ARC CAMP.H

Modular Tall Buildings

Prof Priyan Mendis
Director
Australian Research Council Centre for Advanced Manufacturing of Prefabricated Housing
Professor of Civil Engineering (CPEng; Chartered Engineer, FIEAust)

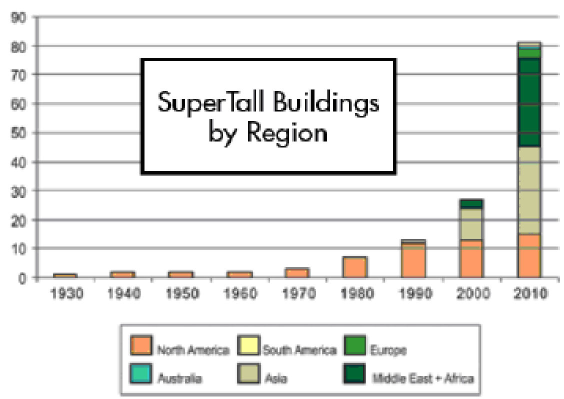
The University of Melbourne

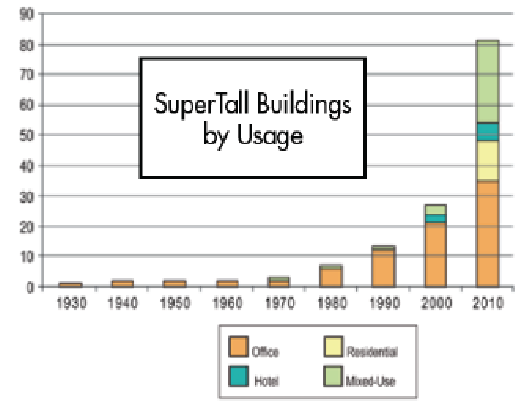
Some Facts

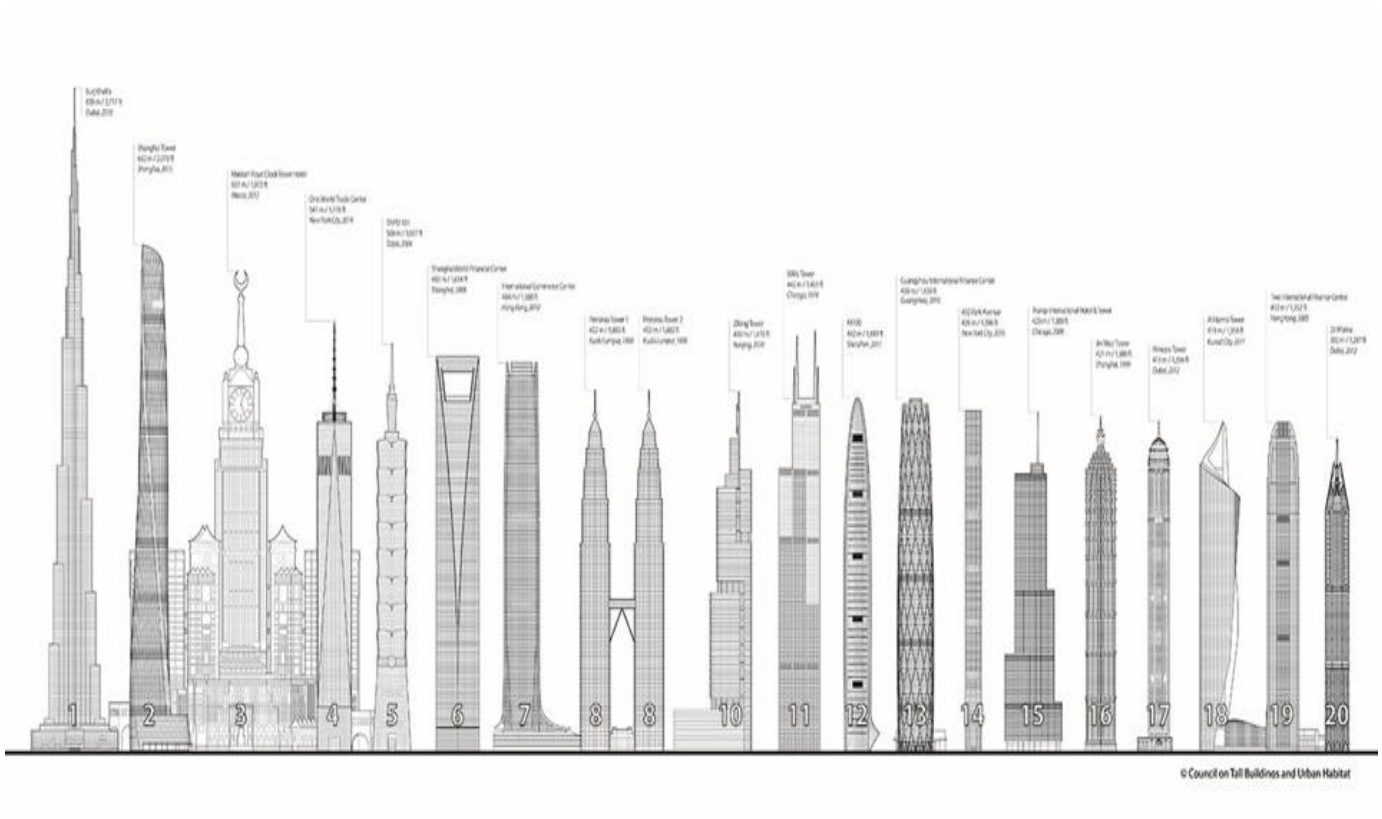
- Number 1 Ranked University in Australia. Founded in 1853
- 18 Faculties and Schools
- 8500 + Staff
- 50000+ Students (around 35% International Students)

