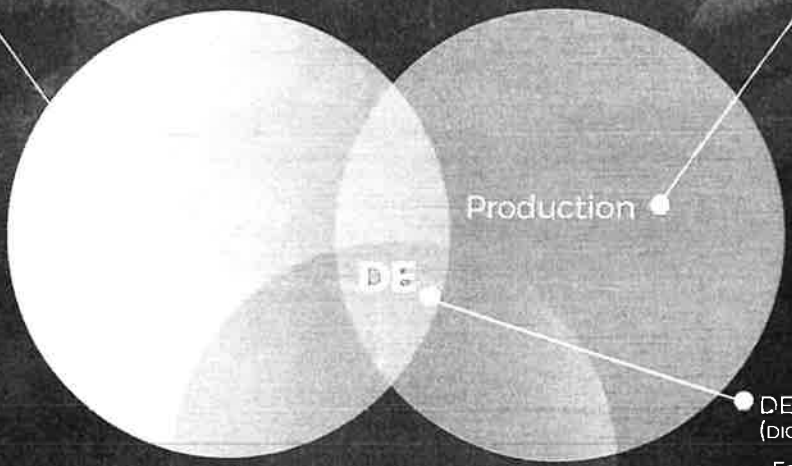
WHAT IS DfMA?
DfMA is Gradually being used in Construction

What is DfMA?
The DfMA Envelope : 3 Components of DfMA
No universal definition of DfMA in the construction industry



3D MODELS
- Visualisation
- Finite element
- Numerical control
- 2-D drawing production

OFF-SITE MANUFACTURE
- Small-scale items
- Panelised systems
- Large-scale
- 2-D drawing production
- Mass-customisation
- Modularised components & sub systems

DE
(DIGITAL ENGINEERING)
- Each of the 3 components yield benefits
- Greatest benefits are achieved in overlapping DE portion
- The DFMA envelope delivers optimum solutions

METADATA (BIM)
BUILDING INFORMATION MODEL
- Programme (time & costs)
- Quality & performance
- Safety & maintenance
- Environmental impacts: noise pollution, carbon footprint, disruption to business & residents

Metadata

Case Studies

Port Botany Expansion, Sydney

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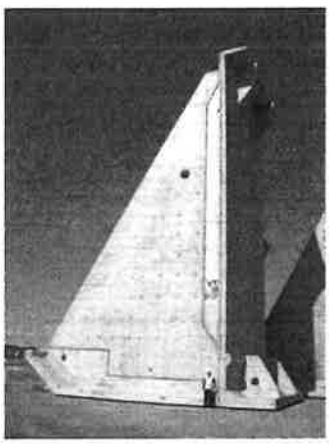
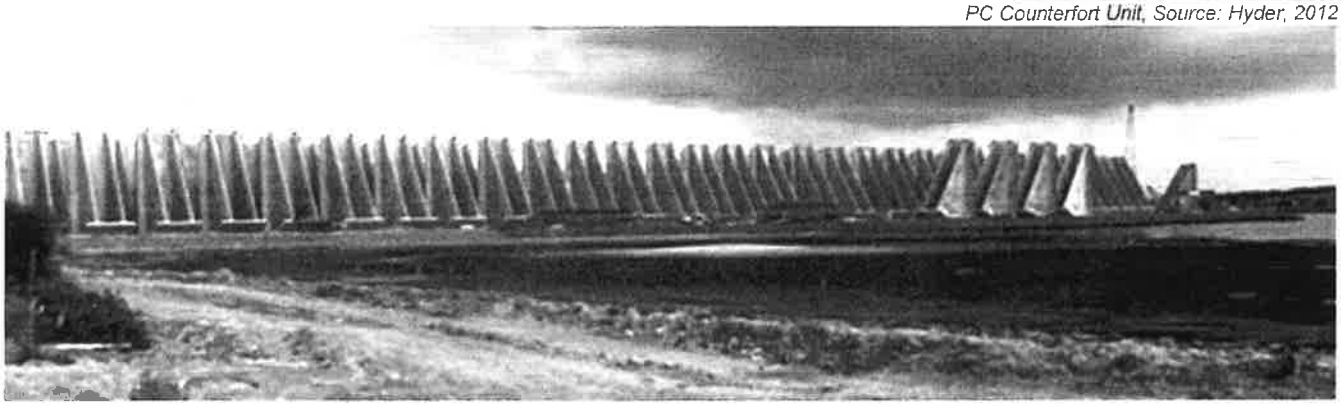
- 216 PC counterfort wall units
- Weight of PC unit ≈ 650 tonnes
- 1.8 km of continuous capping/beam crane runway (no movement joints)



PC Counterfort Unit, Source: Hyder, 2012



Overall View of PC Counterfort Units, Source: Hyder. 2012

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WHAT IS DfMA?

Real-World Examples: FRP

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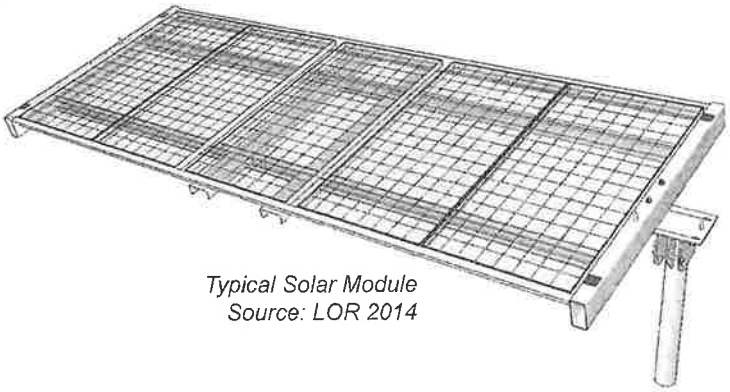
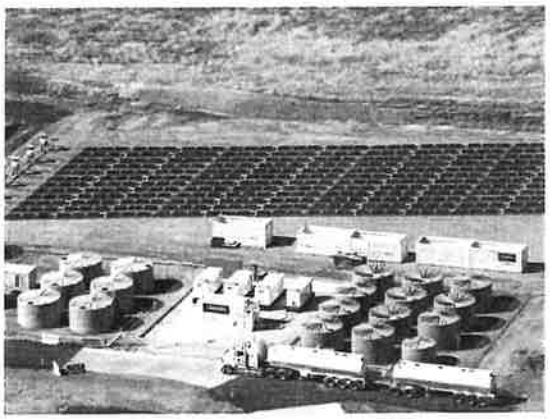
sunSHIFT

- Electrical power generation in remote areas
- 50% replacement of diesel fuel with solar
- Re-deployable Modular Design
  - 1st Generation Steel
  - 3rd Generation FRP



Typical Solar Module
Source: LOR 2014



Typical SunSHIFT Deployment, Source: LOR 2014

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WHAT IS DfMA?

Real-World Examples: Composite

Project:
Leadenhall Building,
London, UK

- 52-storey office tower
- 225 m high
- 36 modules per floor
- 930 modules total
- Modules completely finished in the factory (structural, MEP & fit-out)
- Installation – 36 modules (1 floor) every 3 days

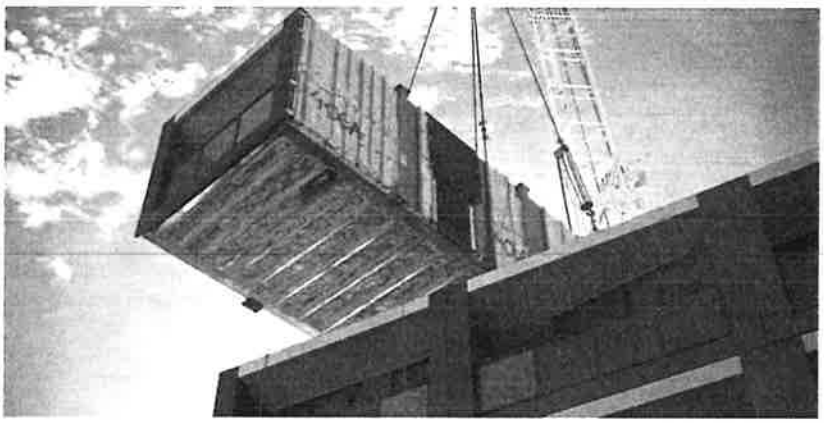




WHAT IS DfMA?

Real-World Examples: Composite

- 7 storeys
- 57 apartments
- 63 modules
- 11 days installation





Bosisto St, Richmond, Melbourne, Hickory Building Systems, 2012

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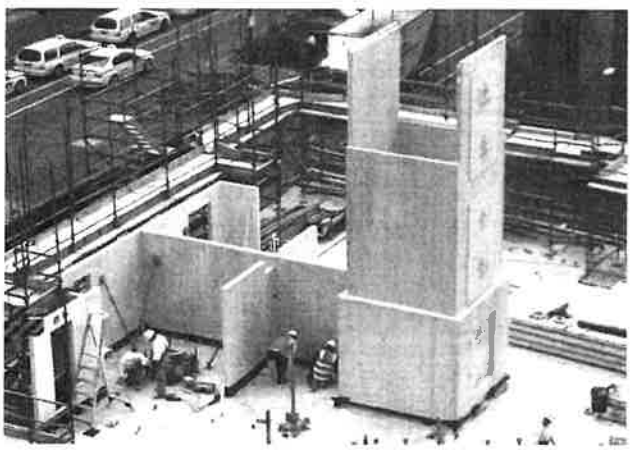
WHAT IS DfMA?

Real-World Examples: CLT (Cross Laminated Timber)

- 9 storeys, 23 apartments
- CLT Start: June 2012
- CLT Complete: Aug 2012 (≈ 3 months)
- Zero Carbon Footprint





Source: LendLease, 2012

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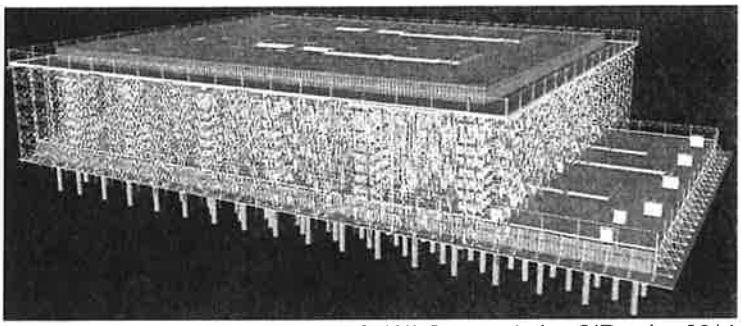
WHAT IS DfMA?

Major Civil Engineering Project



Wheatstone LNG, WA Source: Laing O'Rourke, 2014

Traditional Construction

- **185 days** overall
- **122 days** superstructure

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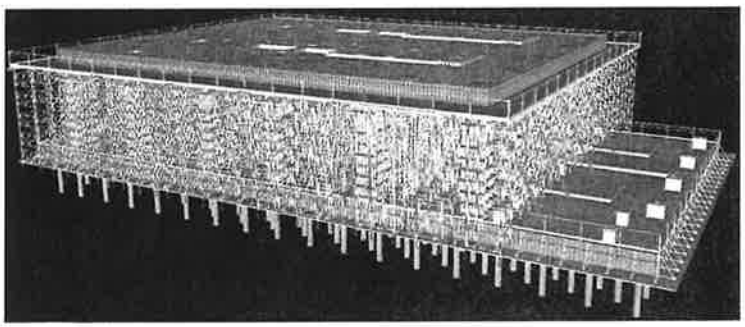
WHAT IS DfMA?

Major Civil Engineering Project



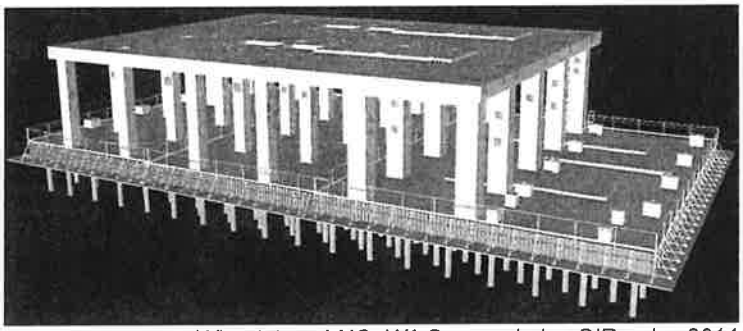
Traditional Construction

- **185 days** overall
- **122 days** superstructure

DfMA Construction

- **120 days** overall
- **61 days** superstructure

50% saving in programme



Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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WHAT IS DfMA?

Topics for Discussion

- DfMA is not New
- Where is DfMA used?
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- DfMA in the Construction Industry
- **Components, Flat-pack & Volumetric Construction (PPVC)**
- Conclusions

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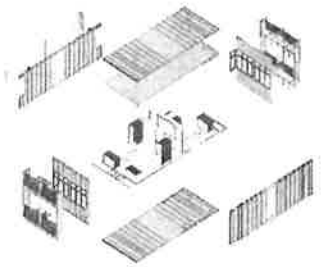
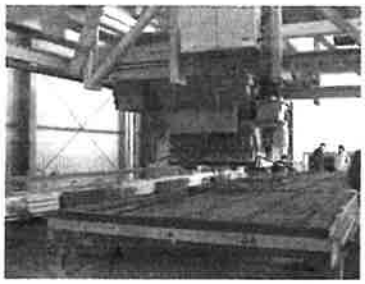
WHAT IS DfMA?

Changing the Way We Build Through DfMA







***D**esign **f**or*

***M**anufacturing*
(off-site and automation)

and ***A**ssembly*
(on-site)

Moving work offsite will improve productivity in 3 ways

- ***Controlled*** offsite environment
- Scope for ***automation*** of offsite work
- Scope for ***offshoring*** of offsite work

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WHAT IS DfMA?

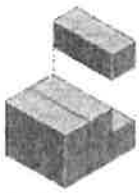
Adoption of DfMA in Construction

DfMA usually Comprises:

- Separate Components (Stick-built)
- Partly-integrated Components
- Volumetric (PPVC)

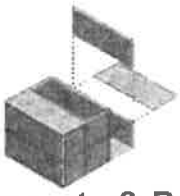
DfMA - Design for Manufacture and Assembly

Modular (volumetric)



Fully Integrated Components

Prefabricated (flat pack, precast)



Components & Partly-integrated Components

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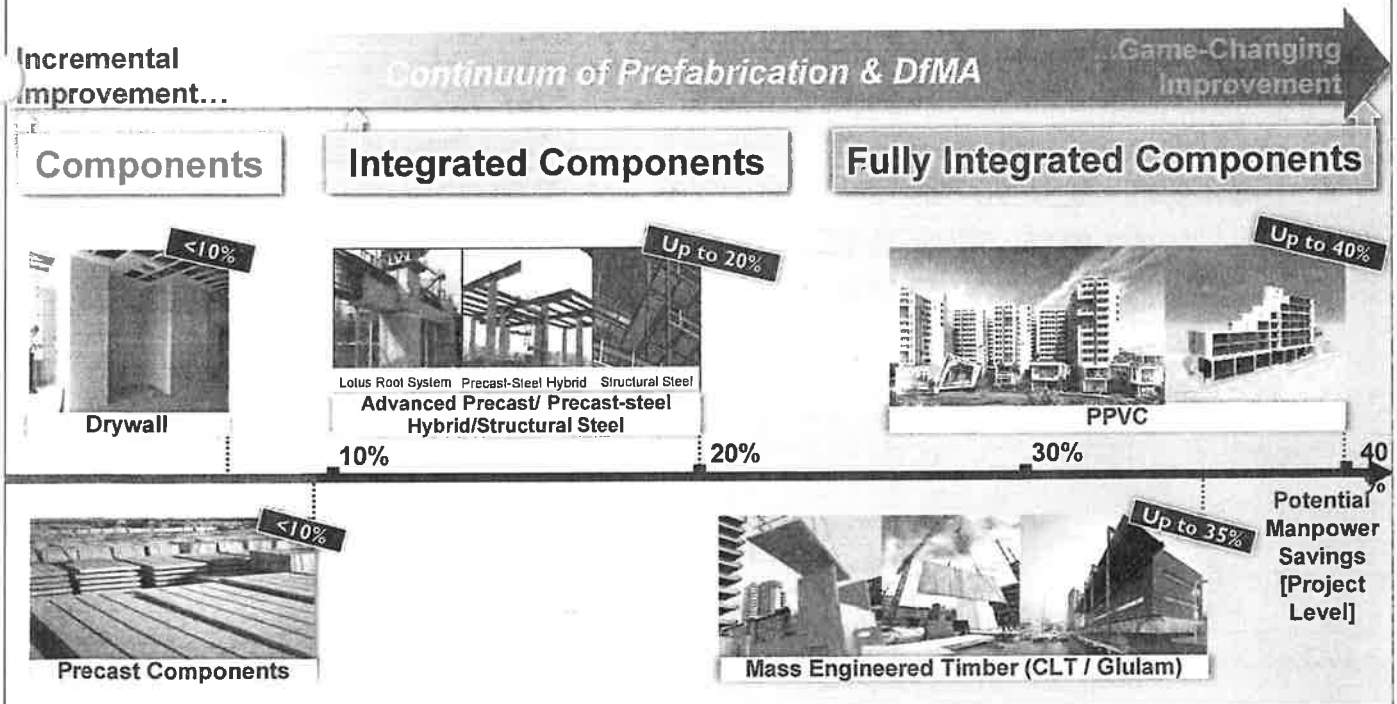
WHAT IS DfMA?

Push for Widespread Adoption of DfMA Technologies...



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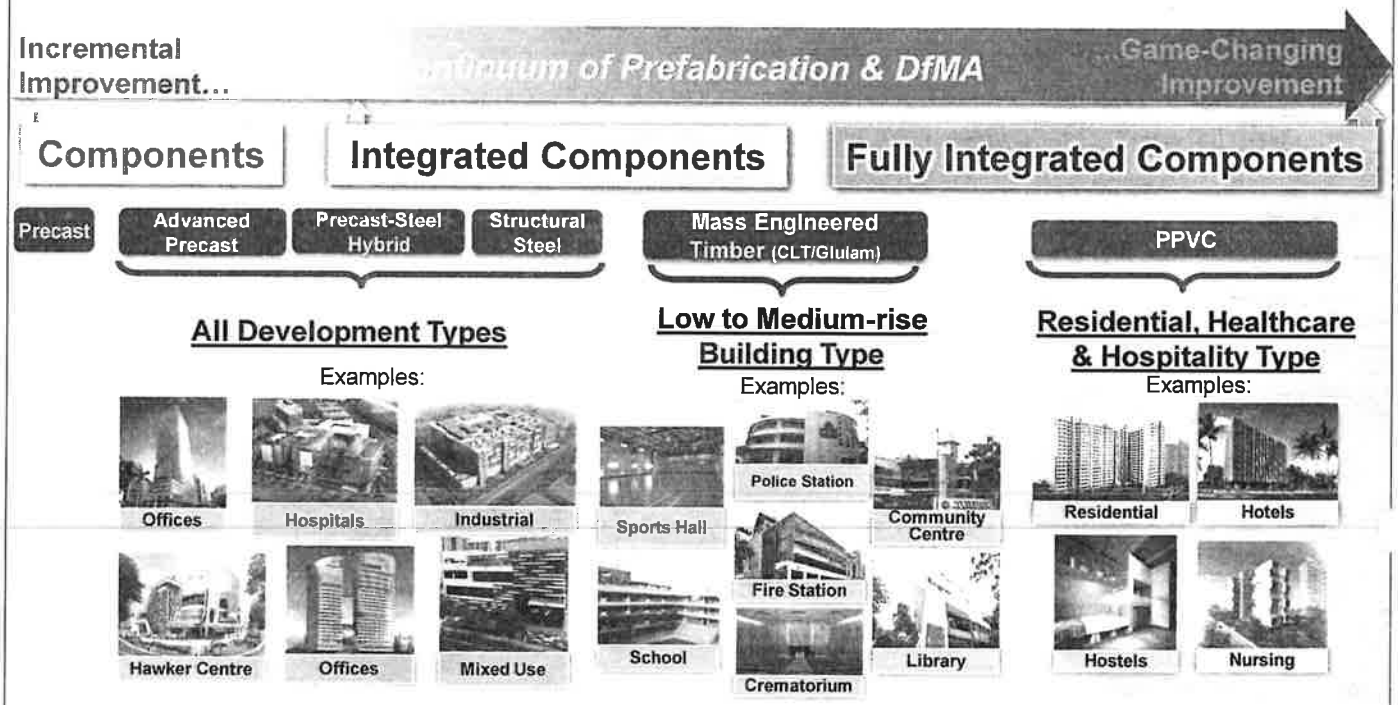
Source of Slide: BCA, 2016

WHAT IS DfMA?

… across different development types



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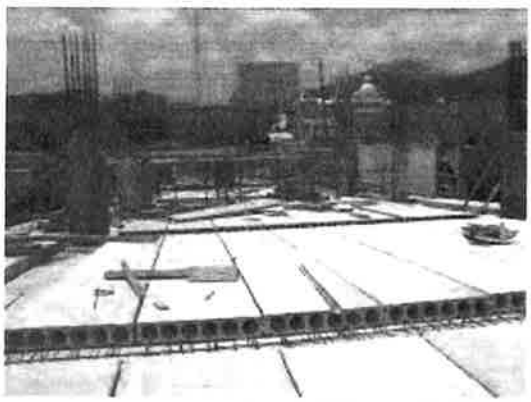
Source of Slide: BCA, 2016

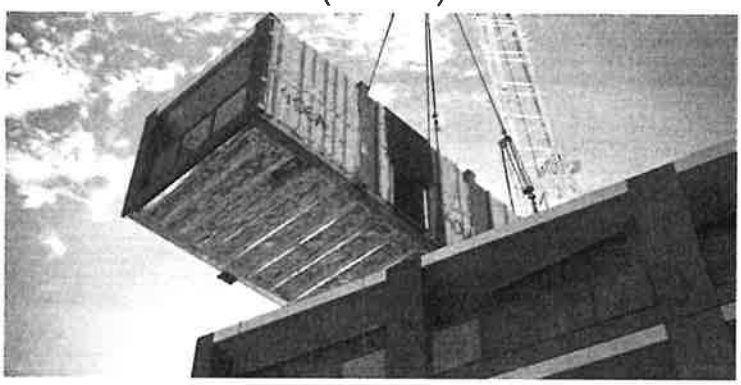
WHAT IS DfMA?

Conclusions

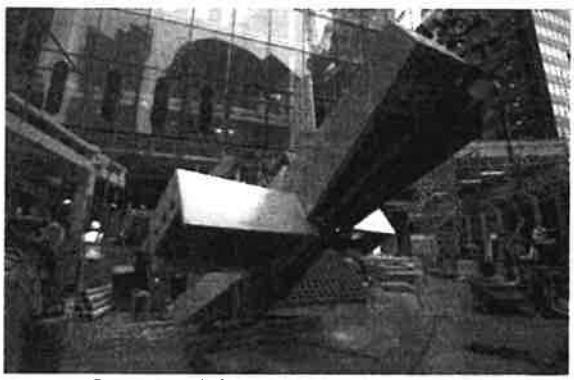
- DfMA is not New
- It applies to all construction projects
  - Not just buildings
- It comes in several forms:
  - Components (stick-built)
  - Integrated components
  - Flat-pack
  - Volumetric (PPVC)



Precast Concrete Floors



Volumetric, Source: Hickory Building Systems, 2012



Structural Steel, Source: Laing O'Rourke

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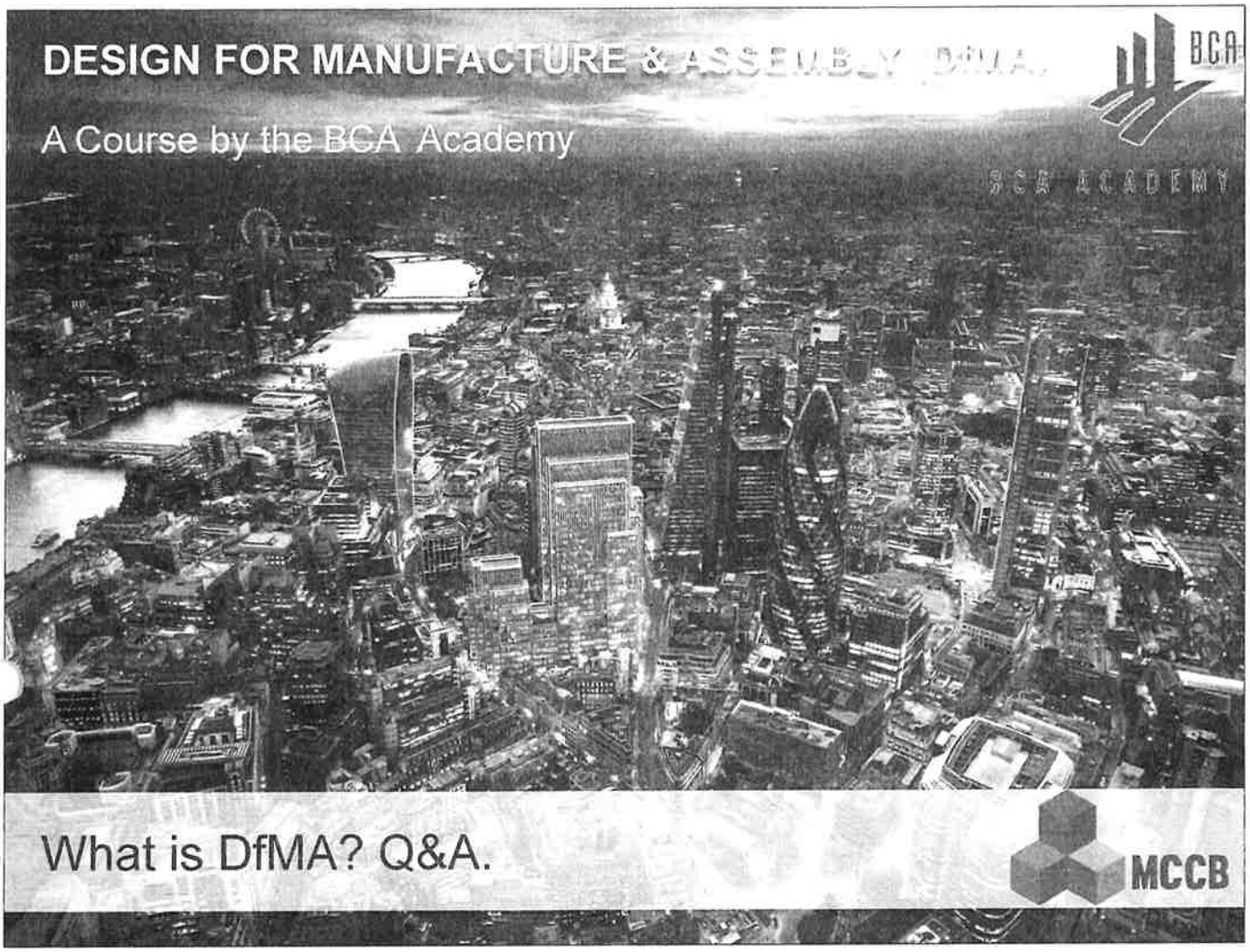
DESIGN FOR MANUFACTURE & ASSEMBLY DfMA
A Course by the BCA Academy
BCA
BCA ACADEMY
What is DfMA? Q&A.
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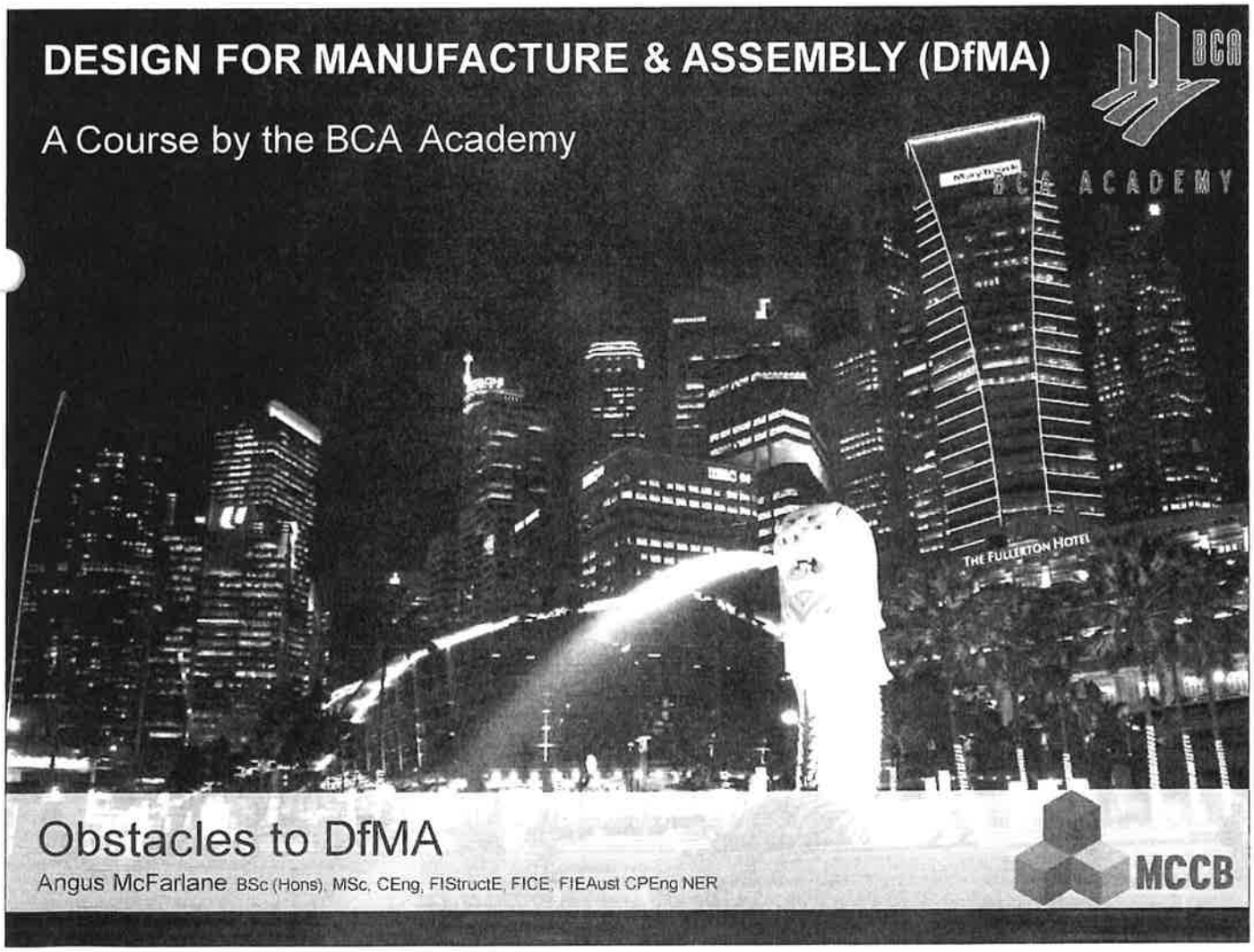
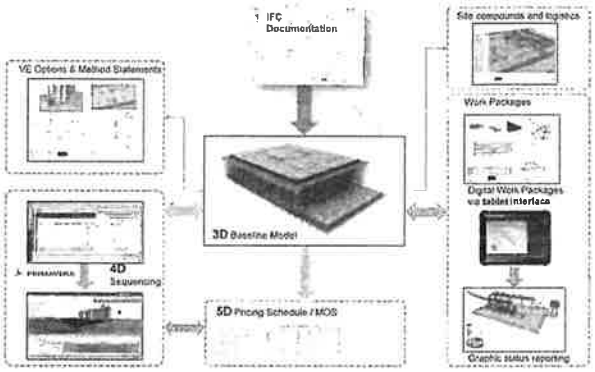
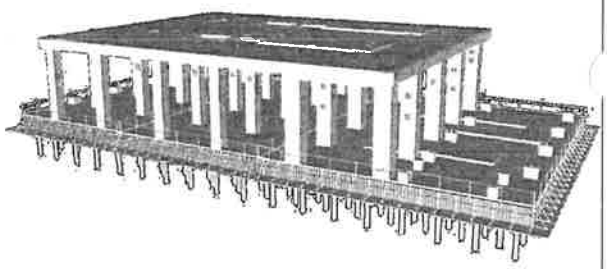

DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)
A Course by the BCA Academy
BCA
BCA ACADEMY
THE FULLERTON HOTEL
Obstacles to DfMA
Angus McFarlane BSc (Hons), MSc, CEng, FIStructE, FICE, FIEAust CPEng NER
MCCB

OBSATCLES TO DfMA

Topics for Discussion

- Procurement Process
- Risk Averse Financial Institutions
- Industry Reluctance
- Negative Associations with "Pre-fabricated" Structures
- Timelag
- Lack of Regulation
- Differing Regulations in Different Countries





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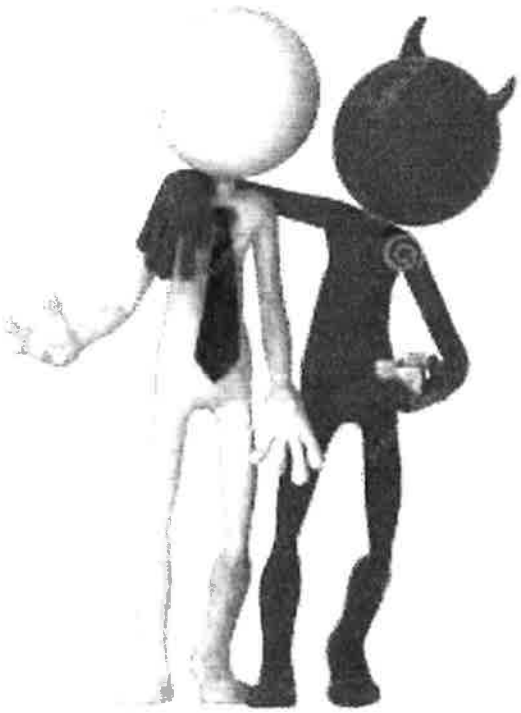
OBSTACLES TO DfMA

Procurement Process

Traditional Procurement Process

- Discourages DfMA



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OBSTACLES TO DfMA

Procurement Process

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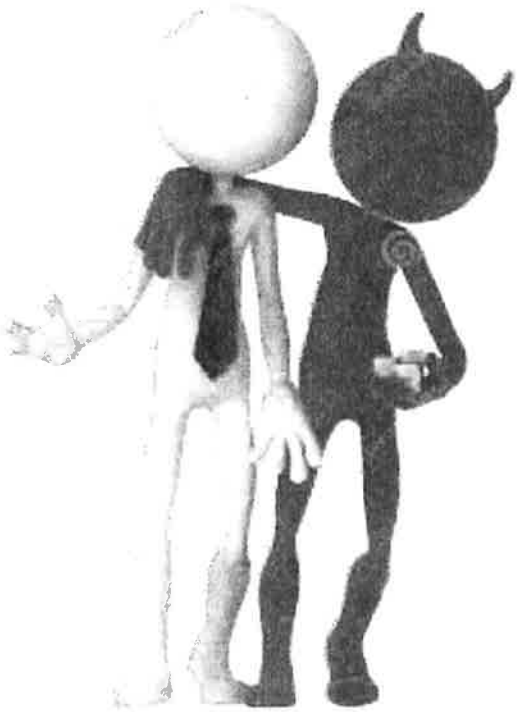
Traditional Procurement Process

- Discourages DfMA

The Process Promotes:

Direct price competition for:

- Specified product
- Project awarded to lowest bidder
- Not necessarily the best product



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OBSTACLES TO DfMA

Procurement Process

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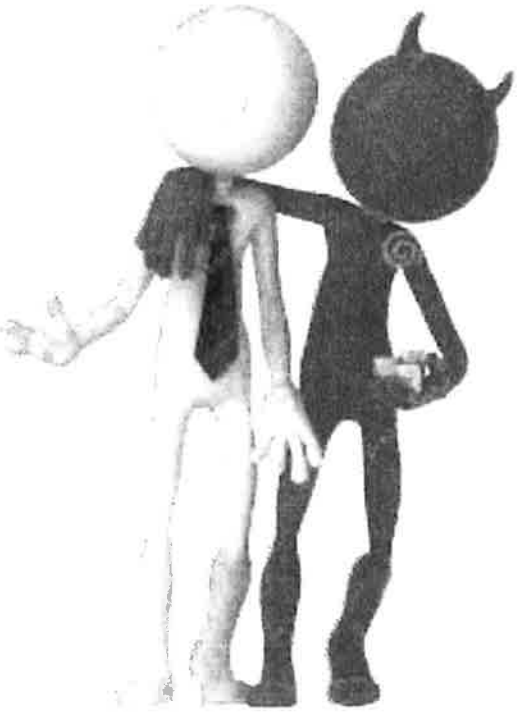
Summary

Traditional Procurement Process

- Discourages DfMA

Traditional Procurement gives:

- **Lowest price for specified product**



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OBSTACLES TO DfMA

Procurement Process

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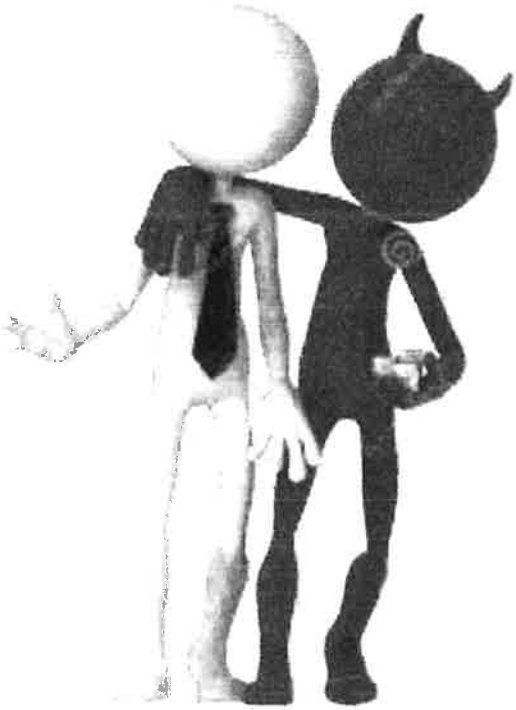
Summary



Traditional Procurement Process

- Discourages DfMA

Traditional Procurement gives:

- Lowest price for specified product

Traditional Procurement does NOT give:

- **The Best Price for the Best Solution**

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OBSTACLES TO DfMA

Integrated Procurement

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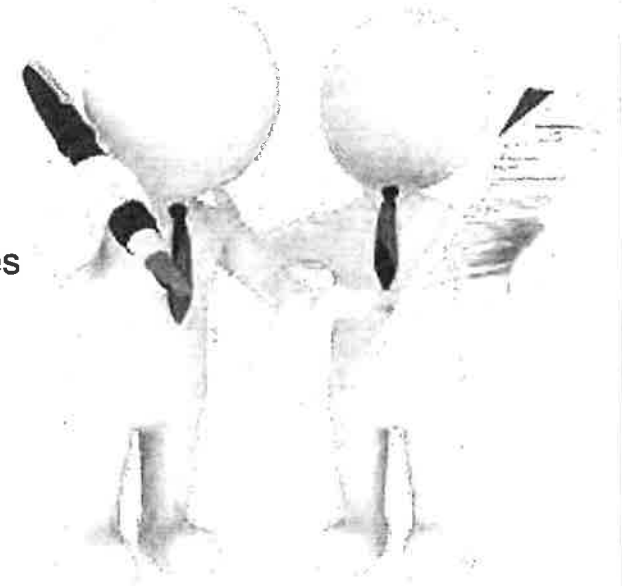
Integrated Procurement (IP) Process

- Method is better.
- Meets Client's functional requirements



IP Allows

- Innovative design
- New materials
- New production & assembly techniques

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OBSATCLES TO DfMA

Integrated Procurement

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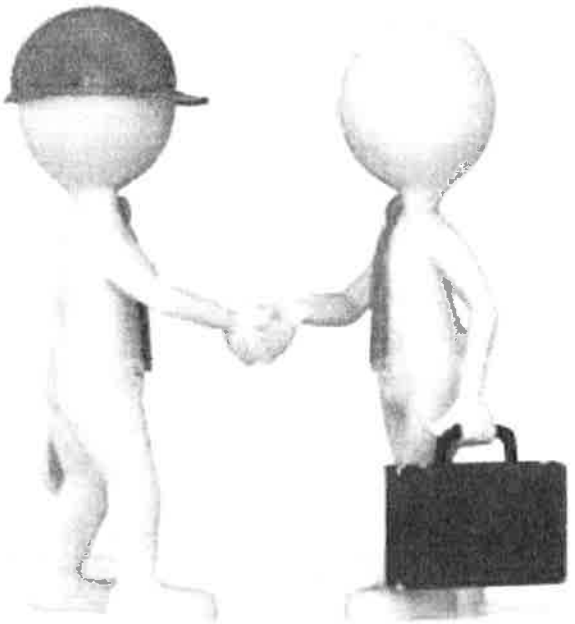
Client Establishes Contract

- With single party (SP)
- SP could be a contractor or designer/contractor consortium



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OBSATCLES TO DfMA

Integrated Procurement

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Client Establishes Contract

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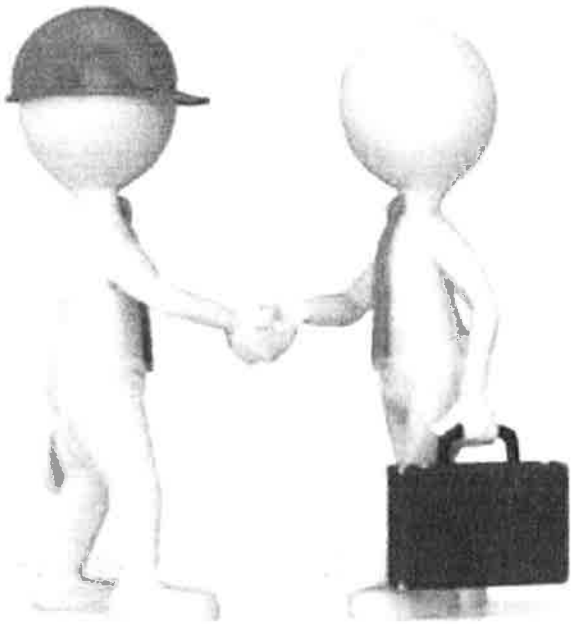
SP has full responsibility for:

- Design
- Construction



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OBSATCLES TO DfMA

Integrated Procurement

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SP has full responsibility for:

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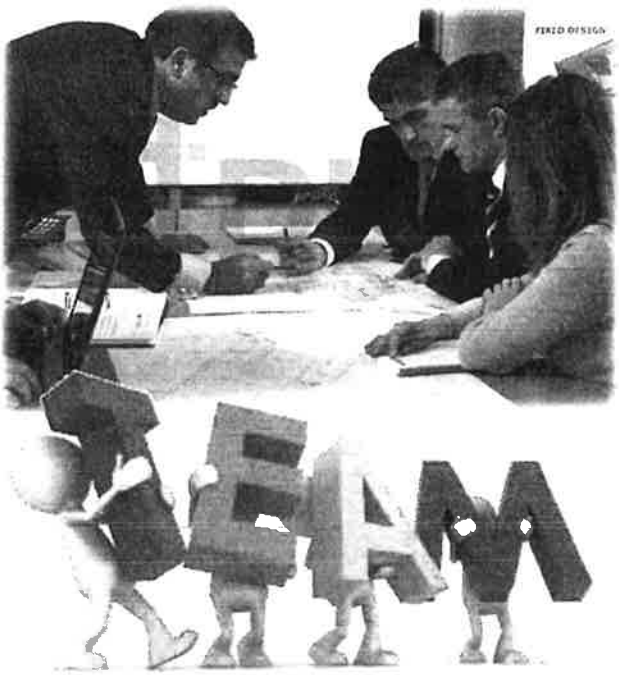
- Construction

Achieves Optimal Design

That is efficient to:

- Construct
- Maintain
- Operate



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OBSATCLES TO DfMA

Integrated Procurement

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Client Establishes Contract

- With single party (SP)
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SP has full responsibility for:

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- Construction

Achieves Optimal Design

That is efficient to:

- Construct
- Maintain
- Operate



Allows all stakeholders (technical & non-technical) to participate in the planning process

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OBSATCLES TO DfMA

Risk Averse Financial Institutions

We (Construction Industry) Need to Show:

Modular (DfMA) projects are:

- Durable – have a long-life
- Higher quality
- Low maintenance
- Attractive to tenants
- Is regulated

This Can be Done by:

Showing that DfMA has successfully used:

- In other industries
- In the construction industry
- Is regulated



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OBSATCLES TO DfMA

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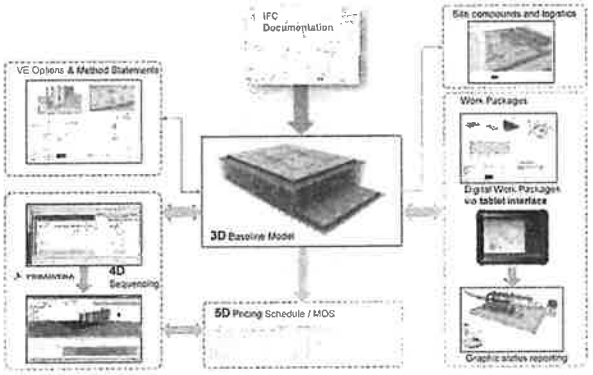

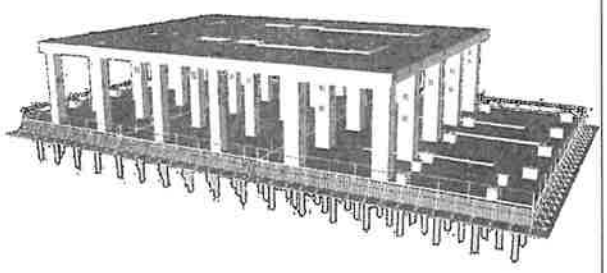

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OBSATCLES TO DfMA

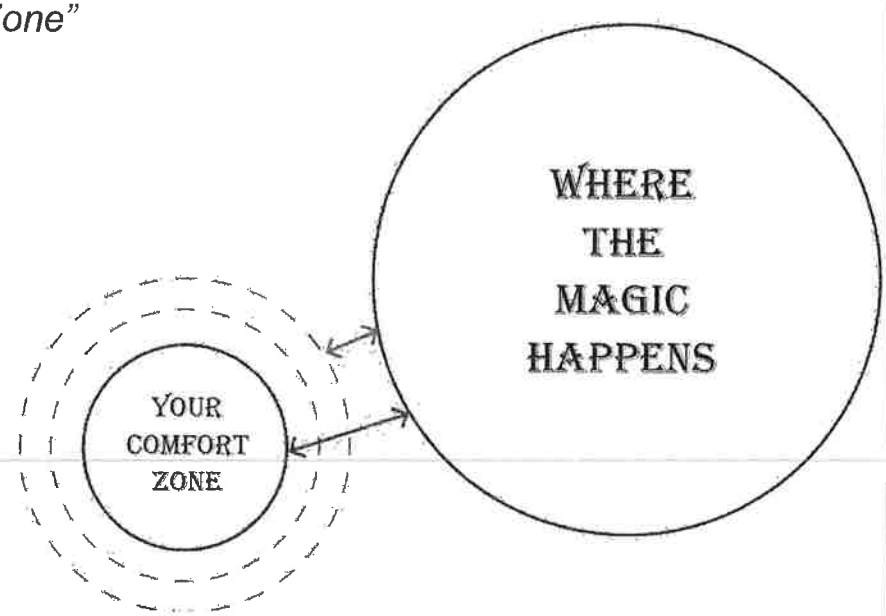
Industry Reluctance

MCCB

The Problem

DfMA can take people

- Out of their *"Comfort Zone"*



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OBSATCLES TO DfMA

Industry Reluctance

MCCB

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Typical Negative Responses are:

- *"We have always done it this way"*
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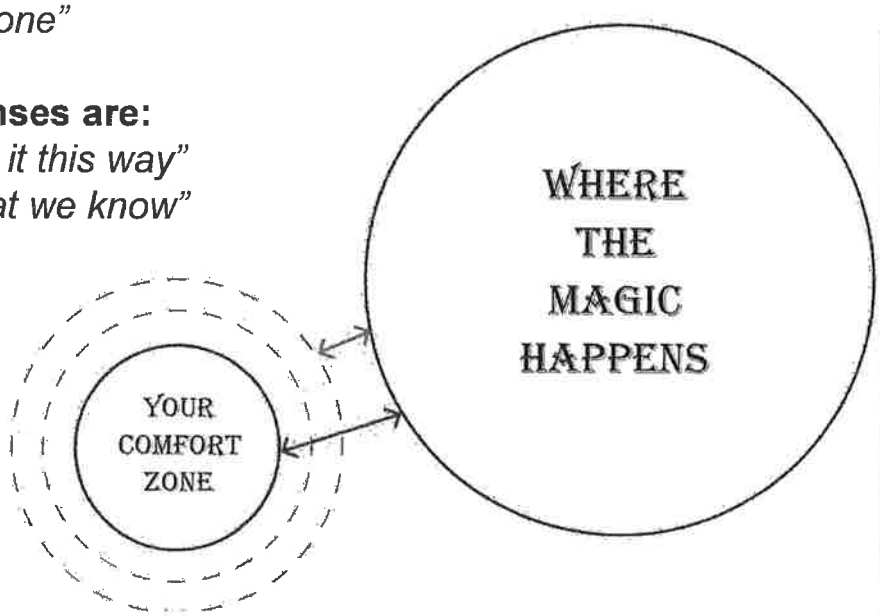

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OBSATCLES TO DfMA

Industry Reluctance

MCCB

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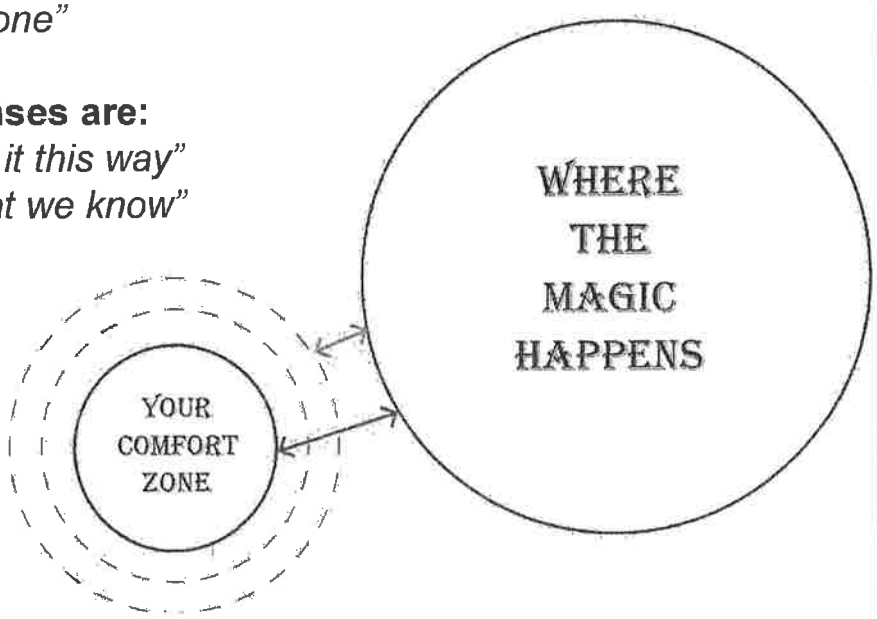
We Need to Educate:

- Clients
- Statutory Authorities
- Project Team
- Our Colleagues



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OBSATCLES TO DfMA

Industry Reluctance

MCCB

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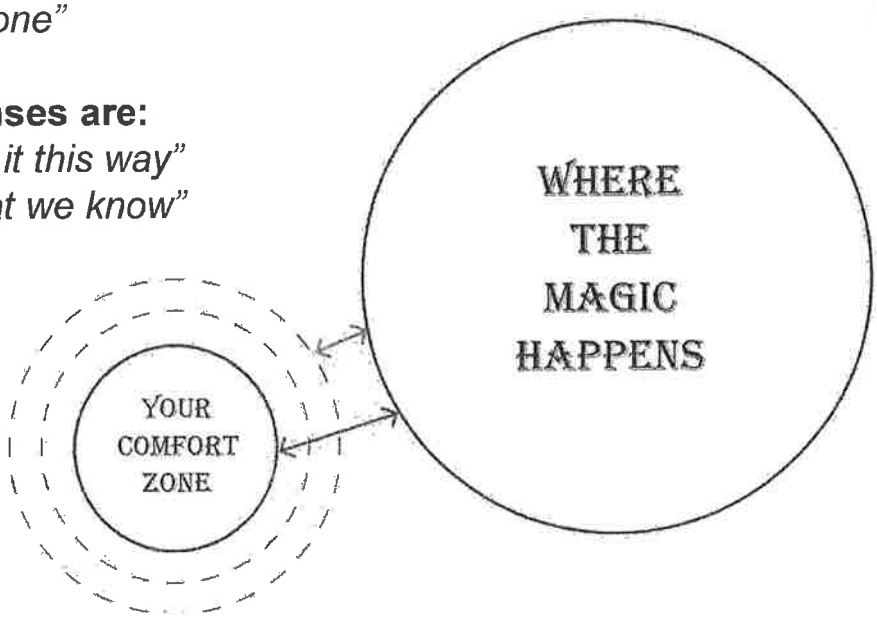
BUT this can be difficult