Introduction

- Tall buildings are introducing new challenges
  - Recent trends towards slender, flexible and light-weight buildings（细长的，柔韧的，轻的建筑）
- Residential, Office and Mixed use purposes



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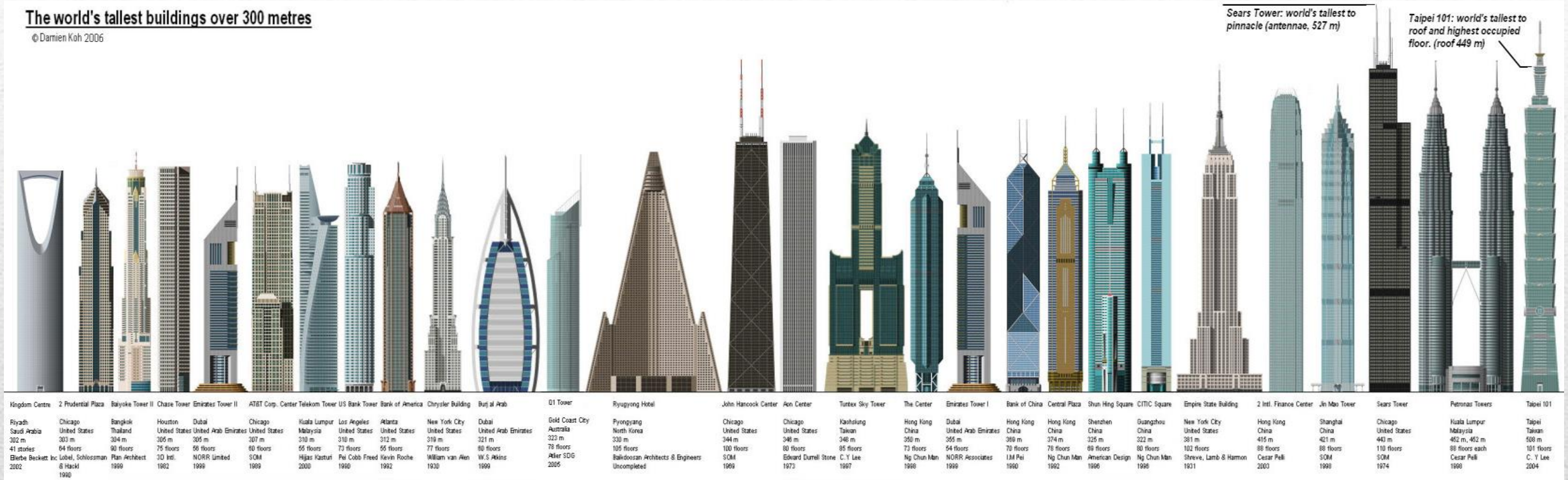
© Council on Tall Buildings and Urban Habitat