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OBSATCLES TO DfMA

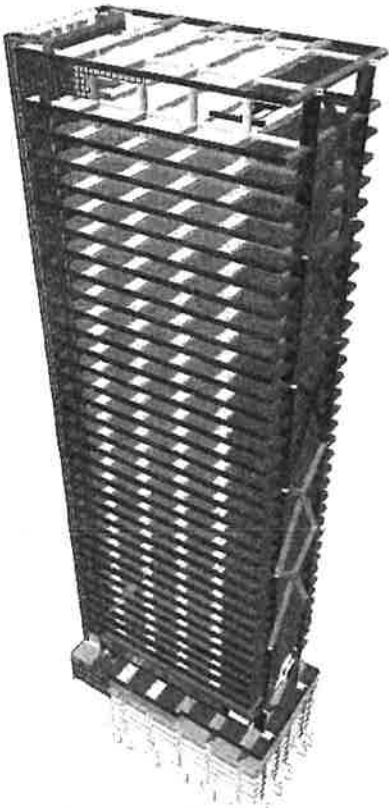
Industry Reluctance

MCCB

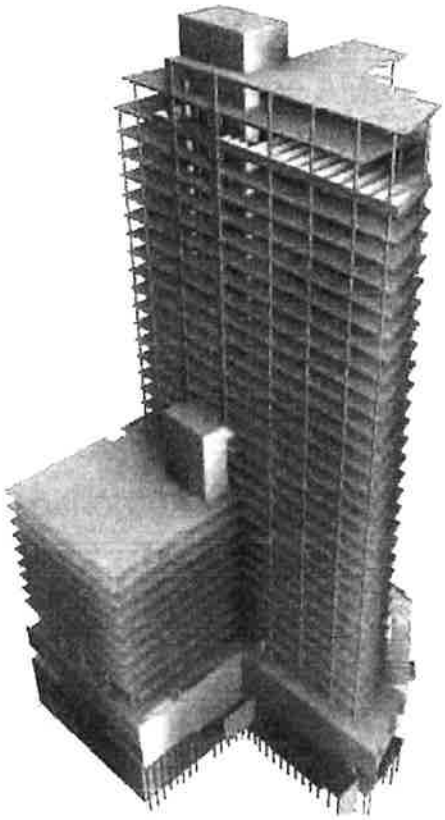
Typical Example

Two Similar Projects

- Grocon: Queen Street Brisbane
- LOR: Mount Street Sydney



100 Mount Street, Sydney
Source: Laing O'Rourke, 2016



480 Queen Street, Brisbane
Source: Grocon, 2016

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OBSATCLES TO DfMA

Industry Reluctance

MCCB

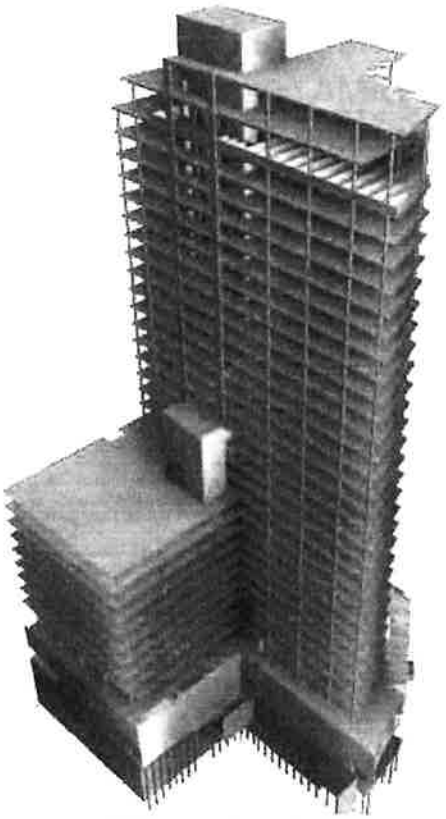
Typical Example

Two Similar Projects

- Grocon: Queen Street Brisbane
- LOR: Mount Street Sydney

Grocon Outcome

- Used a full DfMA solution
- Savings ≈ $12 M



480 Queen Street, Brisbane
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OBSATCLES TO DfMA

Industry Reluctance

MCCB

Typical Example

Two Similar Projects

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- Used a full DfMA solution
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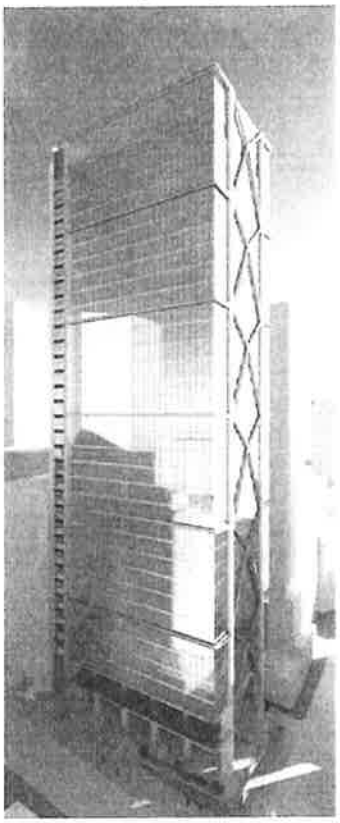
LOR Outcome

- Partial DfMA solution
- Savings ≈ $1.5 M



100 Mount Street,, Sydney
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OBSATCLES TO DfMA

Industry Reluctance

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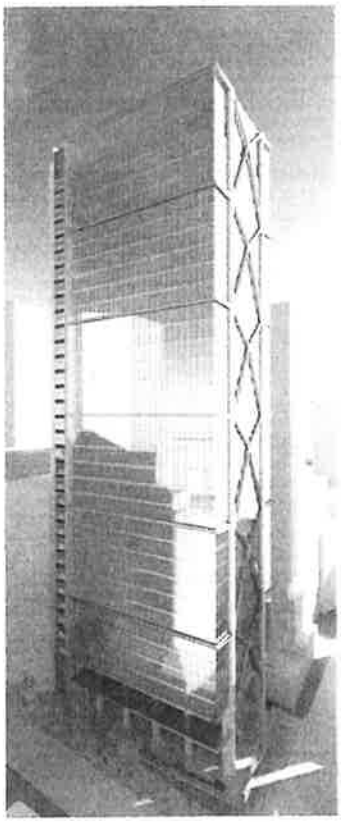
Some people:
"Talk the talk"* BUT don't *"Walk the walk"



100 Mount Street,, Sydney
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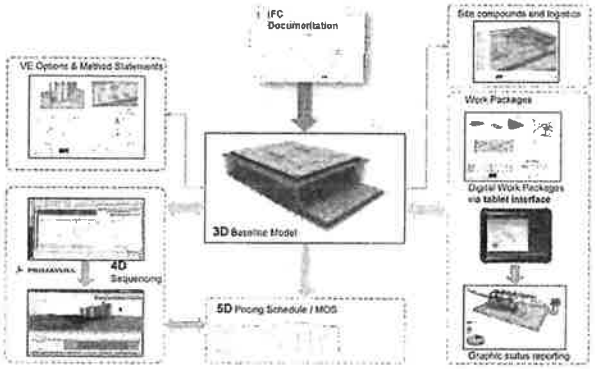
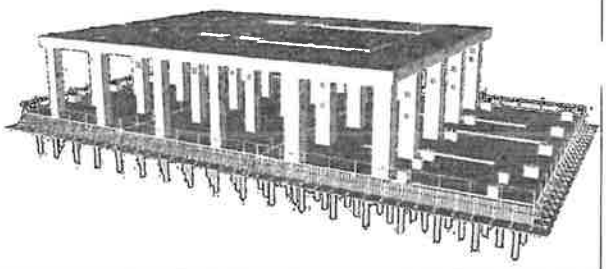
OBSATCLES TO DfMA

Topics for Discussion

- Procurement Process
- Risk Averse Financial Institutions
- Industry Reluctance
- **Negative Associations with "Pre-fabricated" Structures**
- Timelag
- Lack of Regulation
- Differing Regulations in Different Countries





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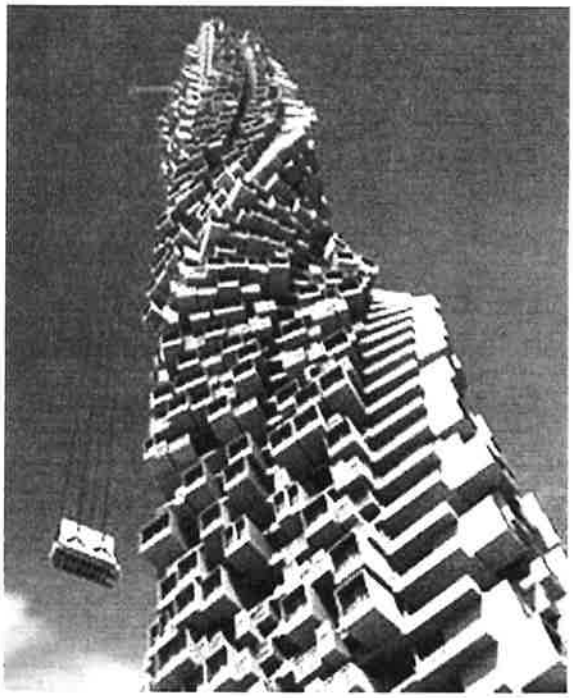
OBSATCLES TO DfMA

Negative Associations with "Pre-fabricated" Structures

General Public Perceive Modular Buildings to be:

- Inferior quality
- *"Boxey"* – they all look the same
  - Probably due to the post-war building boom



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OBSATCLES TO DfMA

Negative Associations with "Pre-fabricated" Structures

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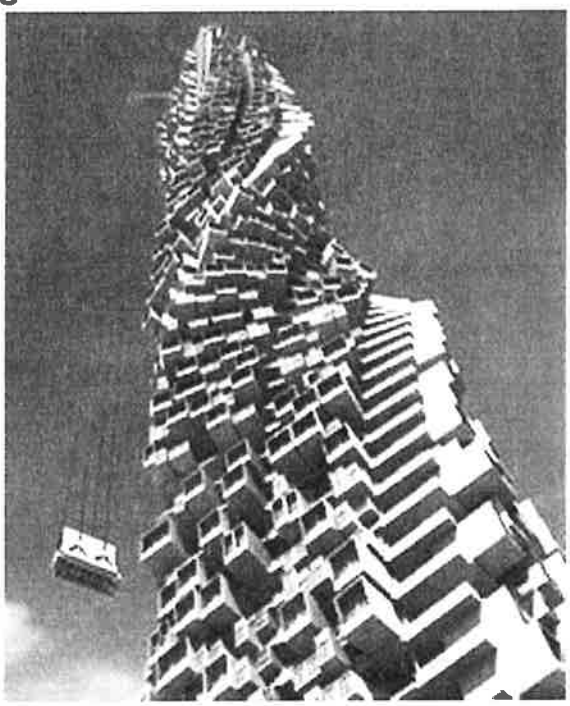

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OBSATCLES TO DfMA

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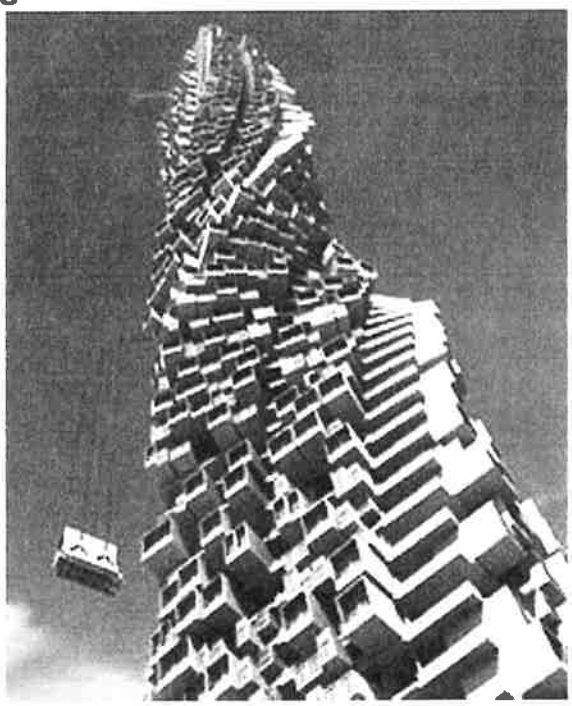
We Can do This by:

Mass-customisation

- Buildings do not need to look the same
- Modules can produce:
  - Different shapes
  - Different room layouts



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OBSATCLES TO DfMA

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"The customer get what the customer wants"

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OBSATCLES TO DfMA

Topics for Discussion

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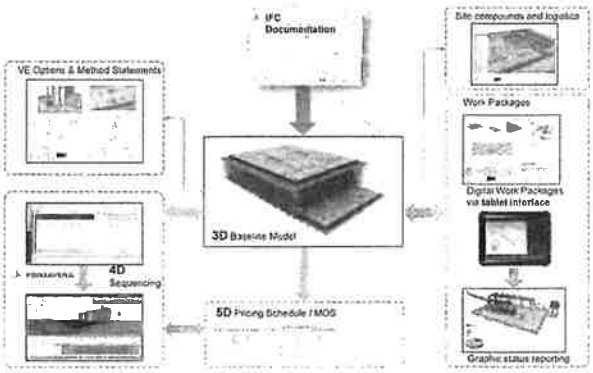

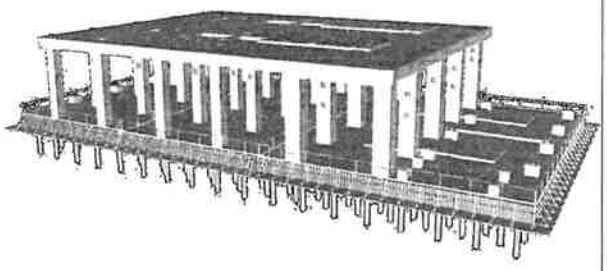

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OBSATCLES TO DfMA

Timelag

Industry Perception is that:

DfMA/Modular needs:

- Huge investment
- New technology
- Hence timelag/reluctance to adopt

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OBSATCLES TO DfMA

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This Perception is Incorrect:

With DfMA we can:

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  - Use precast not insitu concrete
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OBSATCLES TO DfMA

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DfMA is a "Thought Process"

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OBSATCLES TO DfMA

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DfMA is a "Thought Process"

- **It does not need to be technology-driven**
- **There should be no timelag in its adoption**

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OBSATCLES TO DfMA
Topics for Discussion

- Procurement Process
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- **Lack of Regulation**
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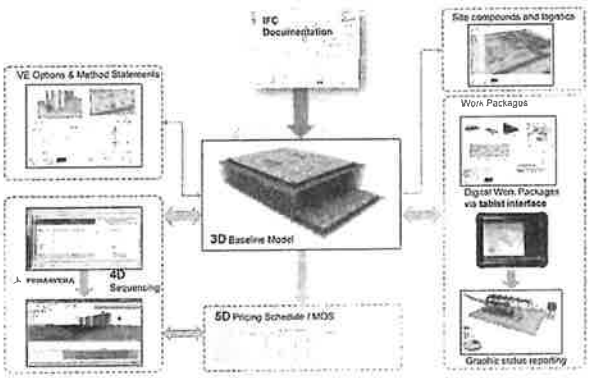

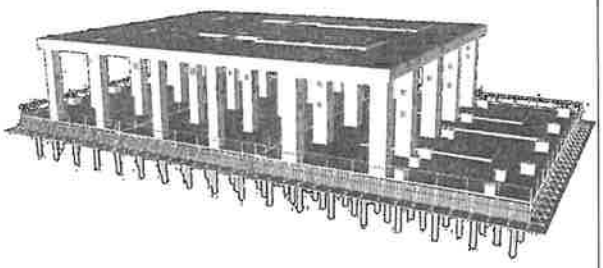

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OBSATCLES TO DfMA
Lack of Regulation

Modular v Conventional Construction:

Modular is different from Conventional

- Subject to a different loading regime

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OBSATCLES TO DfMA

Lack of Regulation

Modular v Conventional Construction:

Modular is different from Conventional

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Prior to Final Structural Integration:

Modules could be:

- A ship
- A truck
- A pendulum (on a crane)

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OBSATCLES TO DfMA

Lack of Regulation

Modular v Conventional Construction:

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Modules could be:

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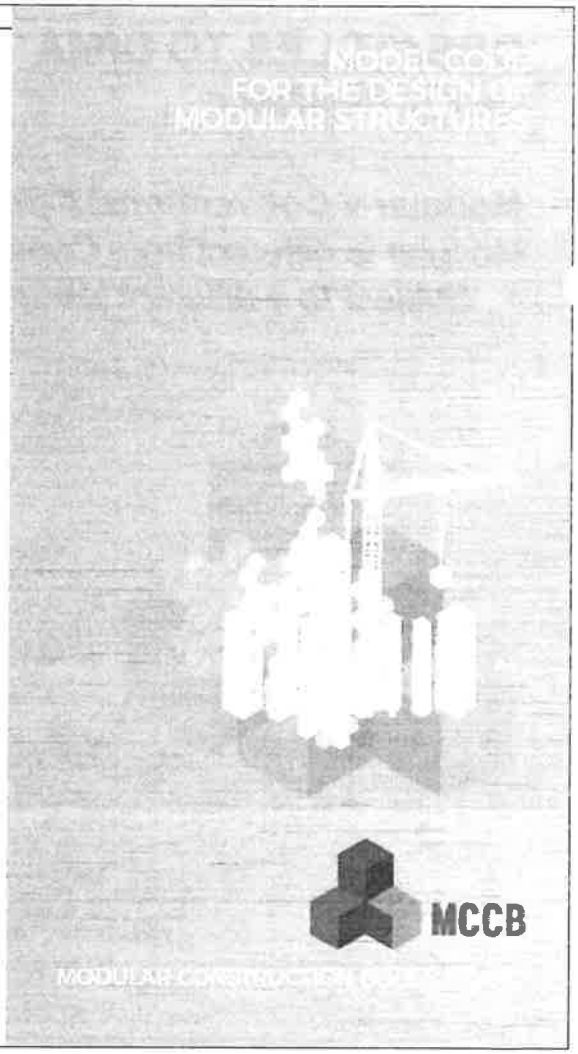
Modular Construction Needs

A different code from conventional construction

- The Model Code



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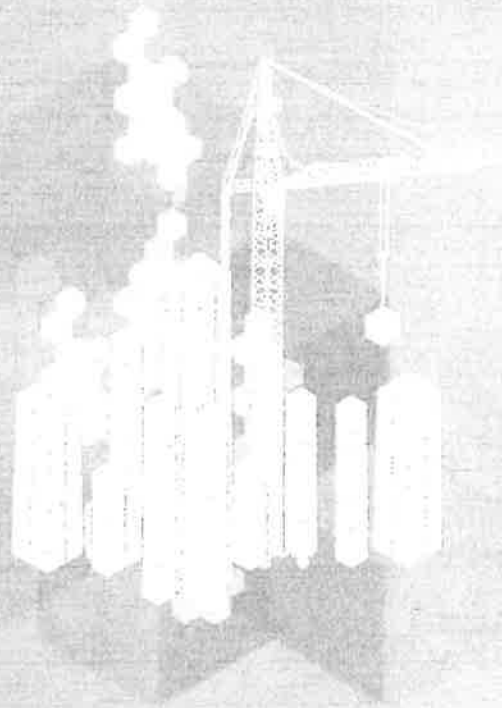
DfMA & REGULATION

The Model Code



Code addresses following issues:

-
-
-

Progress

-

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OBSATCLES TO DfMA

Topics for Discussion

MCCB

- Procurement Process
- Risk Averse Financial Institutions
- Industry Reluctance
- Negative Associations with "Pre-fabricated" Structures
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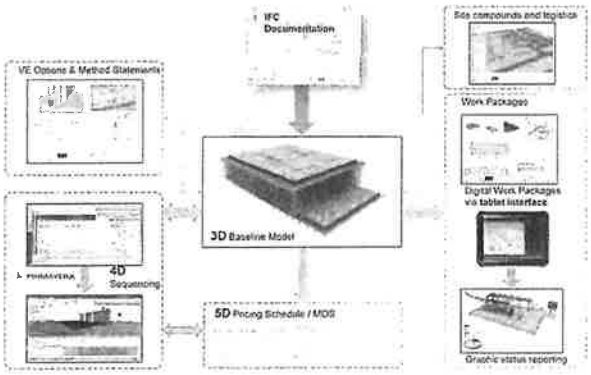
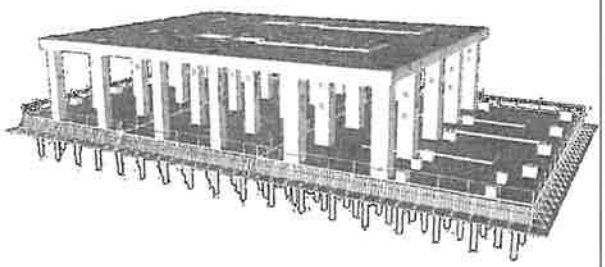
- **Differing Regulations in Different Countries**





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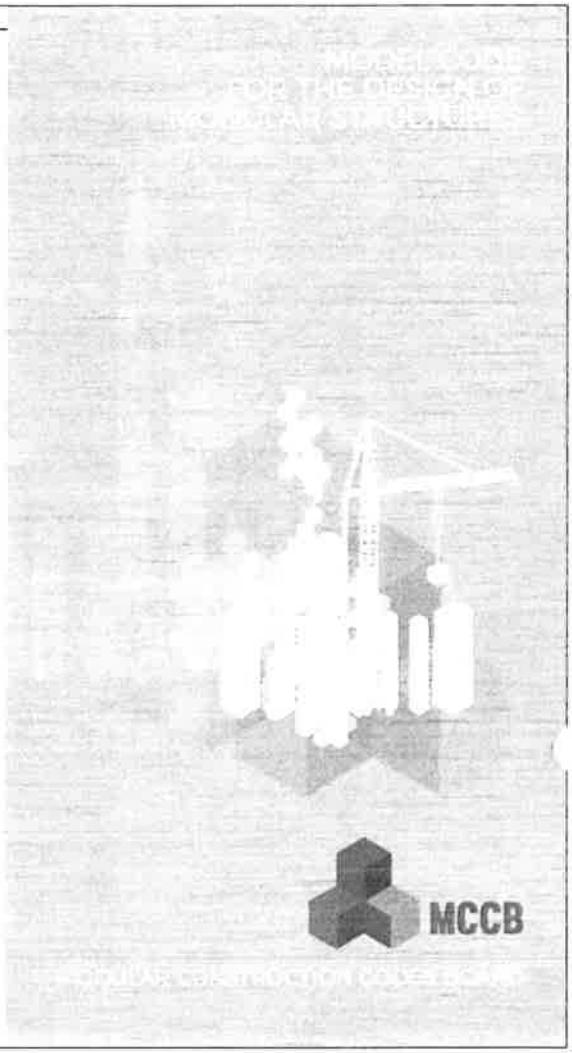
OBSATCLES TO DfMA

Differing Regulations in Different Countries

The Model Code is:

- Applicable to Australia



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OBSATCLES TO DfMA

Differing Regulations in Different Countries

The Model Code is:

- Applicable to Australia

BUT

It is written to be Applicable to:

- Different jurisdictions
- Different countries



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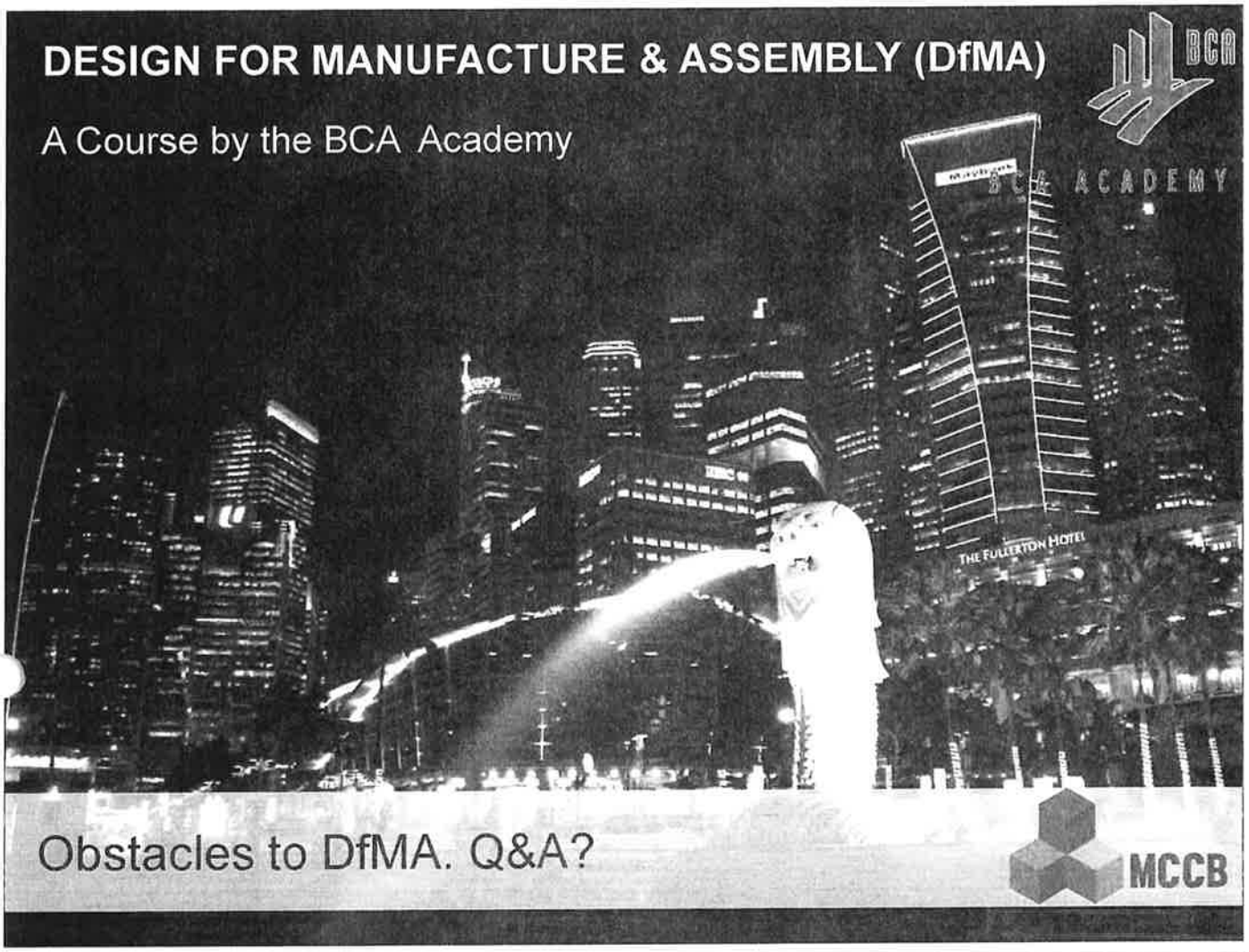
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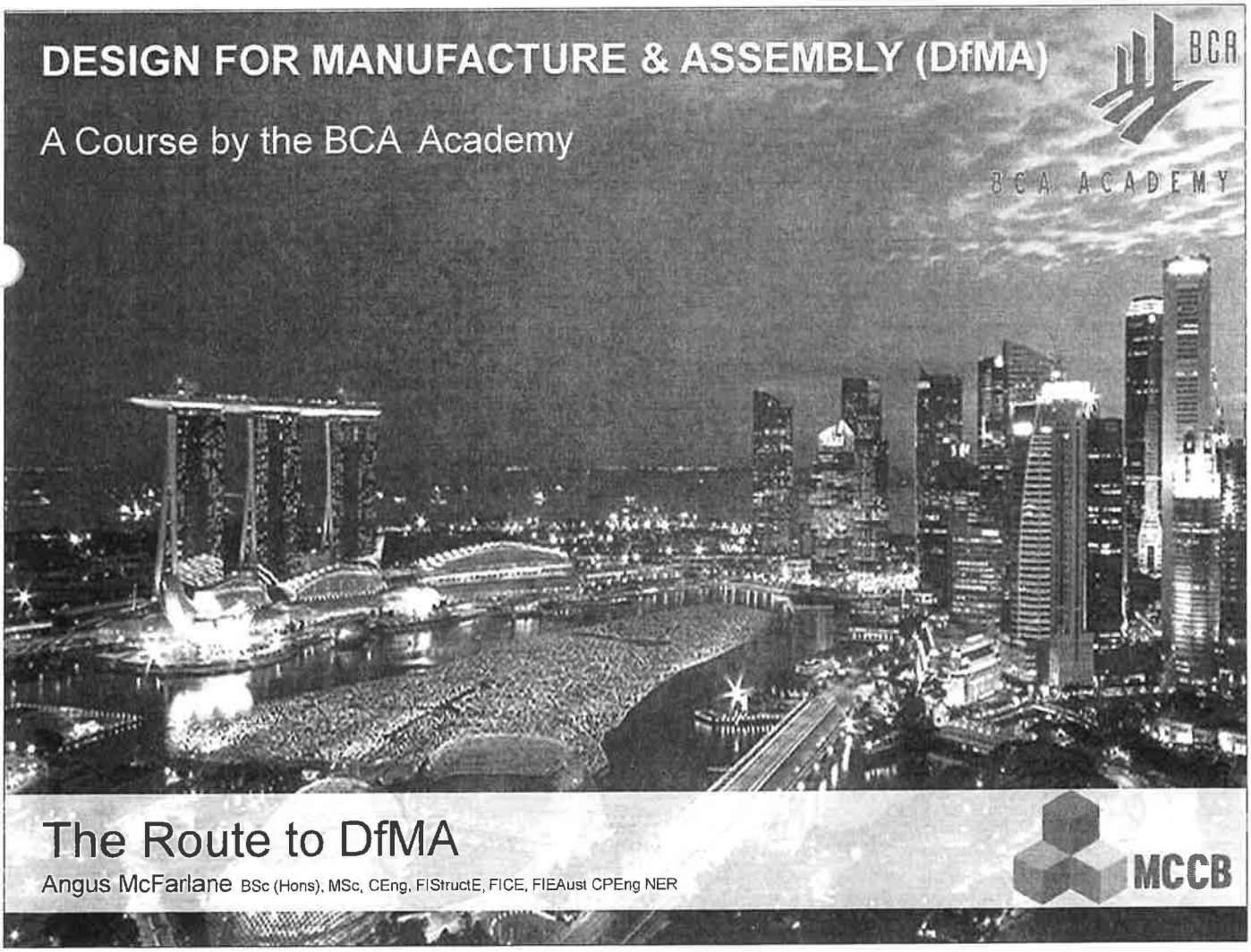
A Course by the BCA Academy
BCA
BCA ACADEMY
THE FULLERTON HOTEL
Obstacles to DfMA. Q&A?
MCCB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The Route to DfMA
Angus McFarlane BSc (Hons), MSc, CEng, FIStructE, FICE, FIEAust CPEng NER
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THE ROUTE TO DfMA
Topics for Discussion

- Keep it Simple
- Investigate Off-site Products
- Example Project
- Establish 3D Methodology
- Digital Design Collaboration

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THE ROUTE TO DfMA
Keep it Simple

Brainstorming

Discuss with the Project Team

- Client, Architects & Engineers
- Include site personnel

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THE ROUTE TO DfMA
Keep it Simple

Brainstorming
Discuss with the Project Team
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Sometimes their ideas are better than yours

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THE ROUTE TO DfMA
Keep it Simple

Brainstorming
Discuss with the Project Team
- Client, Architects & Engineers
- Include site personnel

Sometimes their ideas are better than yours

Determine what can be done

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THE ROUTE TO DfMA
Topics for Discussion

- Keep it Simple
- **Investigate Off-site Products**
- Example Project
- Establish 3D Methodology
- Digital Design Collaboration

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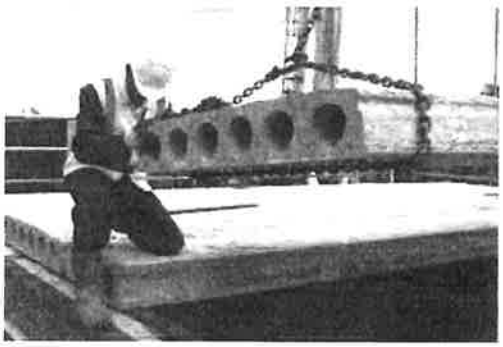
THE ROUTE TO DfMA
Investigate Products for Off-site Manufacture

Use Existing Technology

- Replace insitu with precast





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THE ROUTE TO DfMA

Investigate Products for Off-site Manufacture

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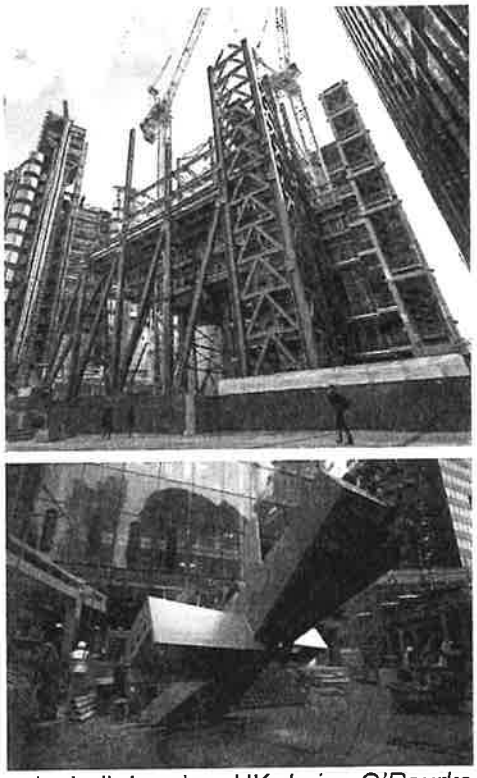
Use Existing Technology

- Replace insitu with precast
- Use efficient steel modules



Leadenhall, London, UK, *Laing O'Rourke*

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THE ROUTE TO DfMA

Investigate Products for Off-site Manufacture

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Use Existing Technology

- Replace insitu with precast
- Use efficient steel modules
- Consider bathroom modules



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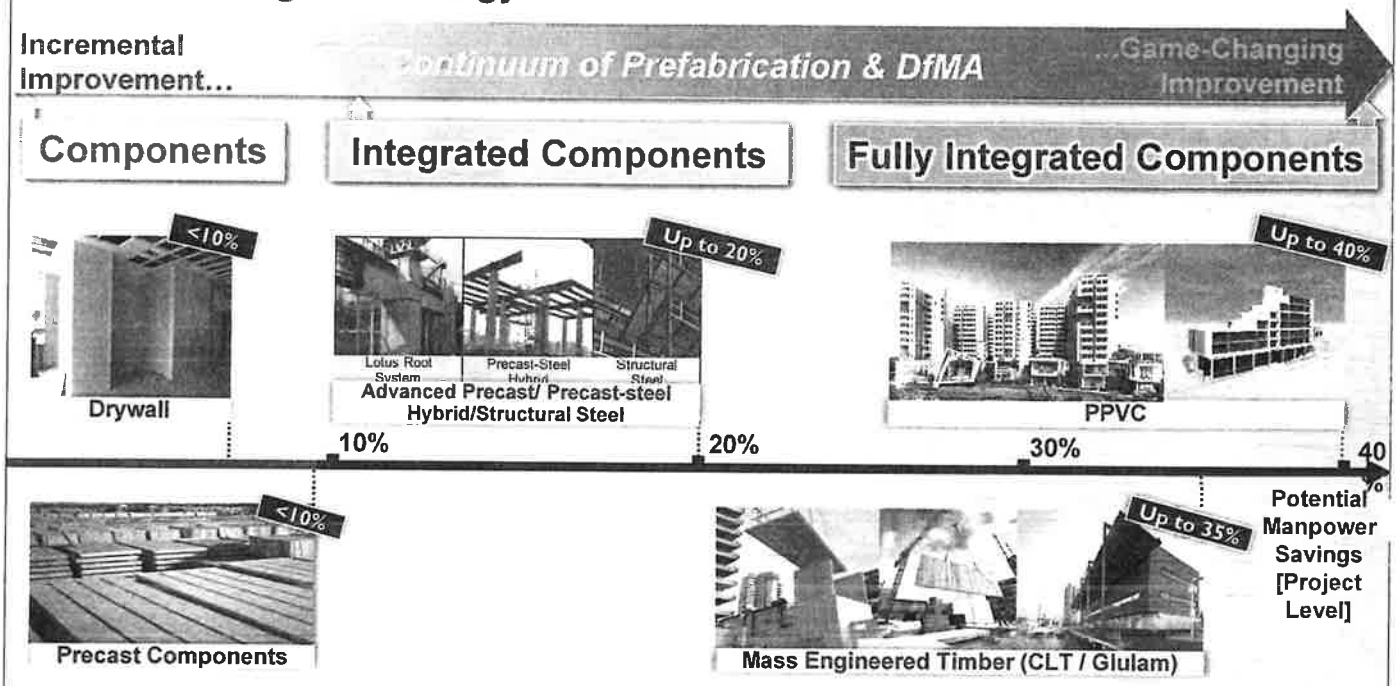
THE ROUTE TO DfMA

Investigate Products for Off-site Manufacture

Use Existing Technology



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Source of Slide: BCA, 2016

THE ROUTE TO DfMA

Topics for Discussion

- Keep it Simple
- Investigate Off-site Products
- **Example Project**
- Establish 3D Methodology
- Digital Design Collaboration

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THE ROUTE TO DfMA
Example Project

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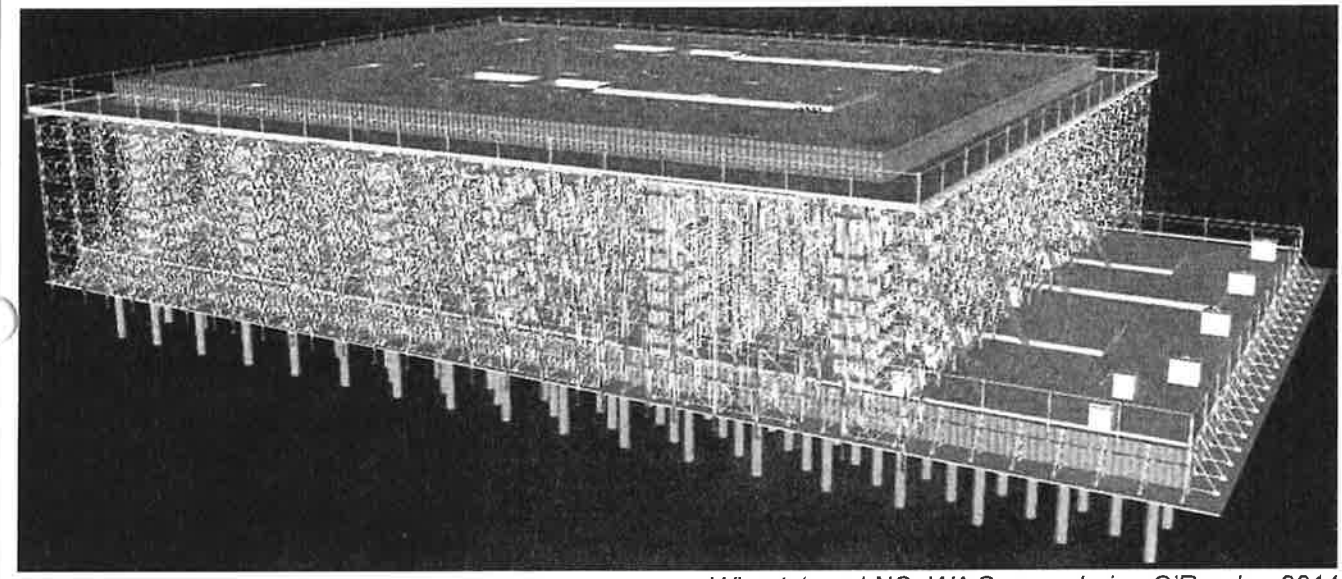
Wheatstone LNG Train

- Traditional construction: Insitu RC Columns & Slab
- Significant shuttering & falsework



Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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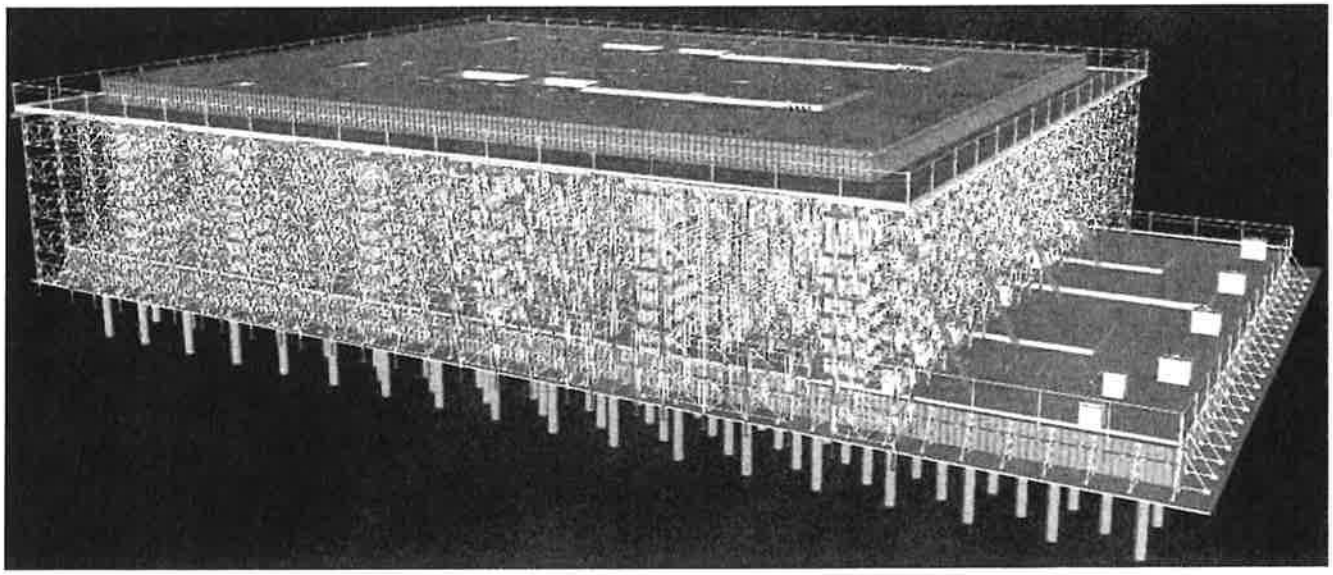
THE ROUTE TO DfMA
Example Project

MCCB

Wheatstone LNG Train

- Traditional construction: Insitu RC Columns & Slab
- Significant shuttering & falsework

Could be Improved



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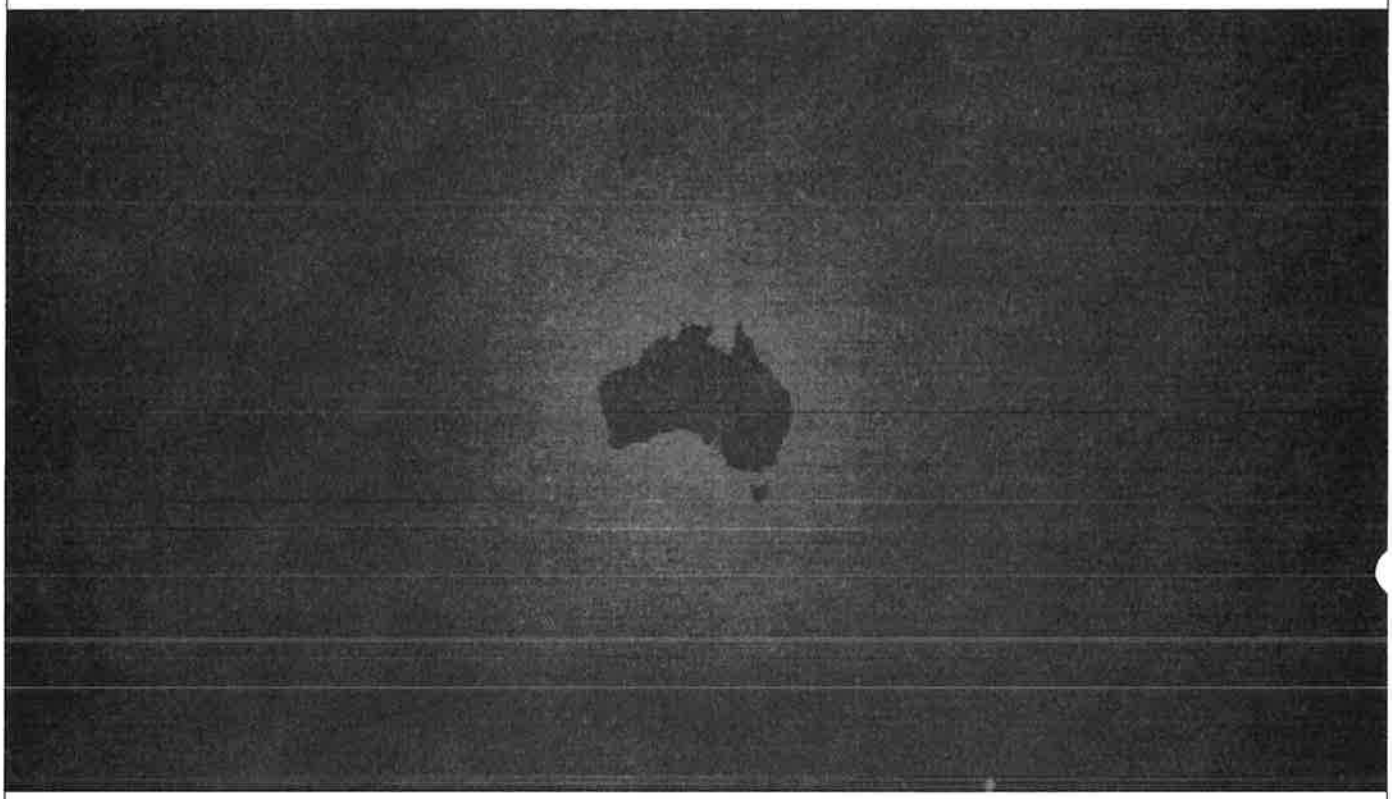
THE ROUTE TO DfMA
Example Project



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THE ROUTE TO DfMA
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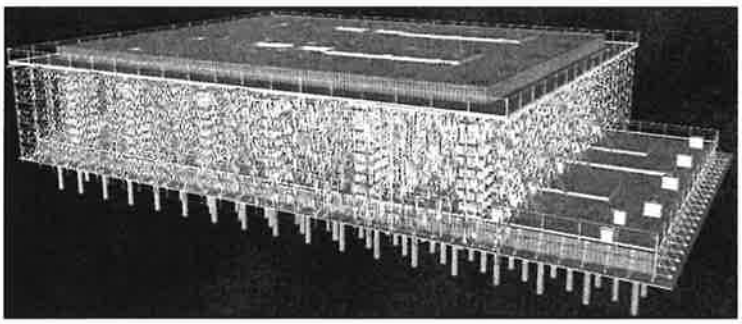


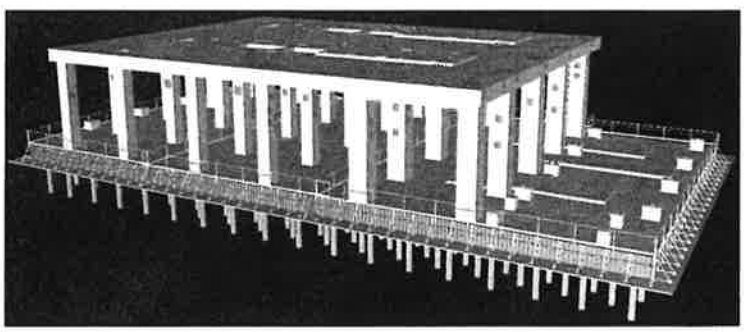
Traditional Construction

- **185 days** overall
- **122 days** superstructure

DfMA Construction

- **120 days** overall
- **61 days** superstructure

50% programme saving



Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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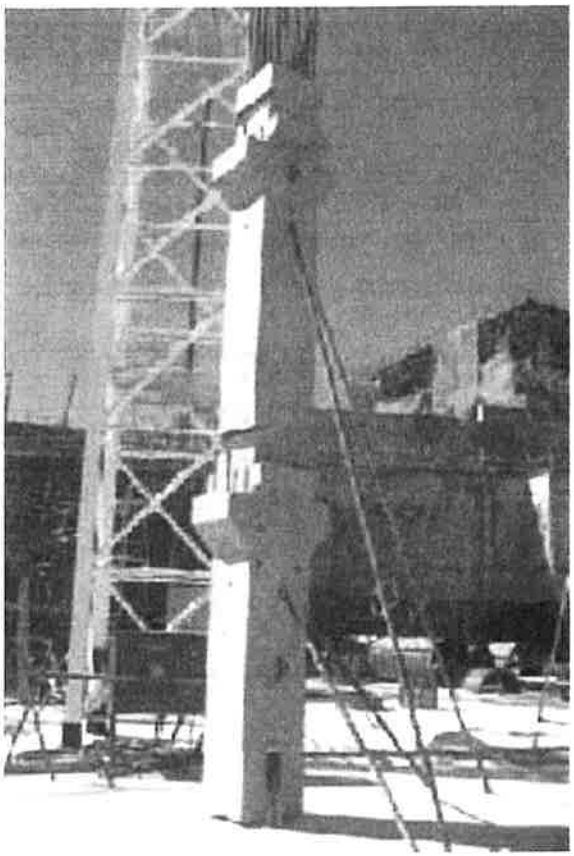
THE ROUTE TO DfMA
Example Project

MCCB



50% Programme Saving
Summary: How it was Done
- PC columns

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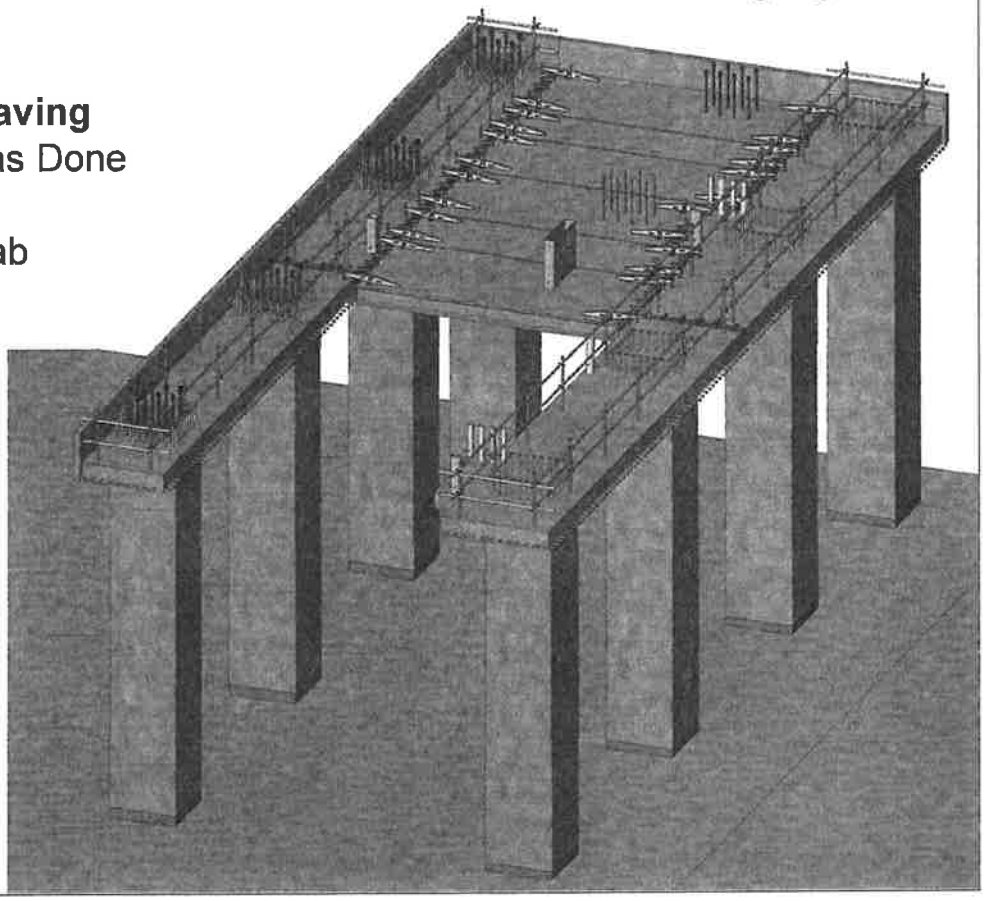
THE ROUTE TO DfMA
Example Project

MCCB



50% Programme Saving
Summary: How it was Done
- PC columns
- PC composite slab

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THE ROUTE TO DfMA
Example Project

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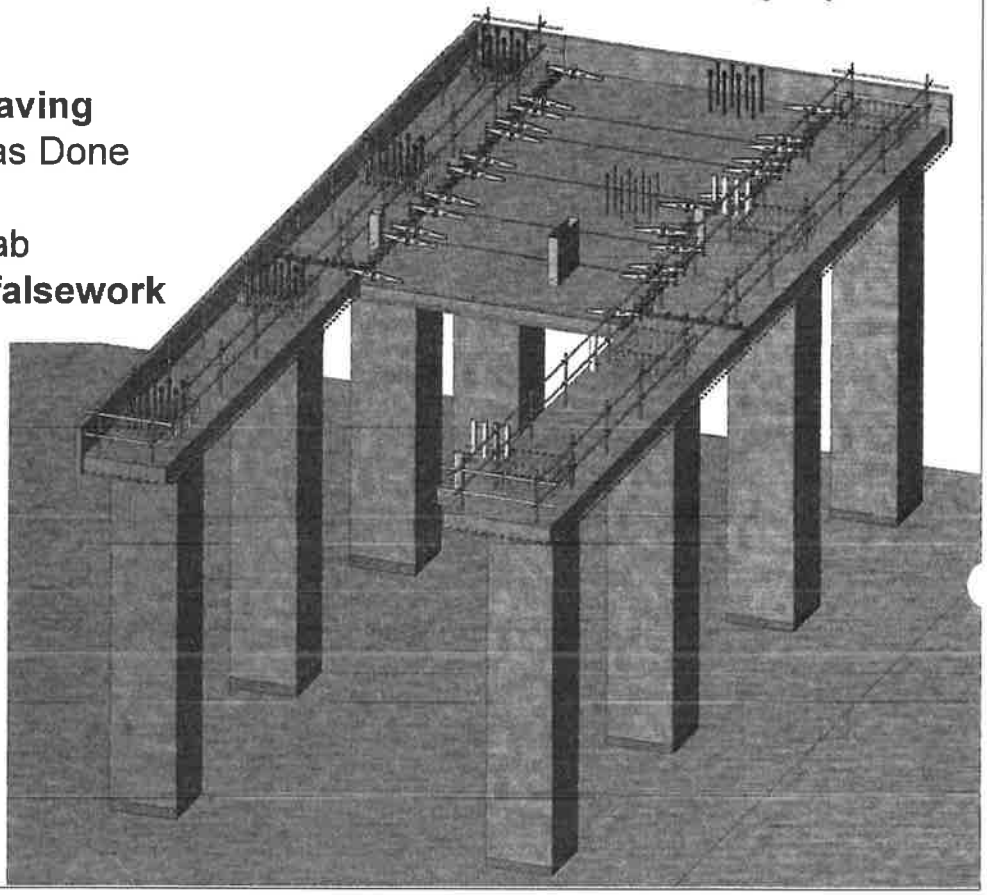
50% Programme Saving

Summary: How it was Done

- PC columns
- PC composite slab

No shuttering. No falsework



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THE ROUTE TO DfMA
Example Project

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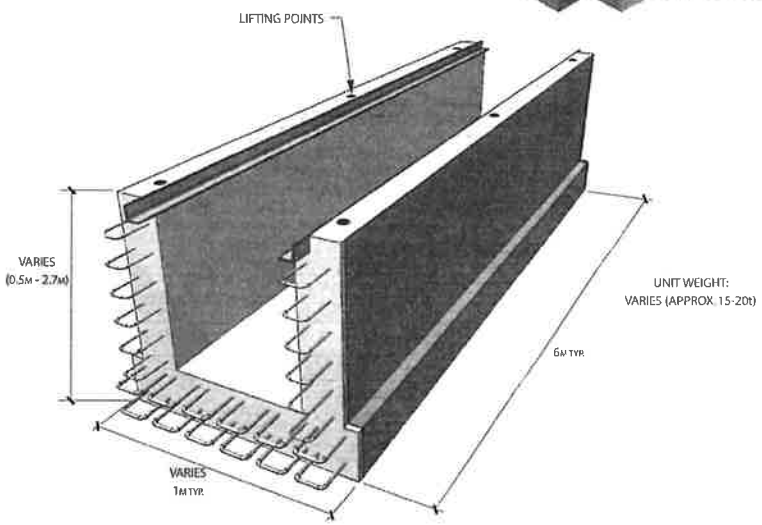
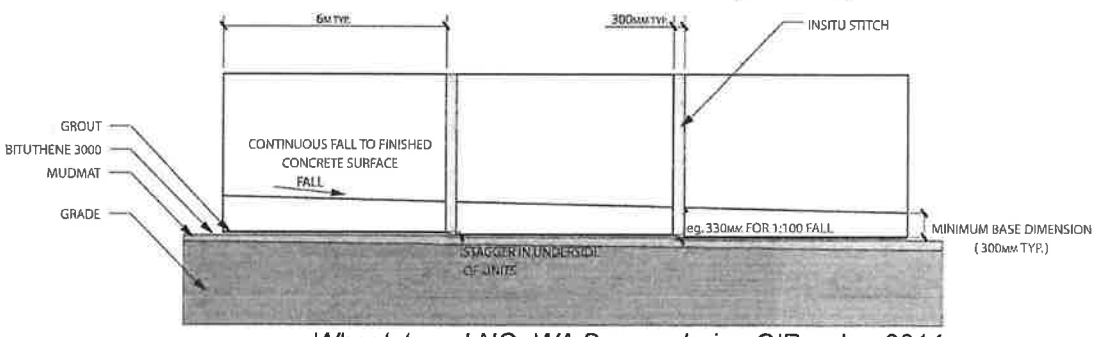
Culverts

PC Also Saved Time & Cost





Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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THE ROUTE TO DfMA
Example Project

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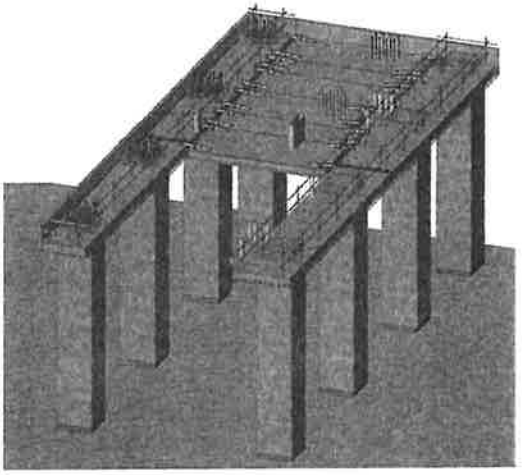
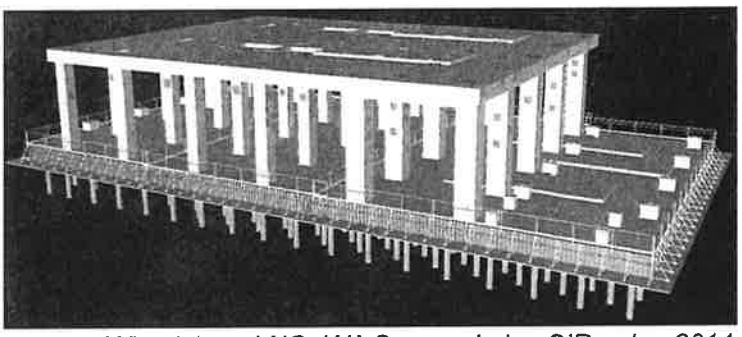
50% Programme Saving
Summary: How it was Done
- Used existing technology

3D DfMA Model was used:
- Because we already had it





Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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THE ROUTE TO DfMA
Example Project

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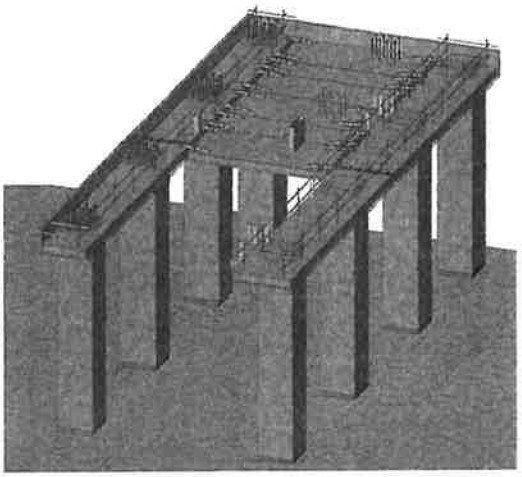
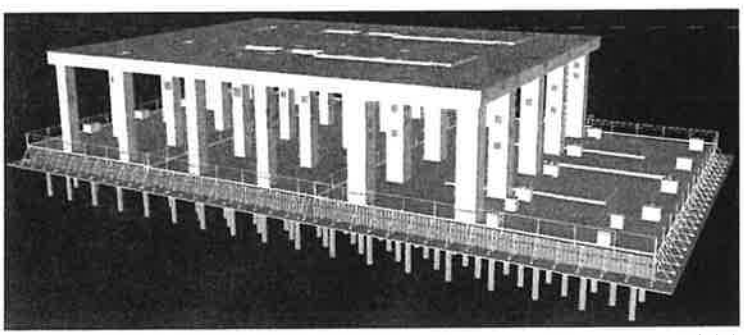
50% Programme Saving
Summary: How it was Done
- Used existing technology

3D DfMA Model was used:
- Because we already had it

Could have been do with 2D CAD





Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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THE ROUTE TO DfMA
Topics for Discussion

- Keep it Simple
- Investigate Off-site Products
- Example Project
- **Establish 3D Methodology**
- Digital Design Collaboration

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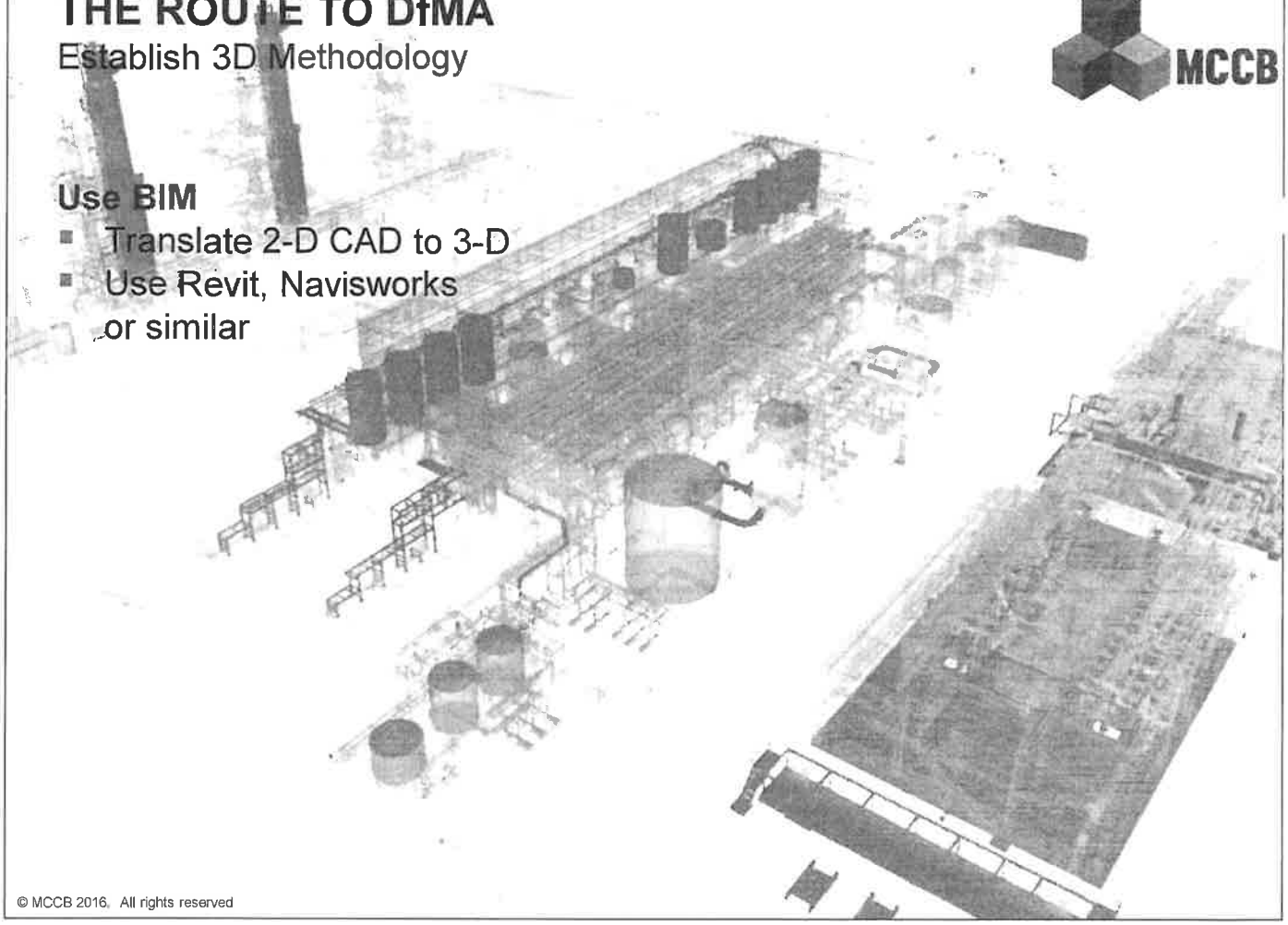
THE ROUTE TO DfMA
Establish 3D Methodology

Use BIM

- Translate 2-D CAD to 3-D
- Use Revit, Navisworks or similar



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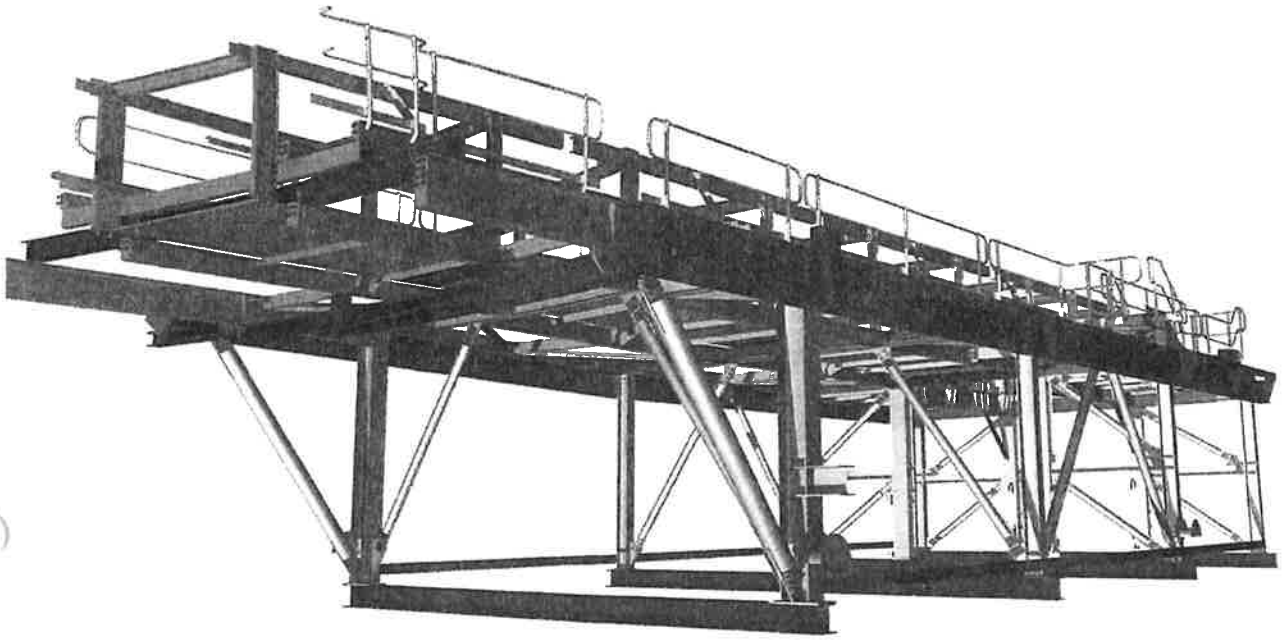
THE ROUTE TO DfMA

Establish 3D Methodology



3D Model of Steelwork Module, Cape Lambert, WA Source: Laing O'Rourke, 2014

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THE ROUTE TO DfMA

Establish 3D Methodology

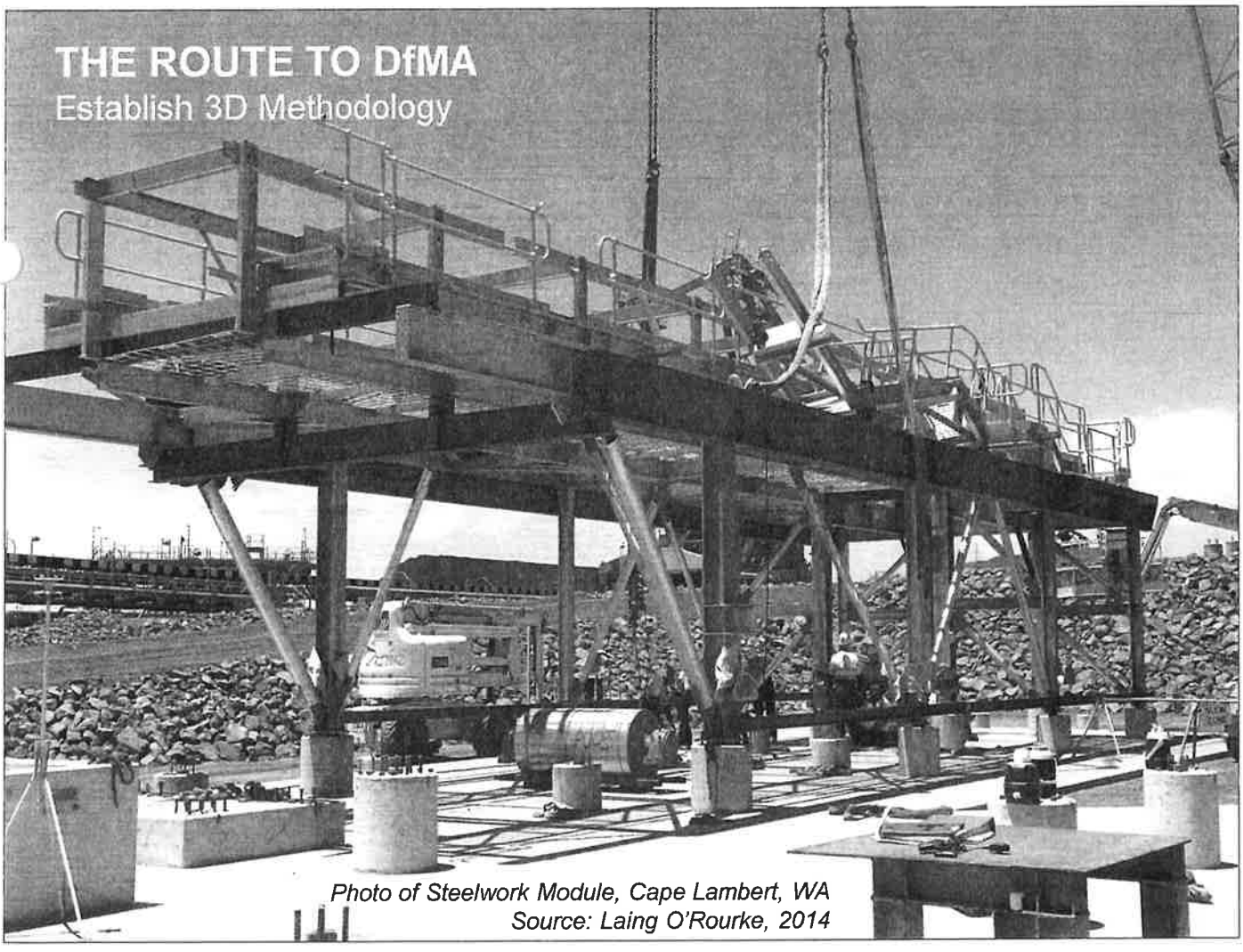

Photo of Steelwork Module, Cape Lambert, WA
Source: Laing O'Rourke, 2014

THE ROUTE TO DfMA
Topics for Discussion

- Keep it Simple
- Investigate Off-site Products
- Example Project
- Establish 3D Methodology
- **Digital Design Collaboration**

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THE ROUTE TO DfMA
Digital Design Collaboration

Move from 2-D drawing production to:

- 3-D design collaboration
- 4-D construction planning
- 5-D quantification & costing

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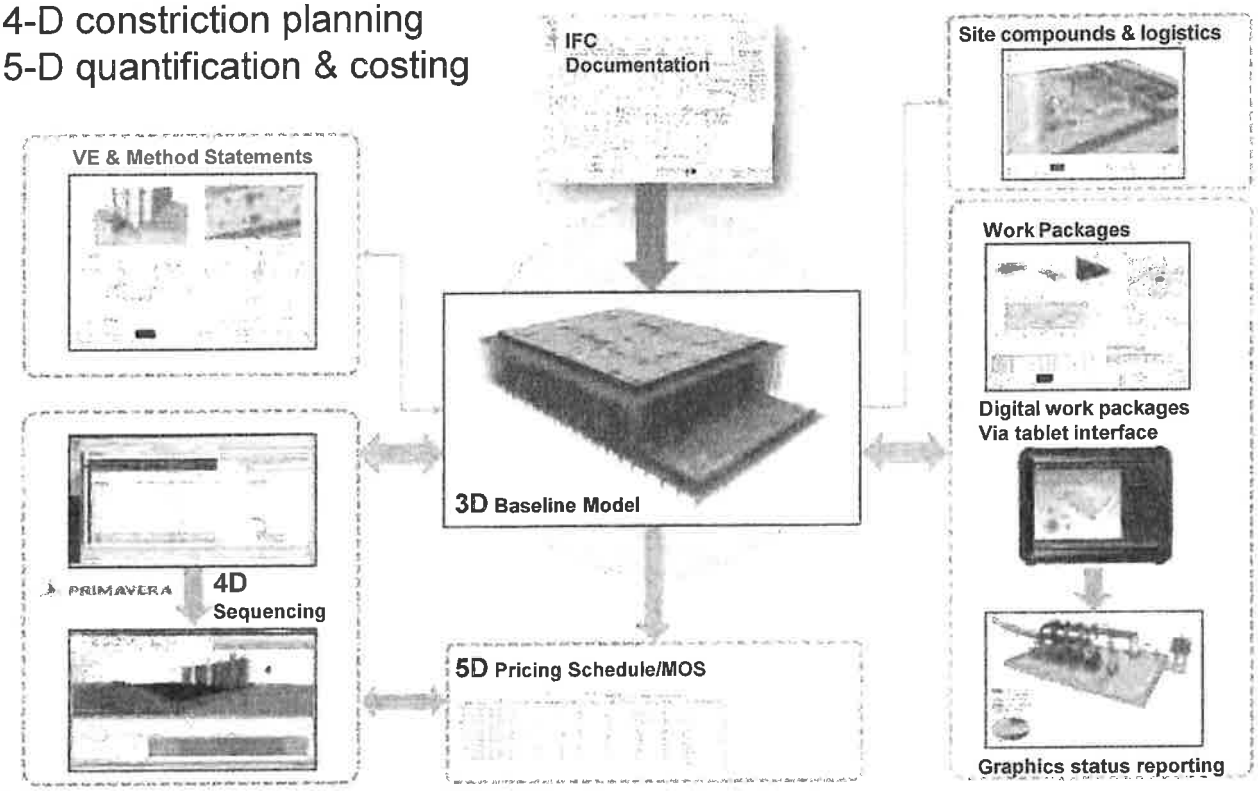
THE ROUTE TO DfMA

Digital Design Collaboration

Move from 2-D drawing production to:

- 3-D design collaboration
- 4-D constriction planning
- 5-D quantification & costing



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THE ROUTE TO DfMA

Conclusions

- Keep it simple
- Use existing technology
- Move to digital design collaboration

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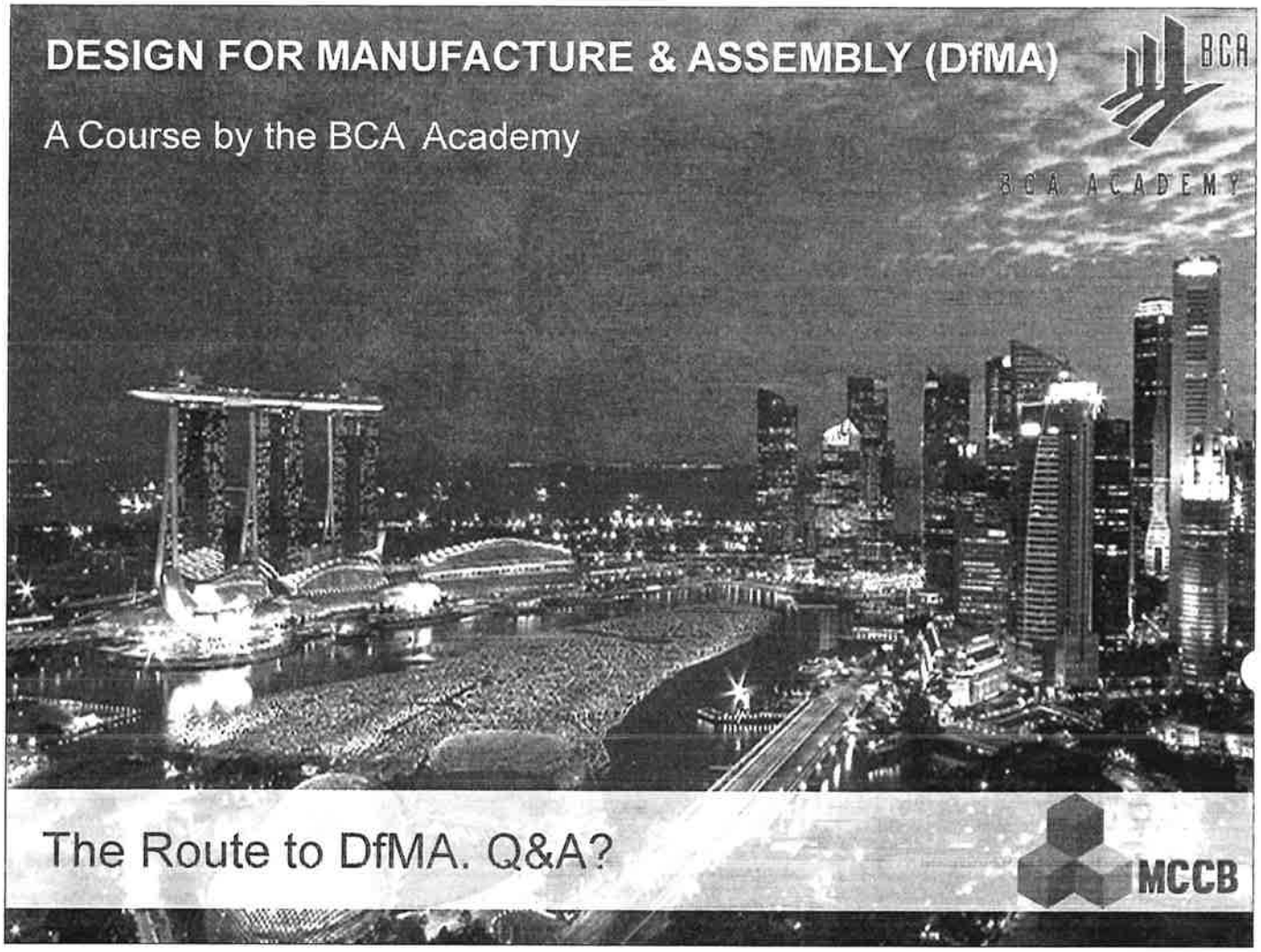
DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)
A Course by the BCA Academy
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The Route to DfMA. Q&A?
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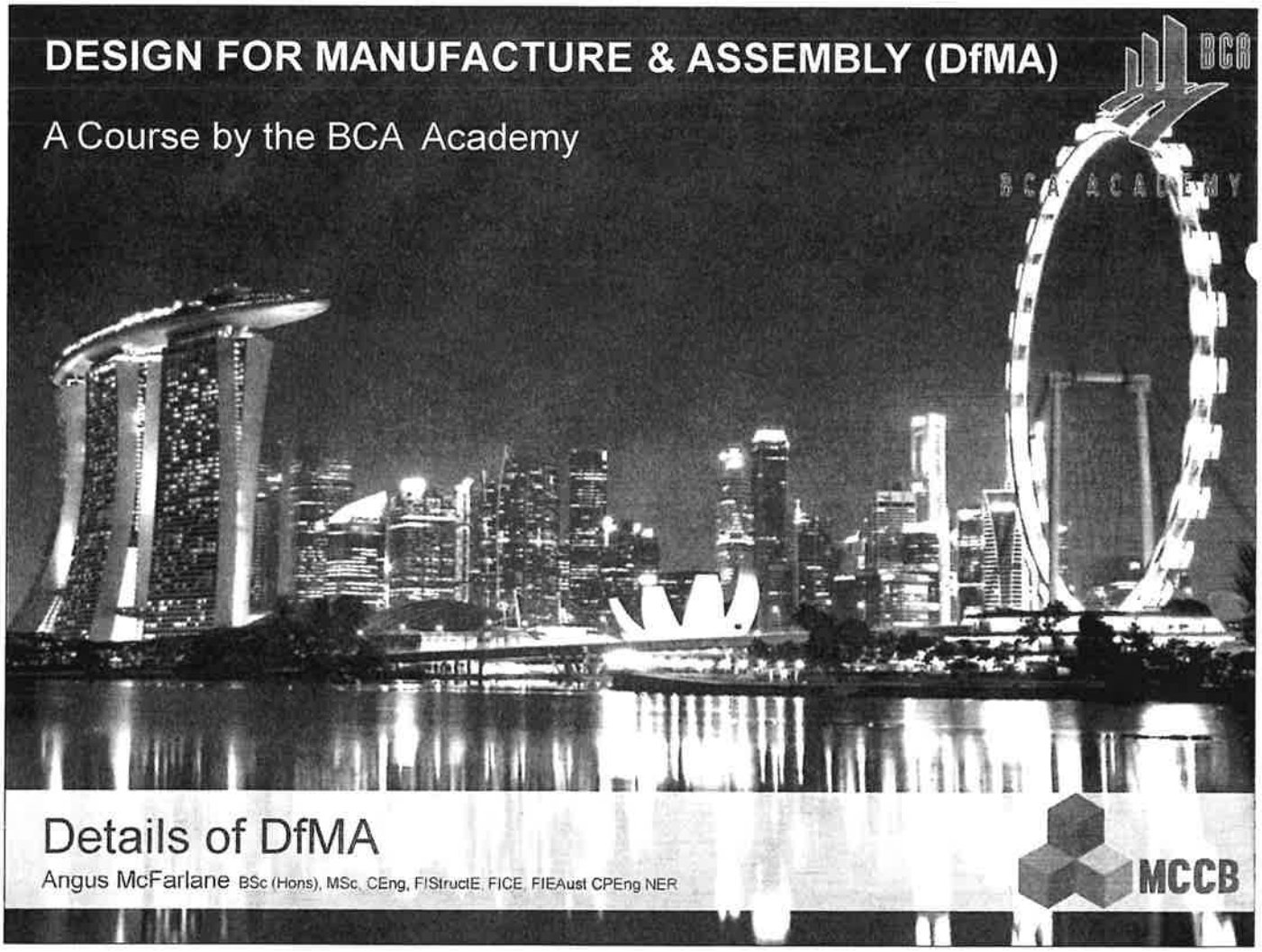
DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)
A Course by the BCA Academy
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Details of DfMA
Angus McFarlane BSc (Hons), MSc, CEng, FIStructE, FICE, FIEAust CPEng NER
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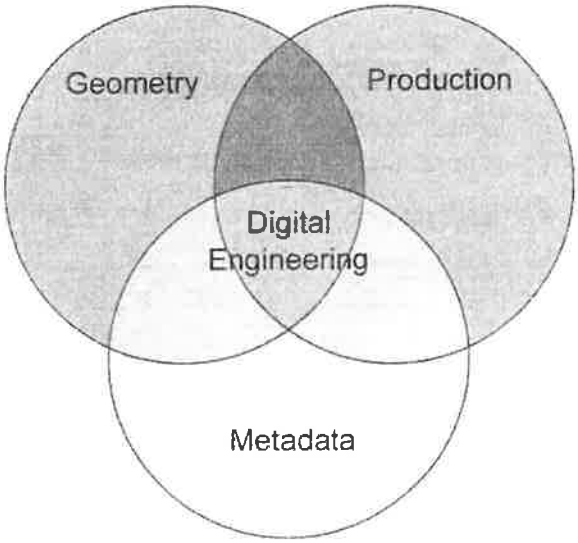
DETAILS OF DfMA
Topics for Discussion

- DfMA can be Simple
- The DfMA Envelope
- Geometry
- Production
- Metadata
- Summary
- Conclusions



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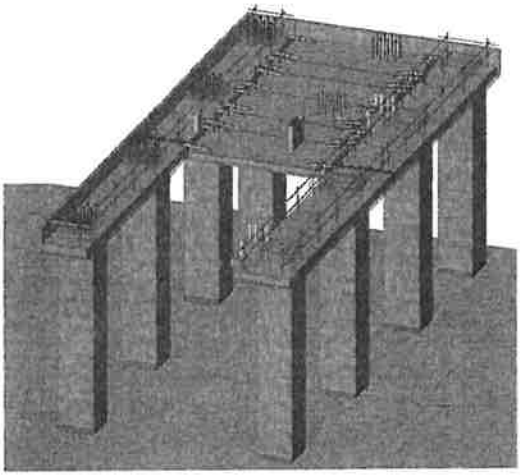
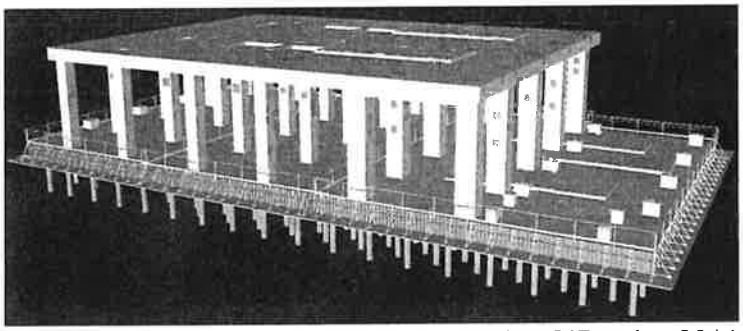
DETAILS OF DfMA
DfMA can be Simple

As Described in Other Presentations

DfMA is a *"Thought Process"*

- It can be simple to implement
- Using existing technology





Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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DETAILS OF DfMA
Topics for Discussion

- DfMA can be Simple
- **The DfMA Envelope**
- Geometry
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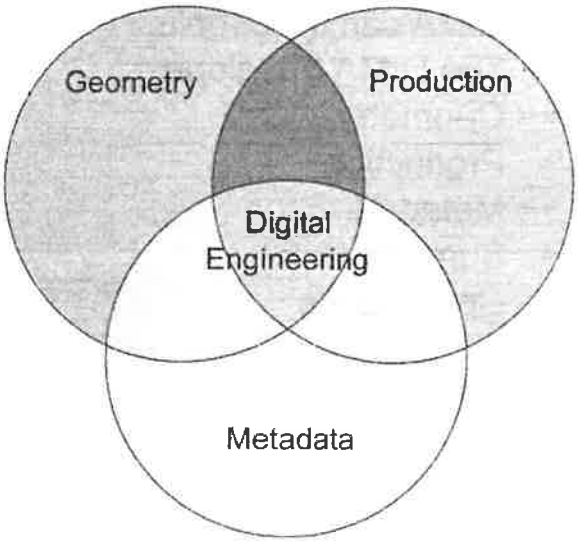
- Conclusions



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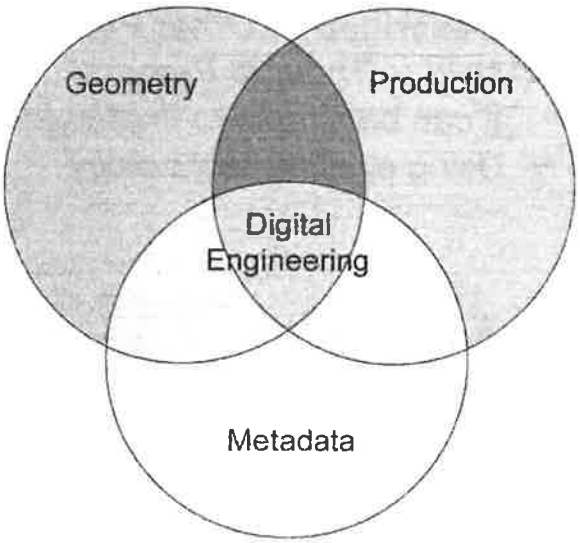
DETAILS OF DfMA
The DfMA Envelope

No Universal Definition of DfMA

DfMA & Modular Construction

- Often used interchangeably



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DETAILS OF DfMA

The DfMA Envelope

No Universal Definition of DfMA

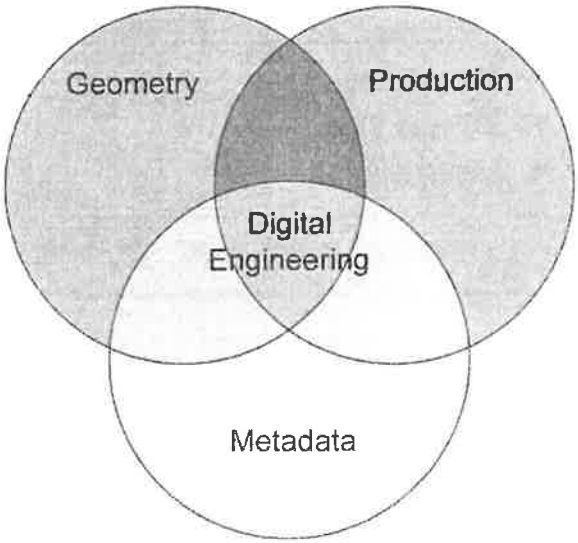
DfMA & Modular Construction

- Often used interchangeably

However

More explicit definition is:

- Modular Construction is part of DfMA



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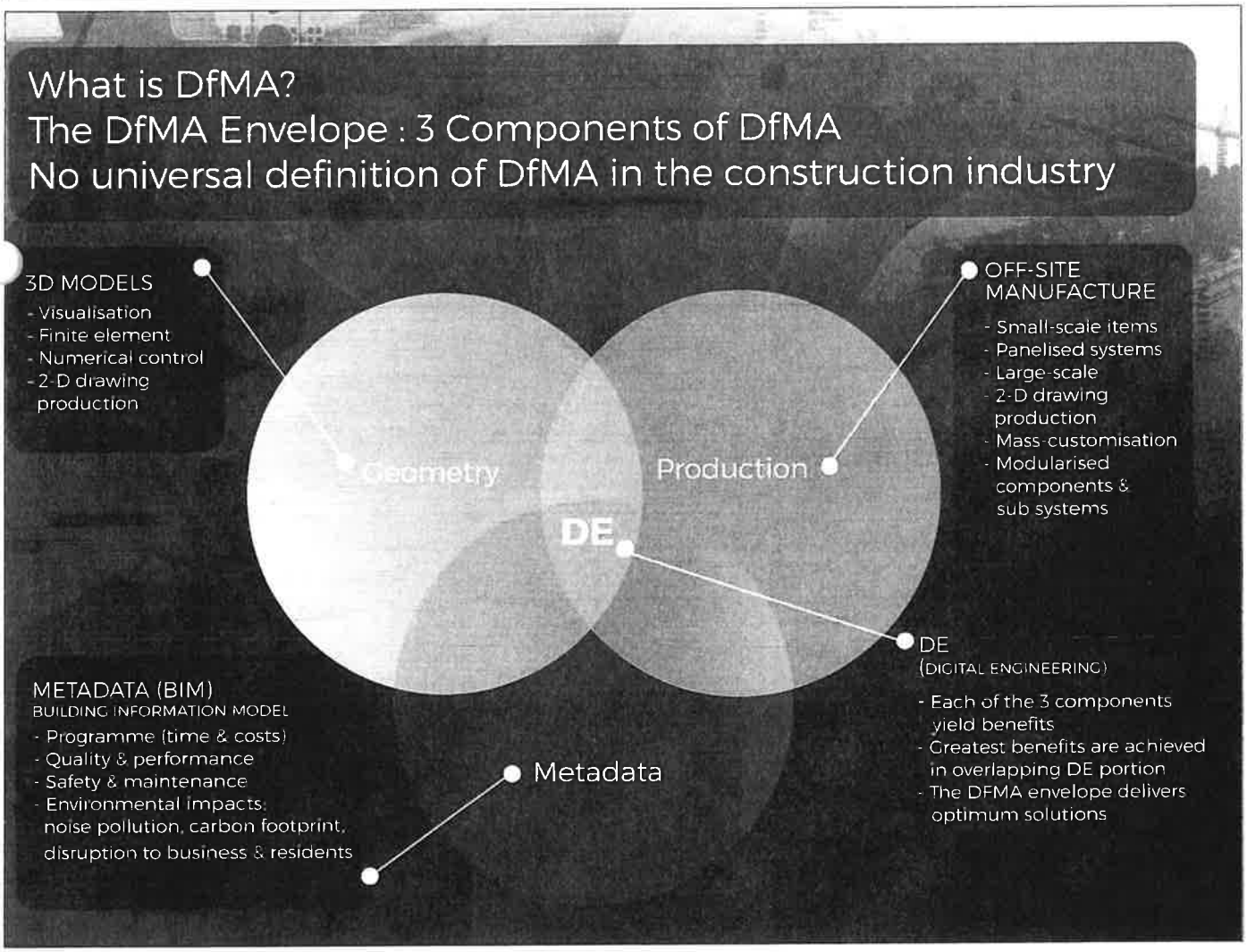
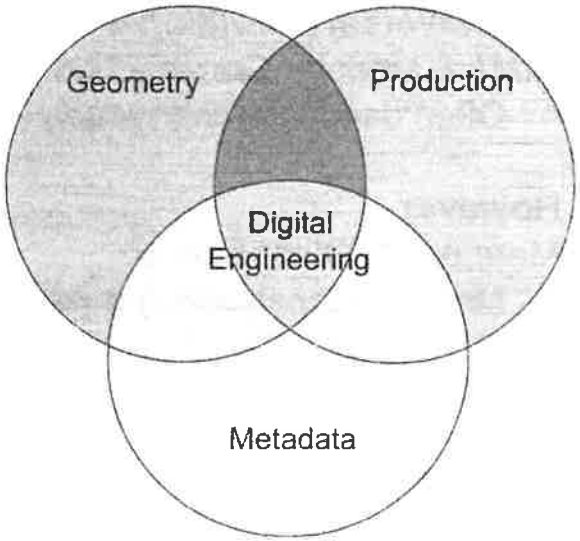
What is DfMA?
The DfMA Envelope : 3 Components of DfMA
No universal definition of DfMA in the construction industry



DETAILS OF DfMA
The DfMA Envelope

Key Components of DfMA
- Geometry
- Production
- Metadata



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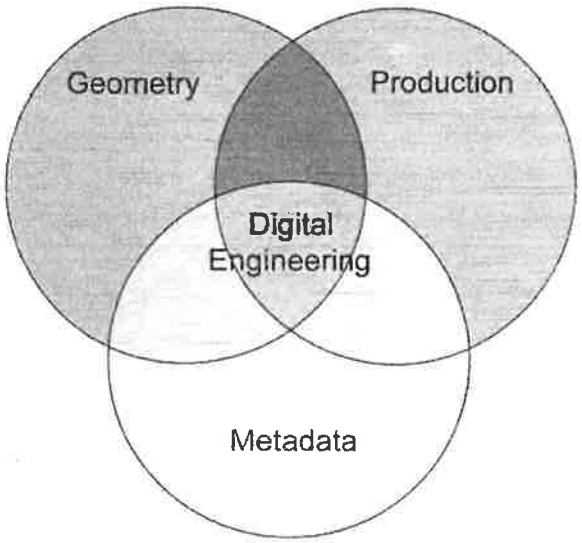
DETAILS OF DfMA
The DfMA Envelope

Key Components of DfMA
- Geometry
- Production
- Metadata

DfMA Process Facilitated By:
- Low-cost, high-performance computer hardware & software



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DETAILS OF DfMA
Topics for Discussion

- DfMA can be Simple
- The DfMA Envelope
- **Geometry**
- Production
- Metadata
- Summary
- Conclusions

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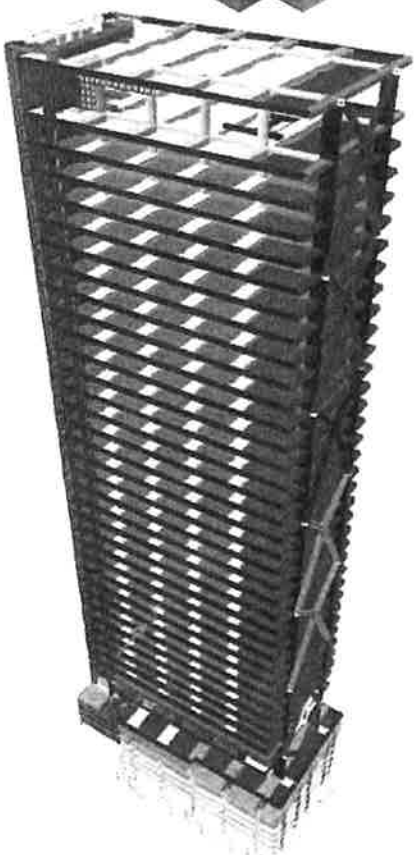
DETAILS OF DfMA
Geometry

Geometry Model is 3D Virtual Reality Model
Technical & Non-technical staff can:

- Visually understand & interrogate the design intent



Typical Geometry Model

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DETAILS OF DfMA
Geometry

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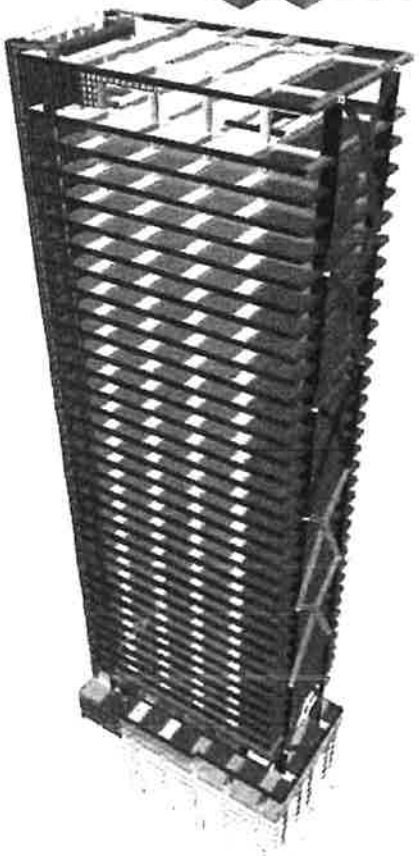
Geometry Model is 3D Virtual Reality Model
Technical & Non-technical staff can:
- Visually understand & interrogate the design intent

Main Components are:
- Architects 3D models
- Engineers finite element models
- Fabricators CNC models



Typical Geometry Model

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DETAILS OF DfMA
Geometry

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Geometry Model is 3D Virtual Reality Model
Technical & Non-technical staff can:
- Visually understand & interrogate the design intent

Main Components are:
- Architects 3D models
- Engineers finite element models
- Fabricators CNC models

Geometry Model Also used For:
2D drawing production for non-automated processes:
- Statutory authority approvals
- Third-party manufacture
- Small-scale items



Typical Geometry Model

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DETAILS OF DfMA
Topics for Discussion

- DfMA can be Simple
- The DfMA Envelope
- Geometry
- **Production**
- Metadata
- Summary
- Conclusions

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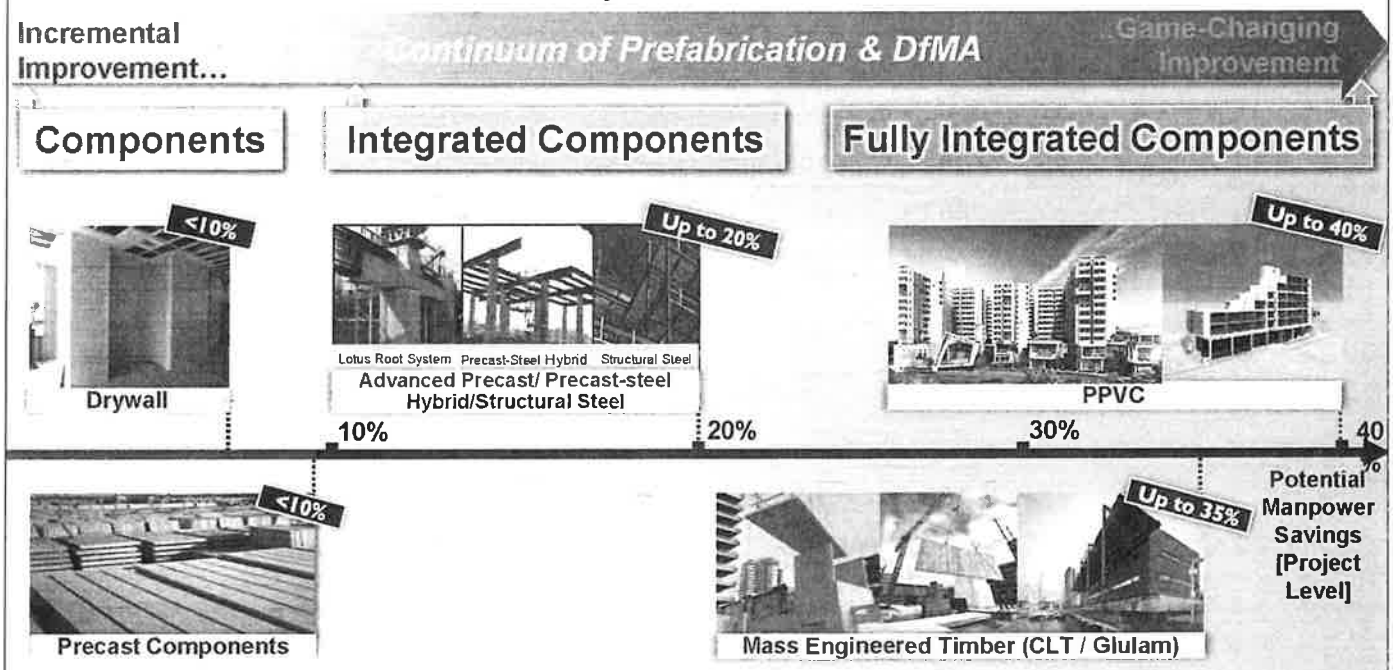
DETAILS OF DfMA
Production

DfMA Production is:
Off-site Manufacture in a Factory Environment



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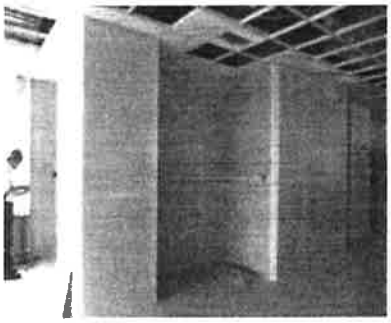
DETAILS OF DfMA
Production

DfMA Production is:
Off-site Manufacture in a Factory Environment

Modules (Components) can be:
- Small-scale
  - electrical fittings
- Large-scale
  - PC floors & walls
  - Drywall



Drywall



Precast Components

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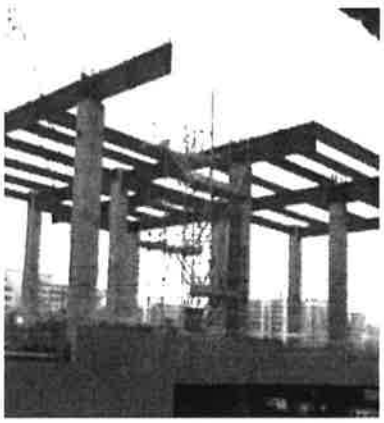
DETAILS OF DfMA
Production

DfMA Production is:
Off-site Manufacture in a Factory Environment

Modules can be:
Integrated components
- Structural steel
- Precast Concrete(PC)
- Hybrid PC/Steel



Structural Steel



Hybrid PC/ Steel

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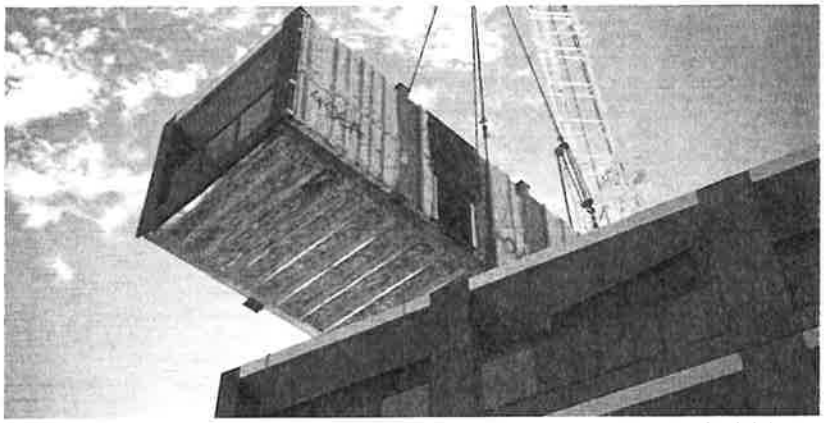
DETAILS OF DfMA
Production

DfMA Production is:
Off-site Manufacture in a Factory Environment

Modules can be:
Volumetric
- Prefabricated Preformed Volumetric Construction (PPVC)





Bosisto St, Richmond, Melbourne, Hickory Building Systems, 2012

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DETAILS OF DfMA
Topics for Discussion

- DfMA can be Simple
- The DfMA Envelope
- Geometry
- Production
- **Metadata**
- Summary
- Conclusions

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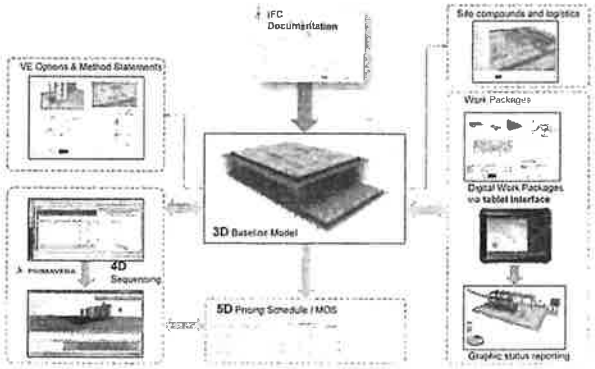
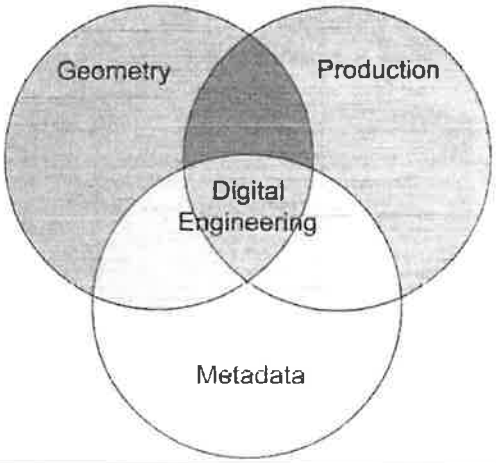
DETAILS OF DfMA
Metadata

Multi-dimensional Database
Contains all relevant project parameters

Used to Calculate Impacts of:
- Time
- Sequencing
- Cost





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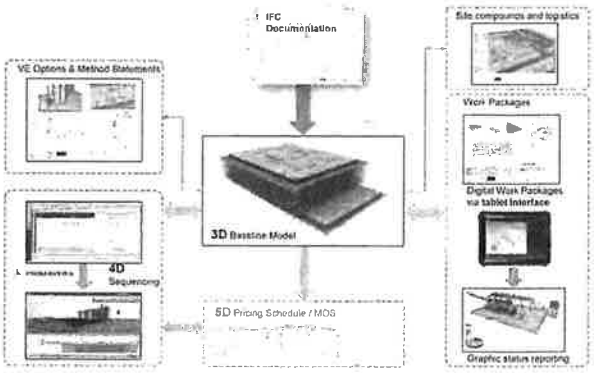
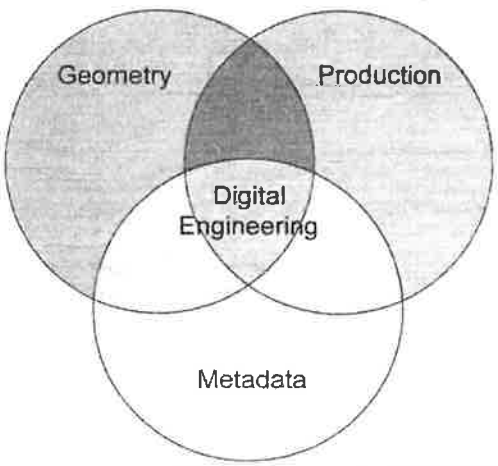
DETAILS OF DfMA
Metadata

Multi-dimensional Database
Contains all relevant project parameters

Used to Calculate Impacts of:
- Time
- Sequencing
- Cost

Can Also Analyse Other Impacts:
- Environmental
- Waste reduction
- Error avoidance





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DETAILS OF DfMA
Conclusions

- DfMA can be relatively simple

BUT

The greatest benefits are achieved by:

- 3 Spheres of DfMA
  - Geometry
  - Production
  - Metadata

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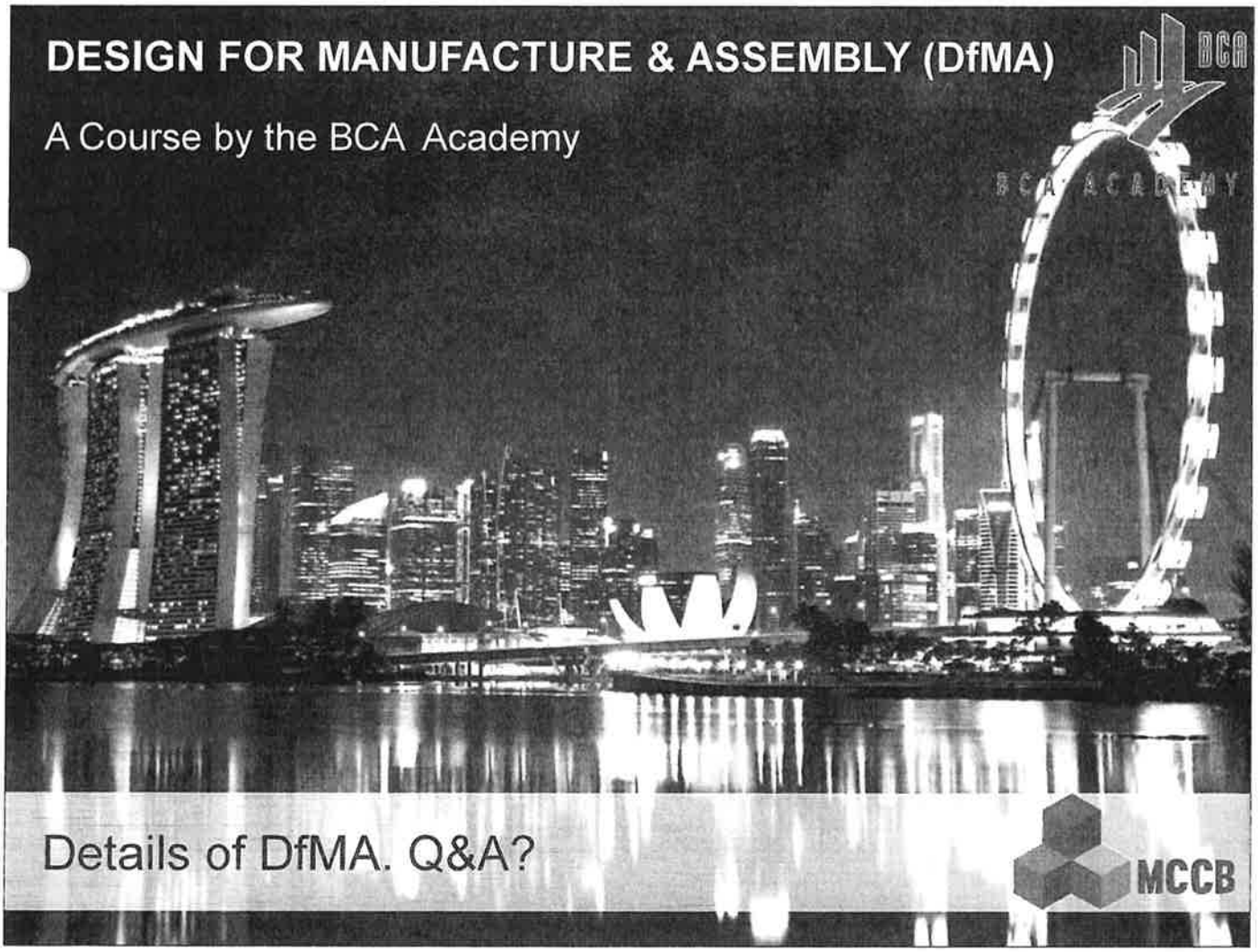
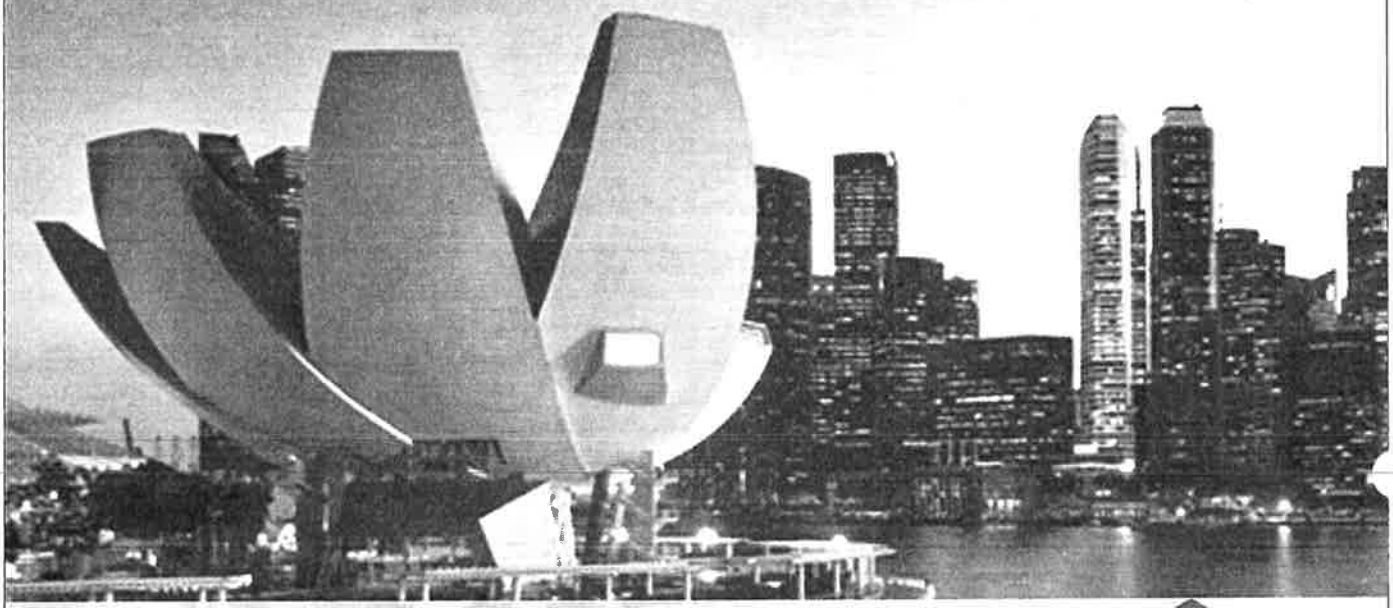


DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)

A Course by the BCA Academy

BCA ACADEMY



Off-site Production

Angus McFarlane BSc (Hons), MSc, CEng, FIStructE, FICE, FIEAust CPEng NER

MCCB

OFF-SITE PRODUCTION

Topics for Discussion

MCCB

- Overview
- Components (Processed Materials)
- Fabricated Components
- Panelised (Integrated) Components
- Volumetric Construction (PPVC)
- Conclusions

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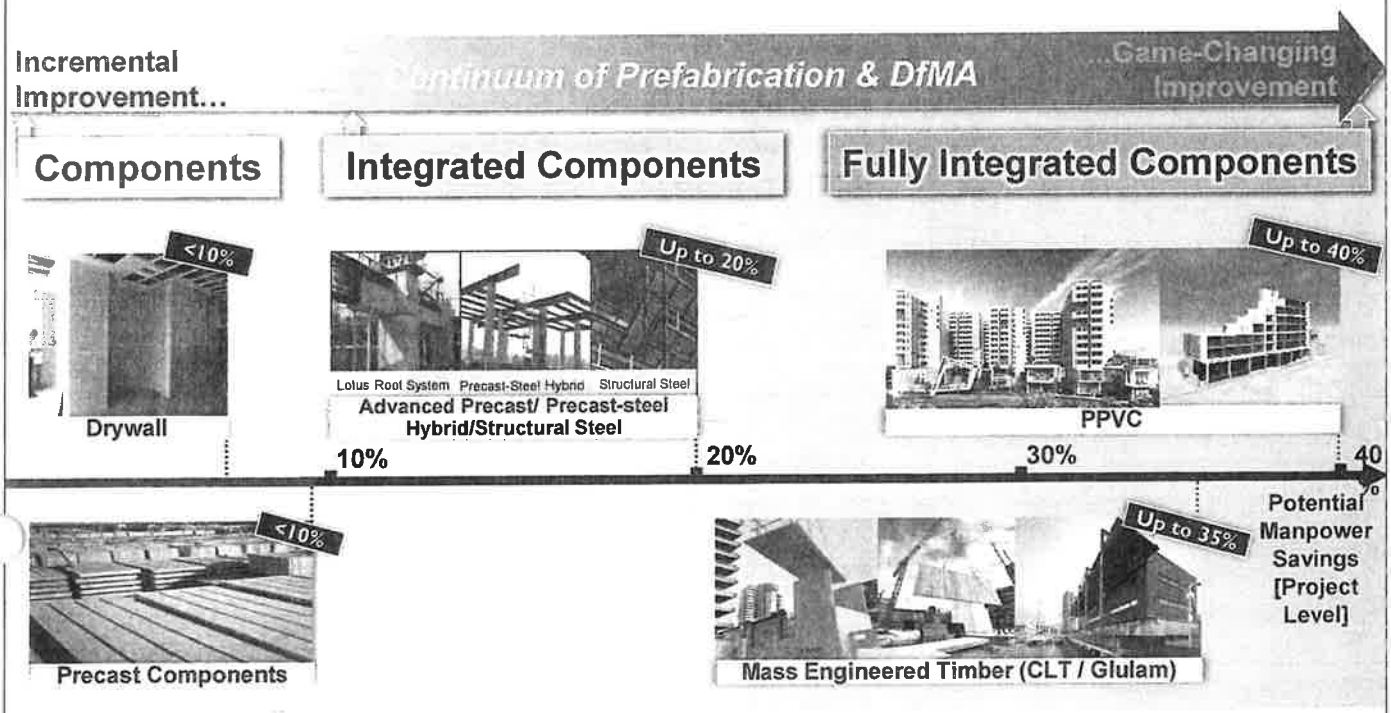
OFF-SITE PRODUCTION

Overview

Continuum of Prefabrication & DfMA



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Source of Slide: BCA, 2016

OFF-SITE PRODUCTION

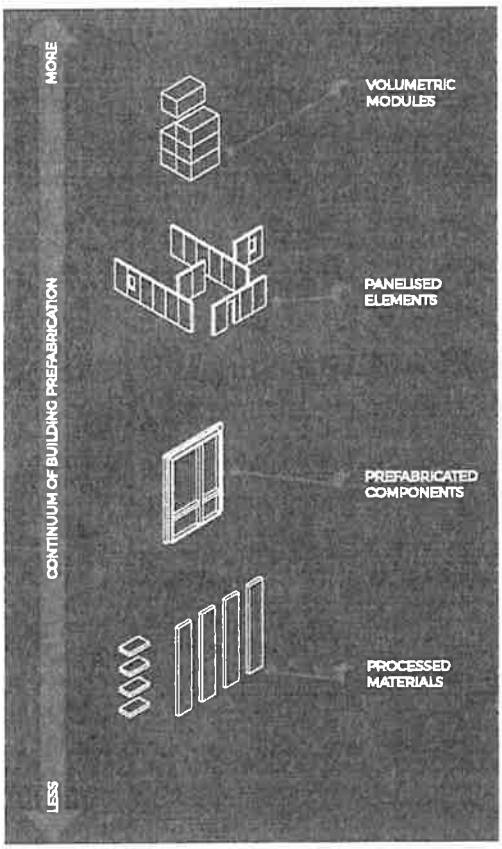
Overview

Continuum of Prefabrication & DfMA

The Model Code Definition of Continuum is similar to BCA

Continuum ranges from:

- Components (Processed Materials)
- Fabricated Components
- Panelised (Integrated) Components
- Volumetric Construction (PPVC)



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Source: Model Code for the Design of Modular Structures, 2016

OFF-SITE PRODUCTION

Topics for Discussion

- Overview
- **Components (Processed Materials)**
- Fabricated Components
- Panelised (Integrated) Components
- Volumetric Construction (PPVC)
- Conclusions

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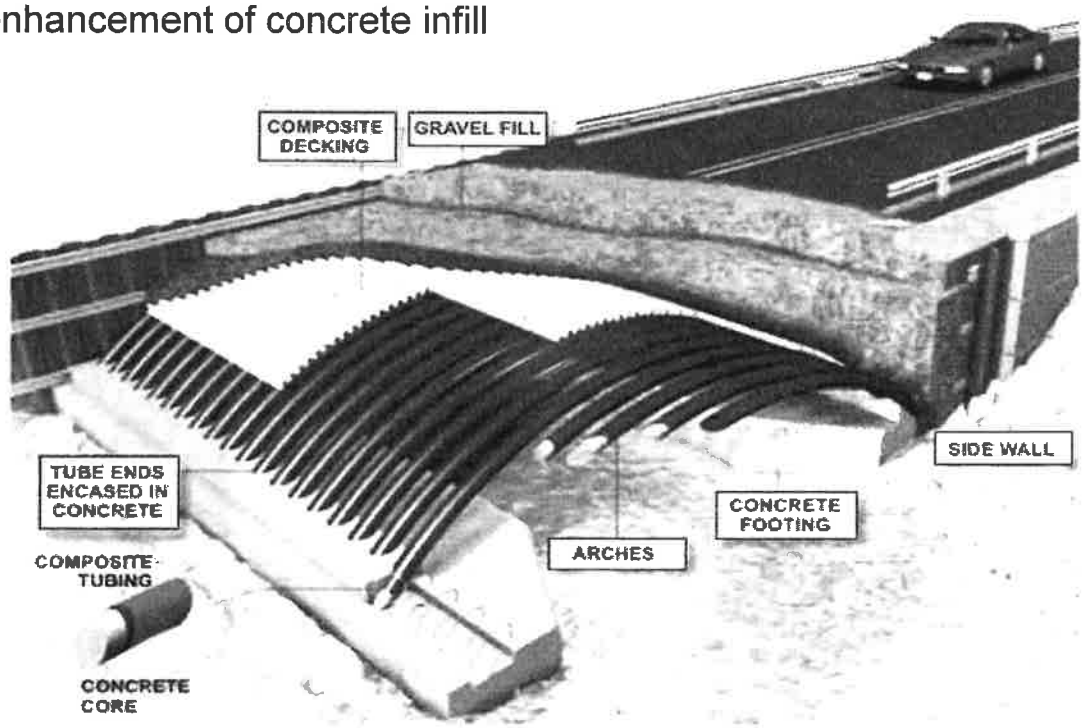
OFF-SITE PRODUCTION

Components: Concrete-filled FRP Tubes in Bridges

Advantages

- Significantly lighter than steel
- Excellent corrosion resistance
- Strength enhancement of concrete infill



Source: AIT, 2013

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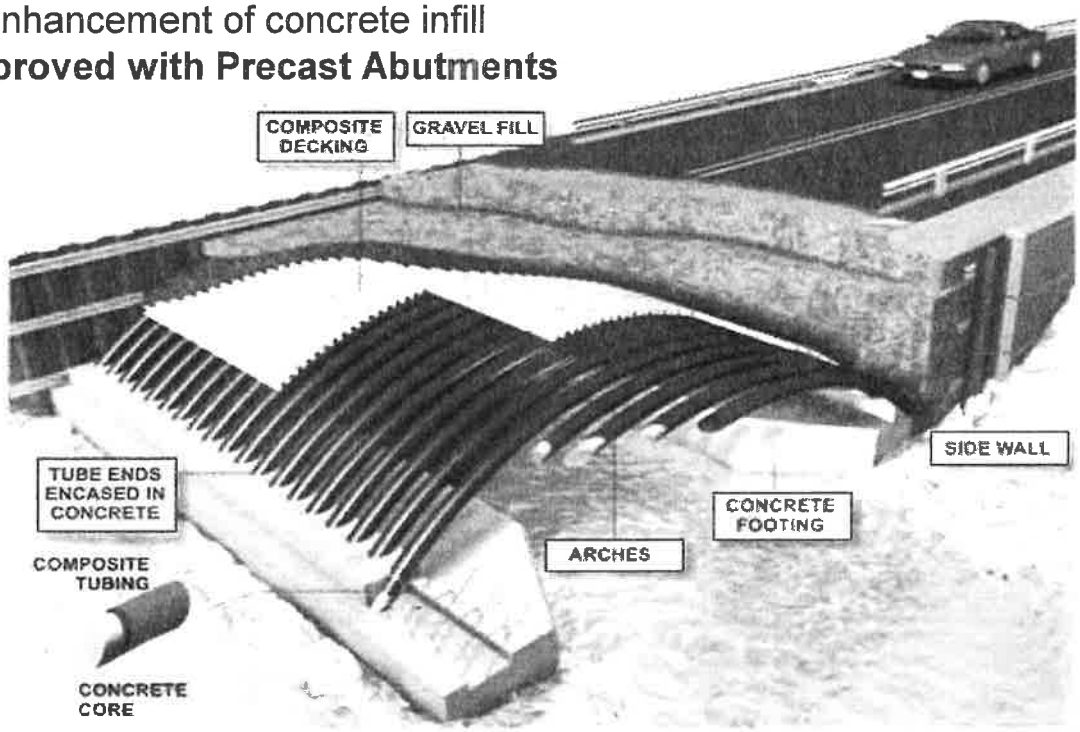
OFF-SITE PRODUCTION

Components: Concrete-filled FRP Tubes in Bridges

Advantages

- Significantly lighter than steel
- Excellent corrosion resistance
- Strength enhancement of concrete infill

Could be Improved with Precast Abutments



Source: AIT, 2013

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OFF-SITE PRODUCTION

Topics for Discussion

- Overview
- Components (Processed Materials)
- **Fabricated Components**
- Panelised (Integrated) Components
- Volumetric Construction (PPVC)
- Conclusions

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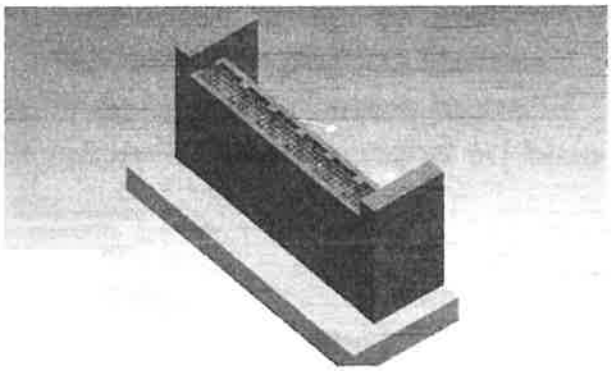
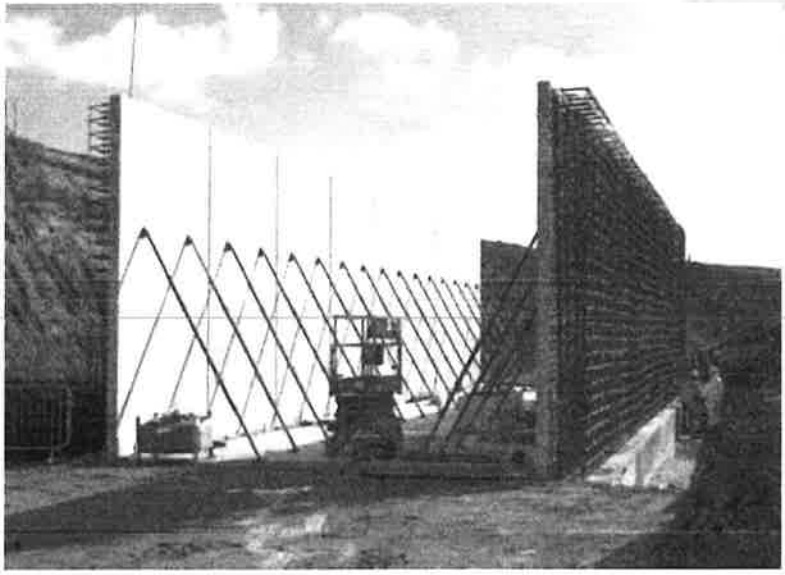
OFF-SITE PRODUCTION

Prefabricated Components: Twinwall (Precast Concrete)

Advantages

- Abutments built in 3 days
- Compared with 3 weeks for insitu





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Source of Images: Source Laing O'Rourke, 2015

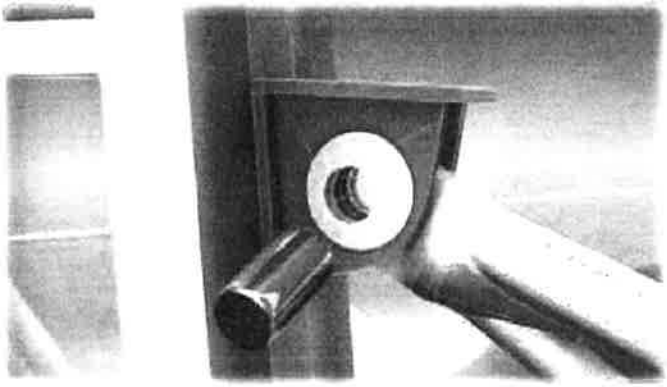
OFF-SITE PRODUCTION

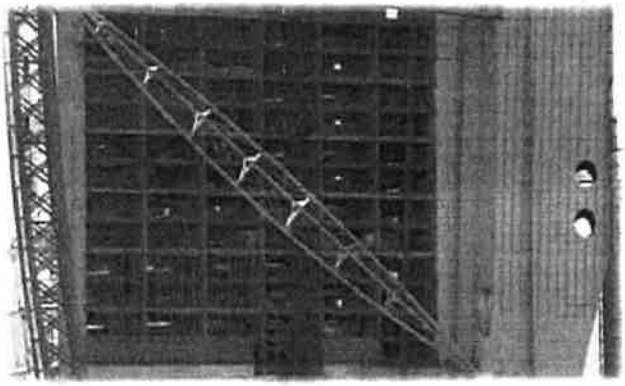
Prefabricated Components: Structural Steelwork

Burj Dubai: Exoskeleton









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Burj Al Arab, Dubai Source: Atkins, 1996

OFF-SITE PRODUCTION

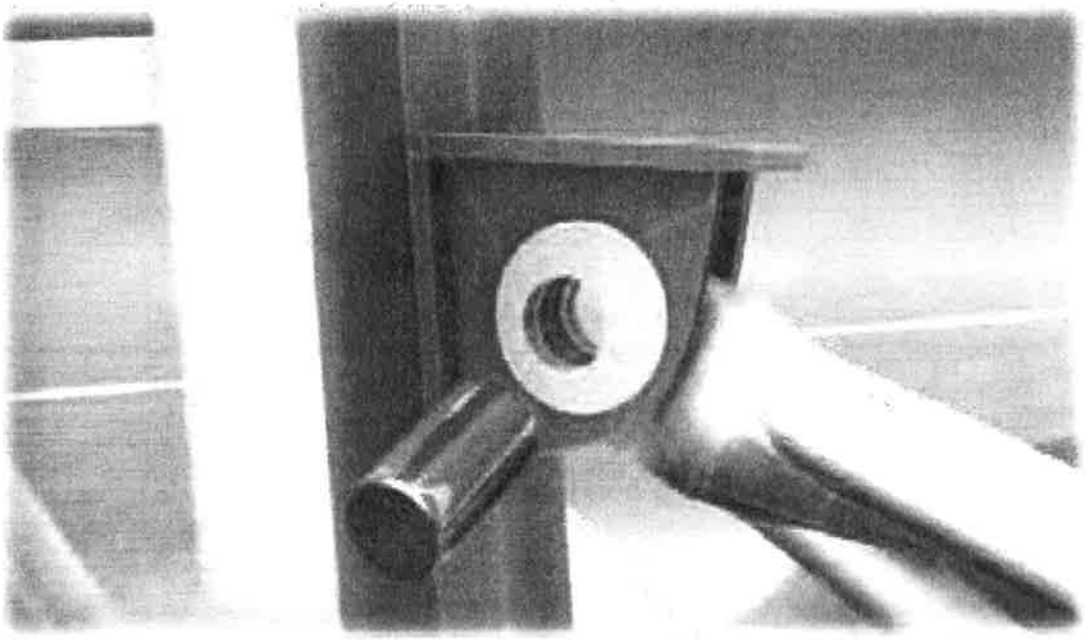
Prefabricated Components: Structural Steelwork

Burj Dubai: Exoskeleton Joint

Innovative Cam Design

- Temperature range for steelwork 15-80°
- Cam allowed ±20 mm movement tolerance at each end

Learning Point: Joints are very important



Burj Al Arab, Dubai Source: Atkins, 1996

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OFF-SITE PRODUCTION

Topics for Discussion

- Overview
- Components (Processed Materials)
- Fabricated Components
- **Panelised (Integrated) Components**
- Volumetric Construction (PPVC)
- Conclusions

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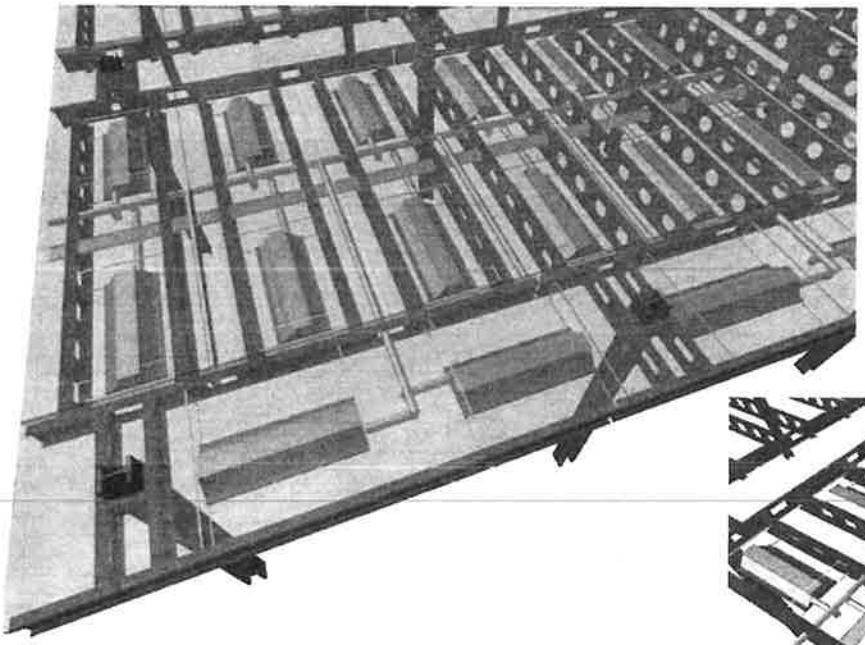
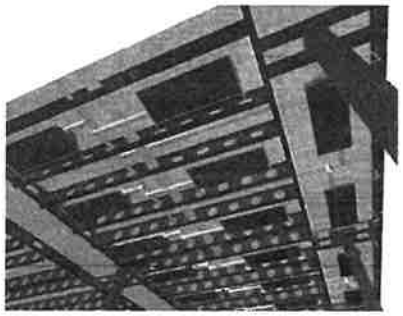
OFF-SITE PRODUCTION

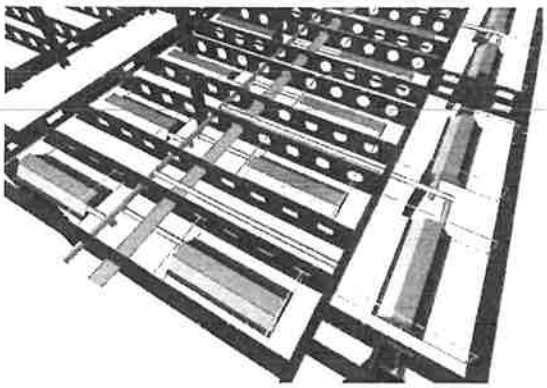
Panelised Components: Floor Cassettes

Advantages

- Floors have preinstalled MEP services







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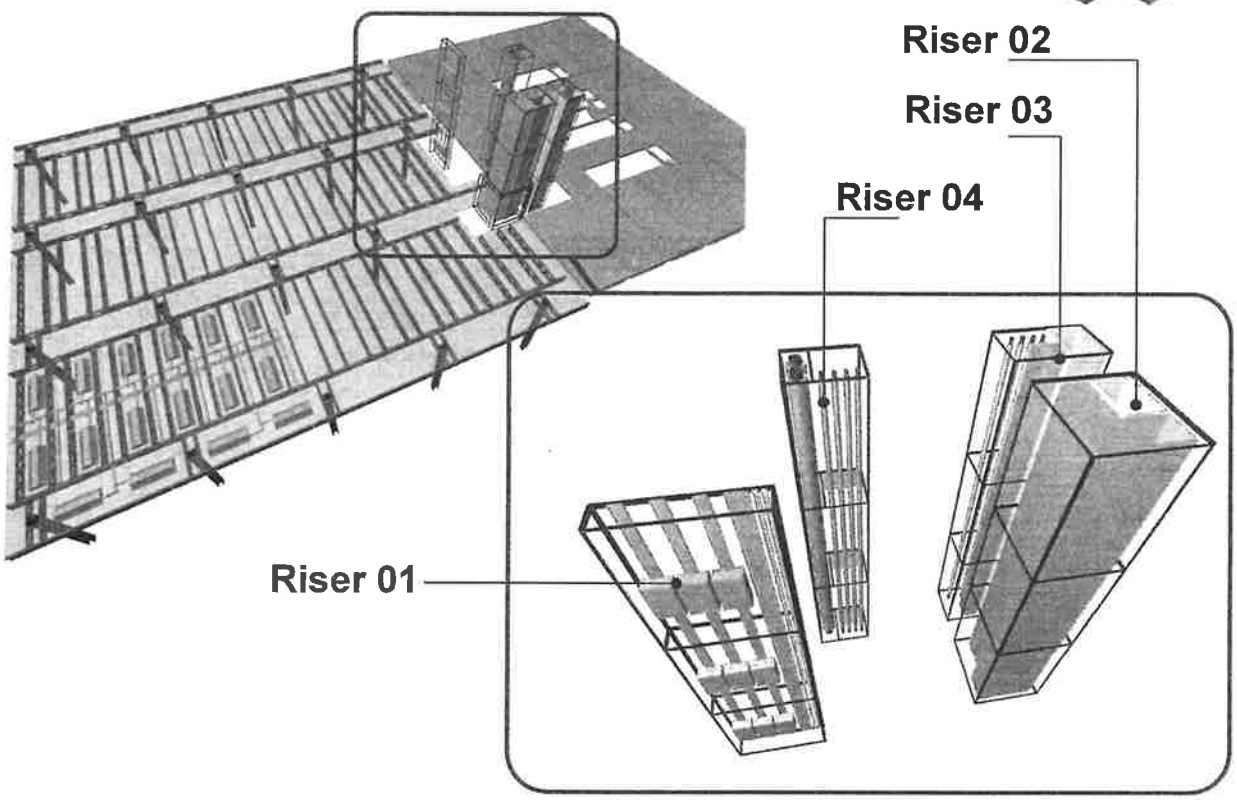
Source of Images: Laing O'Rourke, 2015

OFF-SITE PRODUCTION

Panelised Components: Modular Service Risers



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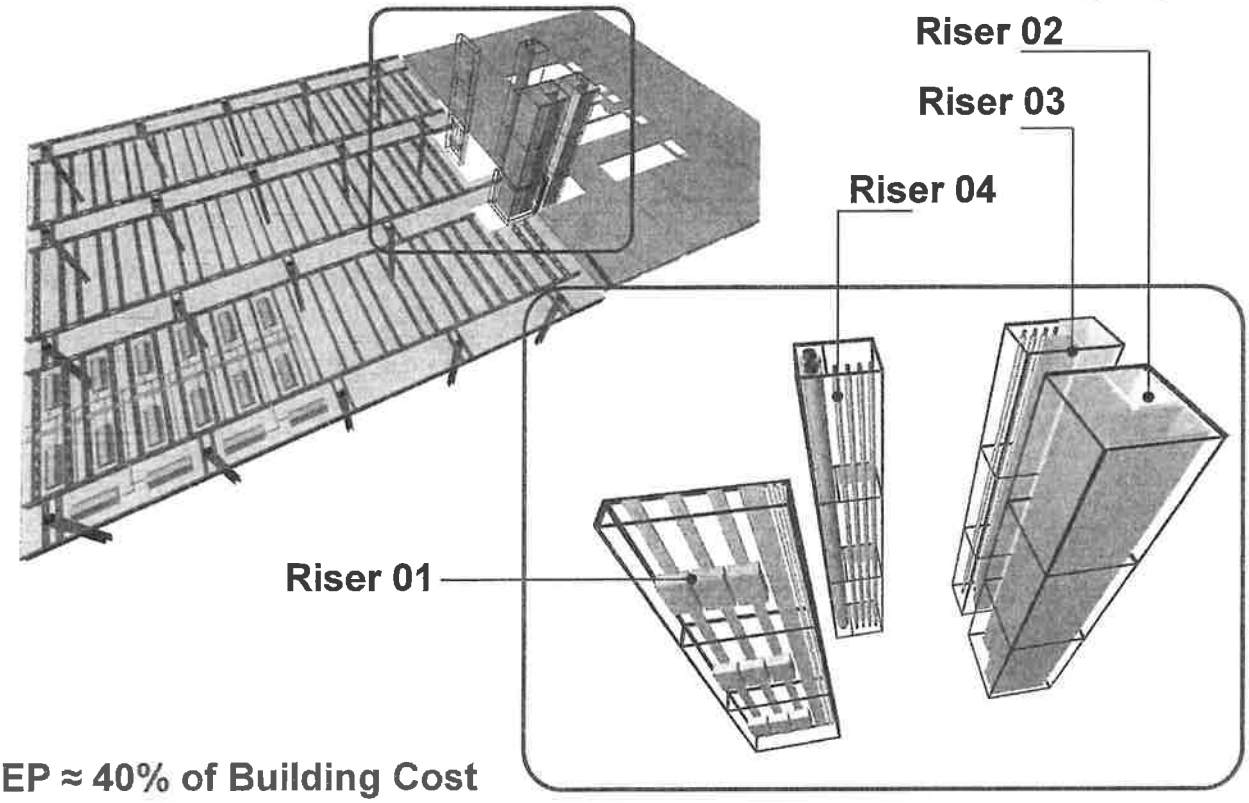
OFF-SITE PRODUCTION

Panelised Components: Modular Service Risers



MEP ≈ 40% of Building Cost
Therefore, Large Savings can be Achieved with Modular Solutions

Source of Images: Laing O'Rourke, 2015

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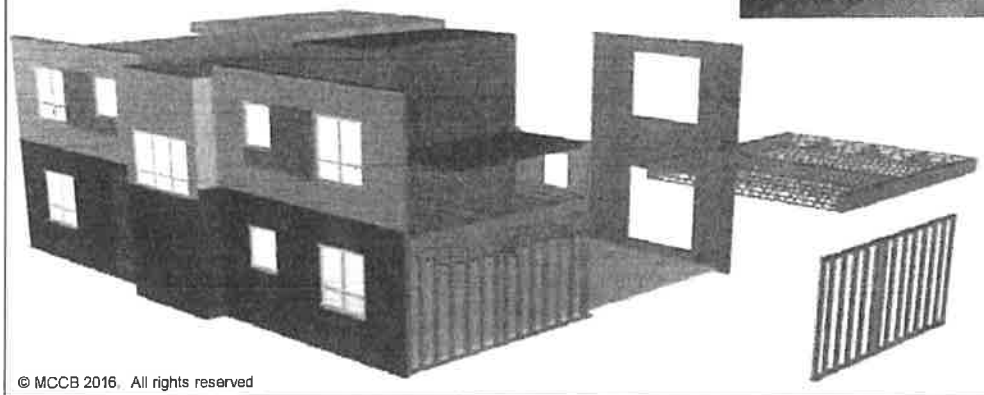
OFF-SITE PRODUCTION

Hybrid Volumetric & Panelised Construction





Source SCI, 2016

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OFF-SITE PRODUCTION
Topics for Discussion

- Overview
- Components (Processed Materials)
- Fabricated Components
- Panelised (Integrated) Components
- **Volumetric Construction (PPVC)**
- Conclusions

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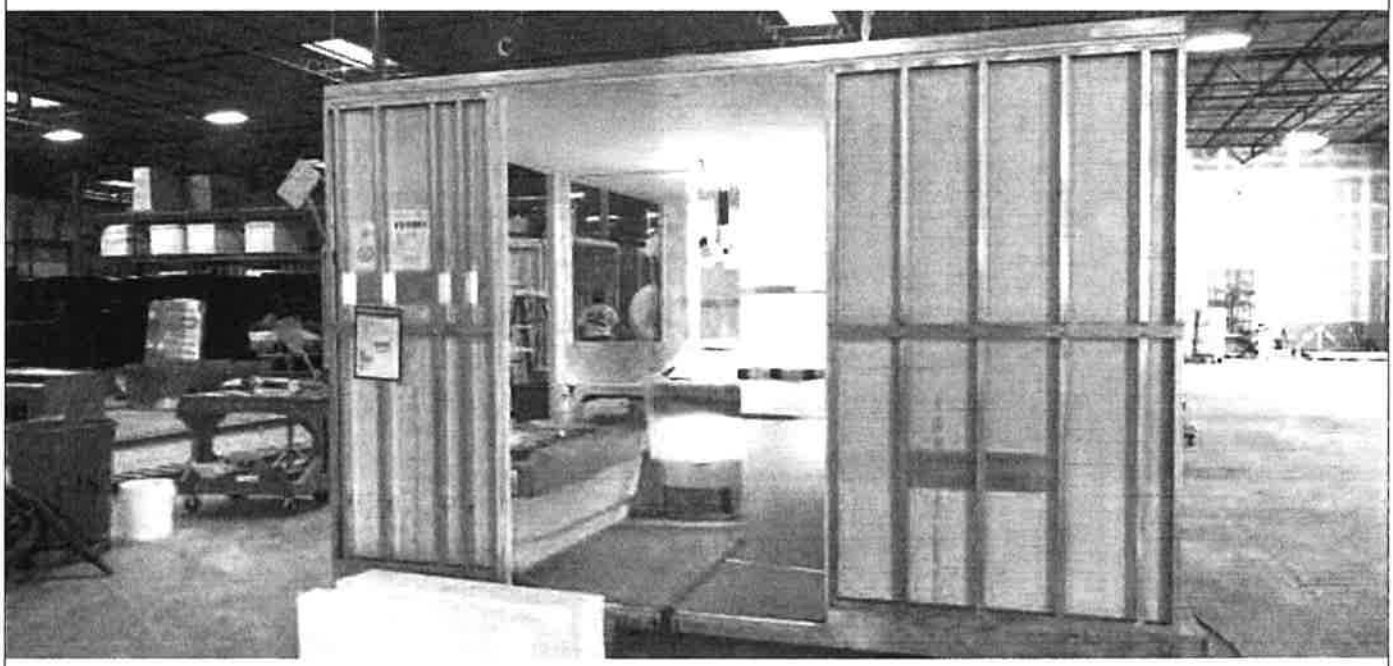
OFF-SITE PRODUCTION
Volumetric Construction: Bathroom & Kitchen Pods

Advantages

- Can be installed in any type construction

BUT in modular (DfMA) construction

- They are plug-and-play



Bathroom Pod, Source: http://www.interiortalent.com 2016

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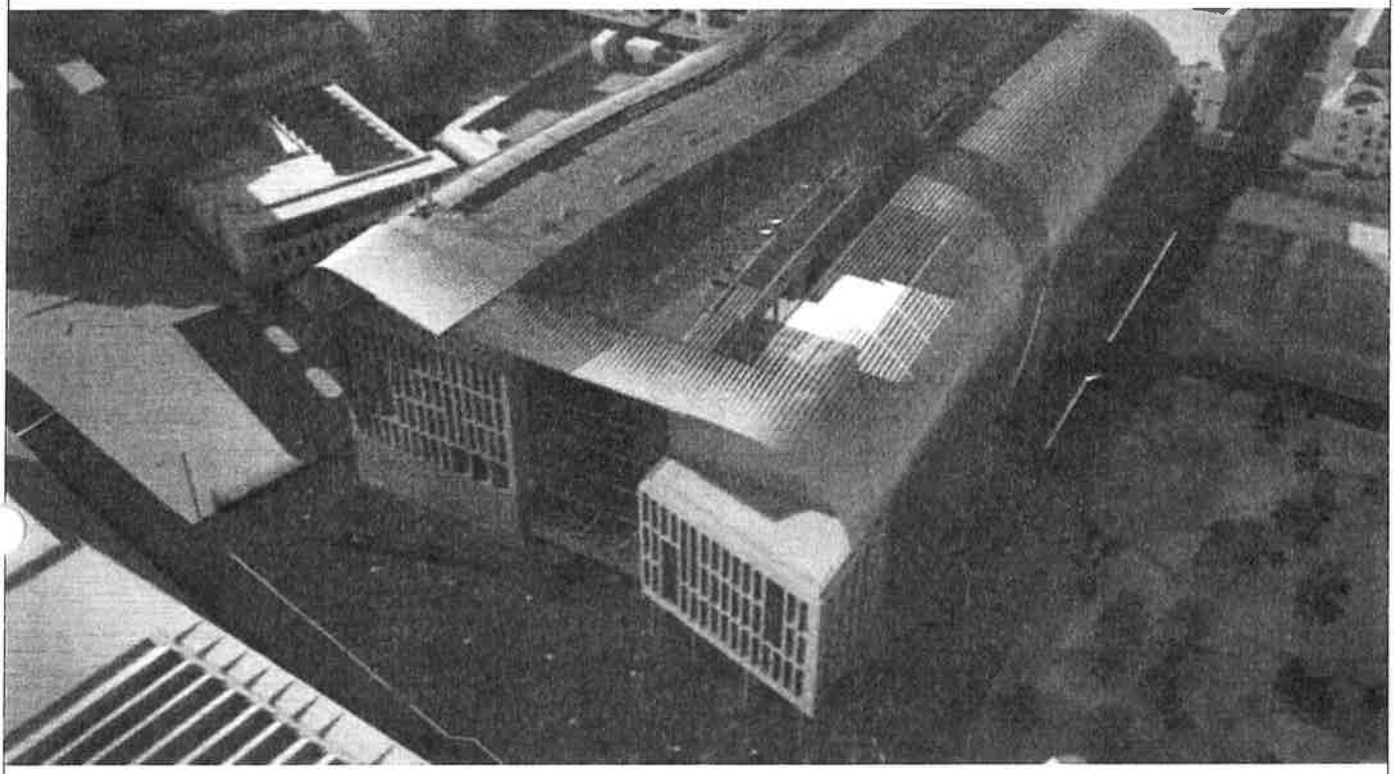
OFF-SITE PRODUCTION

Volumetric Construction (PPVC)

Modular Plant Rooms

Francis Crick Institute, London, UK



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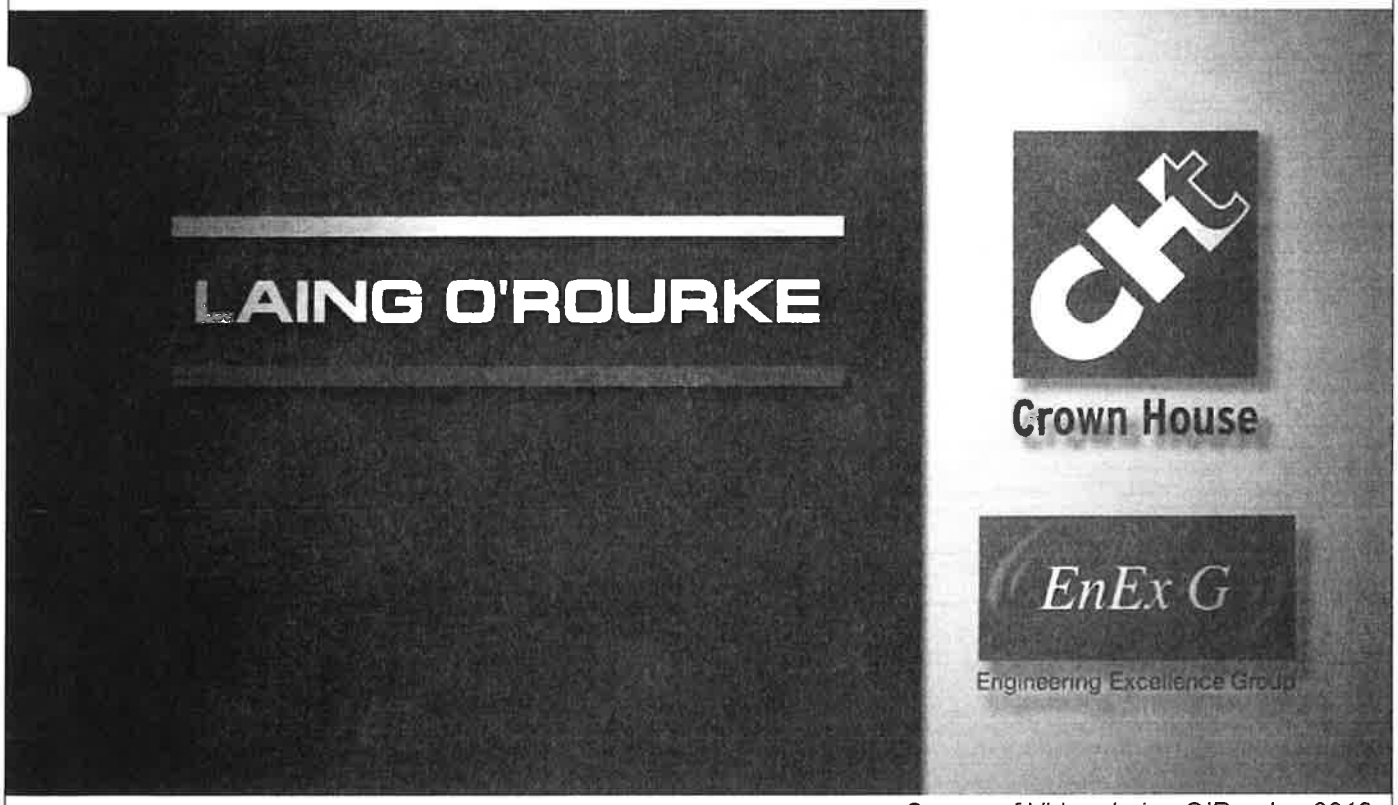
Source of Image: Laing O'Rourke, 2016

OFF-SITE PRODUCTION

Volumetric Construction (PPVC)

Modular Plant Rooms



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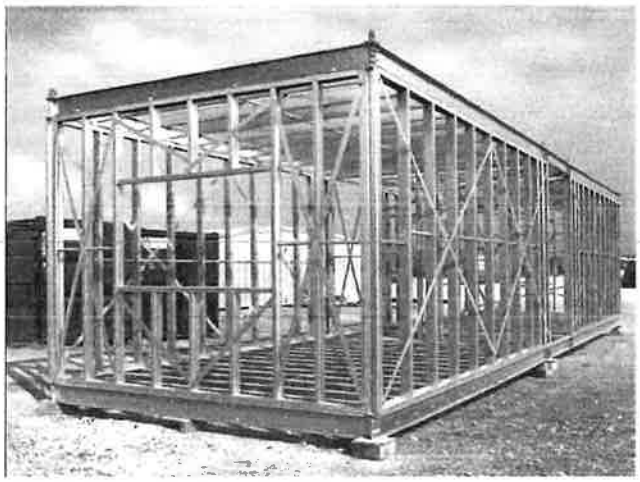
Source of Video: Laing O'Rourke, 2016

OFF-SITE PRODUCTION

Volumetric Construction (PPVC)

Light Steelwork Framed Module



Basic Module, Source SCI, 2016



UB Modules, Crowne Plaza Hotel, Changi Airport, 2016

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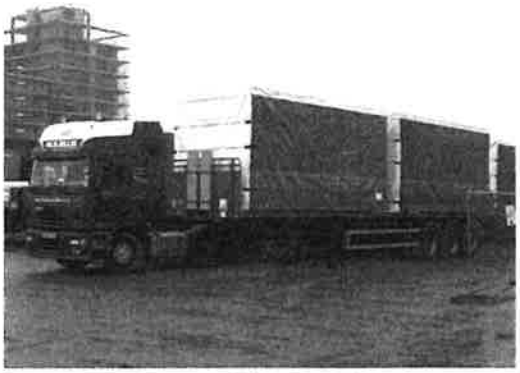
OFF-SITE PRODUCTION

Volumetric Construction (PPVC)

Advantages

- Modules are fully-fitted
- Plug-and-play







Source of Images SCI, 2016

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OFF-SITE PRODUCTION

Volumetric Construction:

Off-site can be Near-site

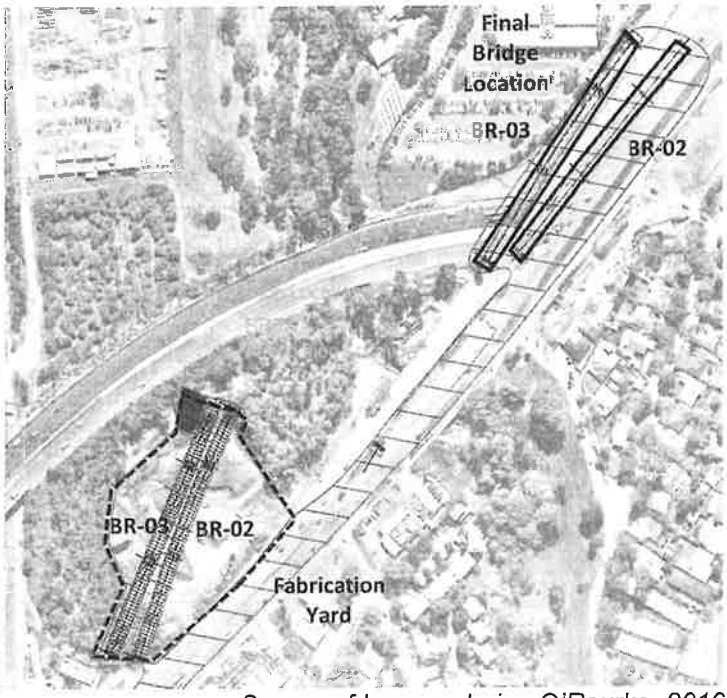
- Provides off-site advantages
- **AND** Minimises travel distances

Bridges can be built:

- In fabrication yard
- Near to ground level
- In a controlled environment

GATEWAY SOUTH





Source of Images: Laing O'Rourke, 2016

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OFF-SITE PRODUCTION

Volumetric Construction: Bridges

Off-site can be Near-site

- Provides off-site advantages
- BUT Minimises travel distances

Bridges can be built:

- Near to ground level
- In a controlled environment

sarens

Source of Video: Sarens, 2016

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OFF-SITE PRODUCTION

Volumetric (PPVC) v Flatpack Modules

Pros & Cons

	Pros	Cons
Panelised Modules with Core/ Skeleton	▪ Can be packed efficiently for transportation – no "dead spaces" ▪ Opportunities for reuse of skeleton after disassembly of original build ▪ Once on site, there is potential to use fork-lifts rather than cranes ▪ Greater flexibility with floor layouts than with volumetric modules	▪ Requires more on-site work than volumetric modules . ▪ Modules cannot arrive on site fully furnished/ completed. Fittings & furnishings need to be completed separately
Volumetric Modules	▪ Modules can be supplied completely fitted-out, "Plug-and-Play" ▪ Quicker onsite assembly requiring fewer personnel/ trades & less skilled labour	▪ Transport inefficiency – large volumes of air (dead space) are transported ▪ Less flexibility in module layout ▪ Module size limited by site access & road width. Police escorts may be required

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OFF-SITE PRODUCTION

Conclusions

Every Site is Unique

Compare the advantage/disadvantages of the system(s)

- Components
- Fabricated Components
- Panelised (Integrated) Components
- Volumetric Construction (PPVC)

Consider a Fabrication Yard

- Especially for large modules

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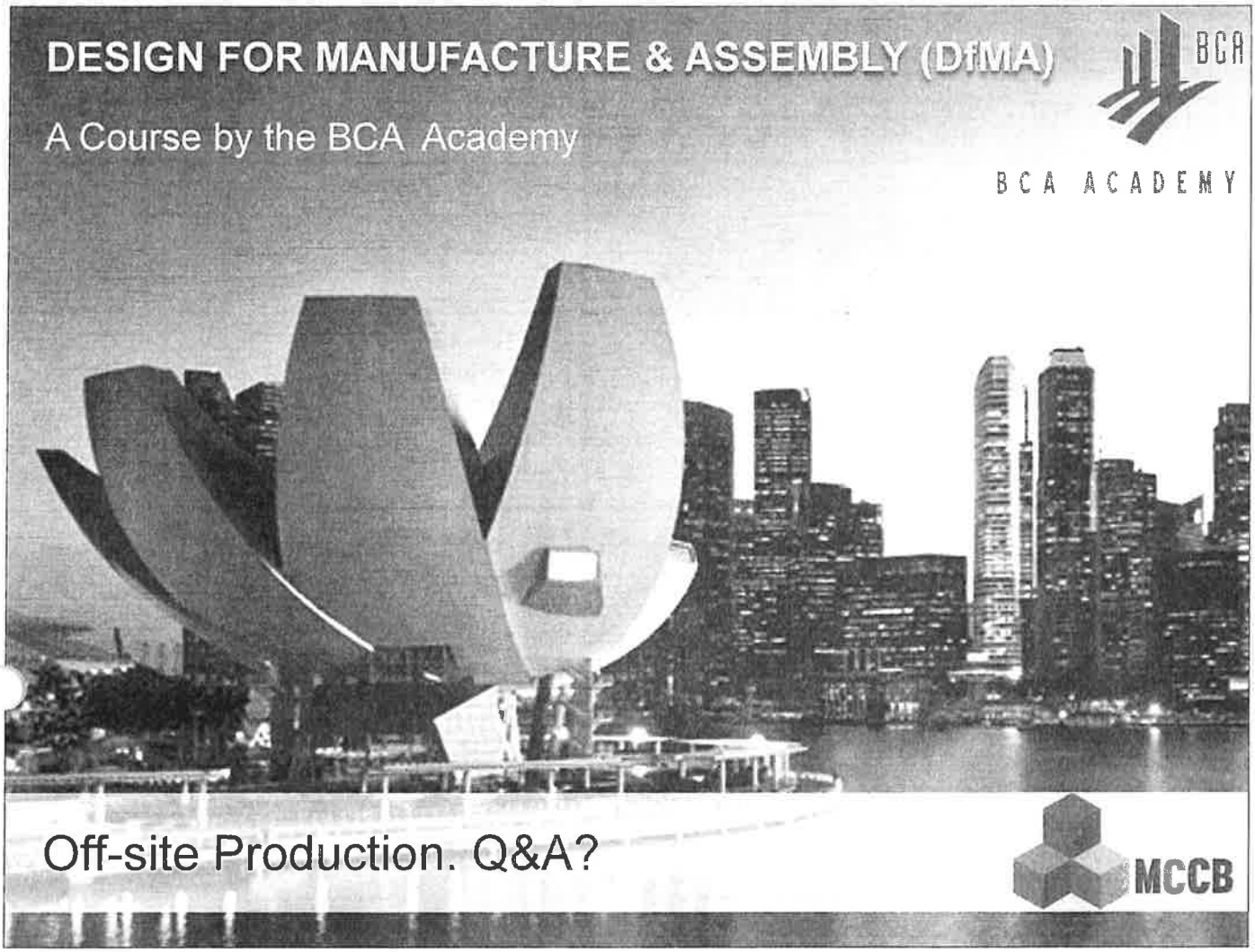
DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)
A Course by the BCA Academy
BCA
BCA ACADEMY
Off-site Production. Q&A?
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DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)
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BCA ACADEMY
Progressive Collapse
Angus McFarlane BSc (Hons), MSc, CEng, FIStructE, FICE, FIEAust CPEng NER
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PROGRESSIVE COLLAPSE
Topics for Discussion

- Historical Context
- Causes of Damage
- Design for Robustness
- Issues & Solutions

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PROGRESSIVE COLLAPSE
Historical Context

Ronan Point, UK, 1968
Precast Large Panel System
Accidental Gas Explosion on 18th Floor

- PC walls at corner blew out
- Floors collapsed onto floors below
  - Overloading them
- Building collapsed:
  "Like a deck of cards"



Ronan Point, London, UK
Source of Images, Griffiths et al. 1968

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PROGRESSIVE COLLAPSE
Historical Context

Ronan Point, UK, 1968
Precast Large Panel System
Accidental Gas Explosion on 18th Floor

- PC walls at corner blew out
- Floors collapsed onto floors below
  - Overloading them
- Building collapsed:
  "Like a deck of cards"