World's Tallest Buildings



THE UNIVERSITY OF MELBOURNE

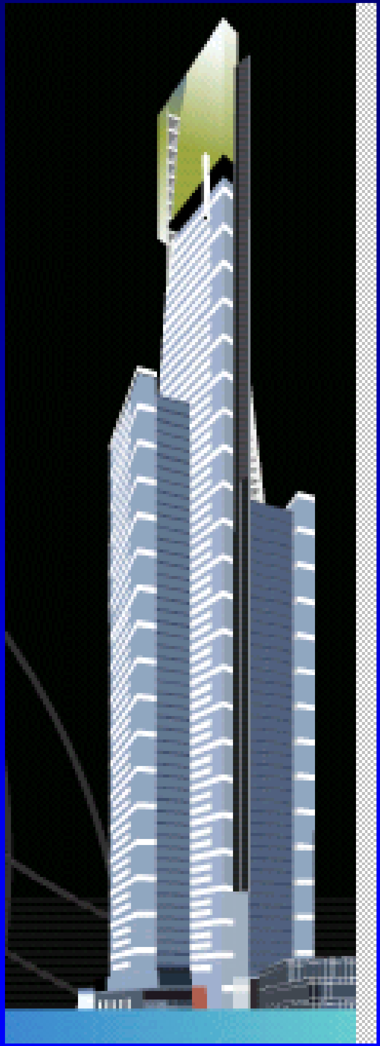
MELBOURNE VICTORIA AUSTRALIA

State Government Victoria AUSTRALIA

Hong Kong 1990s

Hong Kong –recent

Note: These photos were sourced from the web



Eureka Tower
Melbourne

Australia's tallest

Typical example of an advanced formwork system-double storey jump (Eureka Tower Melbourne)

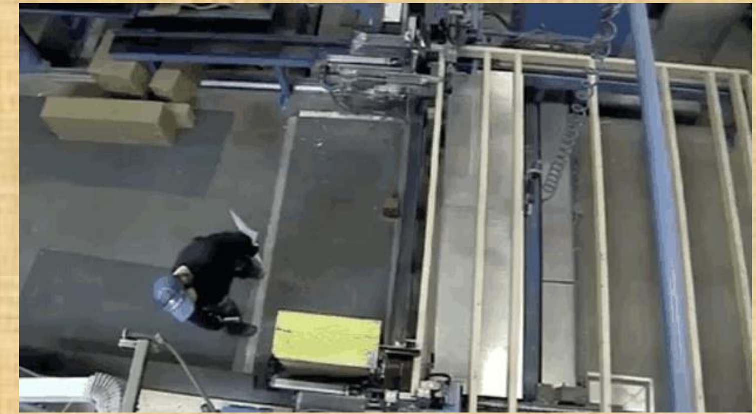
History of Prefabricated Off-site Manufacturing & Modular Structures

Prefabricated Modular Structures - Definition

- Definition
  - ✓ Prefabricated three dimensional units
  - ✓ Repetition of similar modules
  - ✓ Mass produced in a factory – controlled environment
  - ✓ Brought to site and assembled
  - ✓ Minimum finishes required on-site

- Main Characteristics
  - ✓ Fast Construction
  - ✓ Delivered with finishes & facades – Minimum on-site work
  - ✓ Incorporates – stairs, lift shafts, facades, corridors and services
  - ✓ Reusability

Transformational Technologies Automotive to Building Applications



ARC CAMP.H

ARC Training Centre for Advanced Manufacturing of Prefabricated Housing

Centre overview

Australian Government
Australian Research Council

MONASH University

THE UNIVERSITY OF MELBOURNE

THE UNIVERSITY OF SYDNEY

Curtin University

prefabAUS

ARCX

PREBUILT

Fleetwood

BHAPM PROJECT MANAGEMENT

envirosip Structural Insulated Panels

tbs precision construction.

rockend The leader in property software

habitech SYSTEMS

Forest & Wood Products Australia

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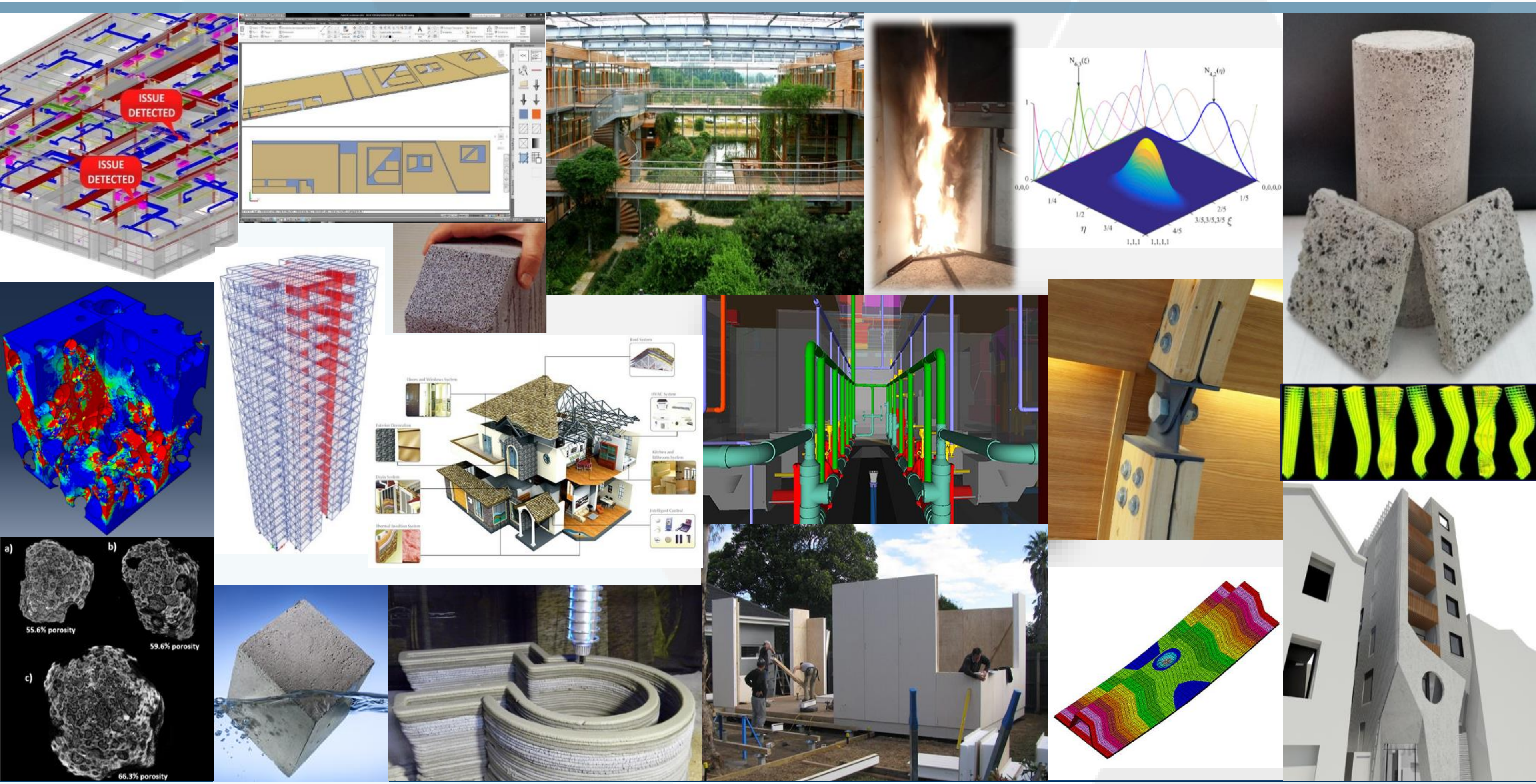
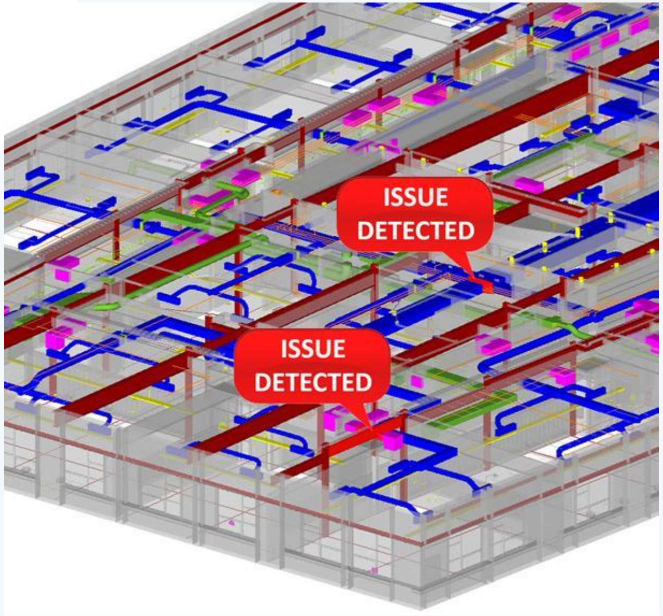
Our research activities (+20 projects)