Main Causes of Failure
Joints between PC Walls & PC Floors

- Could not resist blast loading
- Were not sufficiently well tied together



Ronan Point, London, UK
Source of Images, Griffiths et al. 1968

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PROGRESSIVE COLLAPSE
Historical Context



Close Up of Ronan Point Failure

Ronan Point, UK, 1968
Led to a radical rethink of UK:

- **Design Codes**
- **Building Regulations**

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PROGRESSIVE COLLAPSE
Historical Context



Close Up of Ronan Point Failure

Ronan Point, UK, 1968
Led to a radical rethink of:
- UK Design Codes
- UK Building Regulations

BUT
- **Lessons learnt were ignored by most of the rest of the world**

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PROGRESSIVE COLLAPSE
Historical Context



Close Up of Ronan Point Failure

Ronan Point, UK, 1968
Led to a radical rethink of:
- UK Design Codes
- UK Building Regulations

BUT
- Lessons learnt were ignored by most of the rest of the world

- **EXCEPT**
- **34 kPa for protected elements came from Ronan Point**

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PROGRESSIVE COLLAPSE
Historical Context

Murrah Building, Oklahoma, USA, 1995
Normal Insitu RC Moment Frame System
Large Transfer Beam at 3rd Storey
Terrorist Attack

- Bomb destroyed one of the columns below
- Transfer beam failed
- Caused progressive collapse



Murrah Building, Oklahoma City. 1995

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PROGRESSIVE COLLAPSE
Historical Context



World Trade Center (11-Sep-2001)

World Trade Center, USA, 2011
Structural Steel Frame System
Terrorist Attack

- Aeroplane impact caused damage to columns
- Ensuing fire caused loss of steel strength
- Led to progressive collapse

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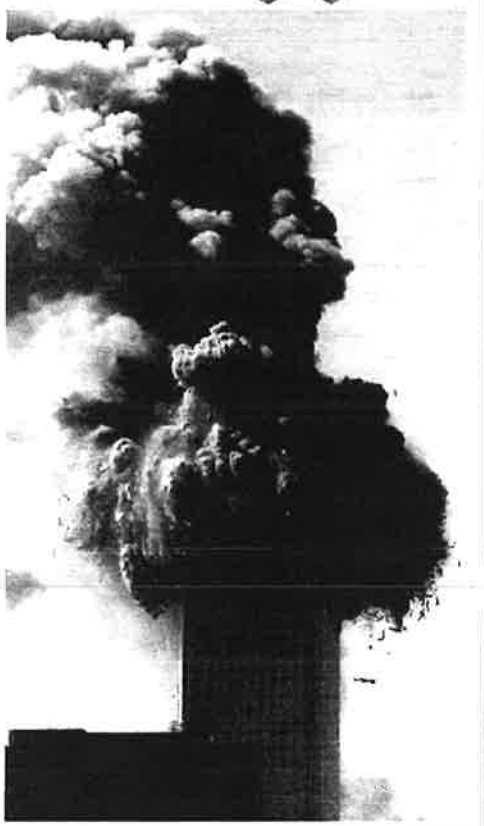
PROGRESSIVE COLLAPSE
Historical Context

World Trade Center, USA, 2011
Terrorist Attack
- Collapse occurred inward without toppling
- Thus minimising collateral damage

Building had been designed to resist progressive collapse

BUT

Engineers had not considered simultaneous Fire & Structural Damage



World Trade Center (11-Sep-2001)

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PROGRESSIVE COLLAPSE
Historical Context

World Trade Center, USA, 2011
Terrorist Attack
- Collapse occurred inward without toppling
- Thus minimising collateral damage

Building had been designed to resist progressive collapse

BUT

Engineers had not considered simultaneous Fire & Structural Damage

This collapse led to worldwide adoption of design to resist progress collapse



World Trade Center (11-Sep-2001)

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PROGRESSIVE COLLAPSE
Topics for Discussion

MCCB

- Historical Context
- **Causes of Damage**
- Design for Robustness
- Issues & Solutions

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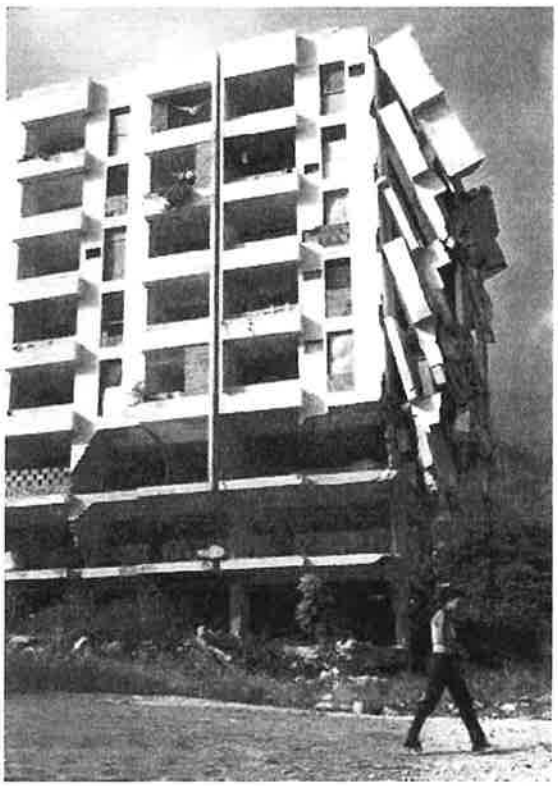
PROGRESSIVE COLLAPSE
Causes of Damage

MCCB

Natural

- Wind
- Temperature
- Floods & tsunamis
- Earthquakes
- Landslides



Progressive Collapse due to Landslide, Venezuela

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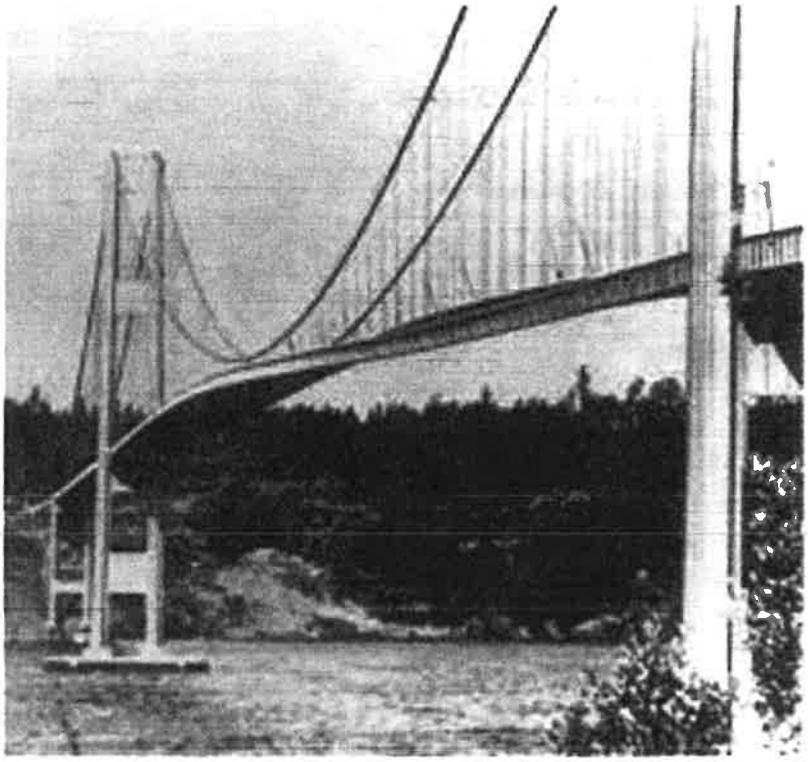
PROGRESSIVE COLLAPSE
Causes of Damage

MCCB

Natural
- Wind
- Measures were put in place to limit dynamic movement



Tacoma Narrows Bridge Collapse, US, 1940

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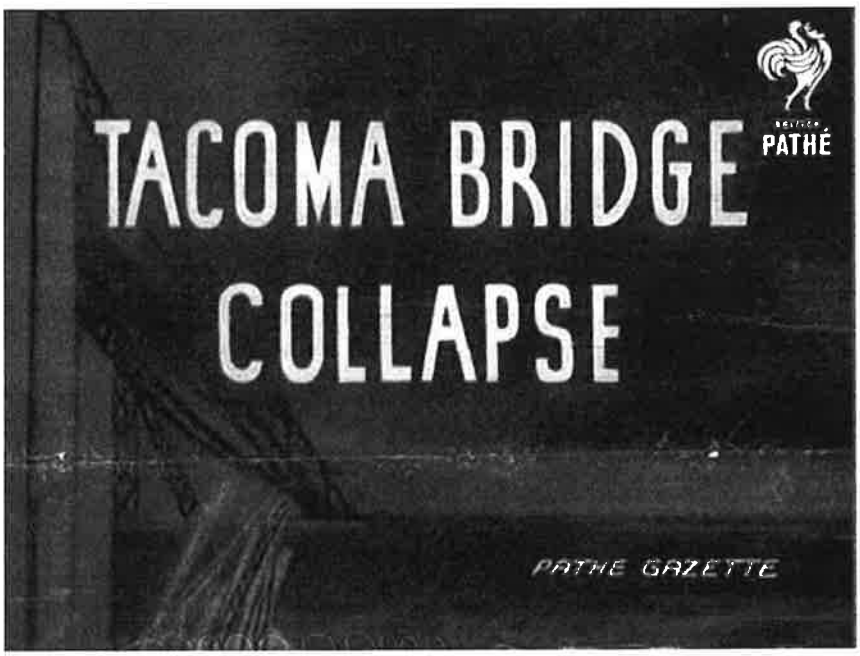
PROGRESSIVE COLLAPSE
Causes of Damage

MCCB

Natural
- Wind
- Measures were put in place to limit dynamic movement



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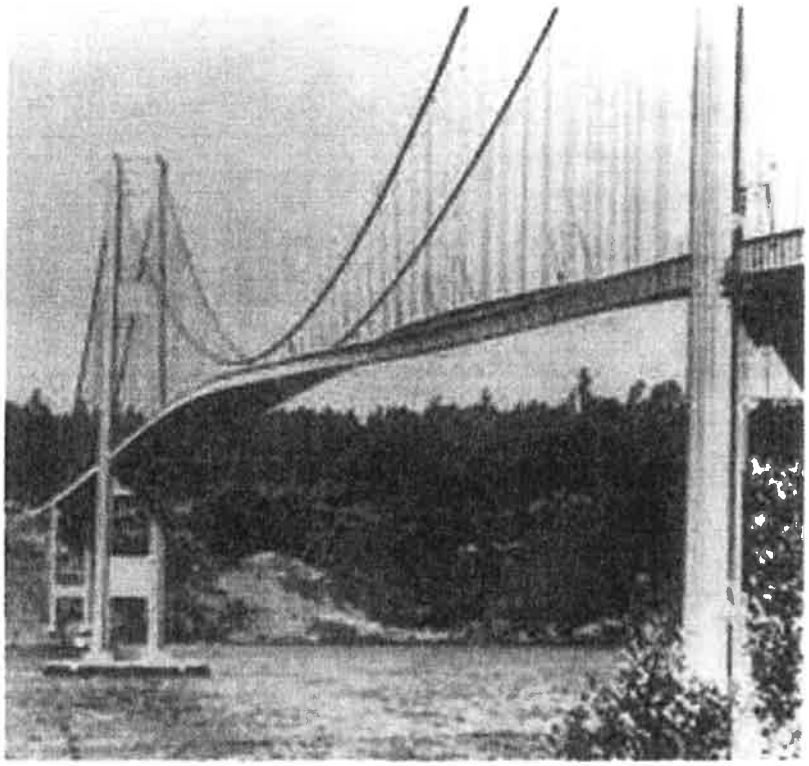
PROGRESSIVE COLLAPSE
Causes of Damage

MCCB

Natural
- Wind
- Measures were put in place to limit dynamic movement

BUT
- **Bridge collapsed at a wind speed of 40 mph (64 km/h or 18 m/s)**
- **Collapse caused by Aeroelastic flutter**



Tacoma Narrows Bridge Collapse, US, 1940

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PROGRESSIVE COLLAPSE
Causes of Damage

MCCB

Natural
- Wind
- Temperature
- Floods & tsunamis
- Earthquakes
- Landslides

Human-made
- Accidental
  - Gas explosions
  - Vehicle impacts
- Malicious
  - Terrorist attack



Accidental Damage from Vehicle Collision

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PROGRESSIVE COLLAPSE
Causes of Damage

Natural
- Wind
- Temperature
- Floods & tsunamis
- Earthquakes
- Landslides

Human-made
- Accidental
  - Gas explosions
  - Vehicle impacts
- Malicious
  - Terrorist attack



Accidental Damage from Vehicle Collision

Rule No. 1
Expect the Unexpected!

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PROGRESSIVE COLLAPSE
Topics for Discussion

- Historical Context
- Causes of Damage
- **Design for Robustness**
- Issues & Solutions

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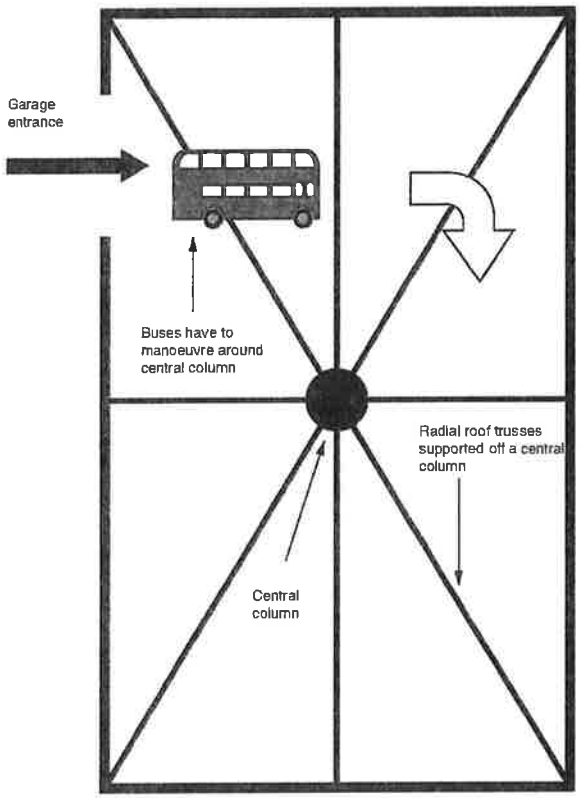
PROGRESSIVE COLLAPSE
Design for Robustness

Make Structure Redundant
Include alternative load paths
Potential options are:

- Place barriers around column
- Redesign roof to span without column
- Design column as protected element



Example of Structure without Redundancy (IStructE, 2010)

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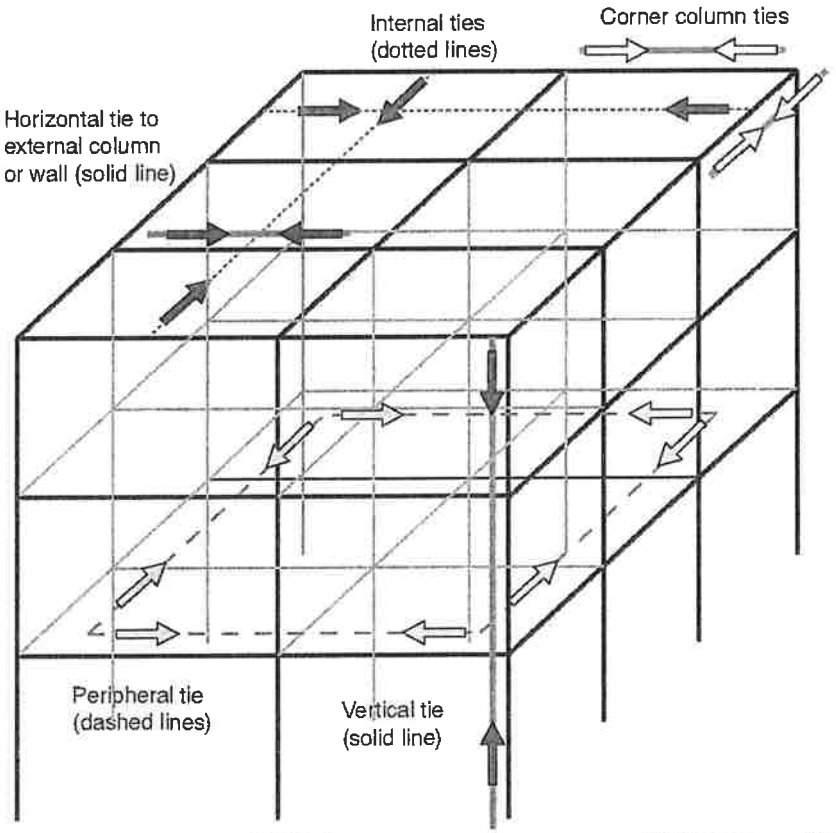
PROGRESSIVE COLLAPSE
Design for Robustness

Provide Horizontal & Vertical Ties

- Simple method of providing redundancy



Typical Horizontal & Vertical Ties (IStructE, 2010)

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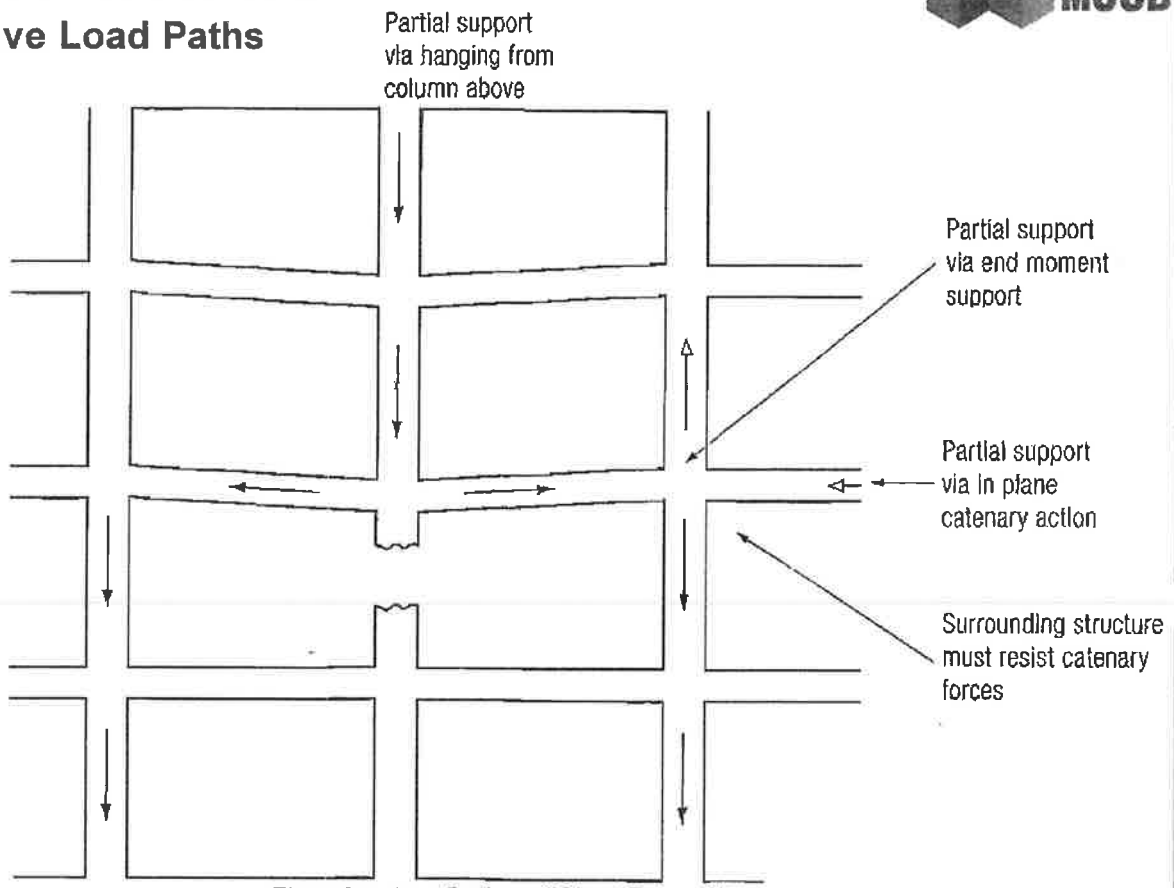
PROGRESSIVE COLLAPSE

Design for Robustness

Alternative Load Paths



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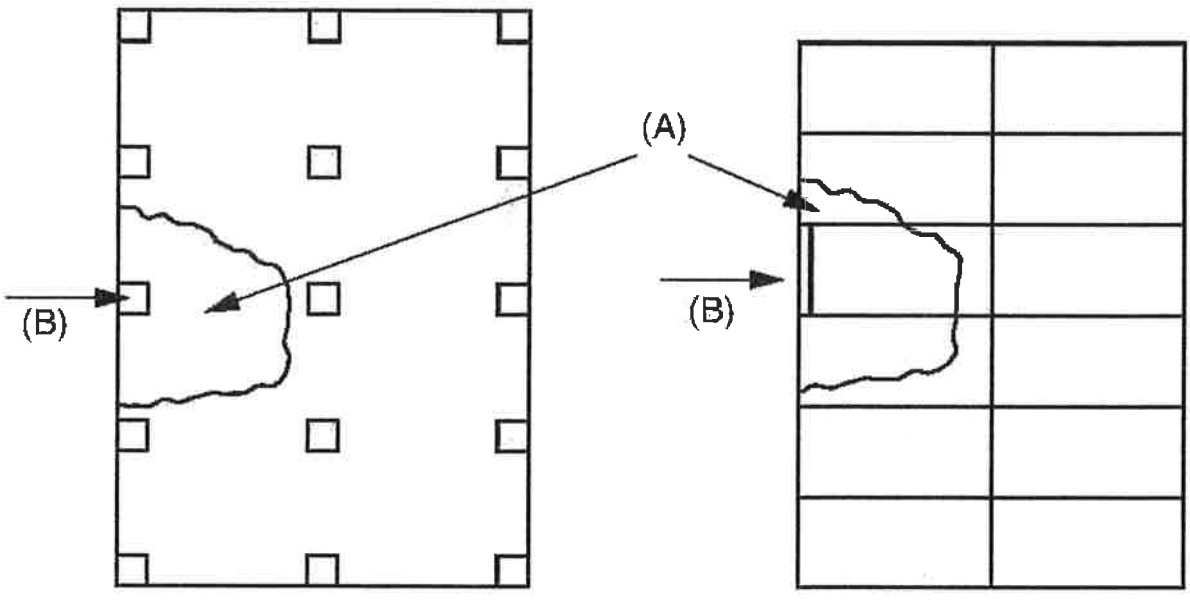
Floor Survival Options (IStructE, 2010)

PROGRESSIVE COLLAPSE

Design for Robustness

Admissible Damage

- 15% of floor area
- BUT not more than 100 m²



Key

(A) Local damage not exceeding 15% of floor area in each of two adjacent storeys

(B) Notional column to be removed

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Admissible Damage Source: Eurocode 1-7,2010

PROGRESSIVE COLLAPSE
Topics for Discussion

- Historical Context
- Causes of Damage
- Design for Robustness
- **Issues & Solutions**

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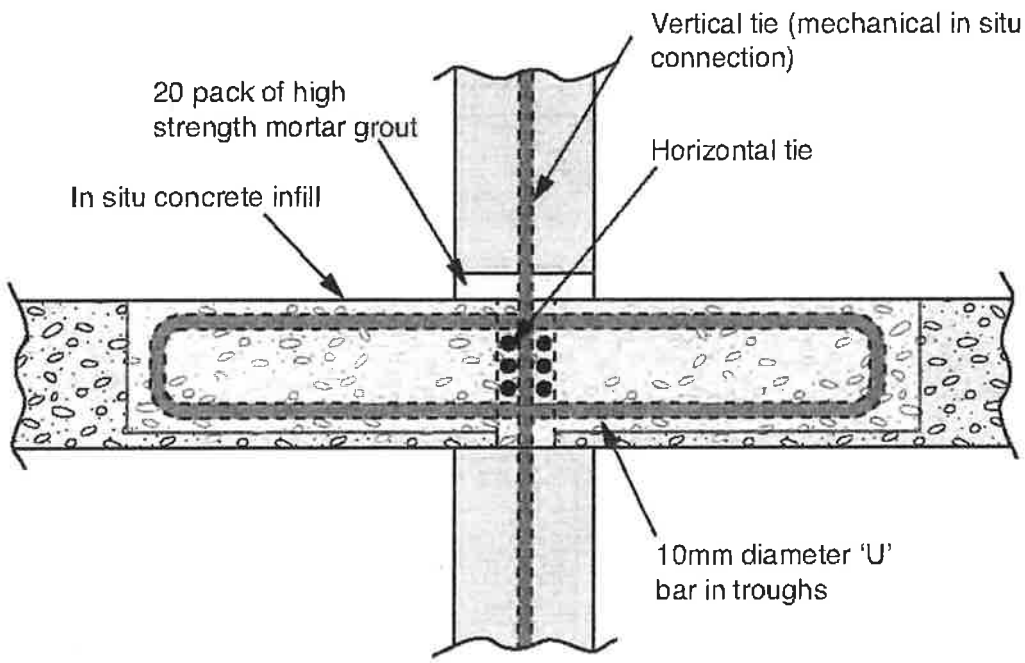
PROGRESSIVE COLLAPSE
Issues & Solutions: Concrete
Precast Concrete
Vertical & Horizontal Ties



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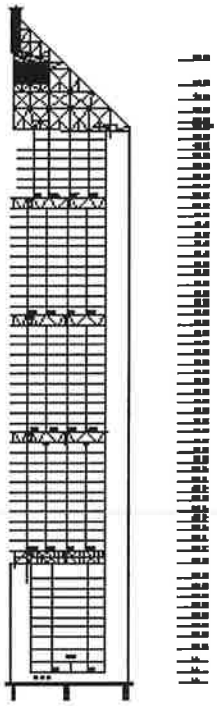
Typical Precast Concrete Tie Detail (IStructE, 2010)

PROGRESSIVE COLLAPSE

Issues & Solutions: Steel

Design of Important Joints

- Joints to have same Capacity as Members



Office Tower Elevation



Ship Analogy



Emirate Towers at Night

Source of Images: Hyder, 1998

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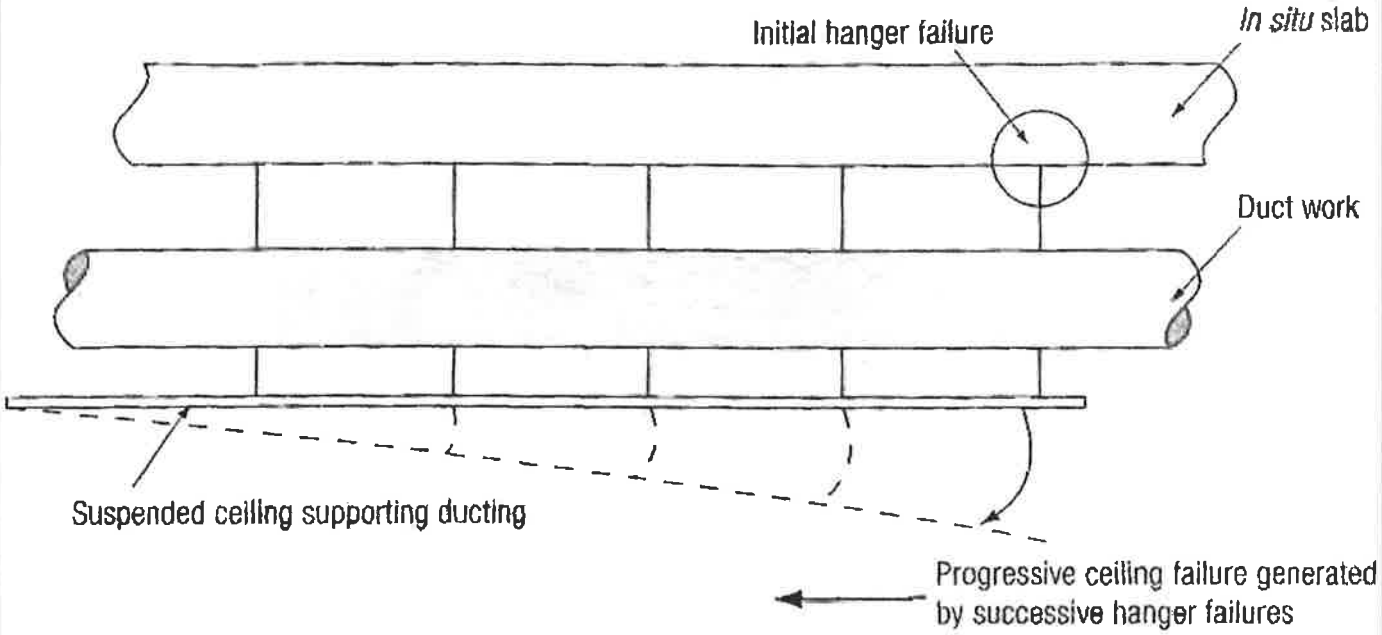
PROGRESSIVE COLLAPSE

Issues & Solutions: MEP

Progressive Collapse of Ceiling

Rigid MEP Duct Work

- Loading on hangers difficult to estimate
- One hanger failed – causing progressive failure of successive hangers



Progressive Collapse of Ceiling (IStructE, 2010)

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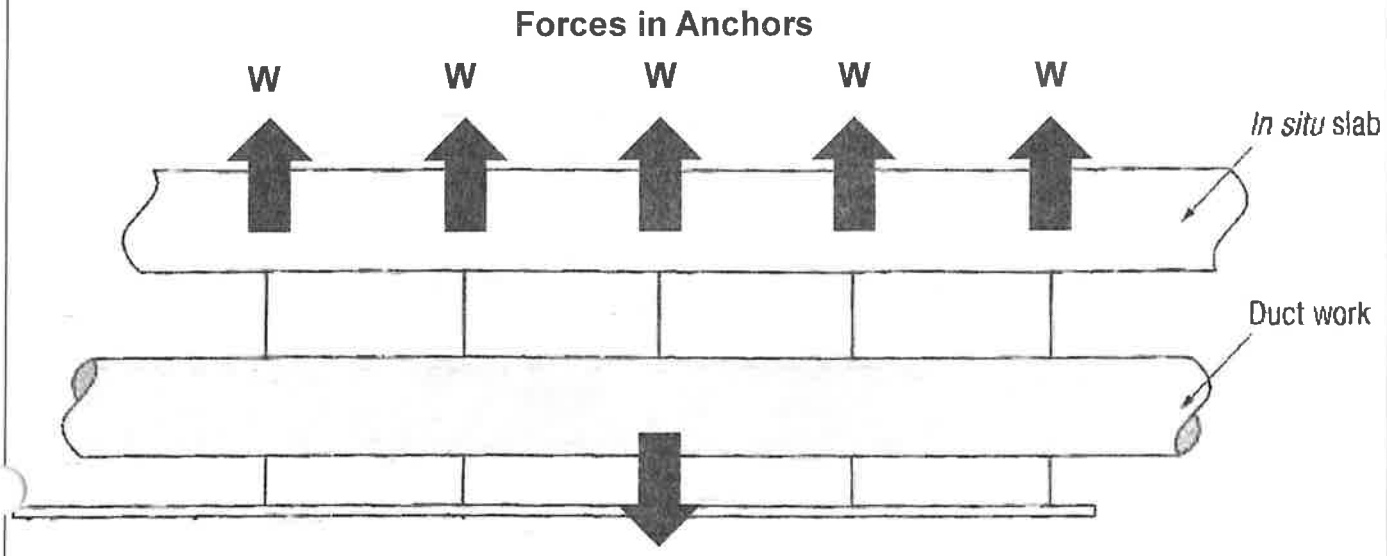
PROGRESSIVE COLLAPSE

Issues & Solutions: MEP

Progressive Collapse of Ceiling

How it was Designed



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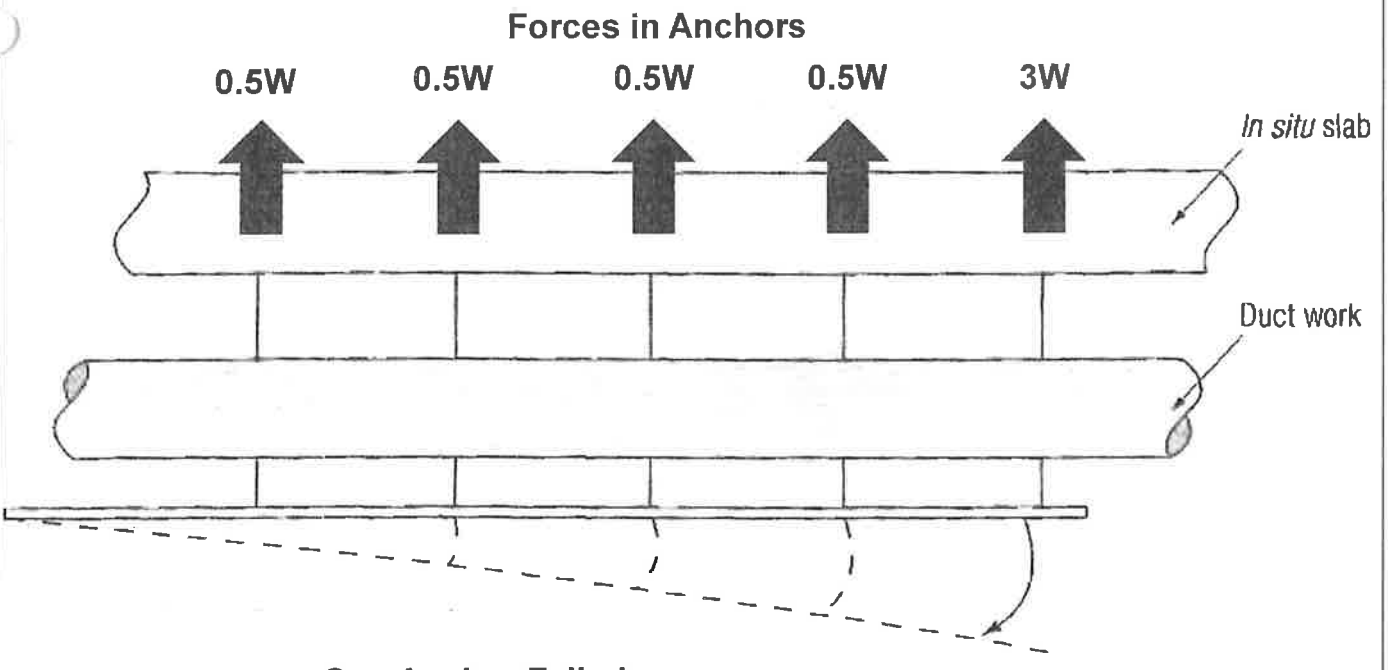
Progressive Collapse of Ceiling (IStructE, 2010)

PROGRESSIVE COLLAPSE

Issues & Solutions: MEP

Progressive Collapse of Ceiling

What Actually Happened



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Progressive Collapse of Ceiling (IStructE, 2010)

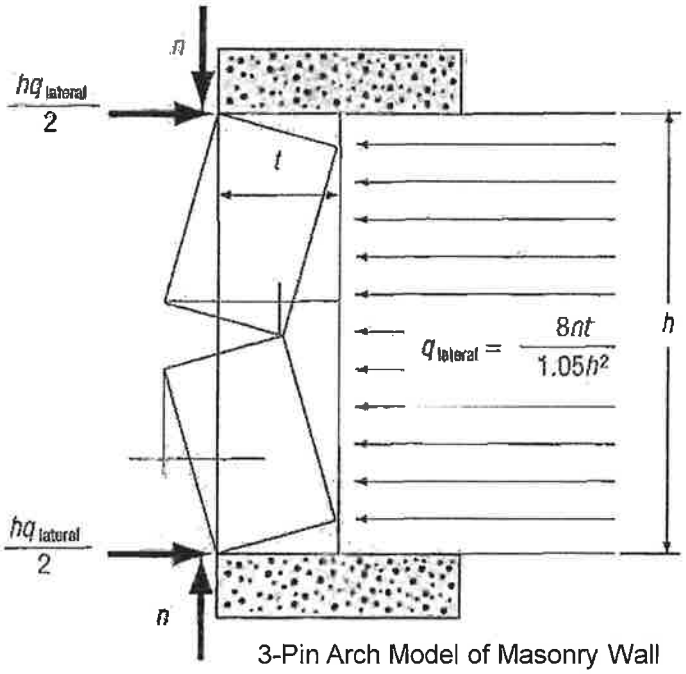
PROGRESSIVE COLLAPSE

Issues & Solutions: Masonry

Protected Elements

Levels below Top 2 Floors

- Design as protected (34 kPa capacity)
- Use 3-pin arch model



3-Pin Arch Model of Masonry Wall



Typical Masonry Collapse

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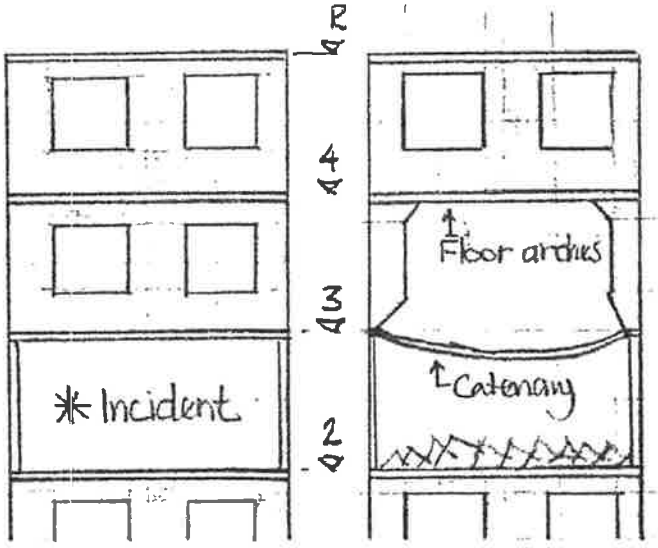
Source of Images IStructE, 2010

PROGRESSIVE COLLAPSE

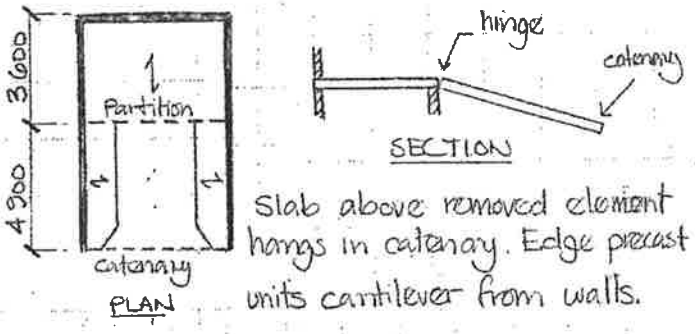
Issues & Solutions: Masonry

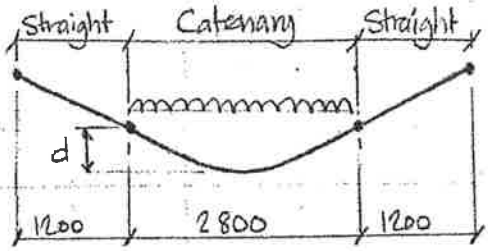
Removal of Wall

Floor Hangs in Catenary



Elevation with Wall Removed: Floor Hangs in Catenary





Details of Catenary

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Source of Images: Angus McFarlane, Bison Concrete, 1980

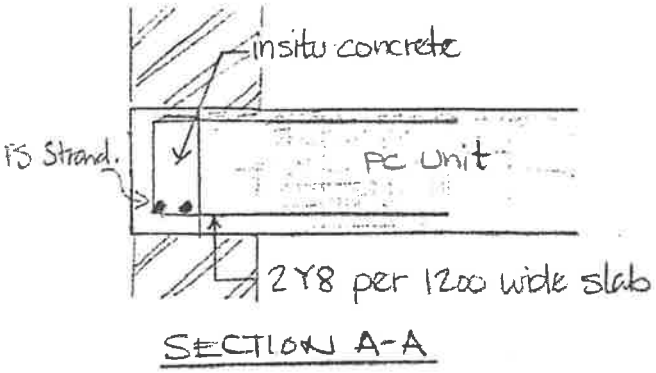
PROGRESSIVE COLLAPSE

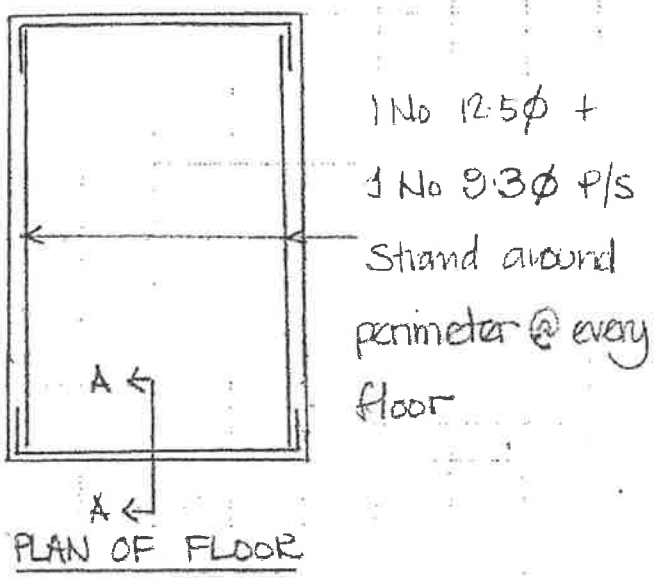
Issues & Solutions: Masonry

Only Horizontal Ties Required

Use Untensioned PT Strand as Ties

- **More Bang-for-Buck (MPa per $)**





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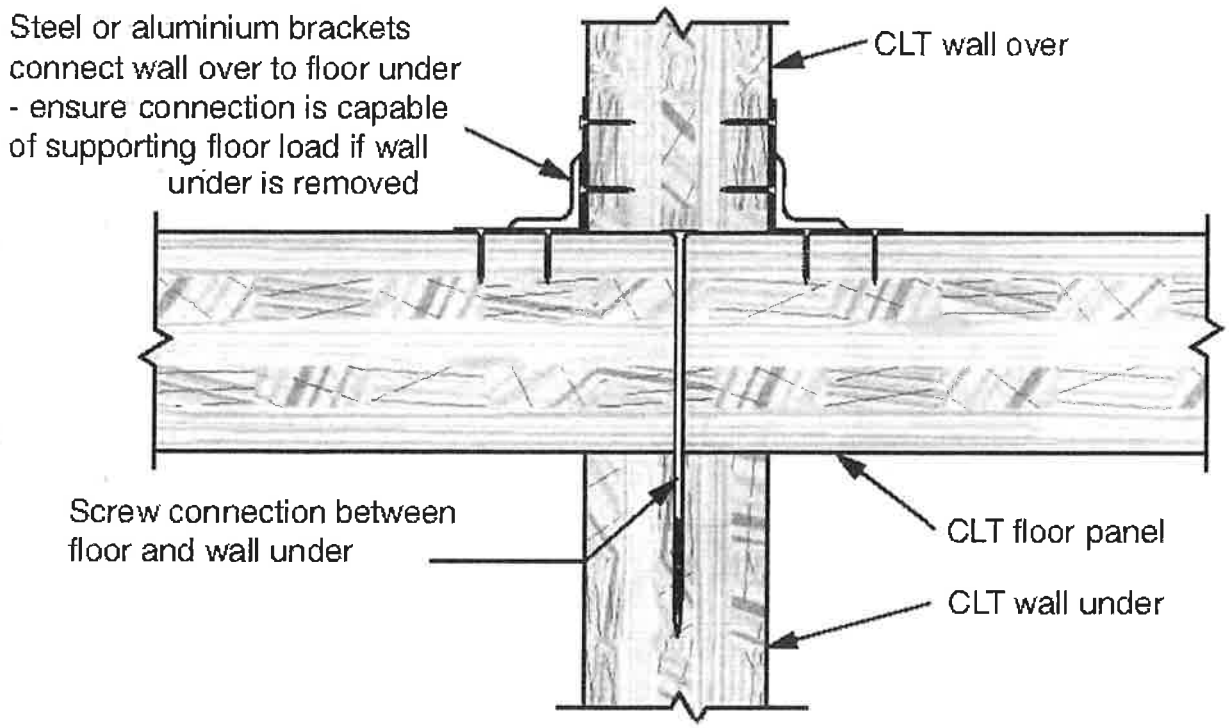
Source of Images: Angus McFarlane, Bison Concrete, 1980

PROGRESSIVE COLLAPSE

Issues & Solutions: Timber

Tie the Building Together

Similar Details Apply to Volumetric (PPVC)



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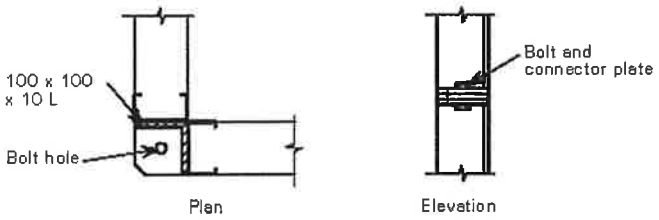
Source of Image: WoodSolutions, 2016

PROGRESSIVE COLLAPSE

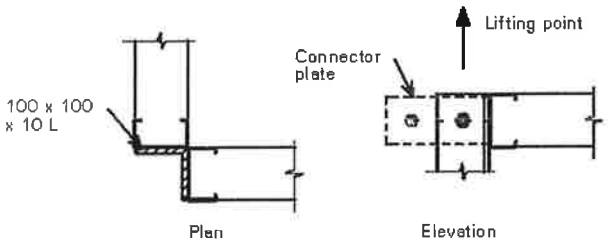
Issues & Solutions: Steel

Tie the Building Together

Volumetric (PPVC)

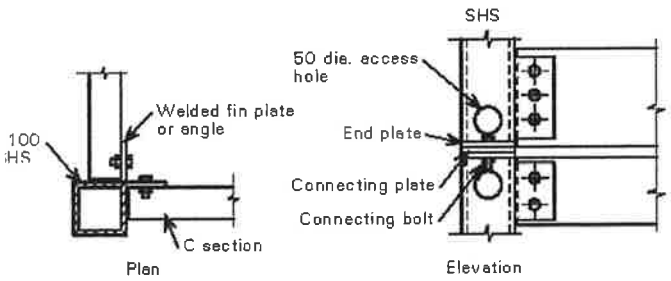


(a) Re-entrant corner with bolted end plate



(b) Re-entrant corner with welded nut

Corner posts using hot rolled steel angles



Corner post using SHS or special sections

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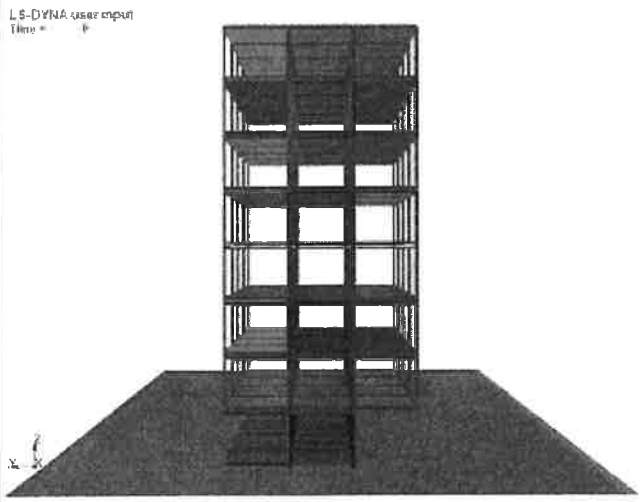
Source of Images: SCI, 2016

PROGRESSIVE COLLAPSE

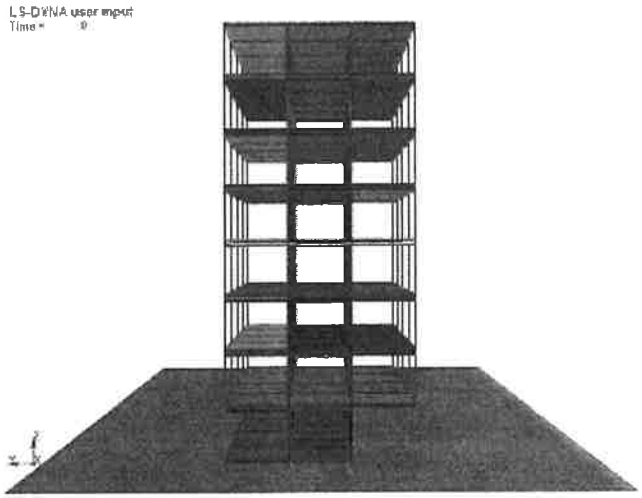
Issues & Solutions: Volumetric Modular (PPVC)

Remove One Module

- Complete (progressive) collapse depends on column size



- Column size = 300 x 200 x 6
- No collapse!



- Column size = 200 x 100 x 6
- Progressive collapse!