Four research programs

Program 1: Innovation in Design for Manufacturing and Assembly



DfMA
BIM for prefab

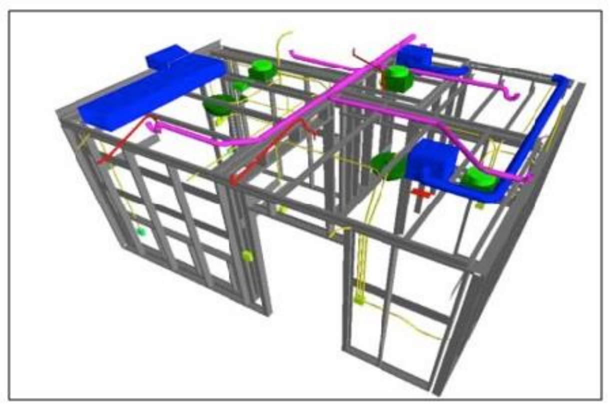
Standardise

↓

Modularise

↓

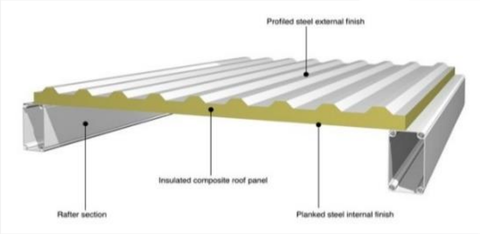
Mass Customise



Four research programs

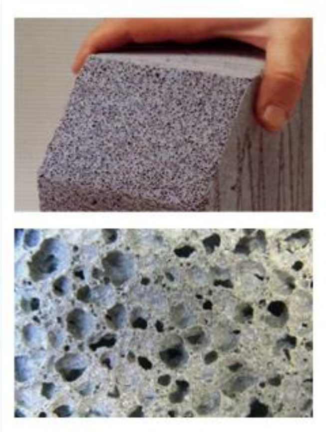
Program 2: Advanced building systems and assembly techniques

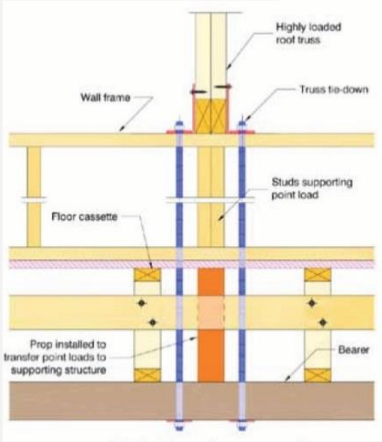
Lightweight Floor Systems
Framing Systems
Panel Systems
Smart MEP Systems
Connections



Four research programs

Program 3: High performance materials





Lightweight

Fire resistant

Affordable

High Strength

Durable

Environmental friendly

Four research programs

Program 4: Supply chain and financing innovation

- New risk profiling tools and procurement frameworks for prefab housing.
- Assist industry to develop a more efficient supply chain and new financing models.

Modular vs Traditional

OLD ←

vs

NEW →

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ABOUT THE CENTRE PARTNERS RESEARCH PEOPLE NEWS AND EVENTS

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Unlocking the potential growth of Australia's prefabricated building industry.

camph.eng.unimelb.edu.au

Prefabricated Homes


PREBUILT.
Merricks Custom Designed House


PREBUILT
Merricks Custom Designed
House

Retail Facilities


PREBUILT
Stockland The Grove Display Suite


PREBUILT.
Stockland Cloverton Display Suite


PREBUILT
Waterbank Display Suite


PREBUILT
Waterbank Display Suite

Public Infrastructure Projects

Schools

The permanent modular school buildings (PMSB) programme of Victorian School Building Authority of Australia (VSBA,2018)

Southmoor Primary School

Warrnambool Special Developmental

Craigieburn Kindergarten

Mount Waverley Heights Primary School

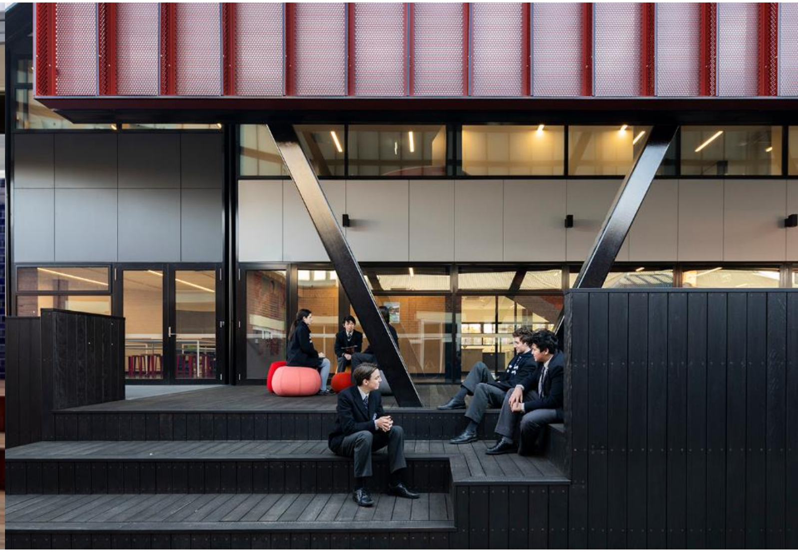
Beaumaris North Primary School

Tarneit North Kindergarten