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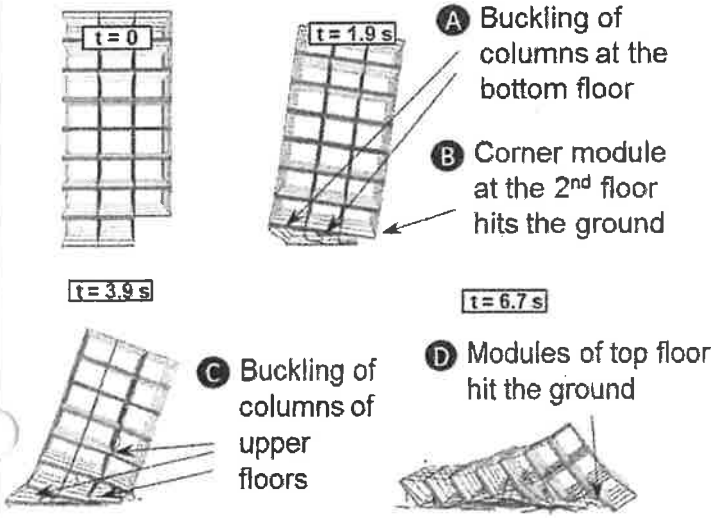
Source: Lou & Bai, Monash University, 2016

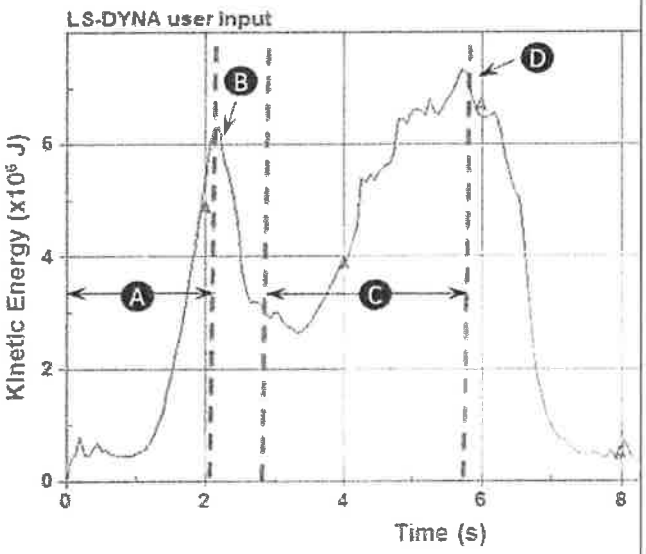
PROGRESSIVE COLLAPSE

Issues & Solutions: Volumetric Modular (PPVC)

Remove One Module

- Complete (progressive) collapse depends on column size





Progressive Collapse Process: Model with Inadequate Column Size

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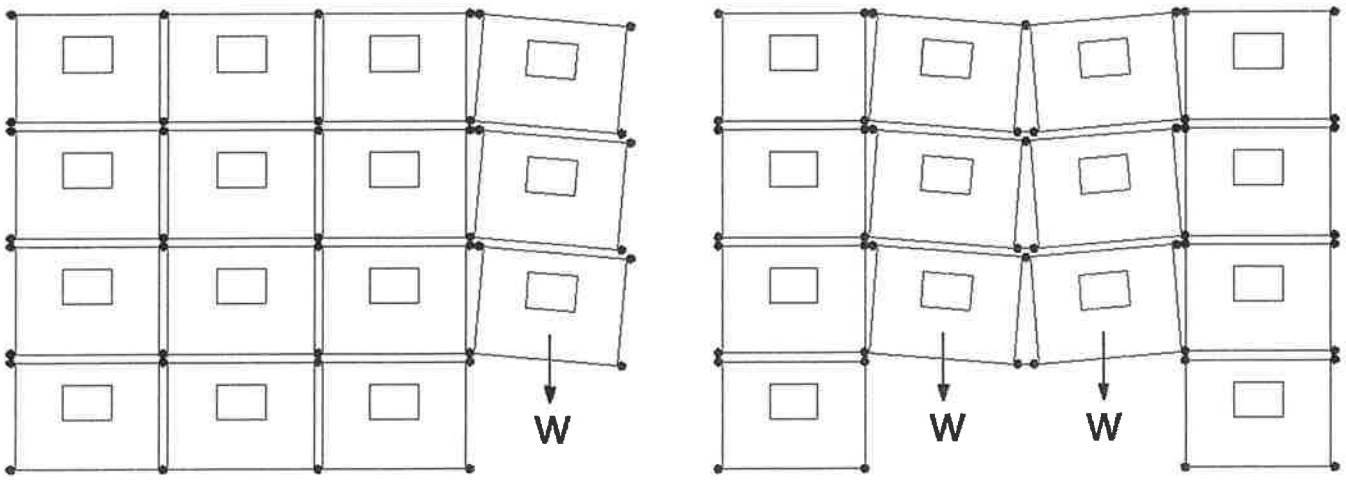
Source: Lou & Bai, Monash University, 2016

PROGRESSIVE COLLAPSE

Issues & Solutions: Volumetric Modular (PPVC)

Remove One Module

- Complete (progressive) collapse depends on column size
- **Engineer to decide:**
  Remove all or part of a module



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Source of Image: Lawson, 2007

PROGRESSIVE COLLAPSE

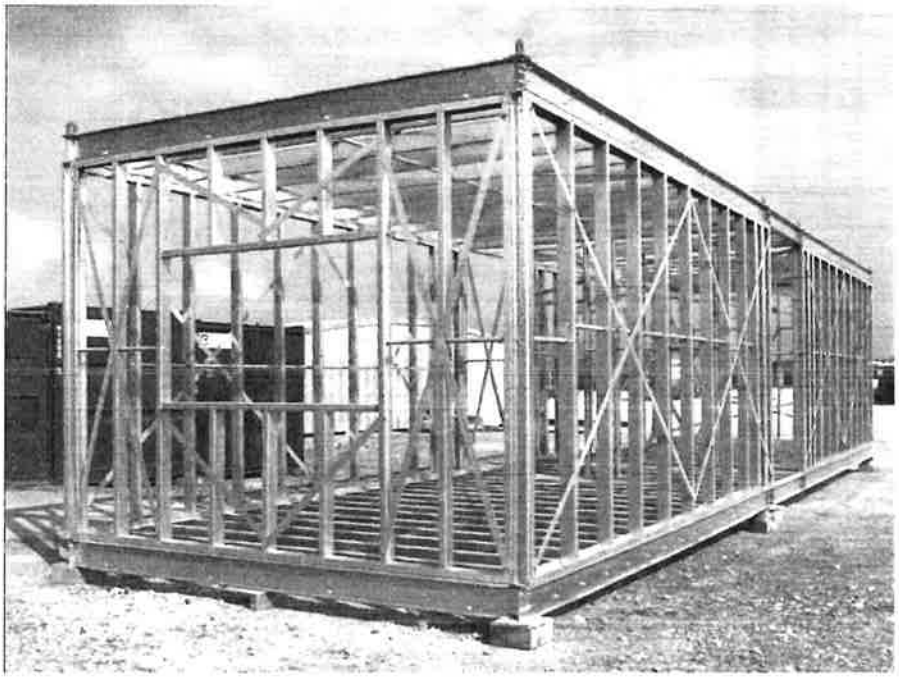
Issues & Solutions: Volumetric Modular (PPVC)

Remove One Module

- Complete (progressive) collapse depends on column size
- Engineer to decide:
  Remove all or part of a module

BUT

- **Difficult to get lightweight steel modules to resist 34 kPa**



Basic Module, Source SCI, 2016

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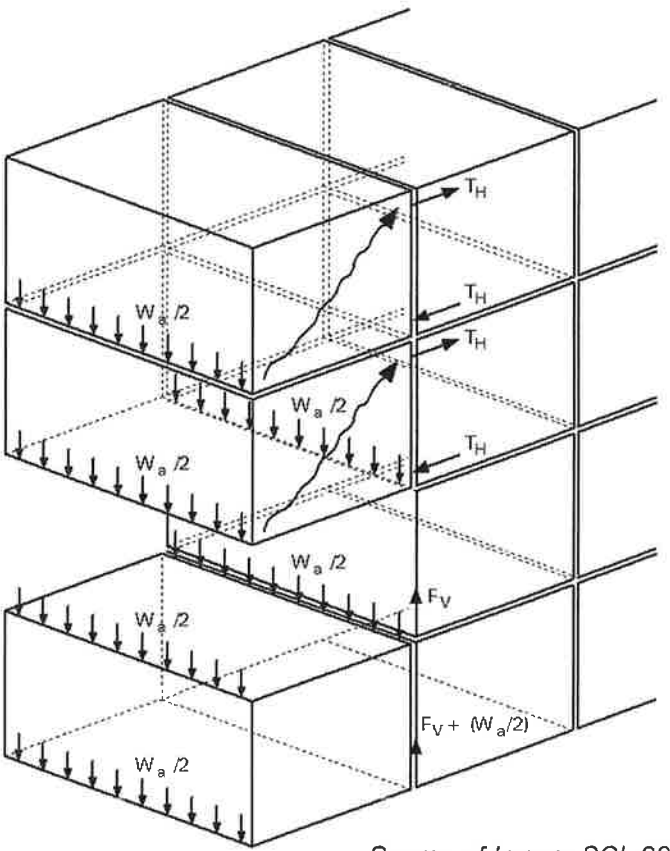
PROGRESSIVE COLLAPSE

Issues & Solutions: Volumetric (PPVC)

Tying Modules Together

Applies to many Volumetric System
Modules act as:

- Either vierendeel frames
- And/or deep beams



Source of Image: SCI, 2016

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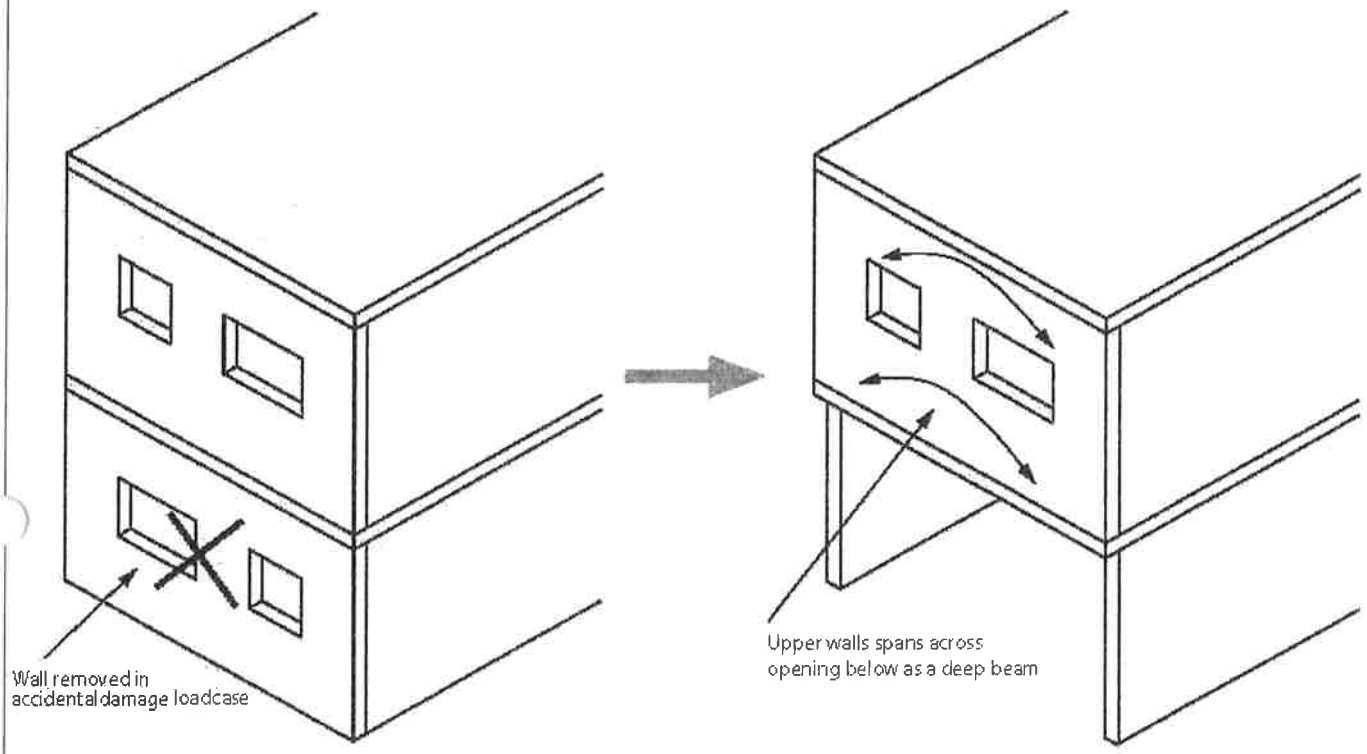
PROGRESSIVE COLLAPSE

Issues & Solutions: Volumetric (PPVC)

Walls Act As Deep Beams

Applies to many Volumetric Systems



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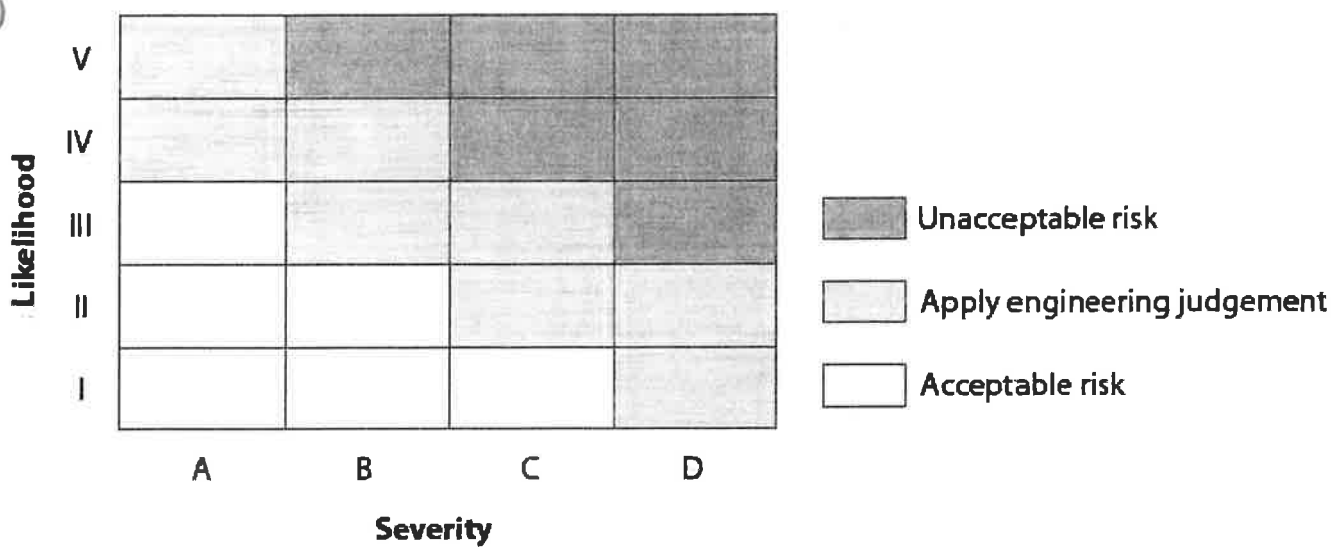
Source of Image: WoodSolutions, 2016

PROGRESSIVE COLLAPSE

Issues & Solutions: Expect the Unexpected

If you are unsure

- Carry out a risk assessment



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Source of Image: SCI, 2016

PROGRESSIVE COLLAPSE
Conclusions

- Tie the structure together
- Expect the unexpected
- **Ensure joints are not the weakest link**

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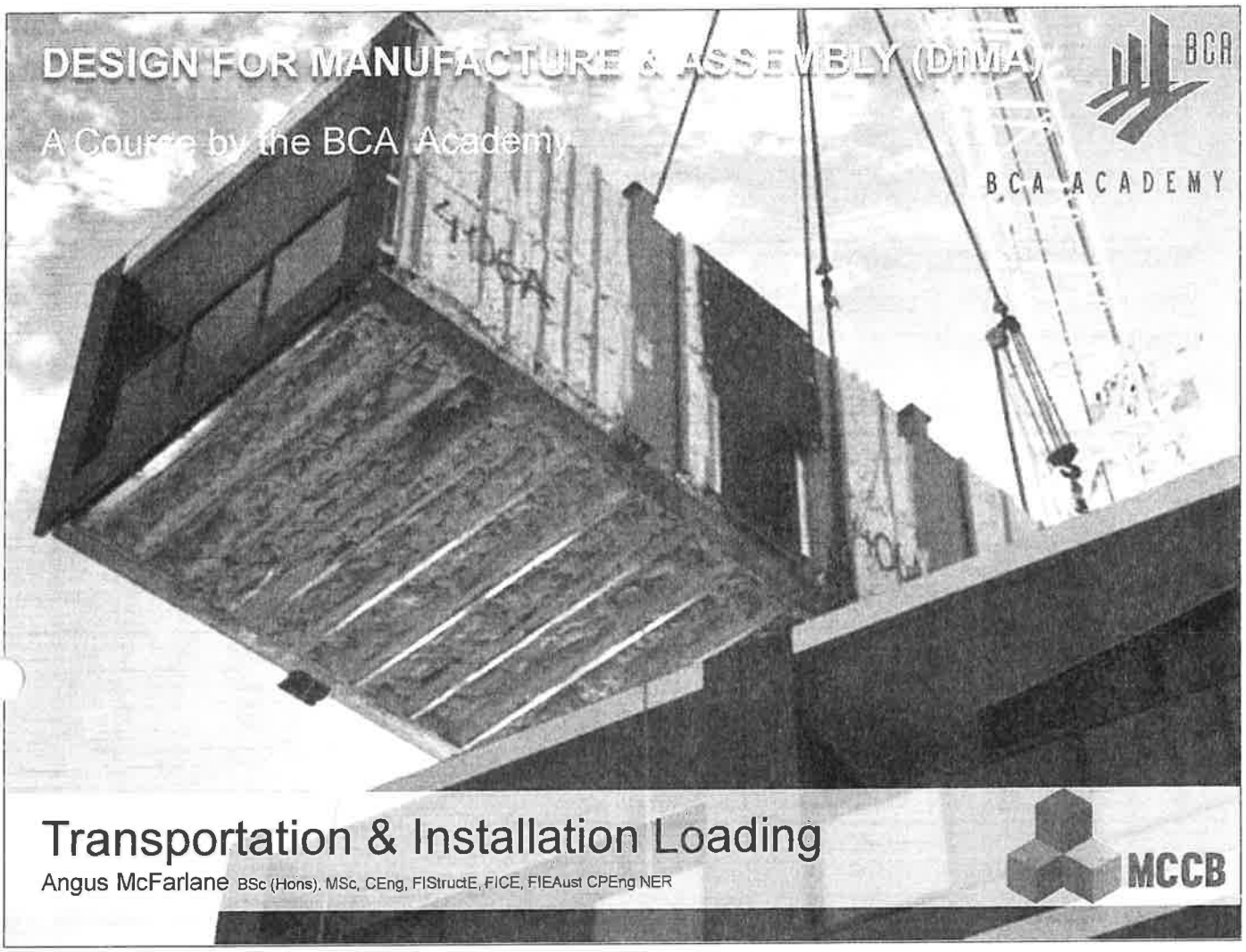

Transportation & Installation Loading

Angus McFarlane BSc (Hons). MSc, CEng, FIStructE, FICE, FIEAust CPEng NER

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TRANSPORTATION & INSTALLATION LOADING

Topics for Discussion

MCCB

- Environment
- Transportation
- Lifting/Erection Loads
- Issues & Solutions
- Conclusions

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TRANSPORTATION & INSTALLATION LOADING
Environment

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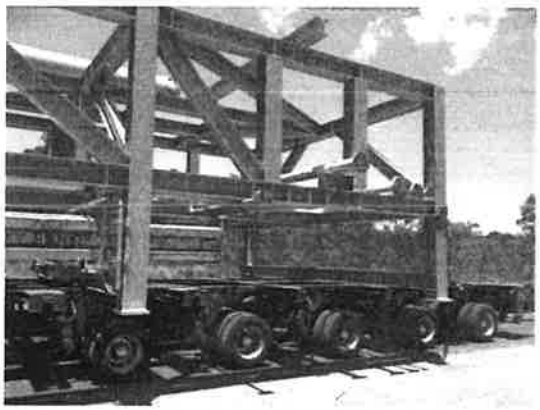
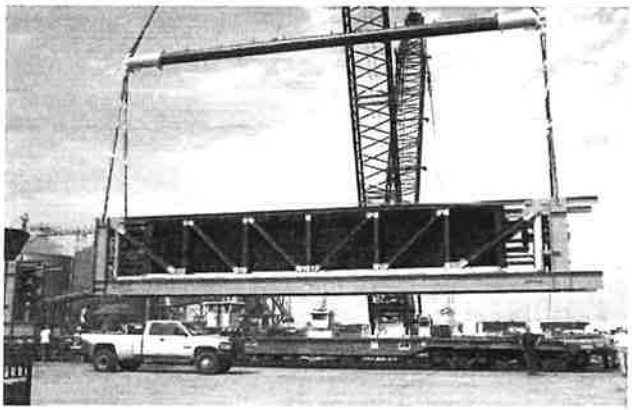
Need an Holistic Design
Not just As-built Condition
Modules can be:
- A ship
- A vehicle
- A pendulum







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TRANSPORTATION & INSTALLATION LOADING
Environment

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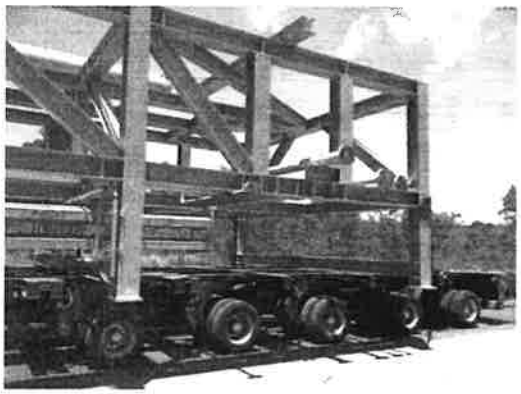
Can be different from final structure
Wind loading
- Typhoons during shipping
- High wind during rail transport

Different Climate
- High humidity
- Exposure to chlorides (salt)







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TRANSPORTATION & INSTALLATION LOADING
Topics for Discussion

MCCB

- Environment
- **Transportation**
- Lifting/Erection Loads
- Issues & Solutions
- Conclusions

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TRANSPORTATION & INSTALLATION LOADING
Transportation: Shipping

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High Loading
- Typhoon ± 1 g
- Heaving
- Pitching
- Rolling
- Swaying



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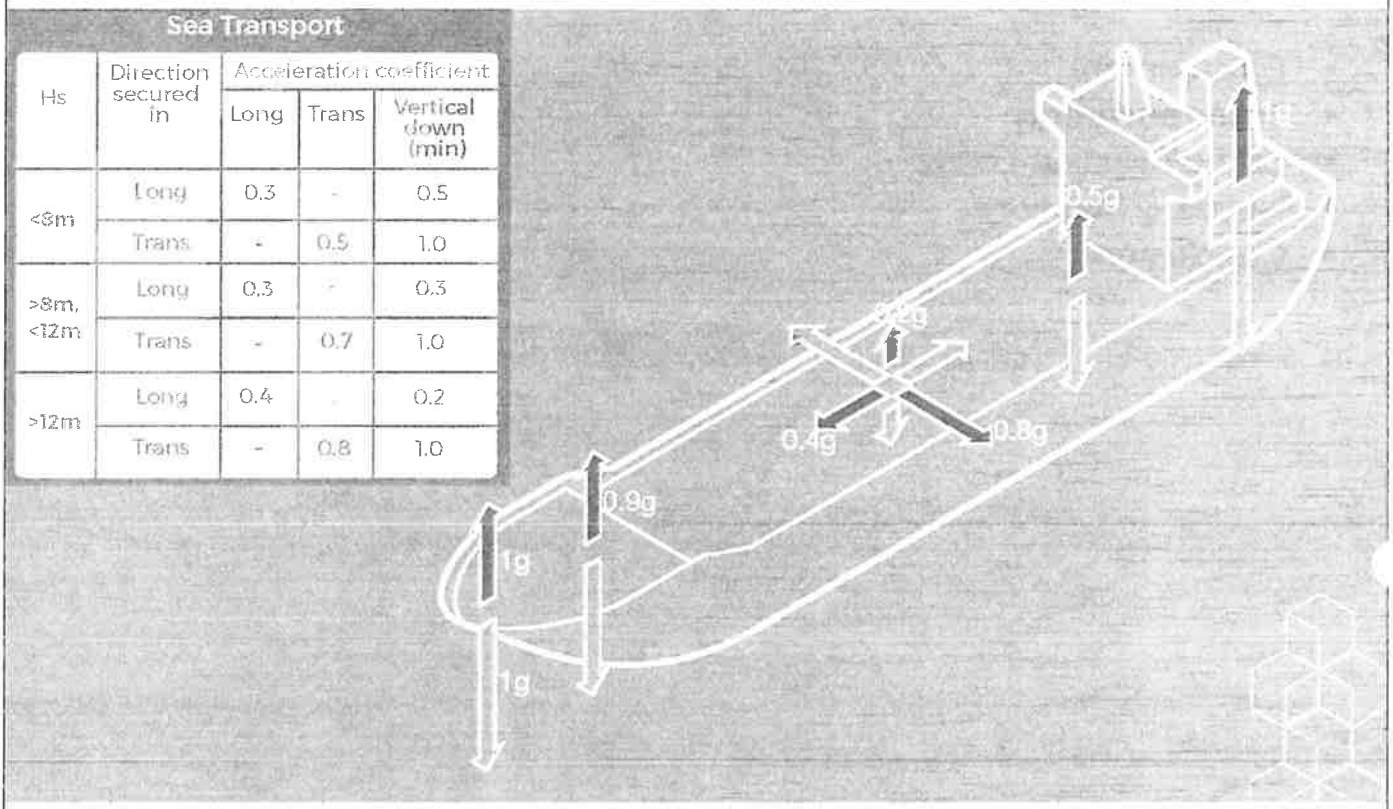
TRANSPORTATION & INSTALLATION LOADING

Transportation: Shipping

Sea Transport

Hs	Direction secured in	Acceleration coefficient		
		Long	Trans	Vertical down (min)
<8m	Long	0.3	-	0.5
	Trans	-	0.5	1.0
>8m, <12m	Long	0.3	-	0.3
	Trans	-	0.7	1.0
>12m	Long	0.4	-	0.2
	Trans	-	0.8	1.0



Source: Model Code for the Design of Modular Structures, 2016

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TRANSPORTATION & INSTALLATION LOADING

Transportation: Shipping

High Loading

- Typhoon ± 1 g
- Heaving
- Pitching
- Rolling
- Swaying

Real-World Example:

- Project in Darwin
- Ship travelled through 3 typhoons in 1 journey



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TRANSPORTATION & INSTALLATION LOADING

Transportation: Road

Loading can be High

- Vertical & Horizontal Accelerations



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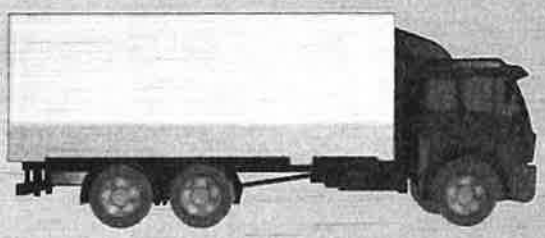
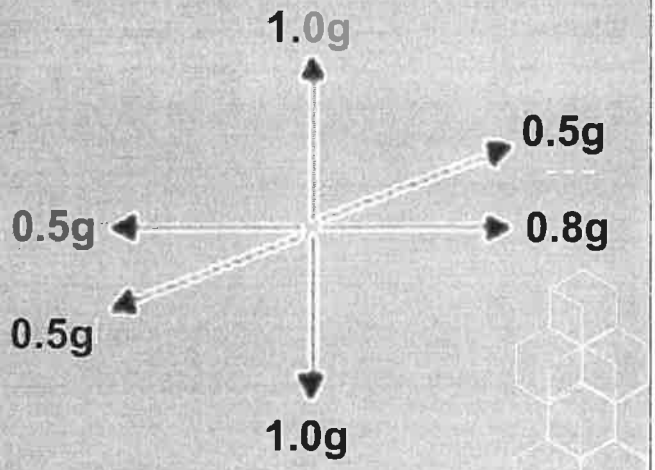
TRANSPORTATION & INSTALLATION LOADING

Transportation: Road

Road Transport

Direction secured in	Acceleration coefficient			
	Long		Trans	Vertical down (min)
	Forward	Rearward		
Long	0.8	0.5	-	1.0
Trans	-	-	0.5	1.0





Source: Model Code for the Design of Modular Structures, 2016

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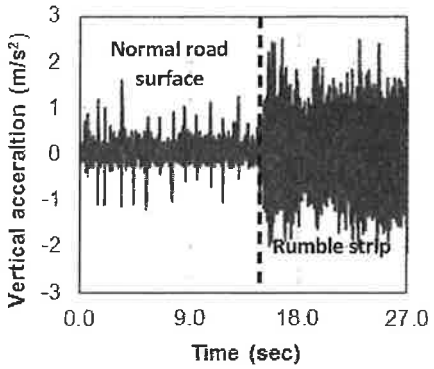
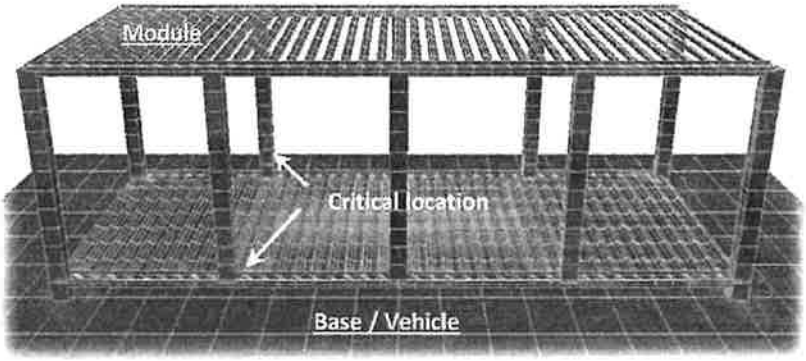
TRANSPORTATION & INSTALLATION LOADING

Land Transportation Loading

Dynamic Loading on Modules





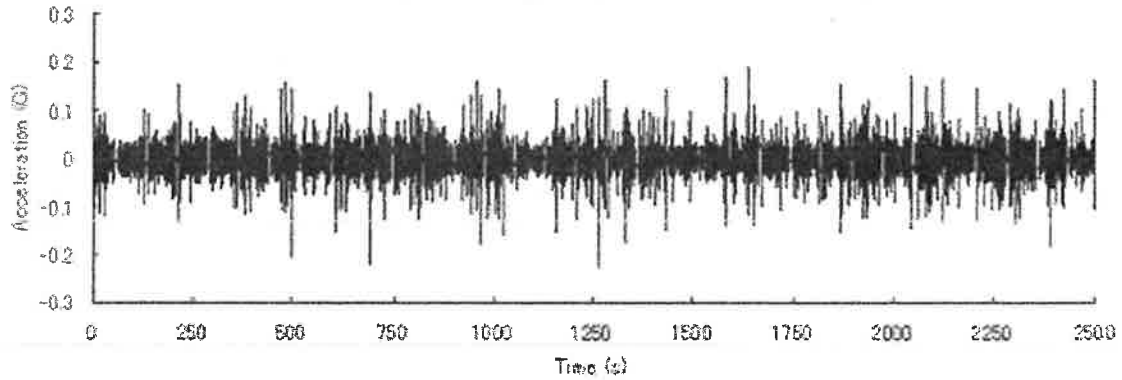


Fig 1. Typical vertical acceleration history vs time in actual truck vibration (11)

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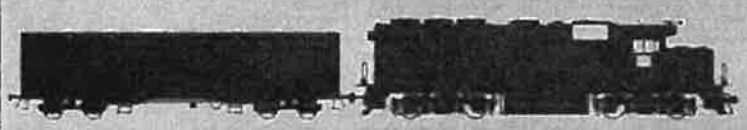
Source: PhD Project No. 1 , Monash University, 2016

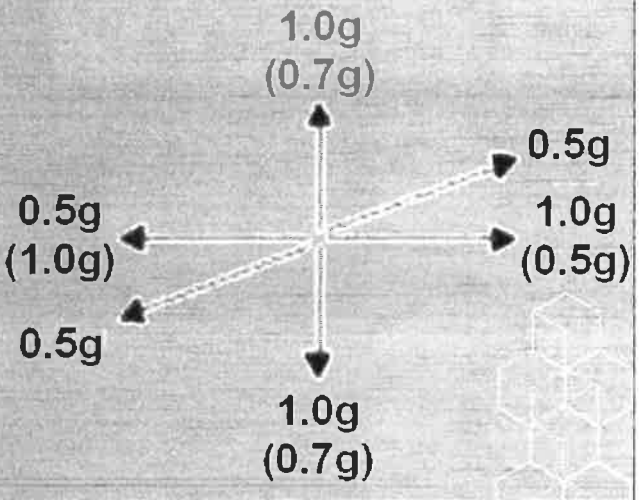
TRANSPORTATION & INSTALLATION LOADING

Transportation: Rail

Rail Transport

Direction secured in	Acceleration coefficient			
	Long		Trans	Vertical down (min)
	Forward	Rearward		
Long	0.5 (1.0)	0.5 (1.0)	-	1.0 (0.7)
Trans	-	-	0.5	1.0 (0.7)





Source: Model Code for the Design of Modular Structures, 2016

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TRANSPORTATION & INSTALLATION LOADING

Transportation: Fatigue

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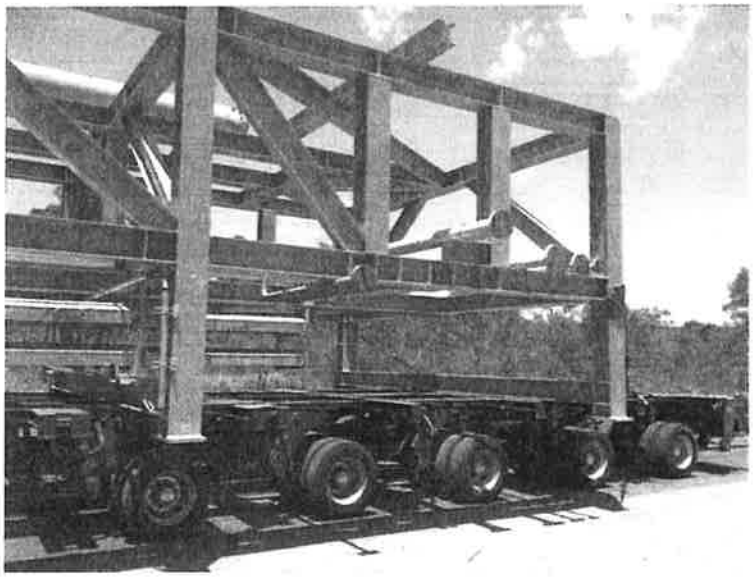
Fatigue Needs to be Considered – Especially for Long Road Journeys

Assess & then monitor to derive real-life spectrum

Potential benefits are:

- Reduced fatigue damage
- Prolonged life cycle



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TRANSPORTATION & INSTALLATION LOADING

Transportation: Fatigue

MCCB

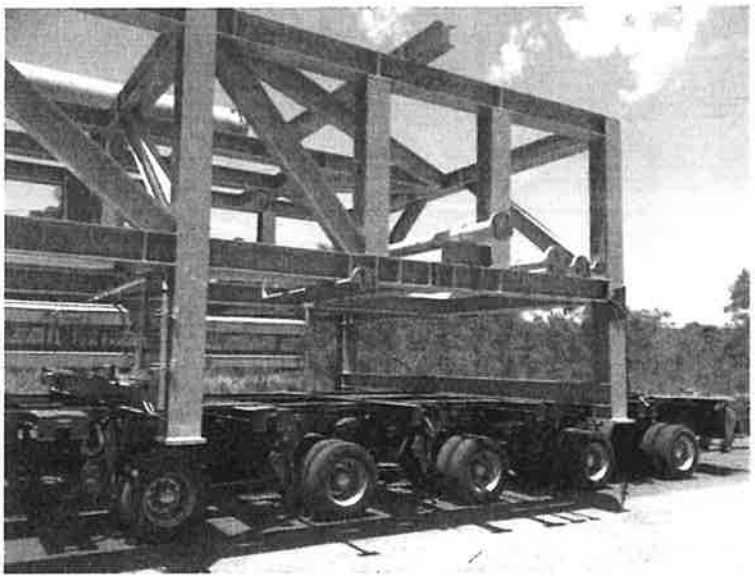
Fatigue Needs to be Considered – Especially for Long Road Journeys

Assess & then monitor to derive real-life spectrum

Potential benefits are:

- Reduced fatigue damage
- Prolonged life cycle

Designer could be negligent by not considering fatigue



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TRANSPORTATION & INSTALLATION LOADING

Topics for Discussion

- Environment
- Transportation
- **Lifting/Erection Loads**
- Issues & Solutions
- Conclusions

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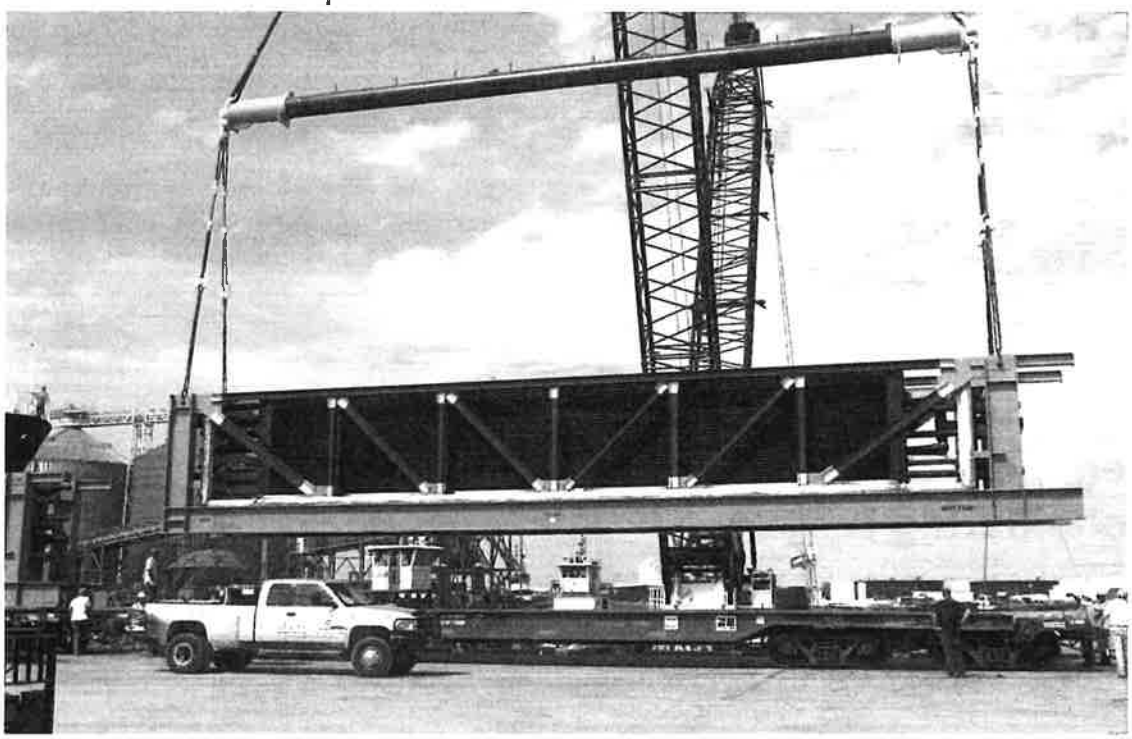
TRANSPORTATION & INSTALLATION LOADING

Lifting/Erection Loads

Lifting loads different from permanent loads

Loads can be higher

- Tension can be compression & vice-versa



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TRANSPORTATION & INSTALLATION LOADING

Lifting/Erection Loads

Lifting loads different from permanent loads

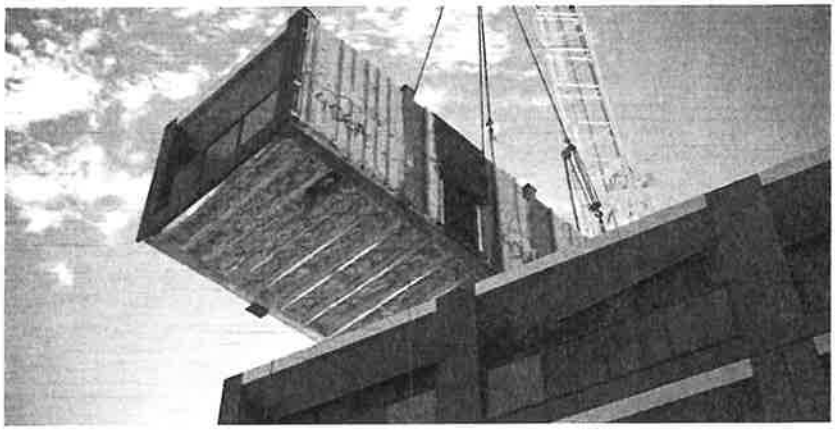
Loads can be higher

- Tension can be compression & vice-versa

Consider:

- Racking of modules
- Deflection of modules





Source of Images: Hickory Building Systems, 2014

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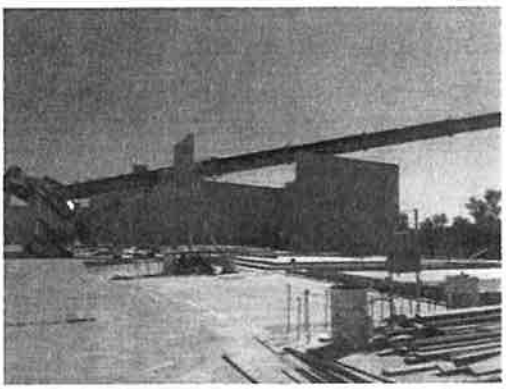
TRANSPORTATION & INSTALLATION LOADING

Lifting/Erection Loads

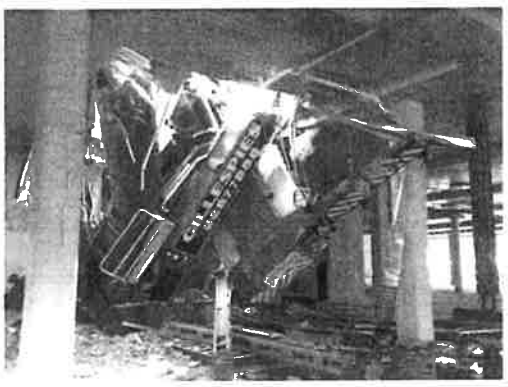
Lifting loads different from permanent loads

- They can impose high loads on existing structures









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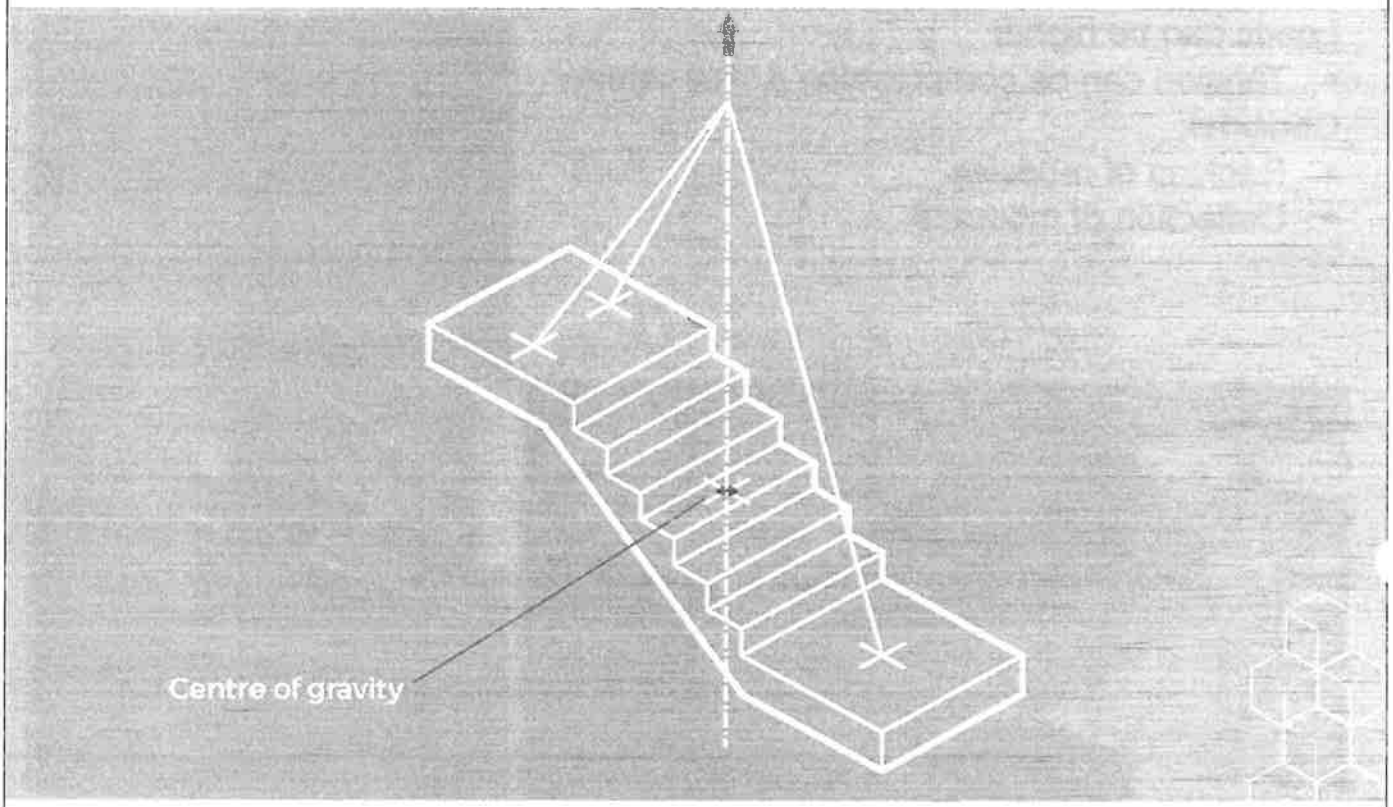
TRANSPORTATION & INSTALLATION LOADING
Lifting/Erection Loads



Source: Model Code for the Design of Modular Structures, 2016

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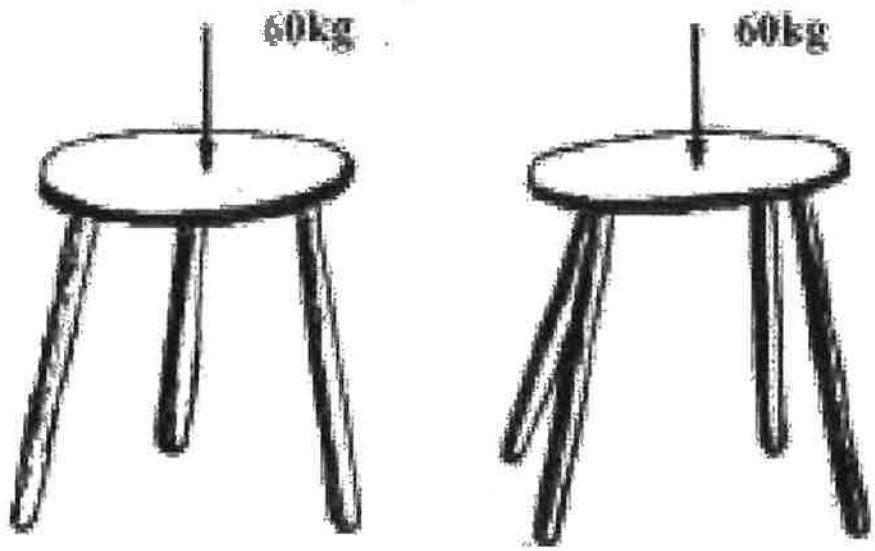
TRANSPORTATION & INSTALLATION LOADING
Lifting/Erection Loads

Don't forget Hambly's Paradox

Which is better? Three legs or four legs?



Source: Hambly, Structural Analysis by Example, 1994

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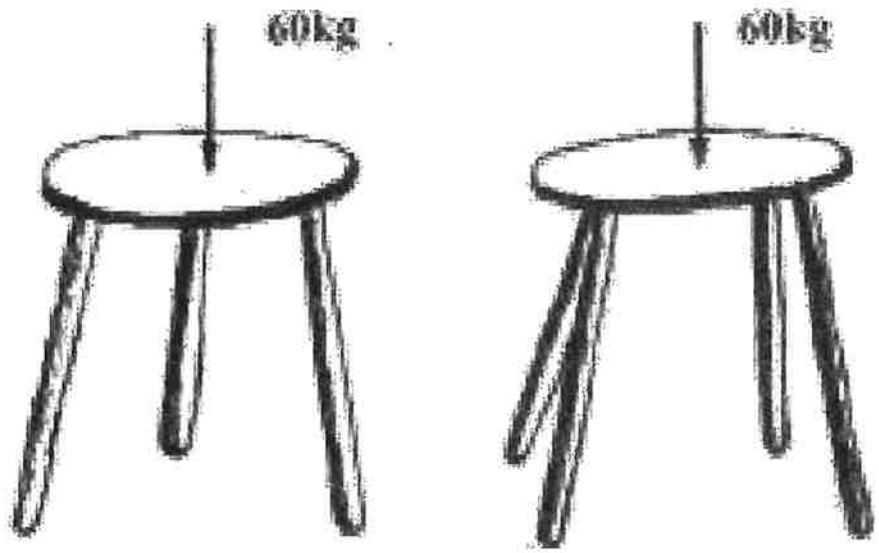
TRANSPORTATION & INSTALLATION LOADING
Lifting/Erection Loads

Don't forget Hambly's Paradox

Which is better? Three legs or four legs?



To paraphrase George Orwell:

Three legs good
Four legs bad

Source: Hambly, Structural Analysis by Example, 1994

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TRANSPORTATION & INSTALLATION LOADING
Topics for Discussion

- Environment
- Transportation
- Lifting/Erection Loads
- **Issues & Solutions**
- Conclusions

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TRANSPORTATION & INSTALLATION LOADING

Issues & Solutions

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Mistakes to Avoid

Planned to be tallest volumetric modular (PPVC) building in the world in 2015

- 32 storeys
- 36 modules per floor, 930 total
- Modules completely finished in the factory (structural, MEP & fit-out)



Atlantic Yards B2, Brooklyn, New York, USA
Source: http://www.treehugger.com/modular-design/

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TRANSPORTATION & INSTALLATION LOADING

Issues & Solutions

MCCB

Mistakes to Avoid

Planned to be tallest volumetric modular (PPVC) building in the world in 2015

- 32 storeys
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- Modules completely finished in the factory (structural, MEP & fit-out)

BUT

Several Errors, including:

- **Lack of tolerance**
- **Misalignment problems**
- **Leaking gaskets**
- **Waterproofing failures**



Atlantic Yards B2, Brooklyn, New York, USA
Source: http://www.treehugger.com/modular-design/

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TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

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Mistakes to Avoid

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BUT

Several Errors, including:

- Lack of tolerance
- Misalignment problems
- Leaking gaskets
- Waterproofing failures

Solutions:

- **Joints to be properly designed**
- **Use experienced team**



Atlantic Yards B2, Brooklyn, New York, USA
Source: http://www.treehugger.com/modular-design/

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TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

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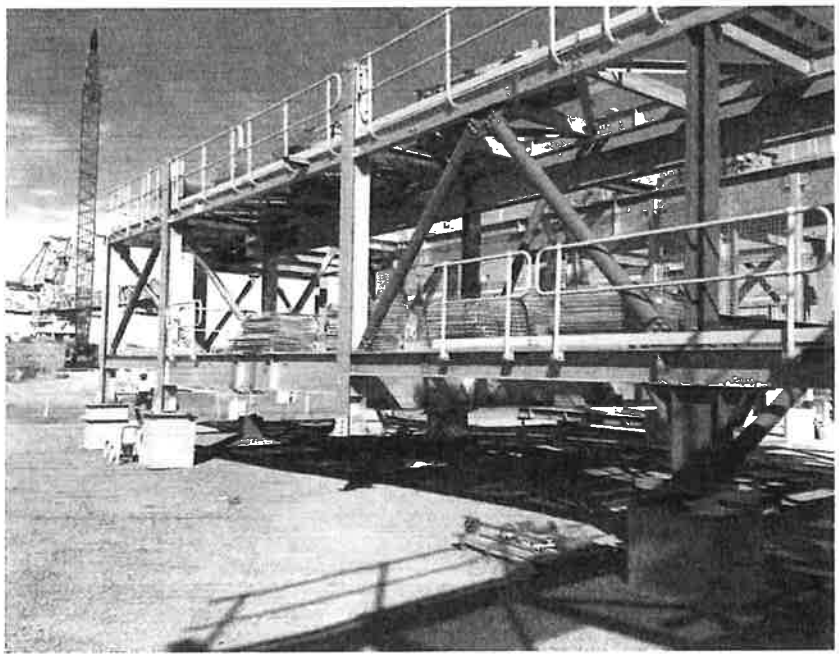
Need to Optimise Temporary Works

- Temporary steel ≈ 20-30% of total weight of steel



Red Oxide is temporary transportation/lifting steel

- 20-100 kg/m

Source of Image: Laing O'Rourke, 2014

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TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

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Need to Optimise Temporary Works

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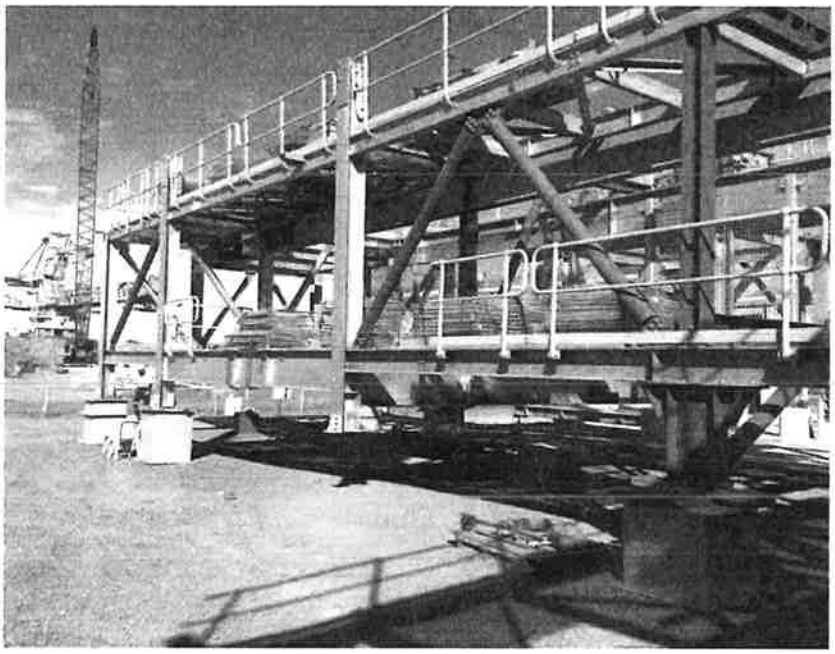

Red Oxide is temporary transportation/lifting steel

- 20-100 kg/m

Replace with:

- **Light, tension-only members**
- **1-2 kg/m**

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Source of Image: Laing O'Rourke, 2014

TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

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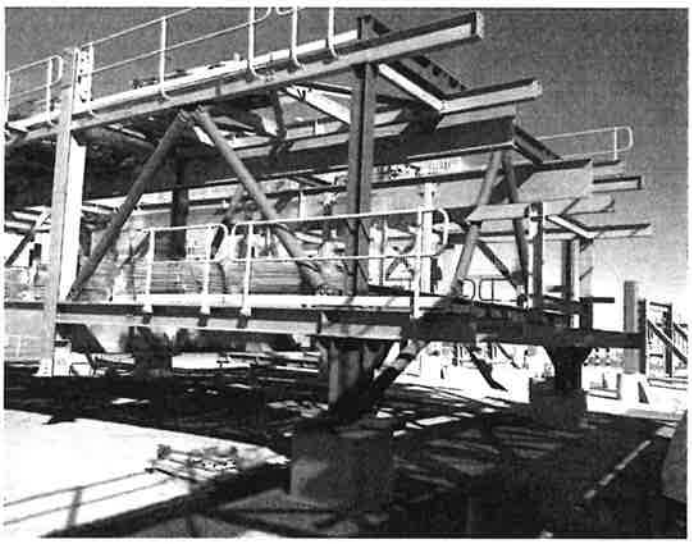
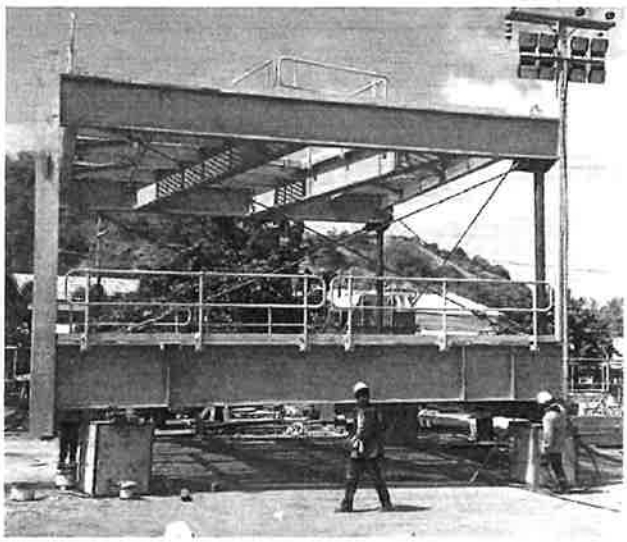
Utilise Tension-only Member for Temporary Worksr



Conventional Temporary Works Design



Tension-only Member Design

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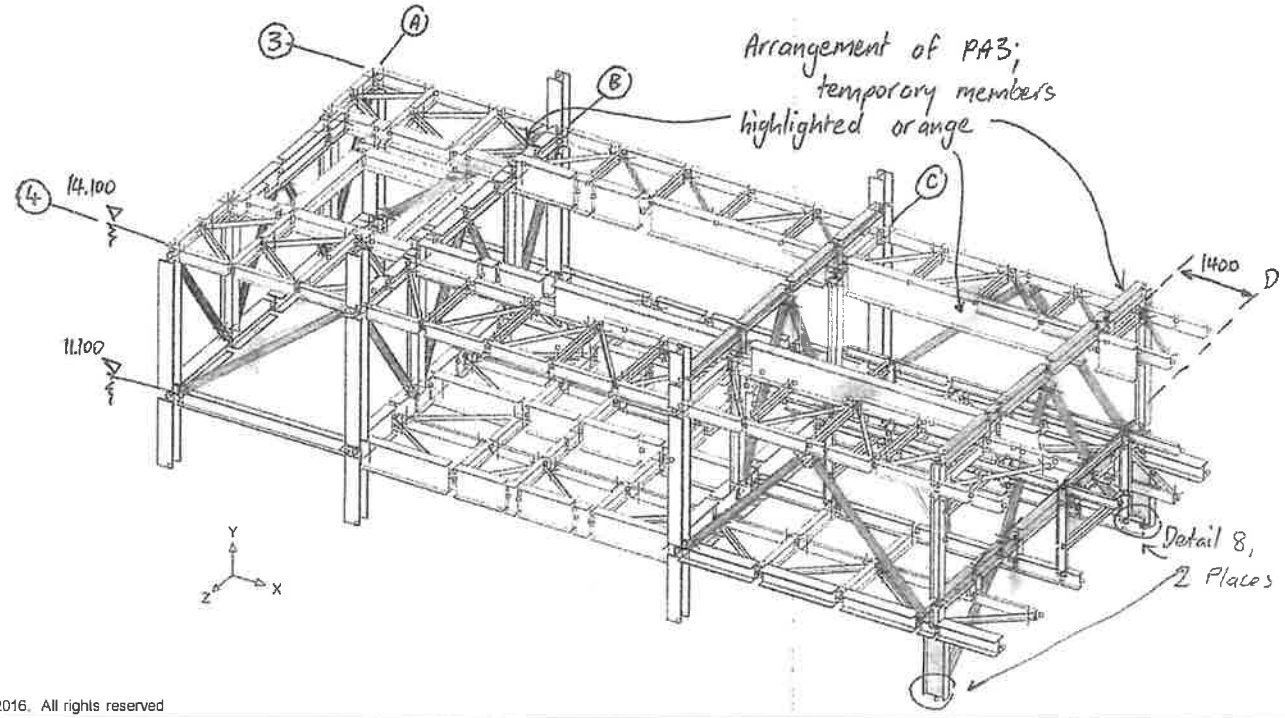
Source of Images: Laing O'Rourke, 2014

TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions



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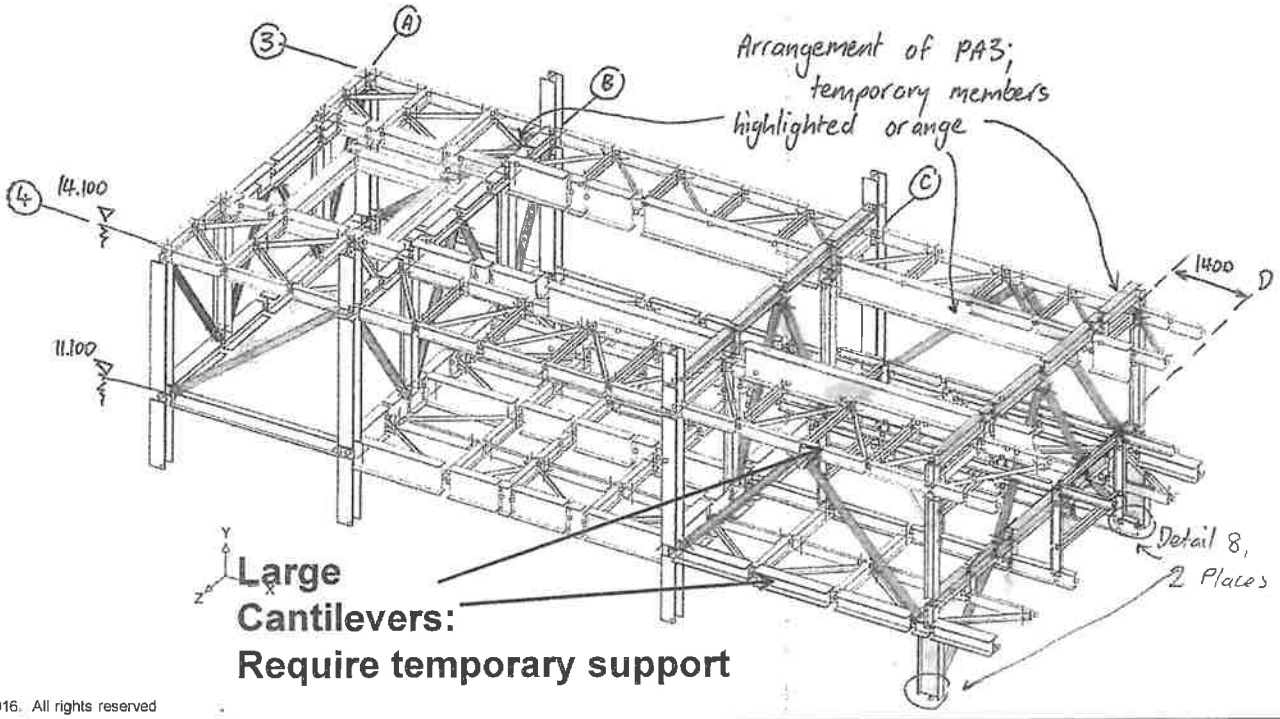
TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

Steelwork Designed for Permanent Loading

- Poor Modularisation by Designer



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TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

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Steelwork Designed for Permanent Loading

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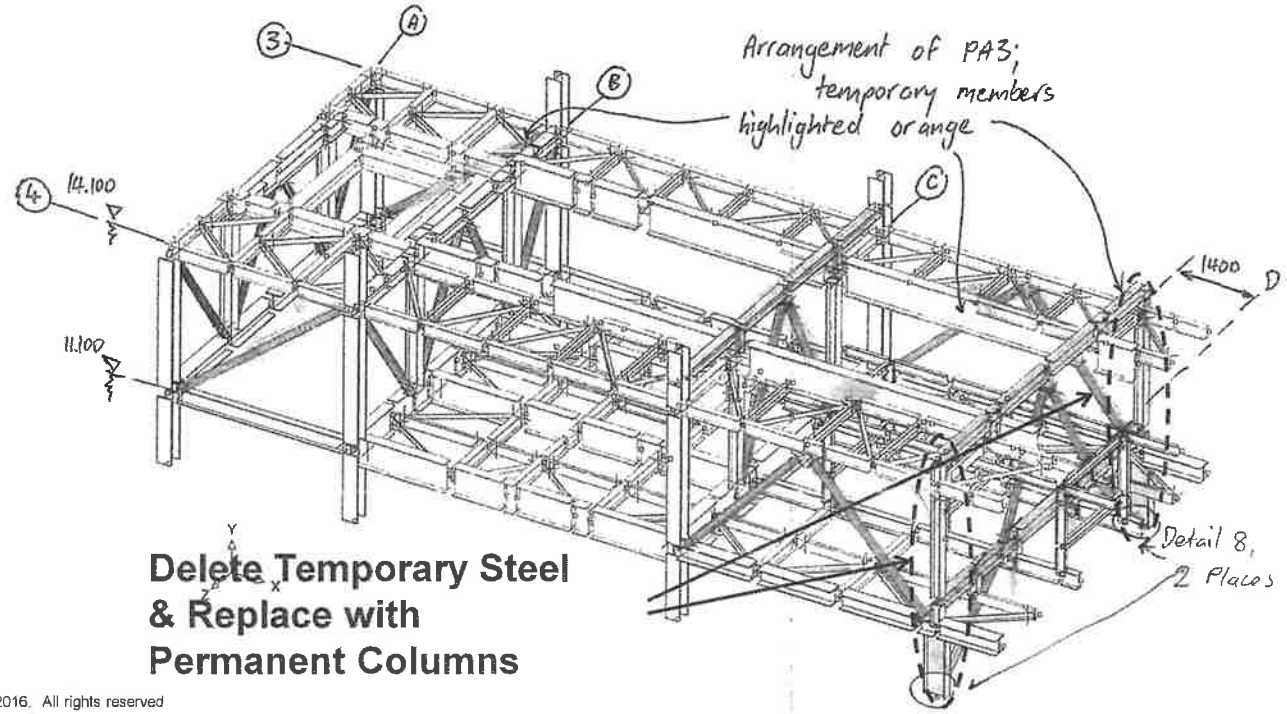

Delete Temporary Steel & Replace with Permanent Columns

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TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

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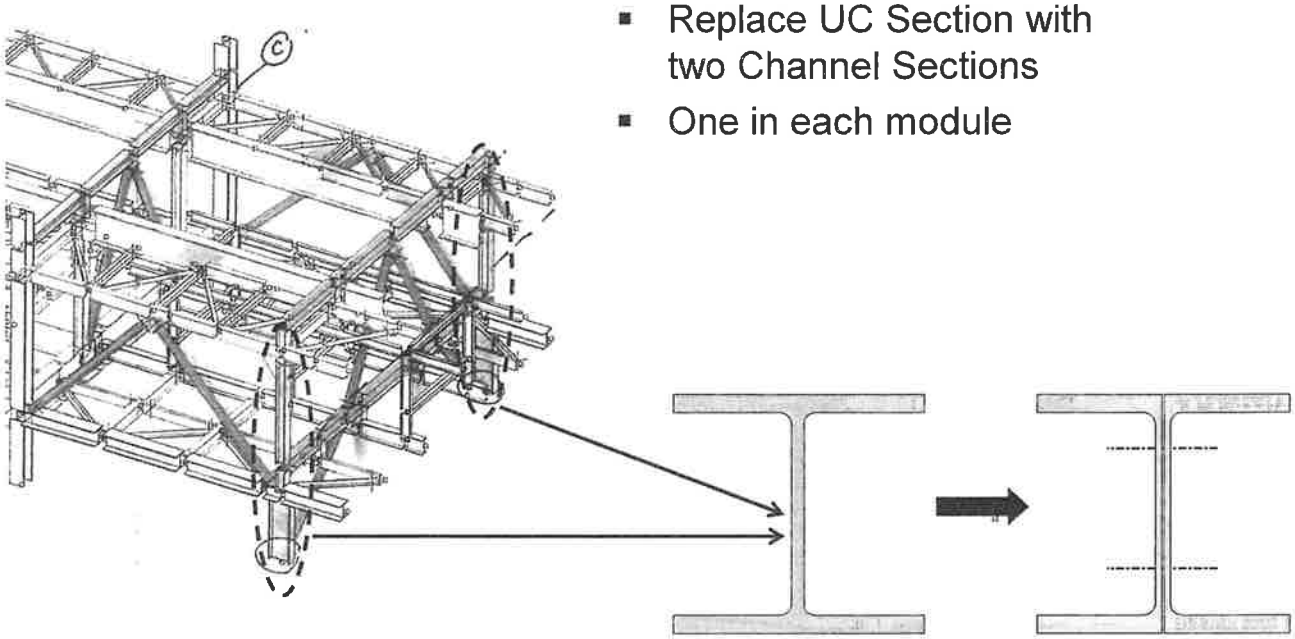
Optimise Permanent Steelwork for Modularisation



- Replace UC Section with two Channel Sections
- One in each module

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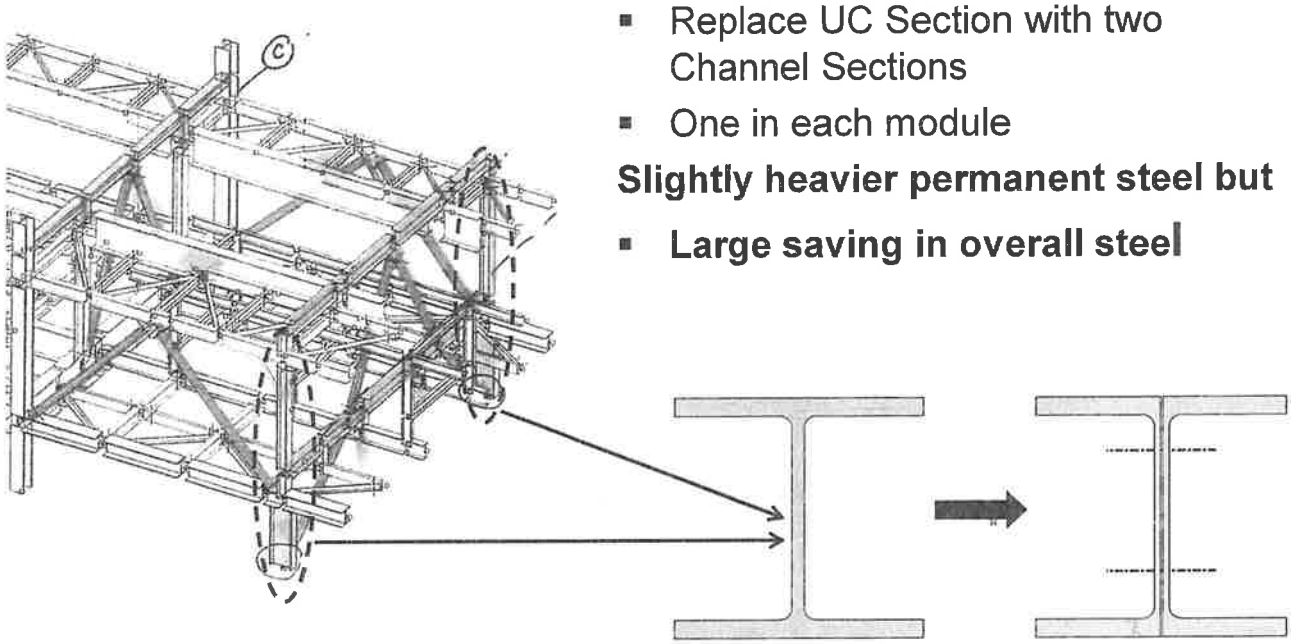
TRANSPORTATION & INSTALLATION LOADING
Issues & Solutions

Optimise Permanent Steelwork for Modularisation



- Replace UC Section with two Channel Sections
- One in each module

Slightly heavier permanent steel but

- **Large saving in overall steel**

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TRANSPORTATION & INSTALLATION LOADING
Conclusions

- Consider the transportation environment
- Transportation loads can be higher than the final loading
- Great care required with installation tolerances

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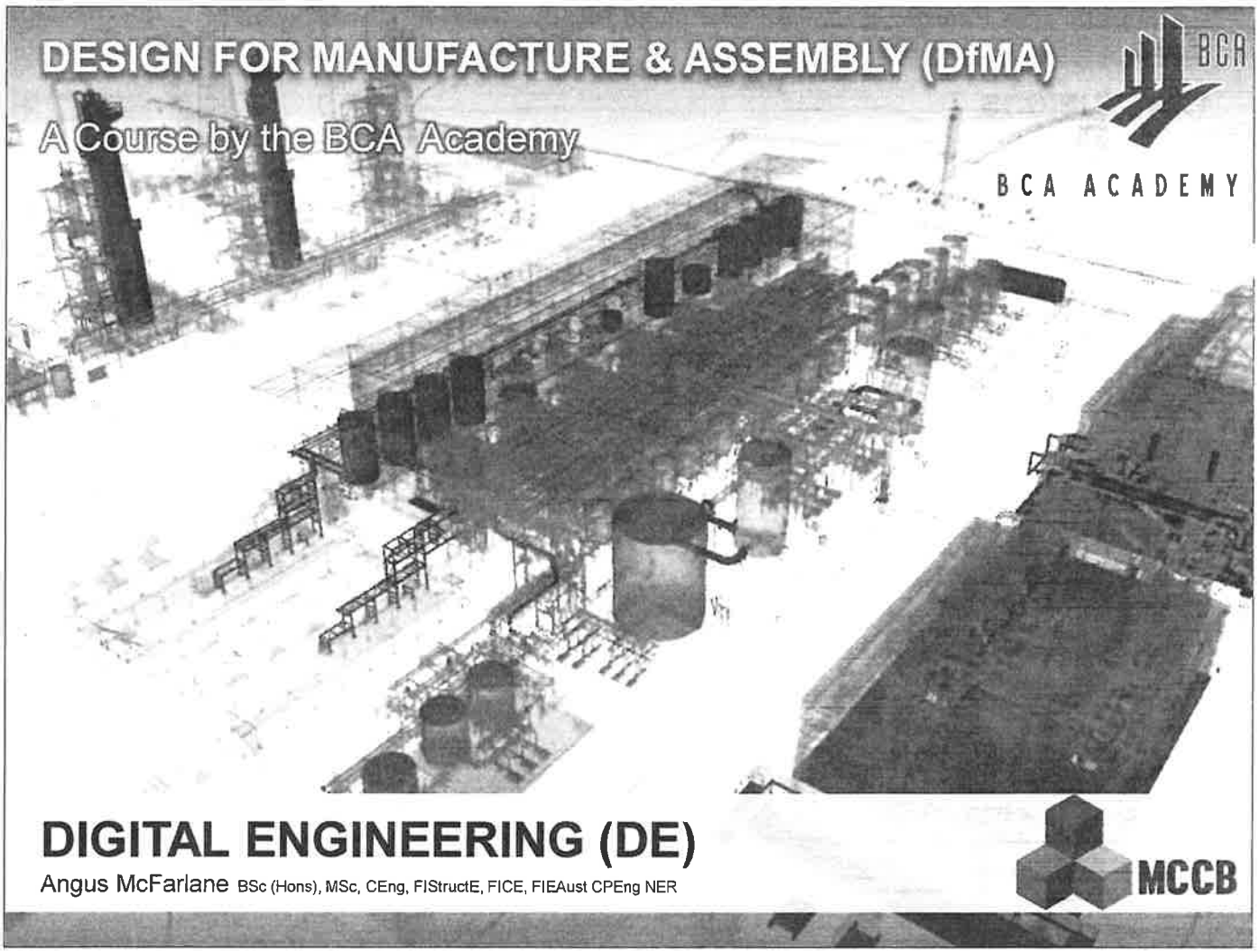
DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)
A Course by the BCA Academy
BCA
BCA ACADEMY
Transportation & Installation Loading. Q&A?
MCCB


DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)
A Course by the BCA Academy
BCA
BCA ACADEMY
DIGITAL ENGINEERING (DE)
Angus McFarlane BSc (Hons), MSc, CEng, FIStructE, FICE, FIEAust CPEng NER
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DIGITAL ENGINEERING
Topics for Discussion



- Trends in Aerospace & Automotive Engineering
- Shipbuilding – an analogy
- DE at LOR
- Augmented Reality & Virtual Reality

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DIGITAL ENGINEERING
Topics for Discussion



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DE (R)Evolution - Trends

From CAD to Digital Engineering

1970 1980 1990 2000 2005 2010 2015 2020

Aerospace/Automotive

Shipbuilding / Petro-Chem

Civil Engineering / Infrastructure

Design Optimisation Focus

Component → Component Groups → Processes Product → Product Lifecycle +

System Focus

CAD / CAM separate systems → Networked systems → ERP & MES → PLM

1. Society
2. Technology
3. Economics & Competitive landscape
4. Civil Engineering Industry
5. Other trends ?

- Big Data
- Sensors
- IoT
- Analytics
- Robotics
- Automation
- VR & AR
- Additive Manufacturing
- AI

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DIGITAL ENGINEERING

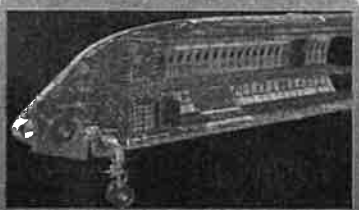
Trends in Aerospace & Automotive Engineering

Digital Mockups

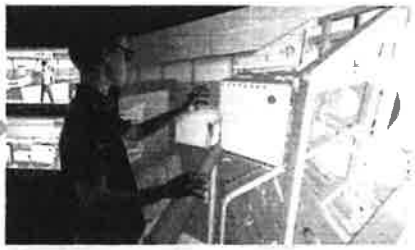


VR Engineering, Design & Client engagement.

{ Unified Systems: ERP, MES, PLM }



single source of truth iDMU



Virtual Maintenance & operation planning



Manufacturing & assembly simulation & planning

Operational models & simulation



Virtual Production simulation & planning

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Trends in Aerospace & Automotive Engineering

"One Line to Rule them all" – flexible manufacturing



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Topics for Discussion

- Trends in Aerospace & Automotive Engineering
- Shipbuilding – an analogy
- DE at LOR
- Augmented Reality & Virtual Reality

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Shipbuilding – an analogy

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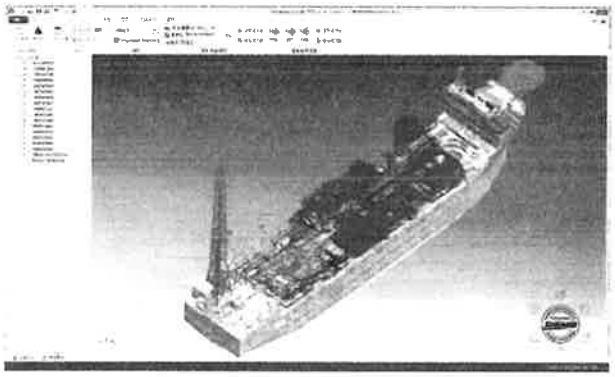
Key Similarities
- High value, low volume products
- Large project size
- High complexity
- High Life-Cycle Cost focus*
- Strong industry competition





Key Differences
- Product design is highly iterative*
- Product is a closed system
- Controlled production environment*
- Tightly integrated Supply Chain

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Shipbuilding – an analogy

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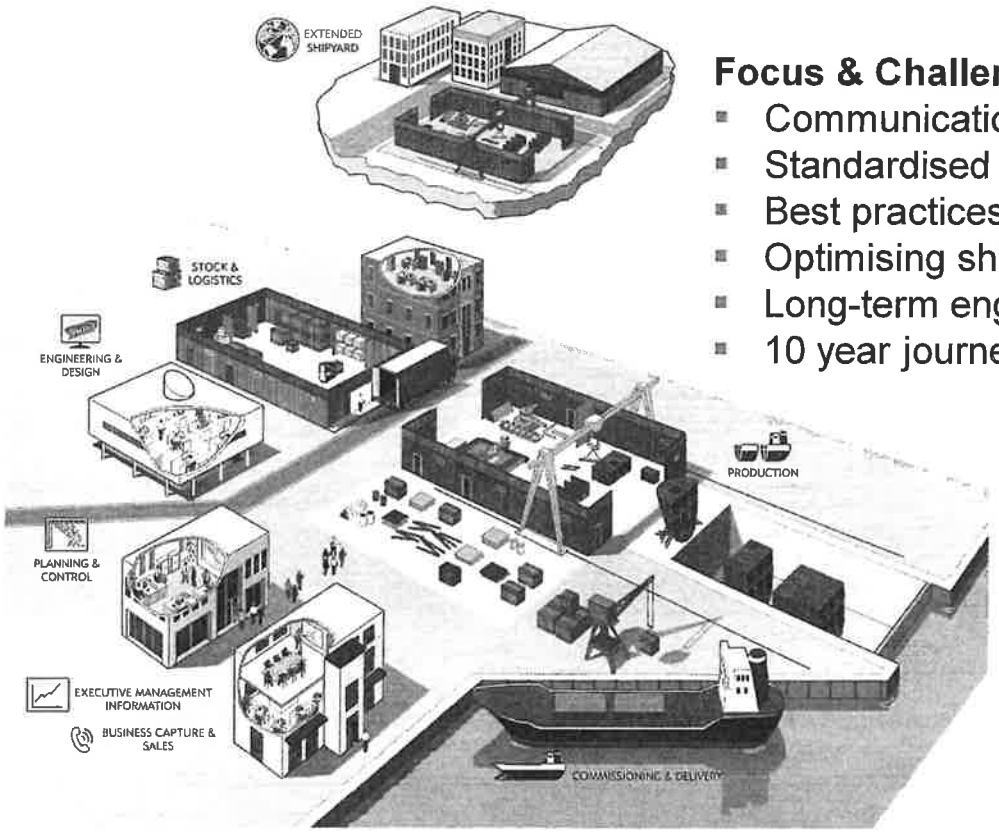

Focus & Challenges addressed
- Communication and collaboration
- Standardised processes
- Best practices (systemic learning)
- Optimising shipyard productivity
- Long-term engineering advances
- 10 year journey from CAD to PLM

Project Lifecycle Management

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DIGITAL ENGINEERING
Topics for Discussion

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- Trends in Aerospace & Automotive Engineering
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Mantra

"Build twice – once virtually"

LAING O'ROURKE

Digital Engineering

Laing O'Rourke Australia (2015)

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DE at LOR

Benefits of Digital Engineering

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1 Increased confidence and **surety of project outcome** in cost, programme and quality, delivering greater understanding of complex construction processes and the associated risks

2 A shared and **collaborative environment** which enables innovative solutions to be identified, developed and rapidly validated by all project stakeholders, the Digital Engineering model being at the heart of the way the project team go to work

3 **Effective communication** of the construction impact on the surrounding environment for all project stakeholders, including external interfaces such as planning authorities and neighbouring parties

4 Ability to plan and deliver **optimum efficiency in asset operation** maximising the value of the asset over its entire life

5 Ability to identify then eliminate, mitigate or **manage health, safety and environmental risks** for the local population, construction personnel and future asset users much earlier in the process

6 Ability to rapidly optioneer different solutions virtually, identify, develop and validate Design for Manufacture and Assembly (DfMA) opportunities to provide the **optimum client solution**

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Laing O'Rourke Australia (2015)

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Application of Central Model

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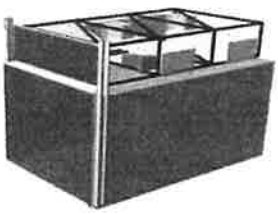
Design Coordination





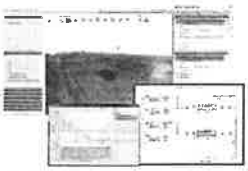
Construction Innovation and DfMA







Costing



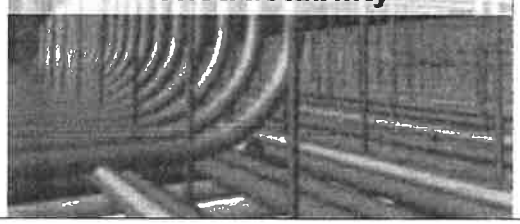
Facilities Management

Sequencing

Logistics Planning



Constructability



Visualisation



Laing O'Rourke Australia (2014)

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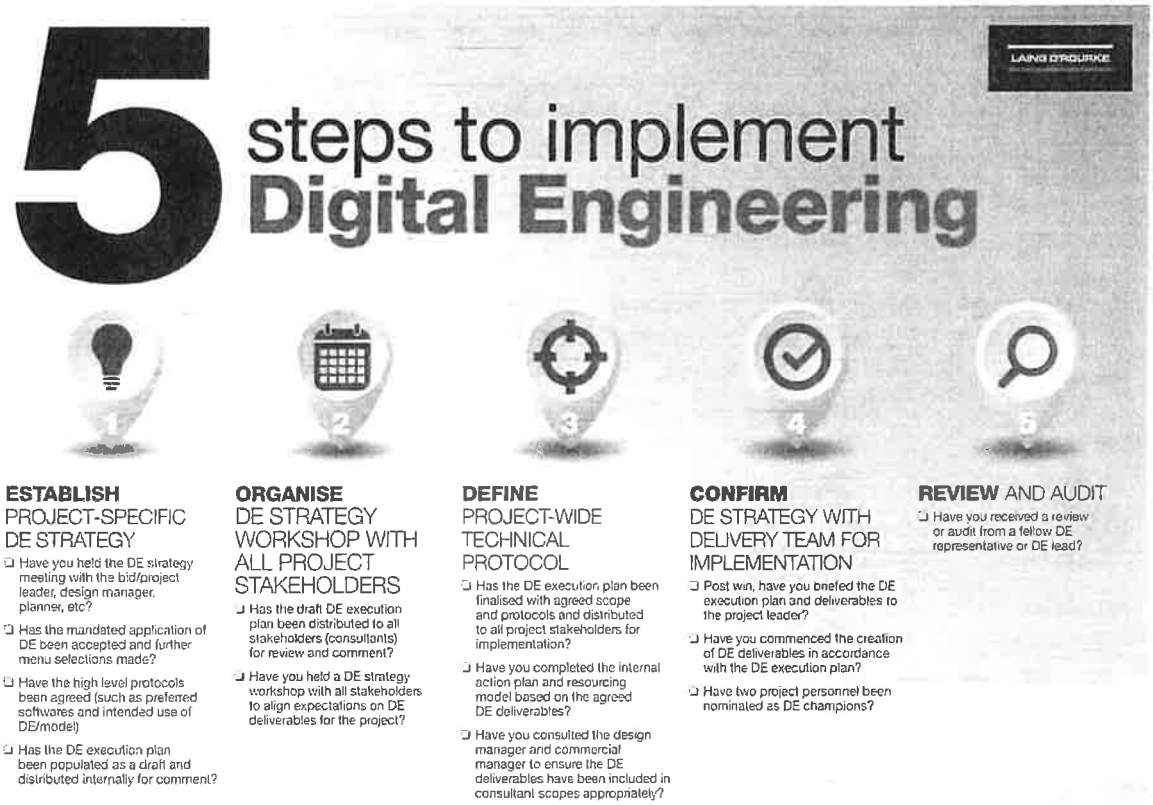
DE at LOR
5 Steps to Implement DE



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5 Steps to Digital Engineering, Laing O'Rourke Australia (2015)

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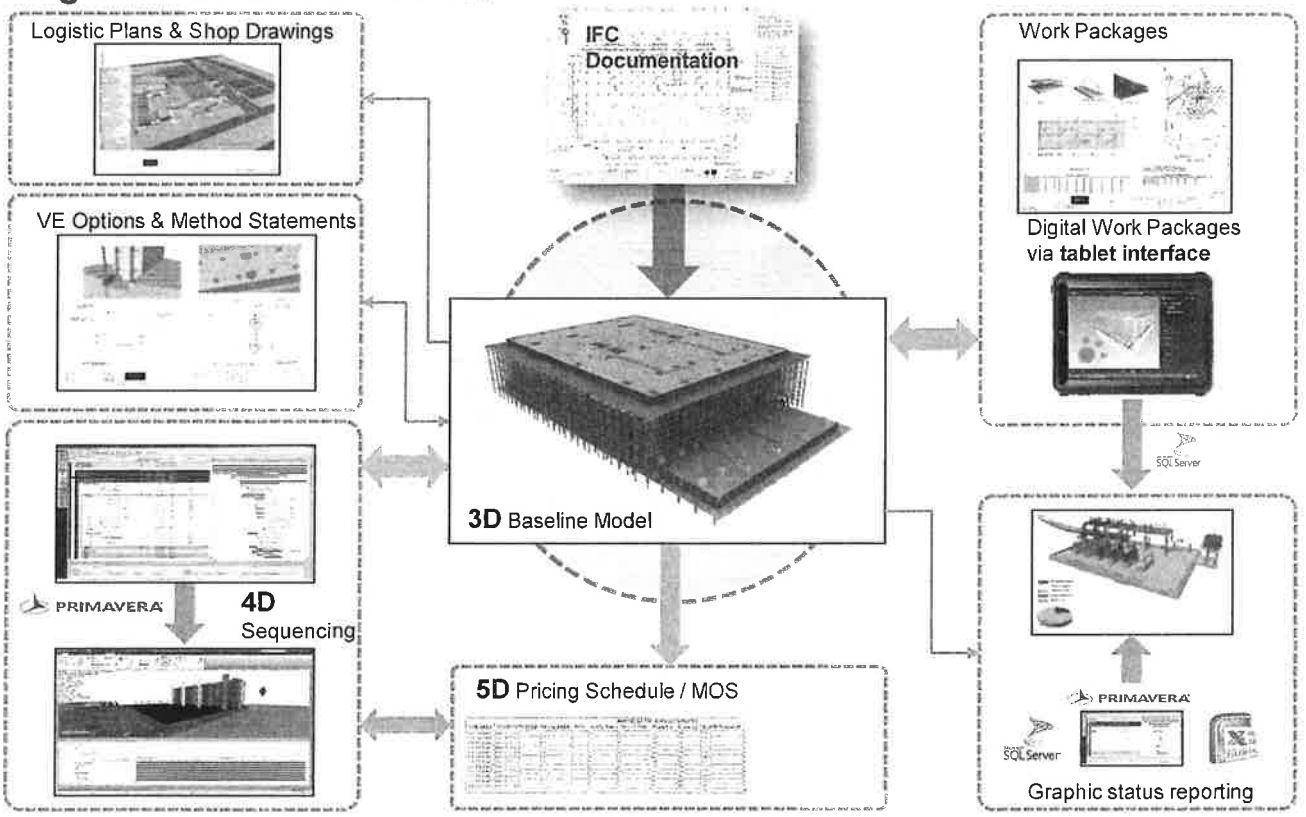
Digital Interface Overview



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Contract reporting example, Laing O'Rourke Aus (2015)

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DE at LOR

Workpacks

WORK PACKS

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Work Pack Summary


IFC Documentation


3D Baseline Model


Programme & Resourced Schedule

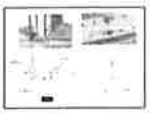

Specifications & Procedures


ITP & Checklists


Temporary Works


Pricing Schedule (A1 & MOS)


SWMS


CVMS



Material Approvals


Plant & Equipment


Lifting Plans


Logistics Plan


Permits

ENGINEERING PLANNING COMMERICIAL PROCUREMENT SAFETY SUPERVISORS QUALITY

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Laing O'Rourke Australia (2015)

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Collaborative Working

WORK PACKS

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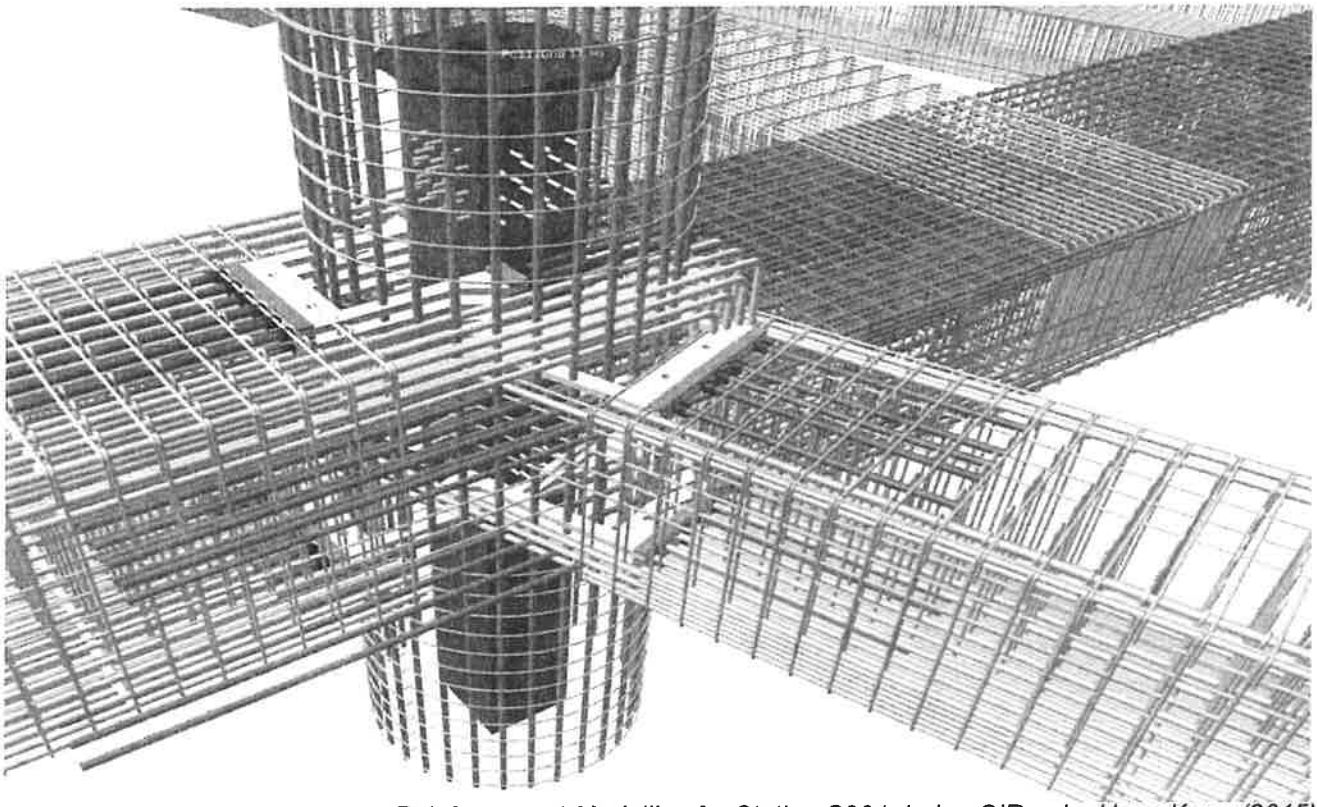
Design Coordination and Clash Detection



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Reinforcement Modelling for Station C901, Laing O'Rourke Hong Kong (2015)

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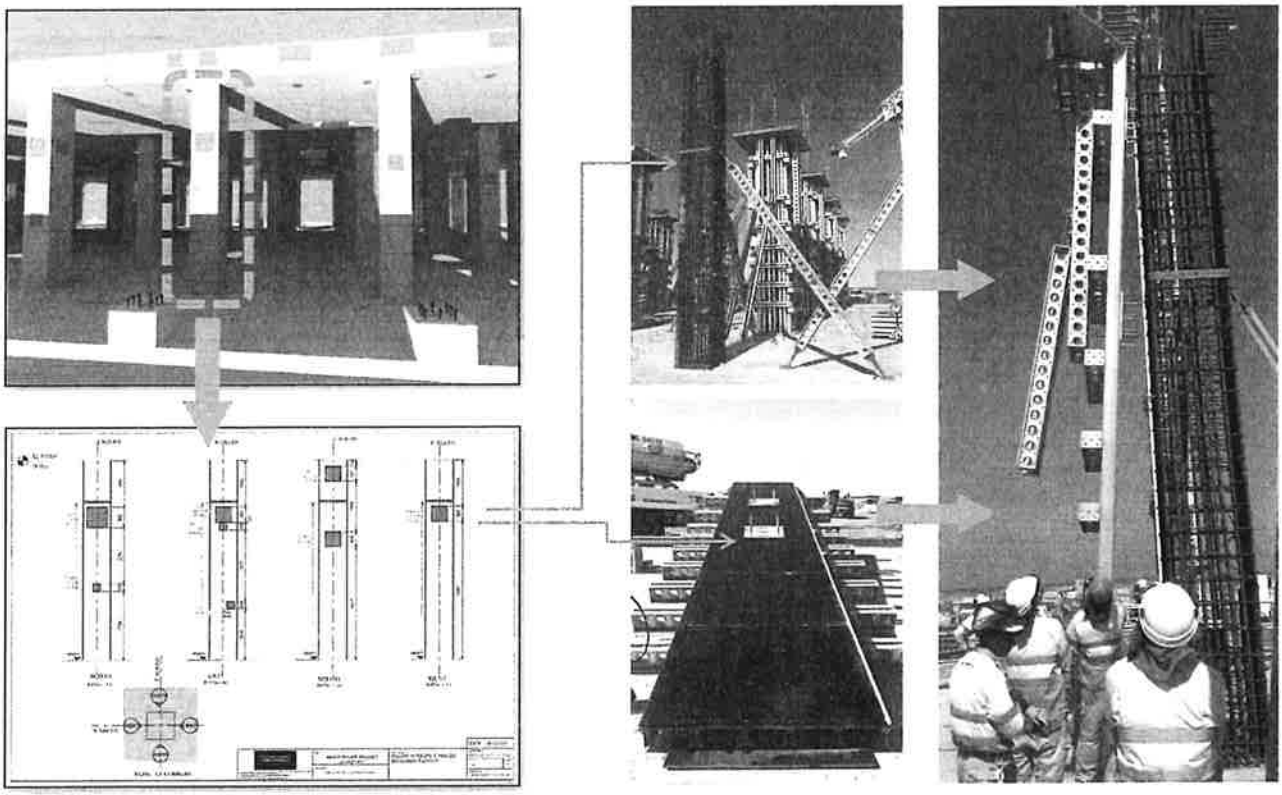
3D Model to Shop Drawings



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Column Process on the Wheatstone Project, Laing O'Rourke Australia (2014)

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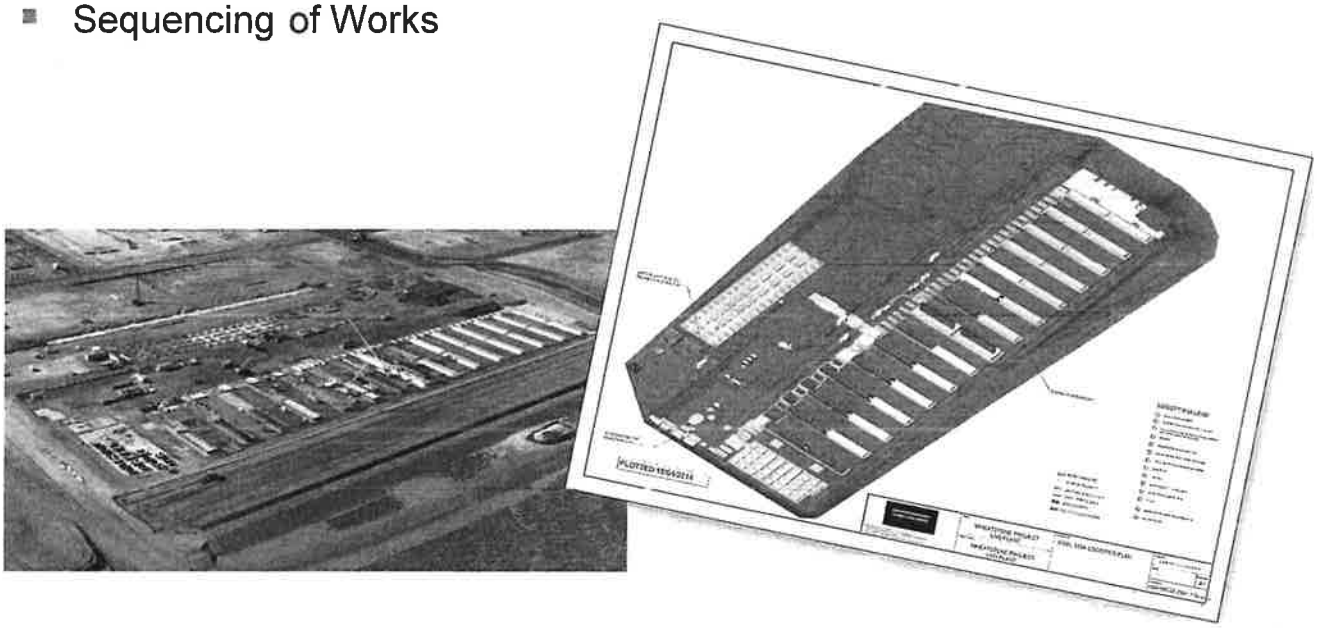
Advanced Planning through 3D & 4D

Early Digital Logistic Plans Enable Checks for

- Safety,
- Access and;
- Sequencing of Works



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DE Logistics Planning, Laing O'Rourke (2014)

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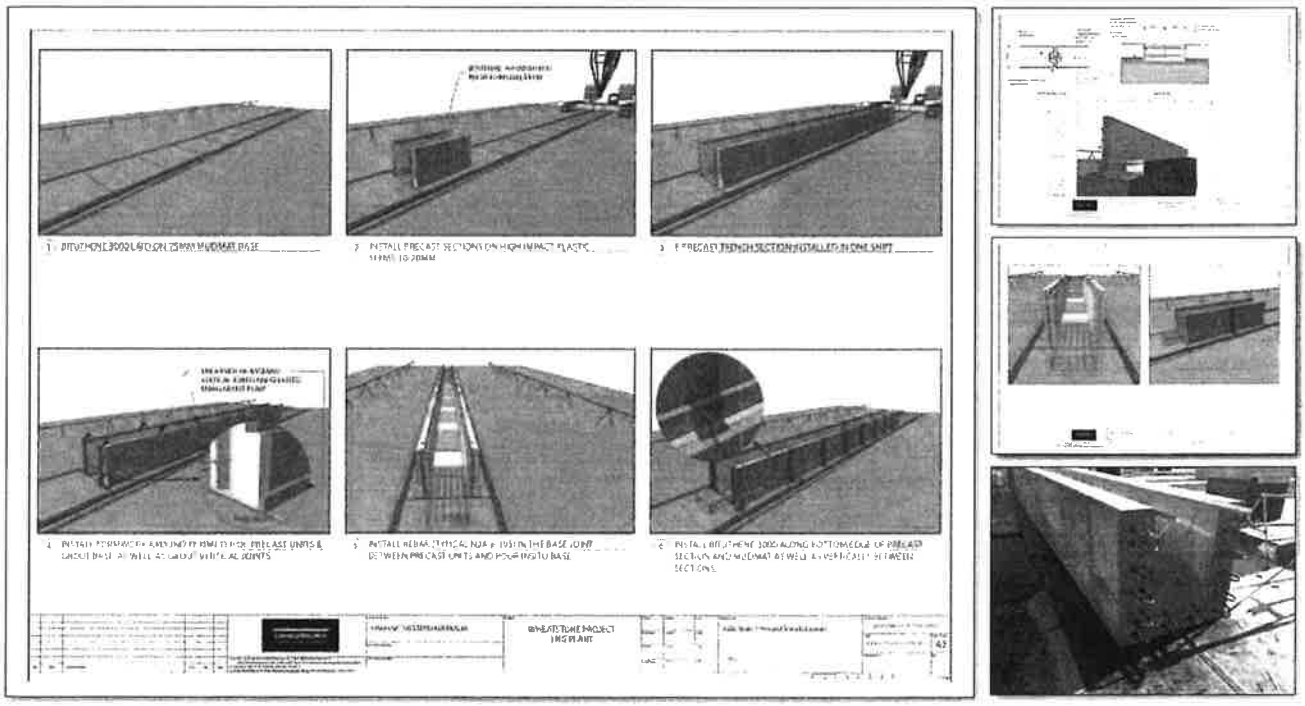
Construction Visual Method Statements



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CVMS example, Laing O'Rourke Australia (2015)

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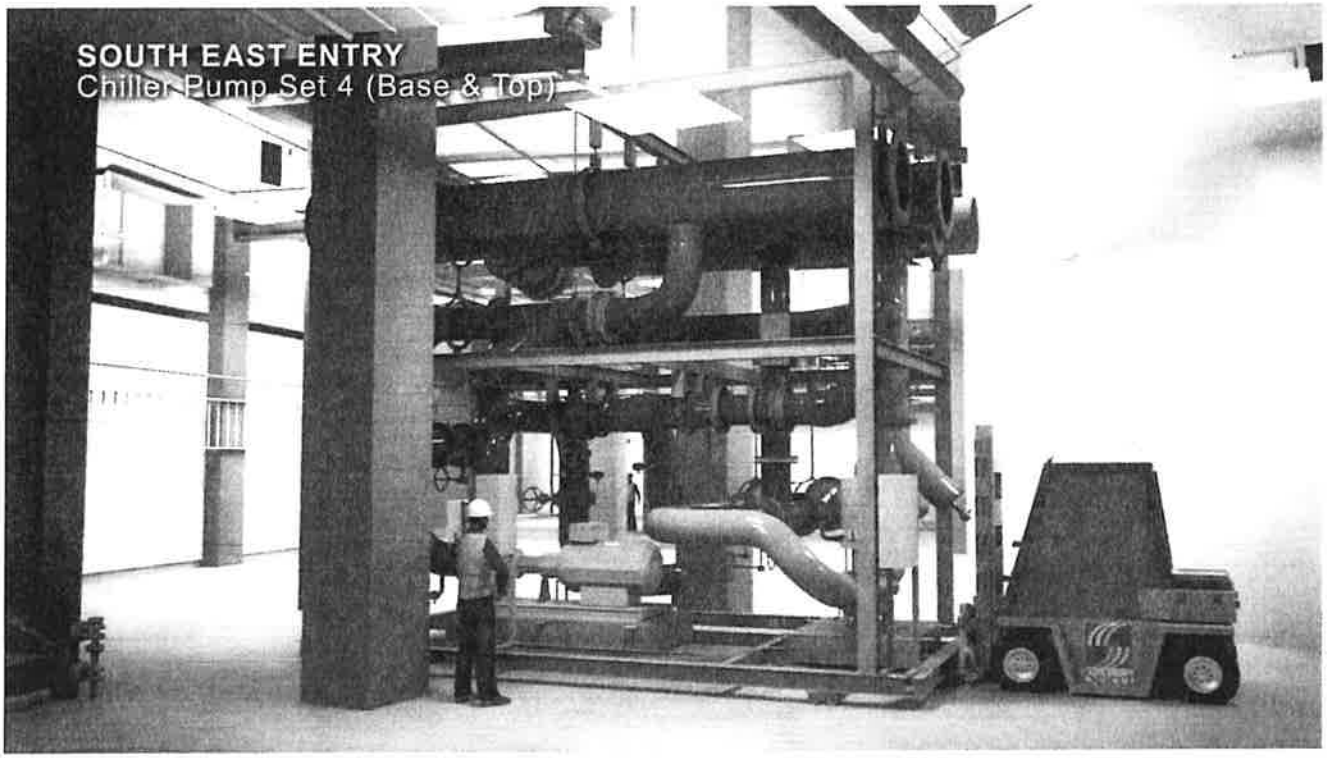
Logistics



Francis Crick Institute, Laing O'Rourke UK (2013)

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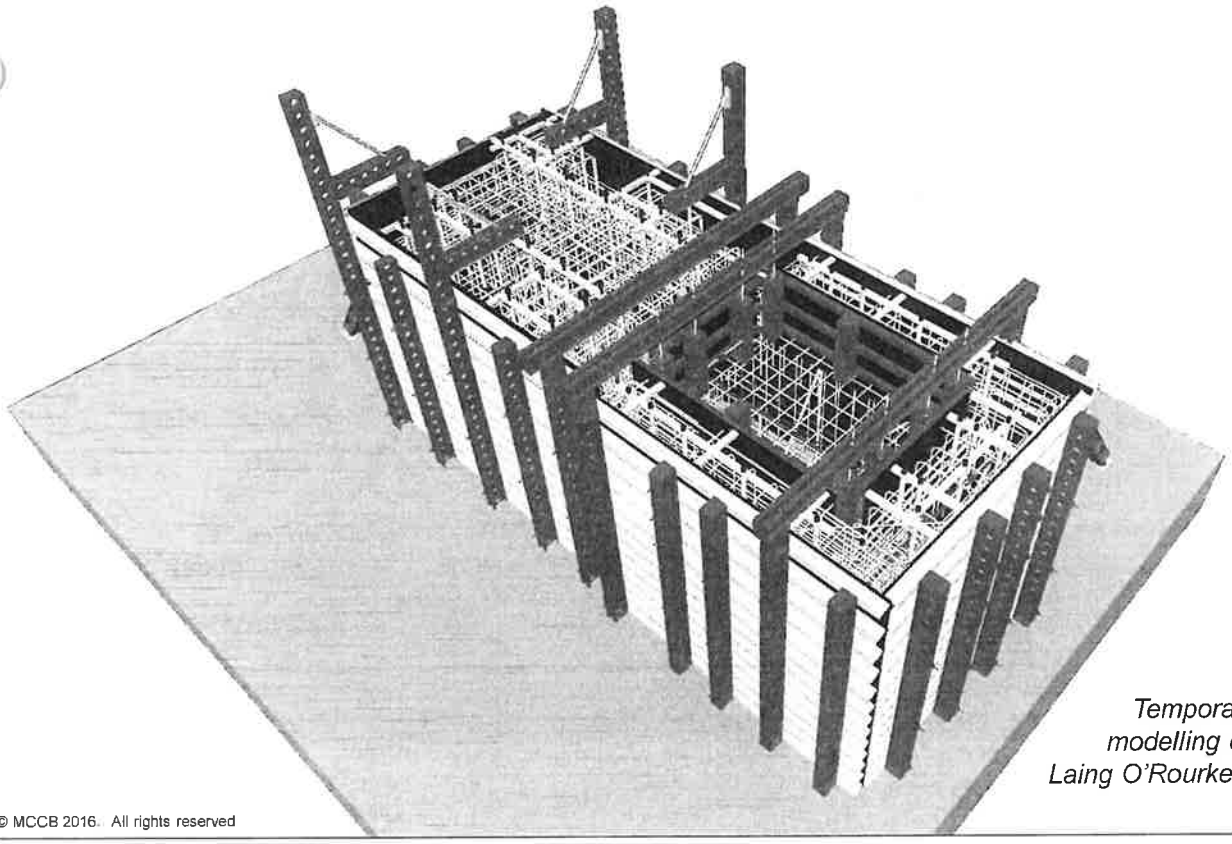
Temporary Works



Temporary works modelling example, Laing O'Rourke Austalia (2015)

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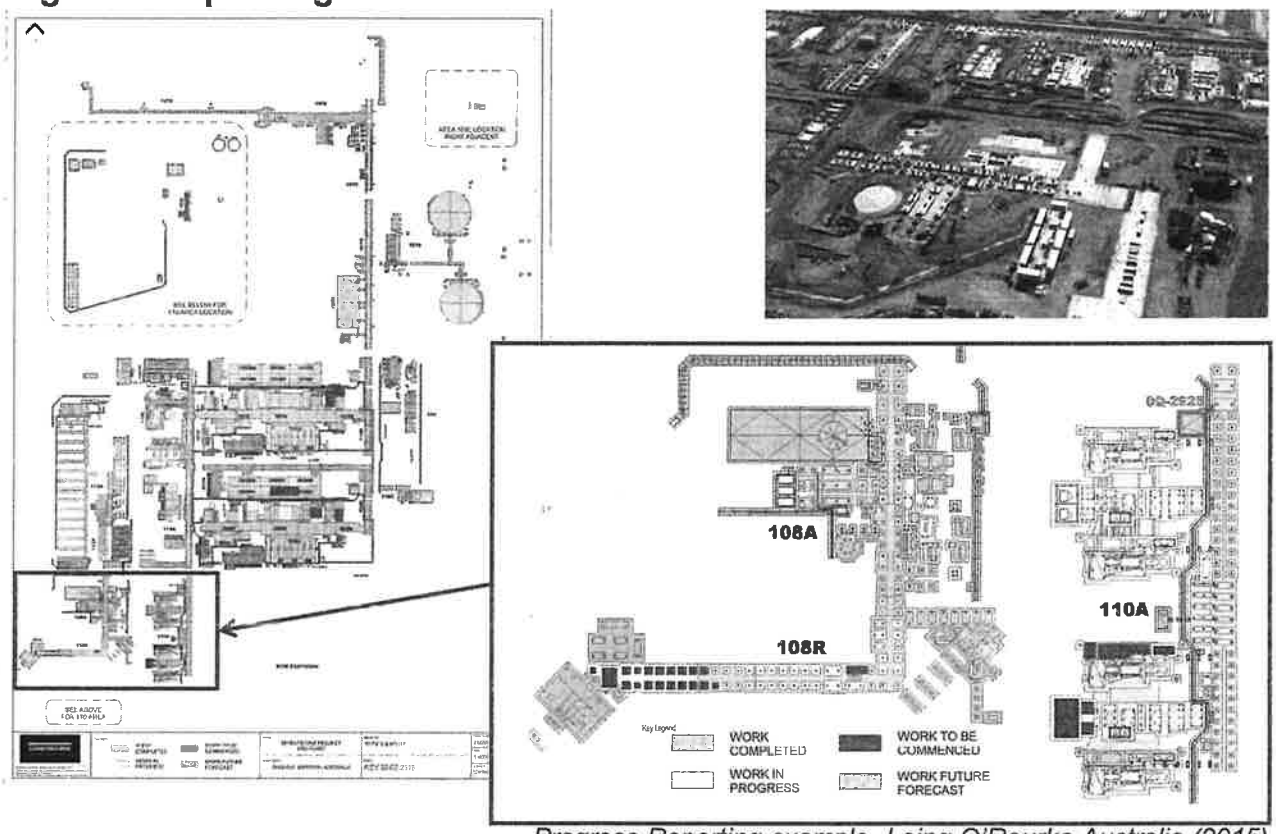
Progress Reporting



Progress Reporting example, Laing O'Rourke Australia (2015)