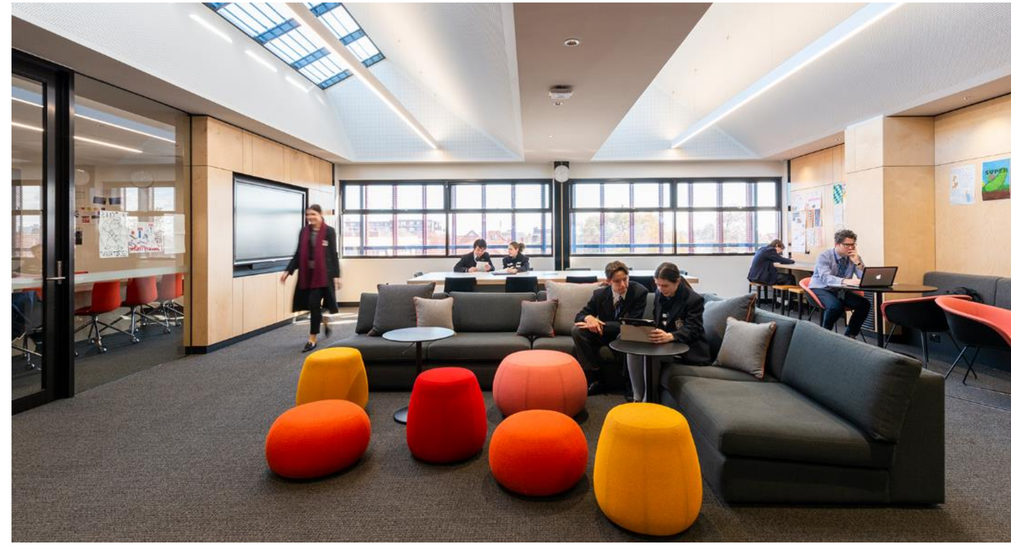
Schools

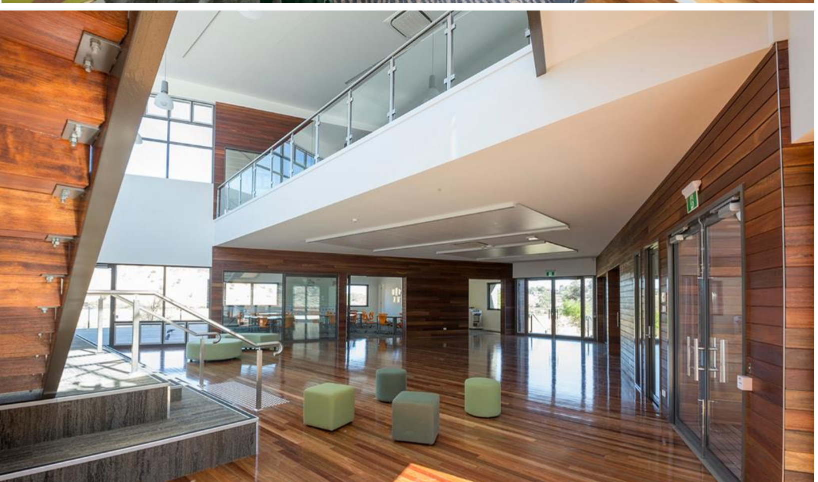
Schools

Schools

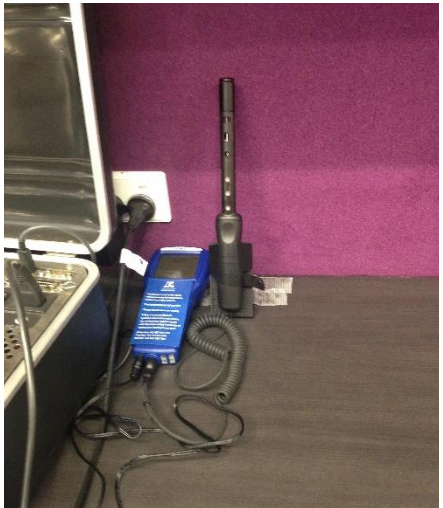


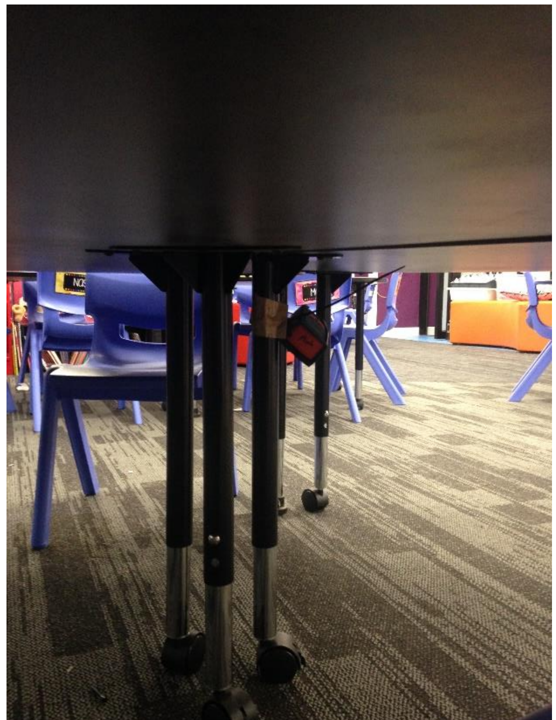
Schools





Taking Measurements of IEQ Assessment (CO_2, RH, Temp)