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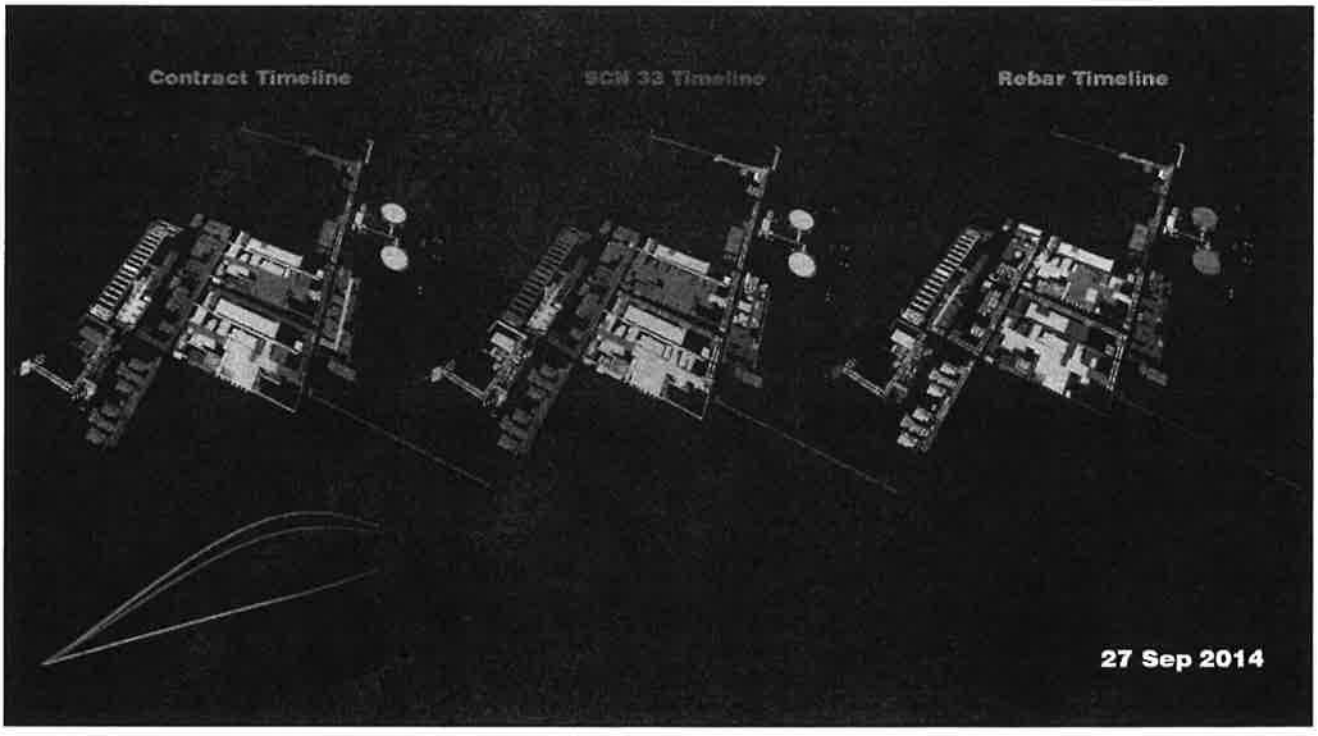
Commercial: Change Management



Contract reporting example, Laing O'Rourke Australia (2015)

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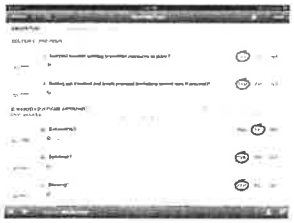
Digitally Enabled Onsite Delivery

Checklists



Drawings



Task scheduling



Issues tracking





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Onsite Tablets, Laing O'Rourke Australia (2014)

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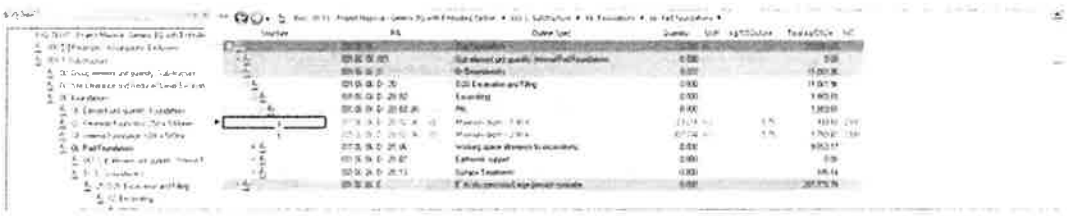
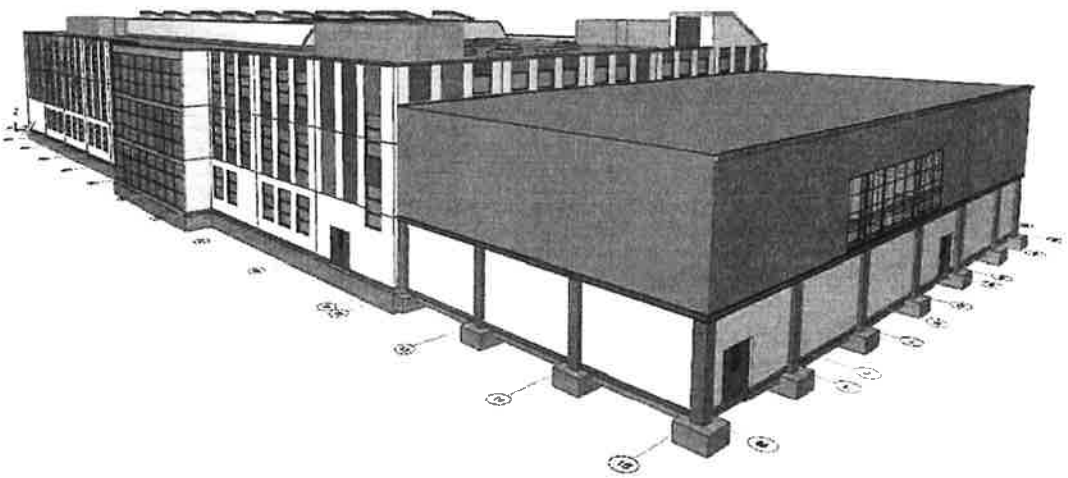
Embodied Energy/Carbon





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Embodied Carbon Analysis, Laing O'Rourke UK (2015)

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DE at LOR

QA/QC, Handover and Closeout

					Verification Record									Survey Report						Test Report			Other Docs		Commercial		
	Total IWP - Commenced	165			CH201 Excavation	CH202 Backfill	CH203 Concrete Pre-pour	CH204 Concrete Pre-pour	CH205 Pour Record	CH206 Formwork	CH207 Formwork	CH208 Cable Installation	CH209 Earthing Cable Test	CH210 Earth Point Test	CH215 Ductbank	Hardcore Surface	Formation Level	Soil Test Locations	Earthing Cable	Top of Building	Top of Concrete	Embedment - Post Pour	Soil Compaction	Earthing Cable	Pile Continuity Test	Concrete Strength	Punchlist/R Cat. A Items)	HOR (where applicable)	As-Built Drawing (Red Line)	A1 Schedule / Variation	LOR Management Sign-off	Handed Sign-off
	Total IWP - Work Complete	121																									
	Total IWP - Work in Progress	44																									
IWP Closeout State WE 15-Aug-2014	Total IWP - Closed/Accepted by BEC	25																									
	Total IWP - On Hold	20																									
Workpack No.	Workpack Description	Work Status	BEC Close Out Status	IWP - Folder Number																									
ISBL - Train 1																											
101A - Propane				1-May-14																							
AA.101AP.A0.00-0102	101AP - Structural Backfill & Excavation	Complete	Closed	1																							
AA.101AP.B2.02-0120	101AP - Mudmat & Tension Connectors	Complete	Closed	2																							
AA.101AP.B2.02-0130	101AP - Foundation - Pour 1	Complete	Closed	14																							
AA.101AP.B2.02-0132	101AP - Foundation - Pour 2	Complete	Closed	14																							
AA.101AP.B2.02-0134	101AP - Foundation - Pour 3	Complete	Closed	5																							
AA.101AP.B2.04-0150	101AP - Columns / Walls	Complete	Closed	46																							
AA.101AP.B2.12-0160	101AP - Elevated Slab	Complete	Closed	57																							
AA.101AP.B2.10-0170	101AP - Pedestals	Complete	Closed	39																							
101A - Ethylene				3-Jun-14																							
AA.101AE.A0.00-0202	101AE - Structural Backfill & Excavation	Complete	Closed	3																							
AA.101AE.B2.02-0115	101AE - Mudmat	Complete	Closed	11																							
AA.101AE.B2.02-0220	101AE - Tension Connectors	Complete	Closed	19																							
AA.101AE.B2.02-0230	101AE - Foundation - Pour 1	Complete	Closed	13																							
AA.101AE.B2.02-0232	101AE - Foundation - Pour 2	Complete	Closed	17																							
AA.101AE.B2.02-0234	101AE - Foundation - Pour 3	Complete	Closed	9																							
AA.101AE.B2.04-0250	101AE - Columns / Walls	Complete	Closed	48																							
AA.101AE.B2.12-0260	101AE - Elevated Slab	Complete	Closed	58																							
AA.101AE.B2.10-0270	101AE - Pedestals	Complete	Closed	73																							
109A - Methane				15-Jul-14																							
AA.101AM.A0.00-0303	101AM - Structural Backfill & Excavation	Complete	Open	4																							
AA.101AM.B2.02-0315	101AM - Mudmat	Complete	Open	12																							
AA.101AM.B2.02-0320	101AM - Tension Connections	Complete	Open	36																							
AA.101AM.B2.02-0330	101AM - Foundation - Pour 1	Complete	Open	6																							
AA.101AM.B2.02-0332	101AM - Foundation - Pour 2	Complete	Open	7																							
AA.101AM.B2.02-0334	101AM - Foundation - Pour 3	Complete	Open	13																							
AA.101AM.B2.04-0350	101AM - Columns / Walls	Complete	Open	48																							
AA.101AM.B2.12-0360	101AM - Elevated Slab	Complete	Open	74																							
AA.101AM.B2.10-0370	101AM - Pedestals	Complete	Open	77																							

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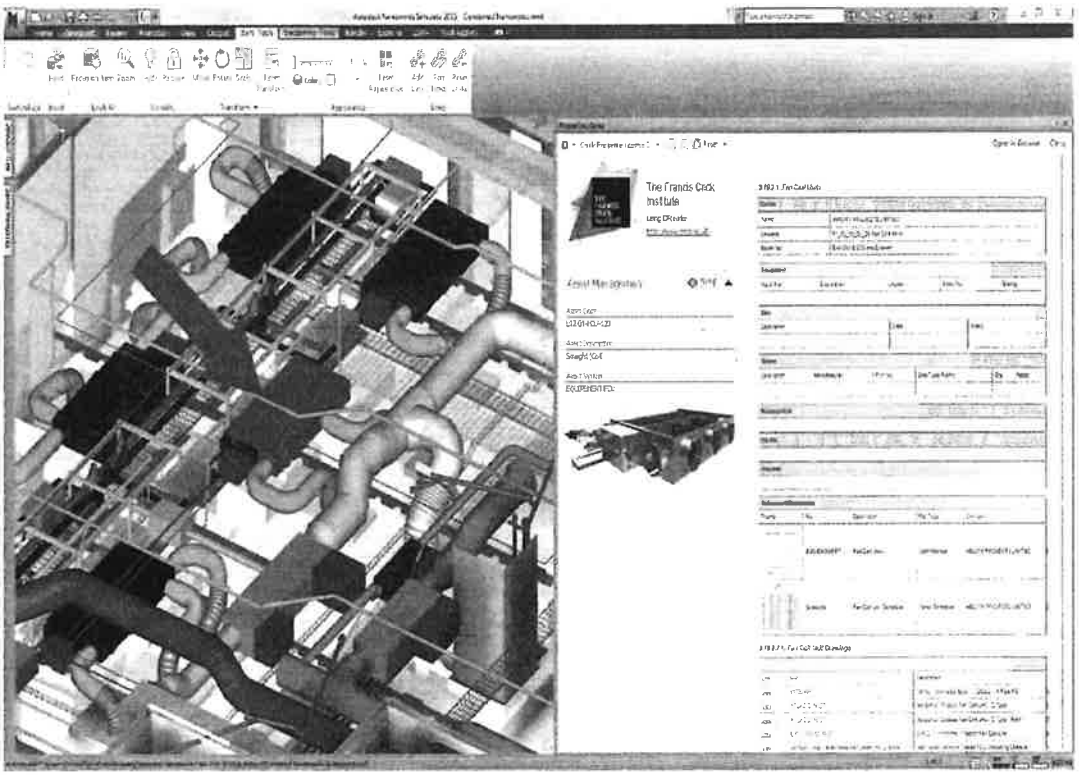
Workpack Closeout Tracker, Laing O'Rourke Aus (2015)

DIGITAL ENGINEERING

DE at LOR

Facilities/Asset Management



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Francis Crick Institute Project, Laing O'Rourke UK (2014)

DIGITAL ENGINEERING
Topics for Discussion

- Trends in Aerospace & Automotive Engineering
- Shipbuilding – an analogy
- DE at LOR
- Augmented Reality & Virtual Reality

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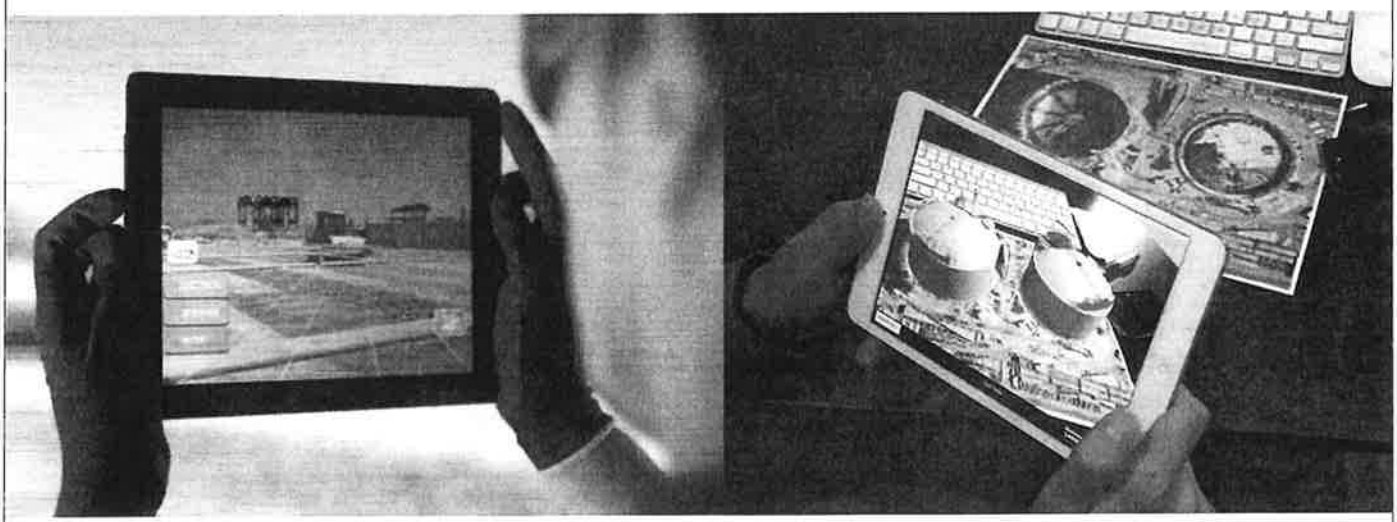
DIGITAL ENGINEERING
Augmented Reality
Uses

- **Stakeholder Engagement:** Immersive technology helps stakeholders, clients and user groups understand the size and scale of our projects
- **Site Delivery:** Assisting site teams with project delivery



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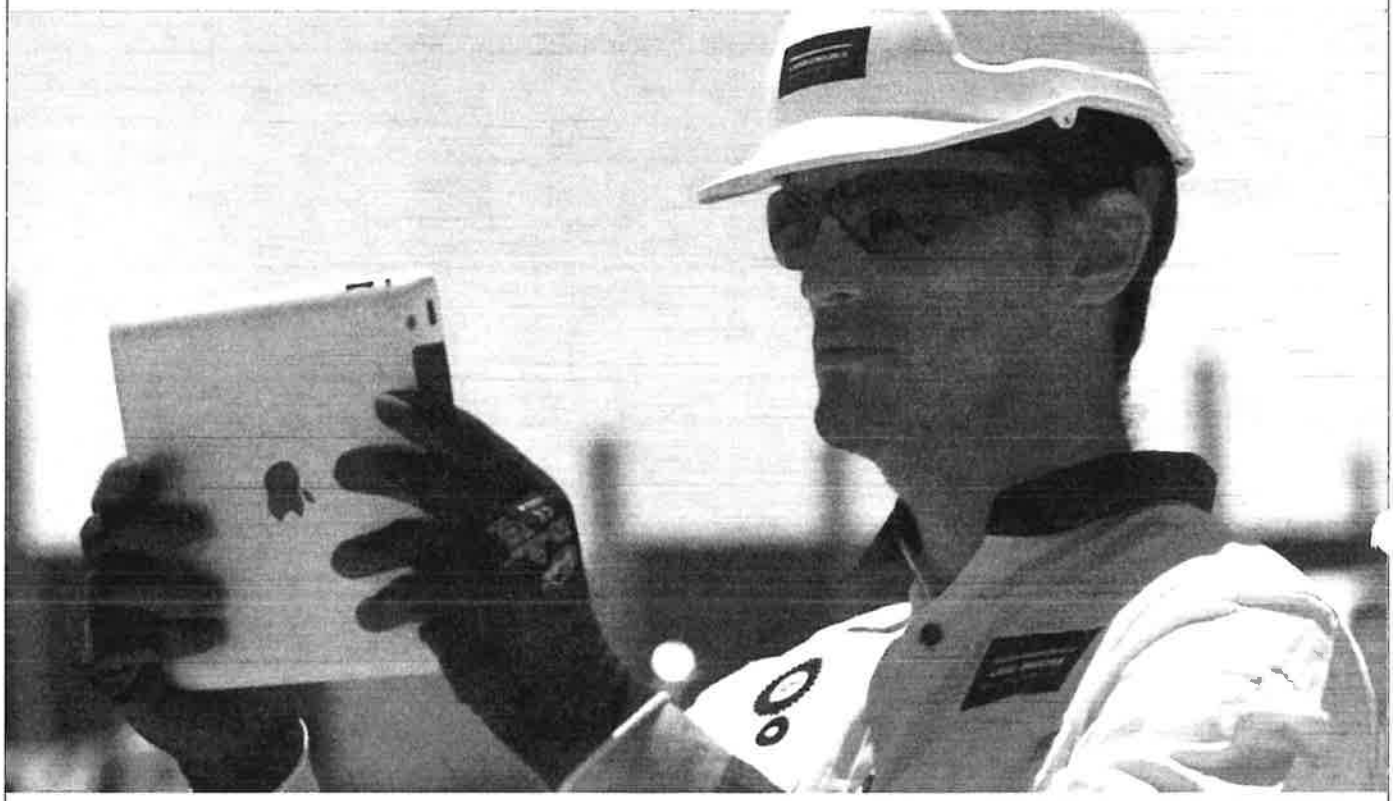
Augmented Reality, Laing O'Rourke Australia (2014)

DIGITAL ENGINEERING

Augmented Reality – Site Delivery



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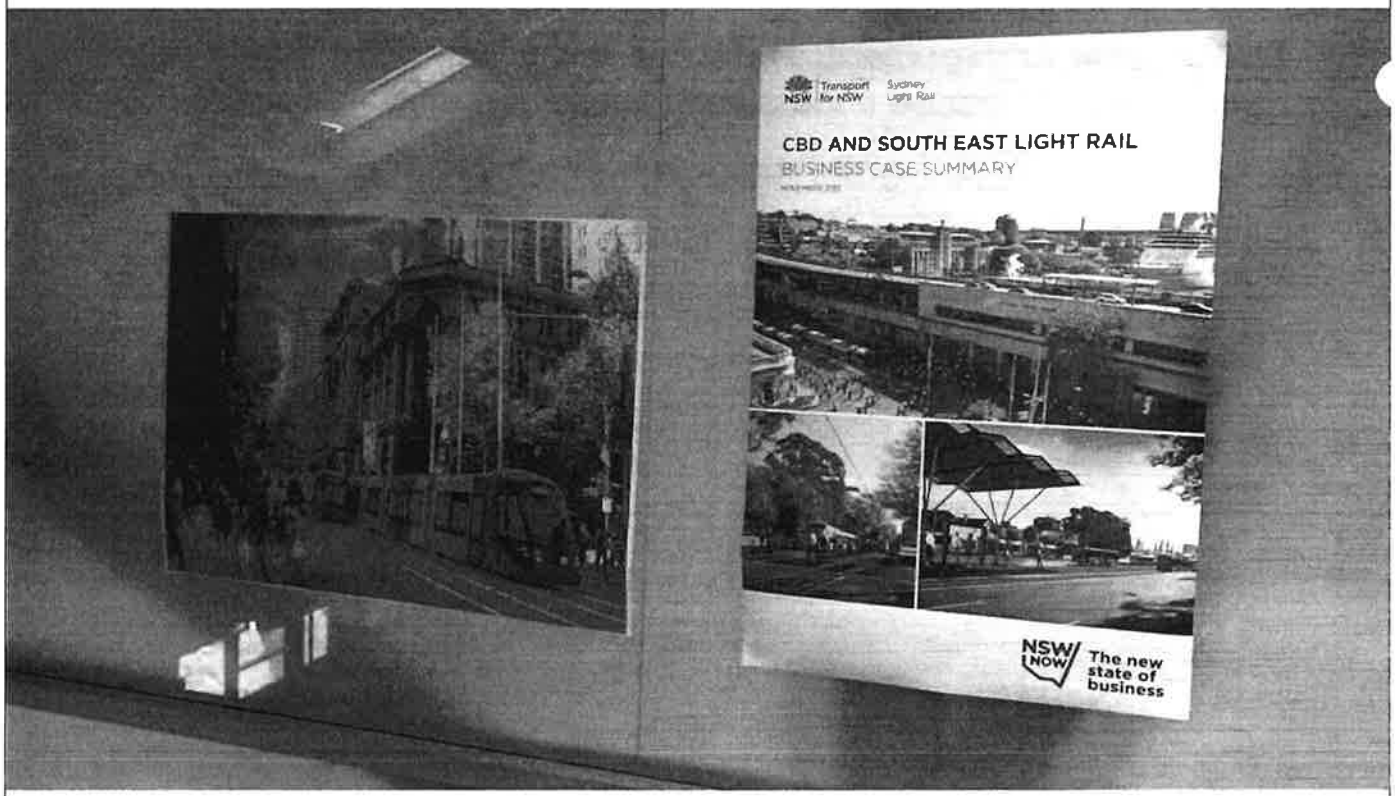
AR at Port Botany, Laing O'Rourke Australia (2014)

DIGITAL ENGINEERING

Augmented Reality – Stakeholder Engagement

Example: SLR Enabling Works



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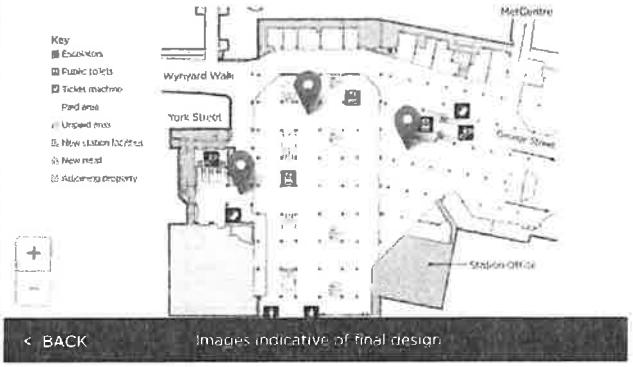
AR on Sydney Light Rail, Laing O'Rourke Australia (2014)

DIGITAL ENGINEERING

Augmented Reality – Stakeholder Engagement

Example: Wynyard Station









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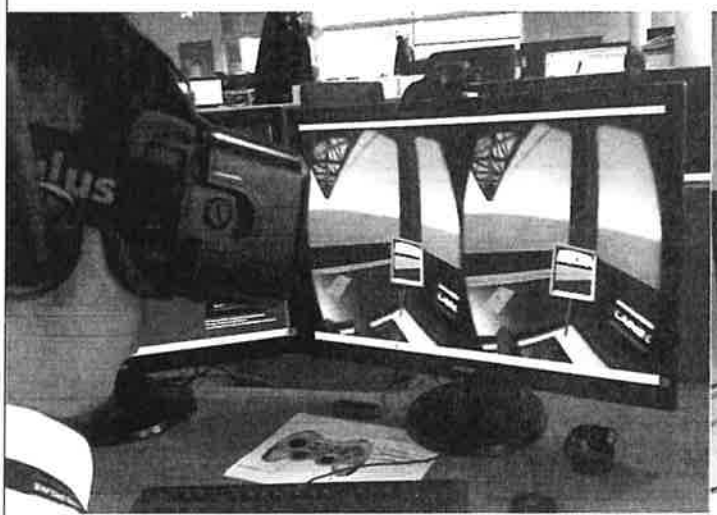
AR on Wynyard Station Upgrade, Laing O'Rourke Australia (2015)

DIGITAL ENGINEERING

Virtual Reality

A fully immersive environment – Oculus Rift

- **Design Collaboration** –opportunity to iteratively progress designs; implementing feedback from end users before construction begins





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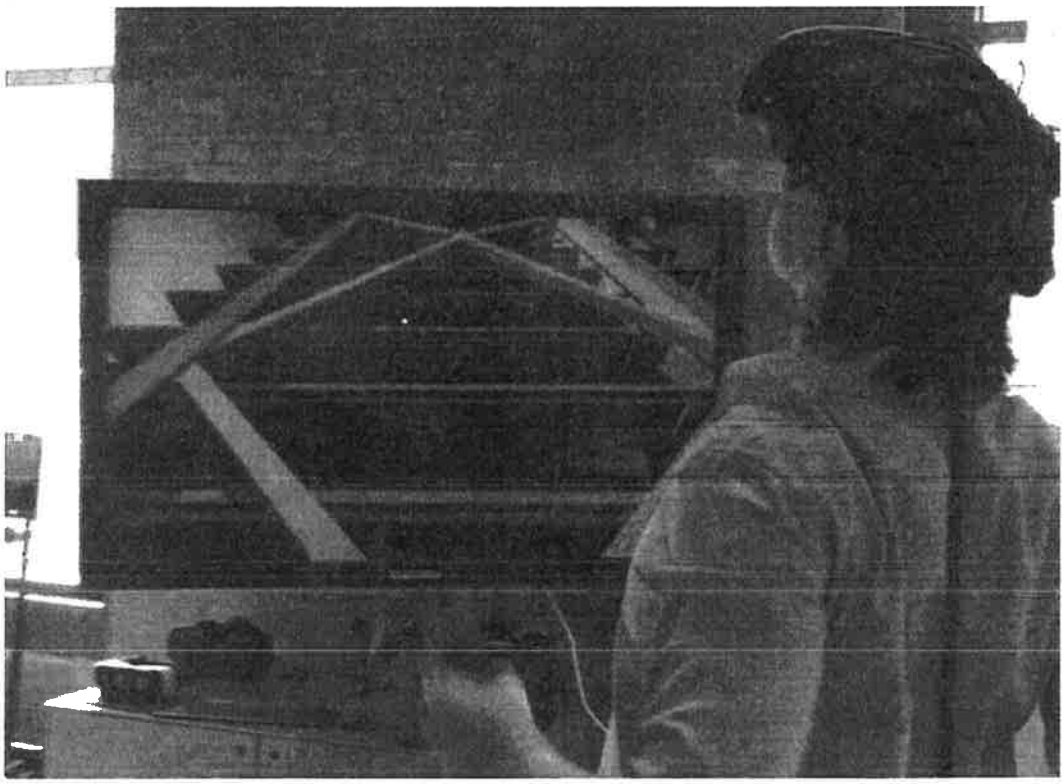
Virtual Reality, Laing O'Rourke Australia (2015)

DIGITAL ENGINEERING
Virtual Reality

A fully immersive environment – HTC Vive



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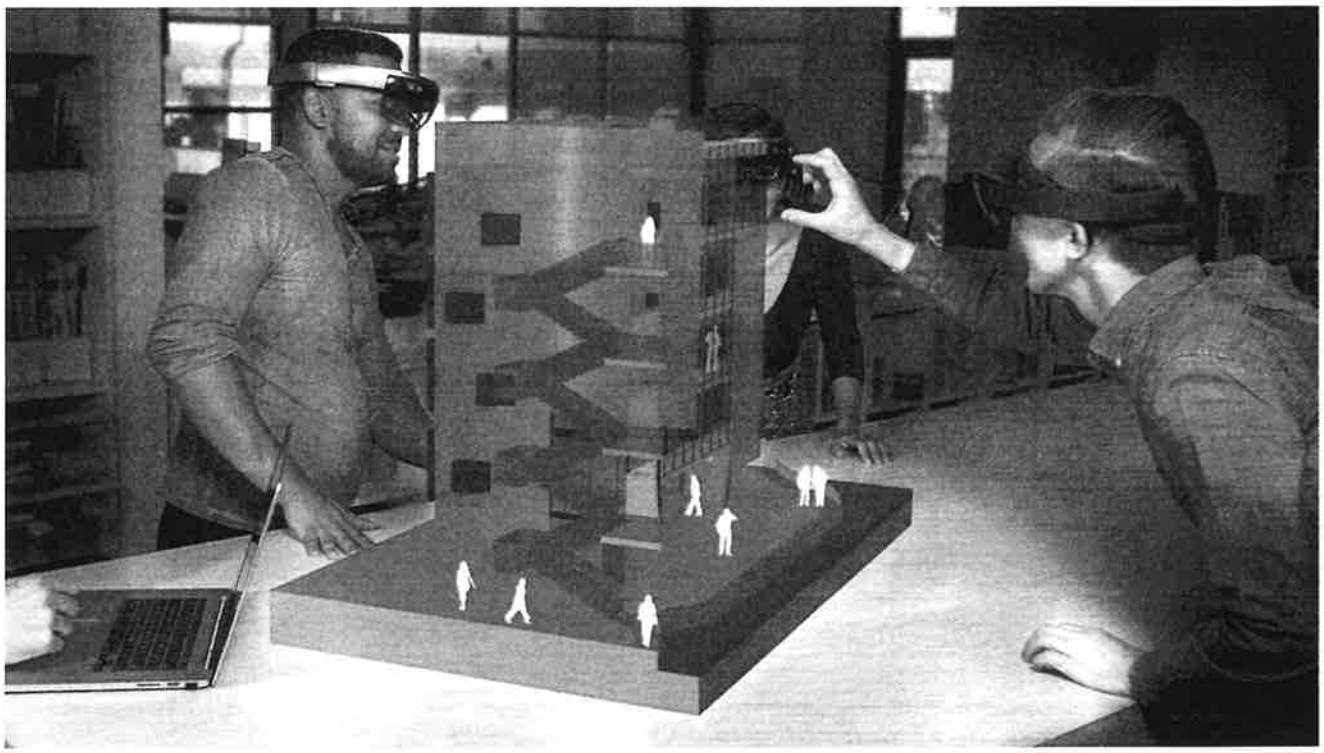
100 Mount Street model viewed through HTC Vive, Laing O'Rourke Australia (2016)

DIGITAL ENGINEERING
Mixed Reality

A fully immersive environment – Microsoft Hololens



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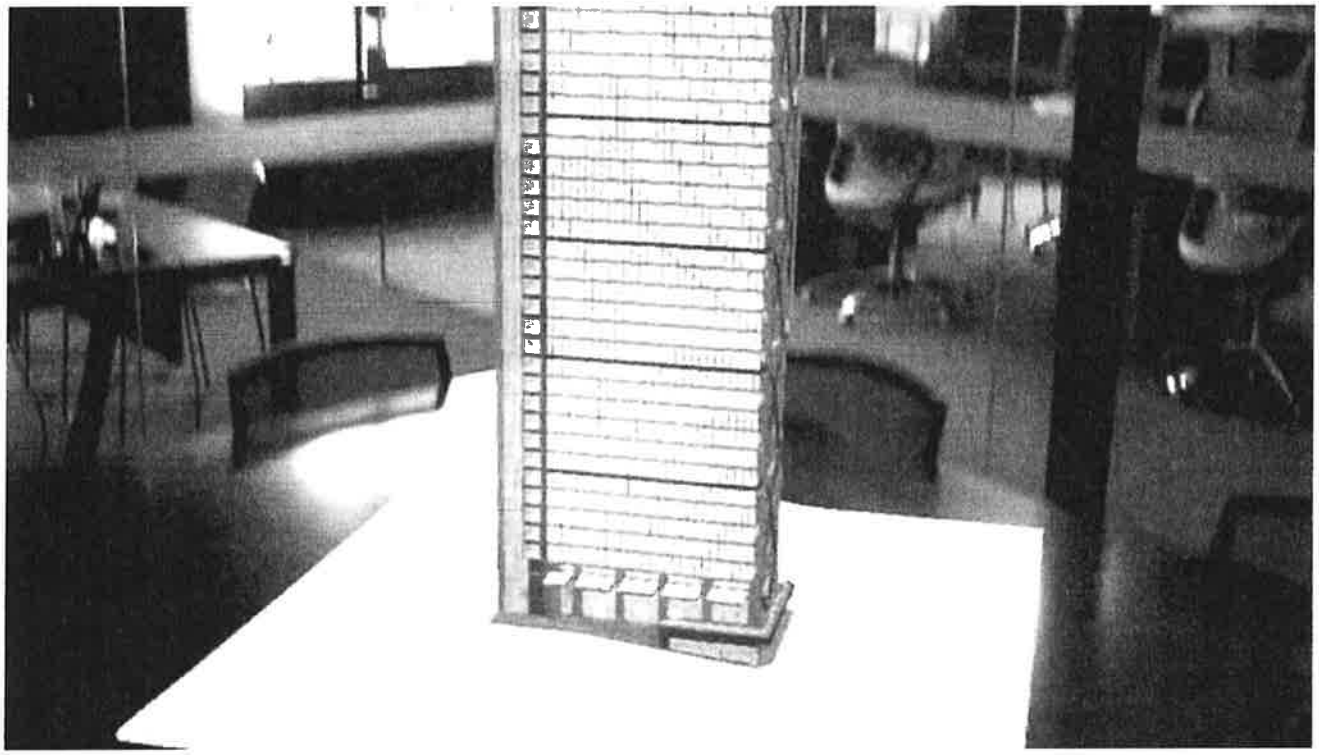
Sketchup model viewed through Microsoft Hololens, Google Sketchup (2016)

DIGITAL ENGINEERING
Mixed Reality

MCCB

A fully immersive environment – Microsoft Hololens



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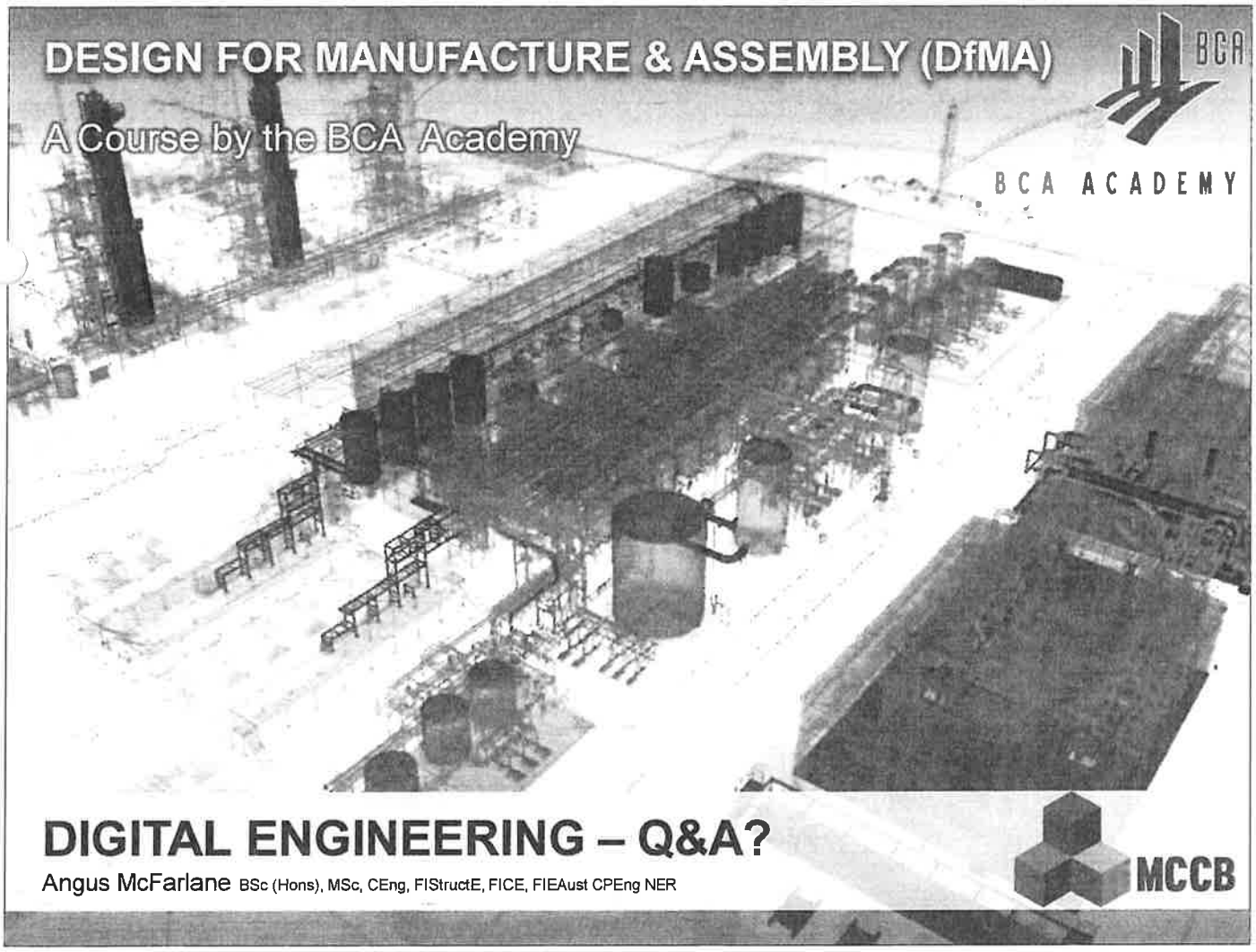
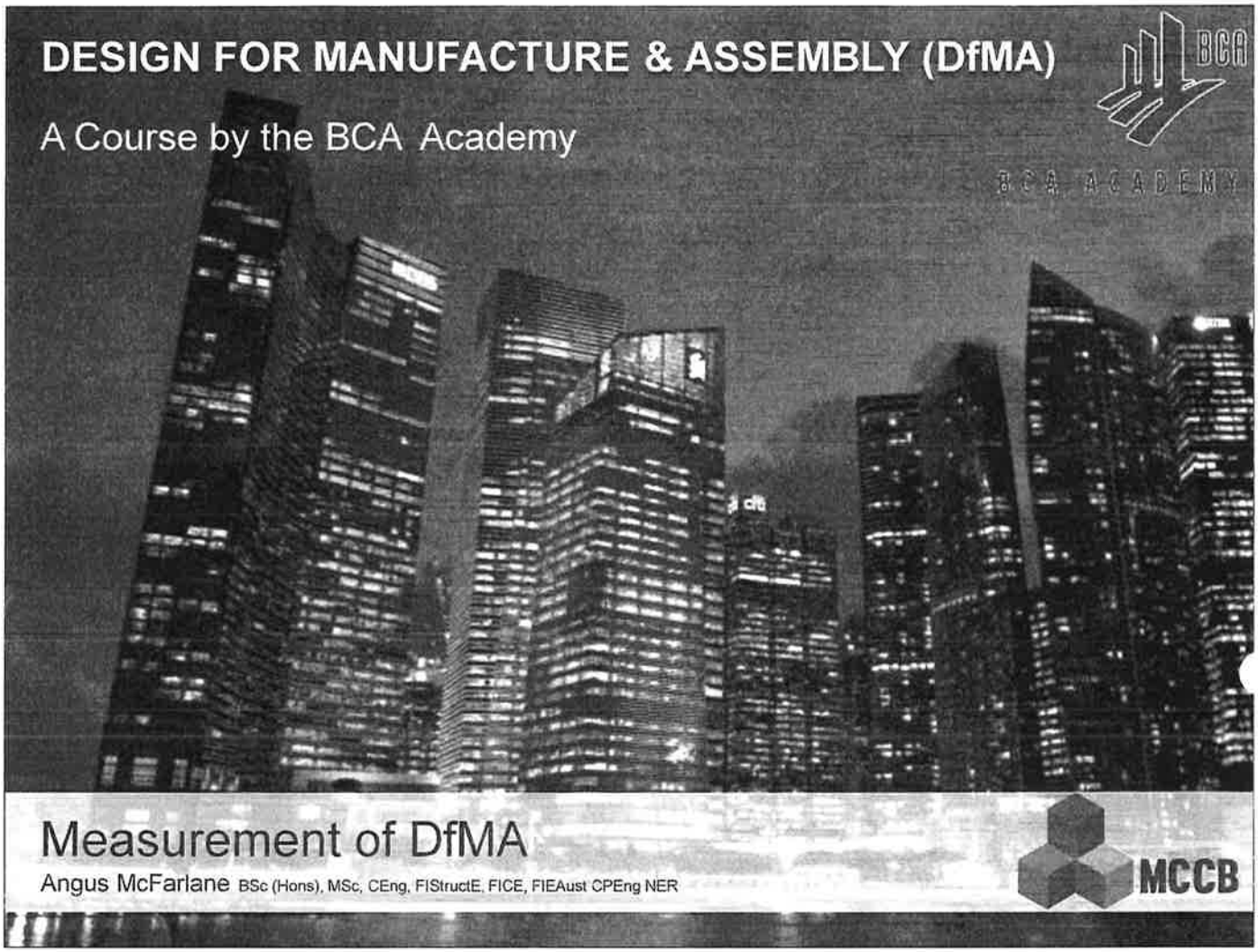
100 Mount Street model viewed through Hololens, Laing O'Rourke Australia (2016)





MEASUREMENT OF DfMA

Topics for Discussion

MCCB

- Overview of DfMA Calculator
- Project Drivers
- Cost Benefit Analysis
- Example Project
- Conclusions

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MEASUREMENT OF DfMA
Overview: Laing O'Rourke DfMA Calculator

LAING O'ROURKE

EnEx G

LORA DfMA Framework

Introduction

The LORA DfMA Framework is a tool designed by the LORA DfMA team and EnExG to enable bid and project teams make informed decisions regarding the implementation of DfMA methodologies on bids and projects.

It does this by stepping the user through a decision making framework that considers:
- Project level drivers and constraints
- Package level drivers and constraints
- Supply chain capabilities
- Project Schedule, and
- Cost

As an output of this process, the LORA DfMA Framework provides a summary of the opportunities for DfMA on a project, and a pathway forward for development of a DfMA strategy.

Having a DfMA strategy in place for every project is essential for maintaining alignment with the company's strategic DfMA targets:
- 70% of the project assets delivered via DfMA
- 60% reduction in on-site labour, and
- 30% reduction in programme in areas we control

Source: Laing O'Rourke, 2014

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MEASUREMENT OF DfMA
Topics for Discussion

- Overview of DfMA Calculator
- **Project Drivers**
- Cost Benefit Analysis
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MEASUREMENT OF DfMA

Project Drivers

Input

Answer Several Questions about:

- Weather
- Labour
- Cost
- Schedule
- Quality
- Logistics
- Efficiency
- Performance & Functionality
- Client Constraints
- Health & Safety
- Environment, Legal & Regulatory
- Intellectual Property

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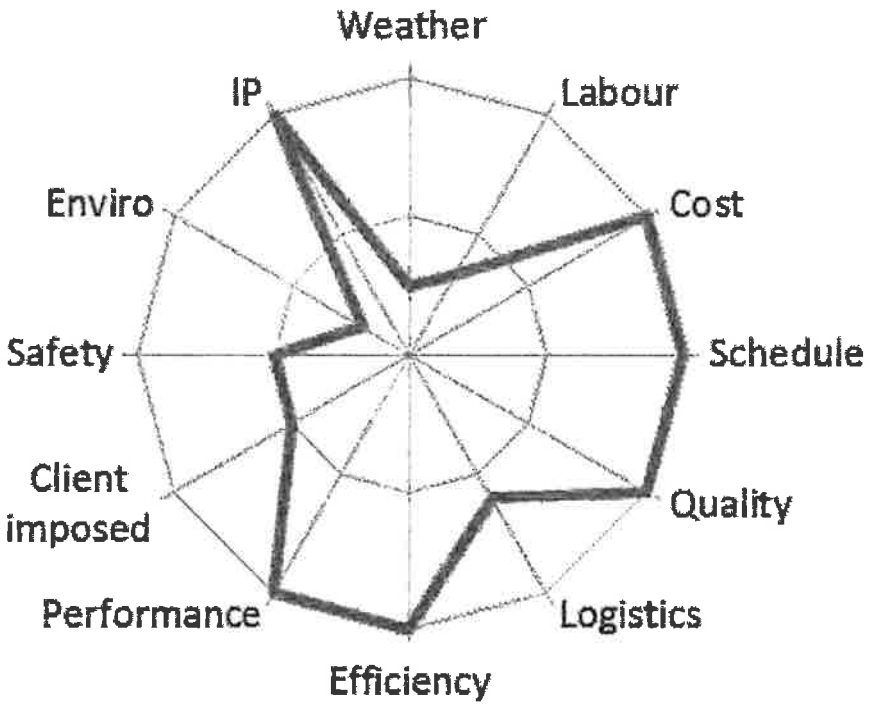
MEASUREMENT OF DfMA

Project Drivers

Output

Radar Chart: Indicates areas favourable to DfMA



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MEASUREMENT OF DfMA

Topics for Discussion

- Overview of DfMA Calculator
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MEASUREMENT OF DfMA

Cost Benefit Analysis

Use the Following Tools

- Framework Guide

Item	Element Description	Standard % Scores: Full Pre Assembly scores % (By Value)	Standard % Scores: Partial Pre Assembly Scores % (By Value)	Standard Definitions / Project Innovation Explanations: Full Pre Assembly Definition	Standard Definitions / Project Innovation Explanations: Partial Pre Assembly Definition
1	**SUBSTRUCTURE**				
1.1	**PILING**				
	Piling				
	Precast Piles	70%	0%	Completely Precast Pile, Driven	
	Insitu	5%	0%	Prefabricated Reinforcement Cage	
1.2	**RAFT FOUNDATION**				
	Prefab cage and shutters, insitu concrete	20%	5%	Rebar and shutters prefabricated	
	In situ	5%	0%	Prefabricated rebar	
2	**SUPERSTRUCTURE**				
2A	**FRAME + ENVELOPE**				
2.1	**FRAME**				
	Precast				
	Columns	85%	70%	Finished, c/w fixings to receive beams	Require minor onsite finishing, fixings
	In Situ				
	Columns	15%	0%	Prefabricated rebar	
2.2	**UPPER FLOORS**				
	Composite Deck & In Situ Topping	70%	60%	Incorporates all penetrations, fixings	Requires some site fixings, finishes
	In Situ Concrete	5%	0%	Prefabricated rebar	

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Source: Laing O'Rourke, 2014

MEASUREMENT OF DfMA

Cost Benefit Analysis

Use the Following Tools

- Framework Guide
- Bill of Quantities

Conventional Construction

Item No.	Description	Qty	Unit	Rate ($)	Amount ($)
2	**Superstructure**				
2.1	Columns				
	Concrete	346	m^3	350.00	121,100
	Reo	42	tonnes	2000.00	84,000
	Formwork Sides	38	m^2	200.00	7,600
	Falsework	38	m^2	2000.00	76,000
2.2	**Deck**				
	Concrete	1434	m^3	350.00	501,900
	Reo	172	tonnes	2000.00	344,000
	Formwork Sides	160	m^2	300.00	48,000
	Formwork Soffit	1304	m^2	200.00	260,800
	Falsework	1304	m^2	2000.00	2,608,000

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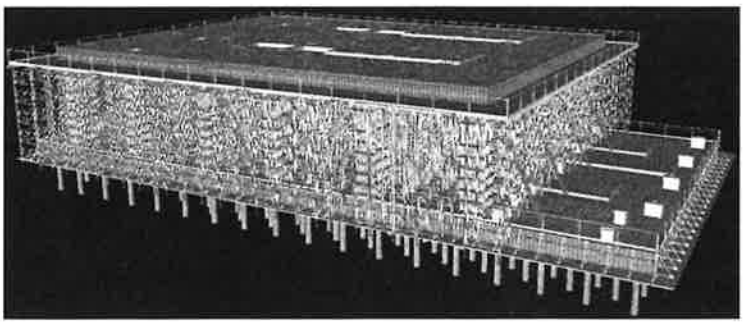
MEASUREMENT OF DfMA

Example Project



Traditional Construction

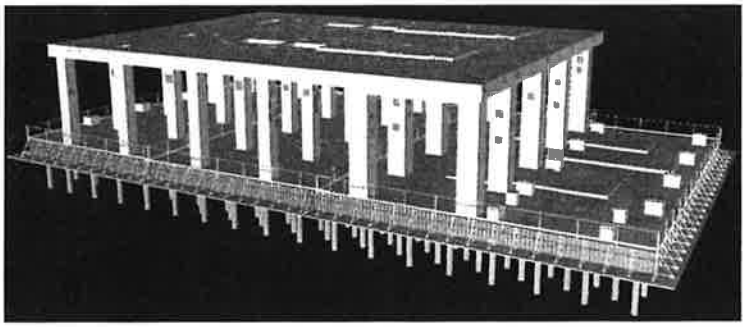
- **185 days** overall
- **122 days** superstructure

DfMA Construction

- **120 days** overall
- **61 days** superstructure

50% Superstructure Programme Saving

34 % Overall



Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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MEASUREMENT OF DfMA
Topics for Discussion

- Overview of DfMA Calculator
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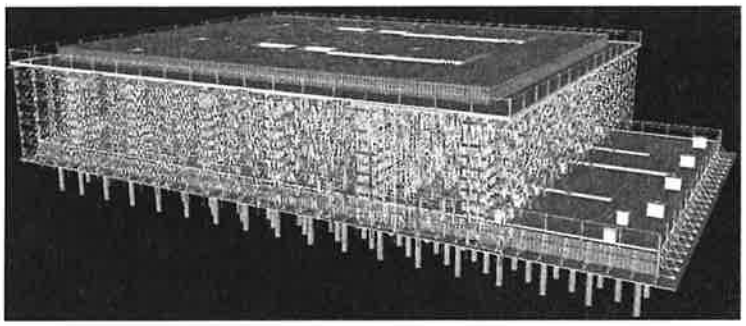
MEASUREMENT OF DfMA
Example Project



Traditional Construction

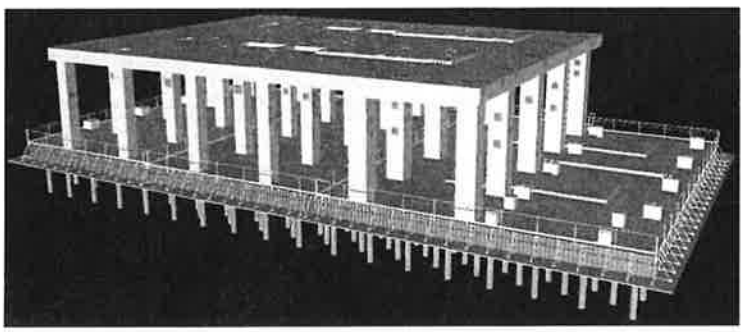
- **185 days** overall
- **122 days** superstructure

DfMA Construction

- **120 days** overall
- **61 days** superstructure

20% Superstructure Cost Saving

13 % Overall



Wheatstone LNG, WA Source: Laing O'Rourke, 2014

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MEASUREMENT OF DfMA
Conclusions

- A brief overview of the LOR DfMA Calculator is presented
- It is shown that this methodology can be adapted by any company

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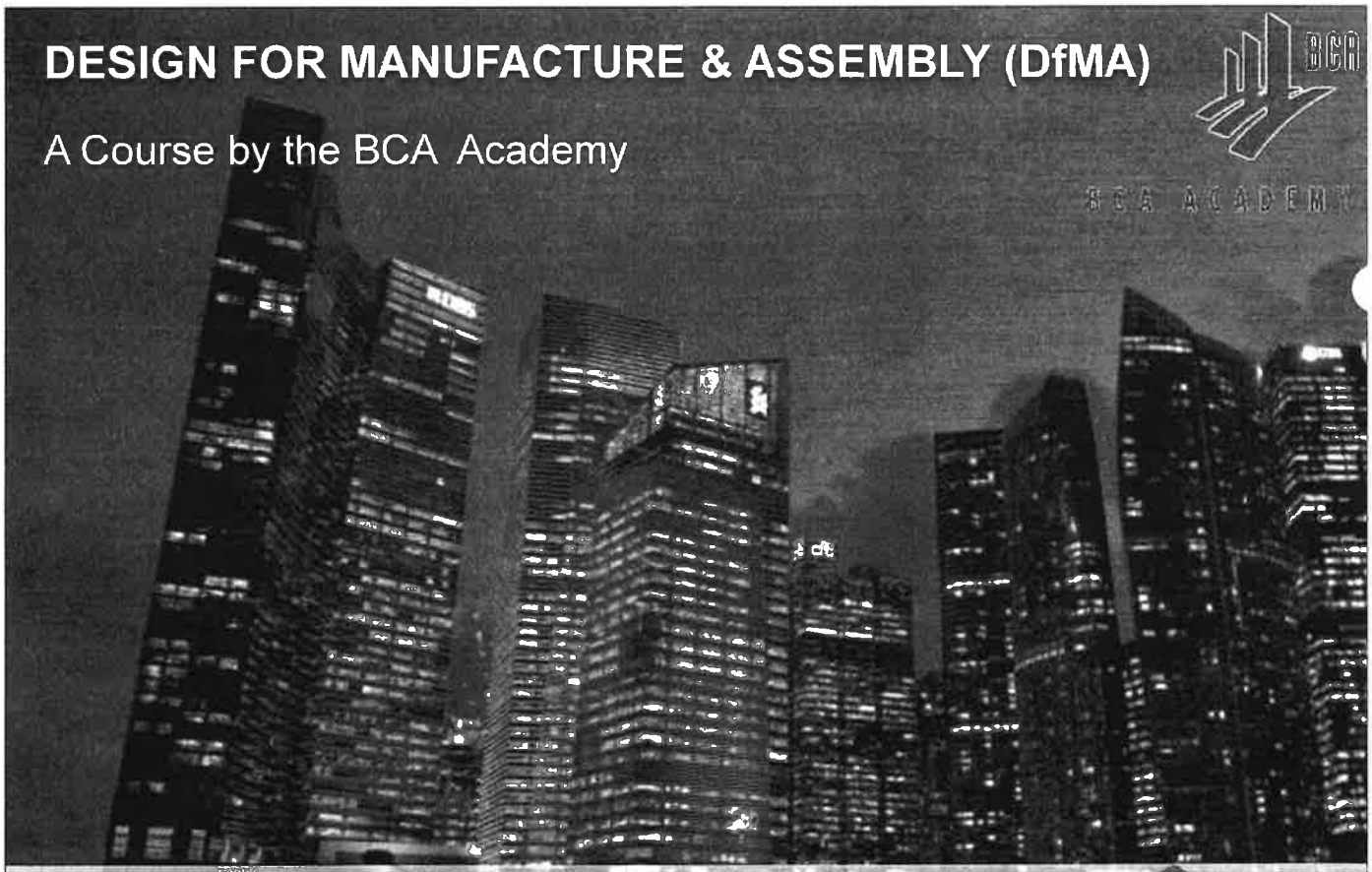
DESIGN FOR MANUFACTURE & ASSEMBLY (DfMA)

A Course by the BCA Academy



Measurement of DfMA. Q&A?