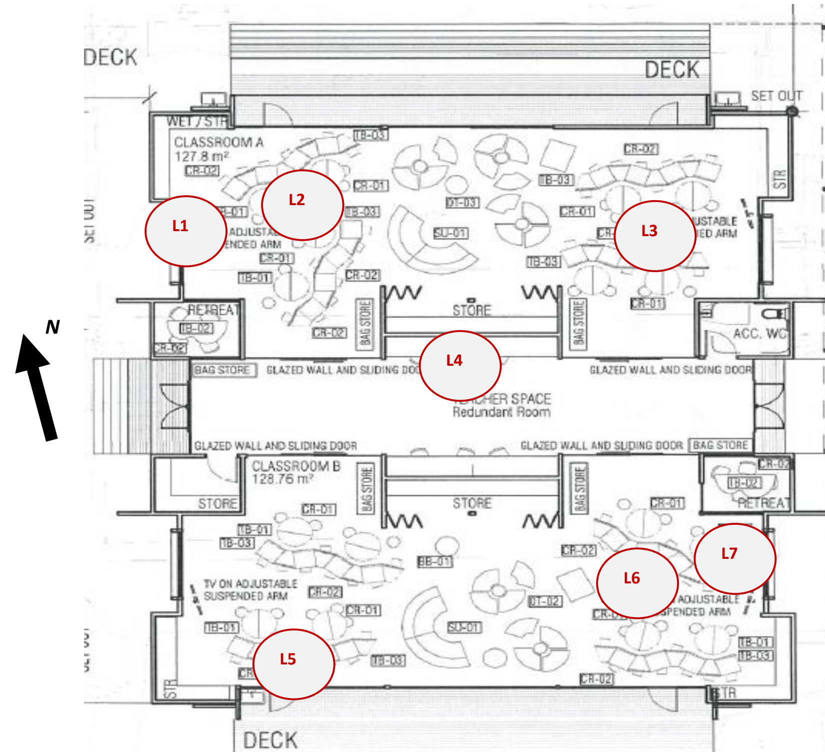
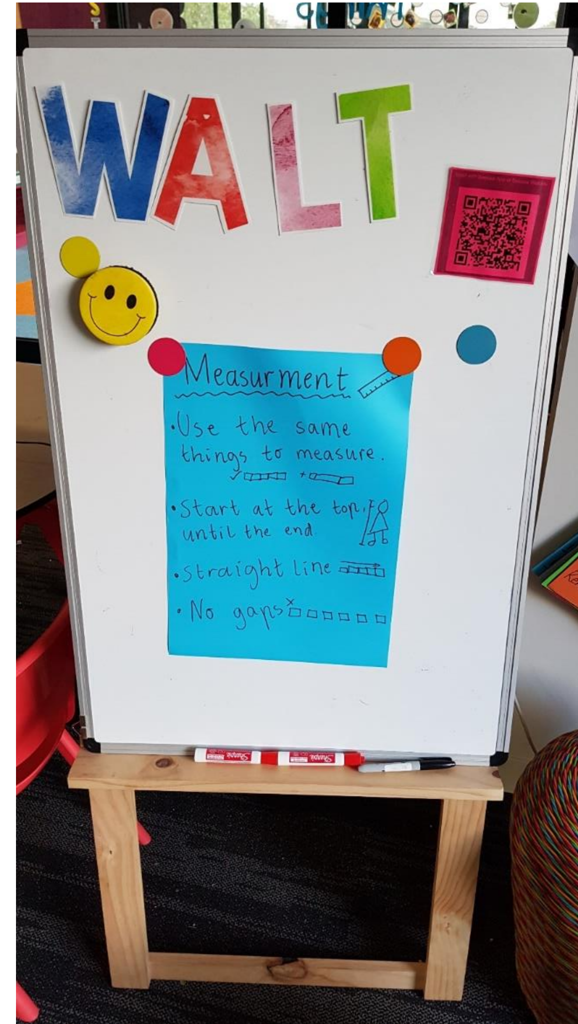


Figure 2: The seven measuring locations (L1 to L7) marked on plan

Schools

testo 545

JOURNAL JOURNEY
I CAN



WALT
Measurment
•Use the same things to measure.
•Start at the top, until the end
•straight line
•No gaps

Railway Stations


METRO
PT>
Ginifer
Station
Parking
Buses
RED ENGINE

PT>

SWL 350t

Healthcare

Hospitals built with modular technology in India

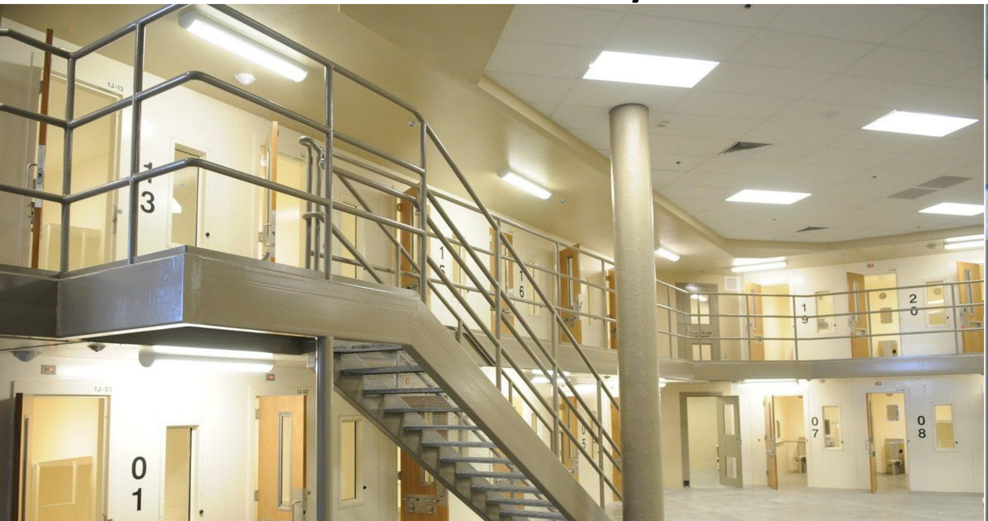

4


Pascoe Vale


124
Pascoe Vale
HEALTH
FAMILY MEDICAL CENTRE

Other Public Facilities – Police Stations

Modular Correctional Facilities / Prisons



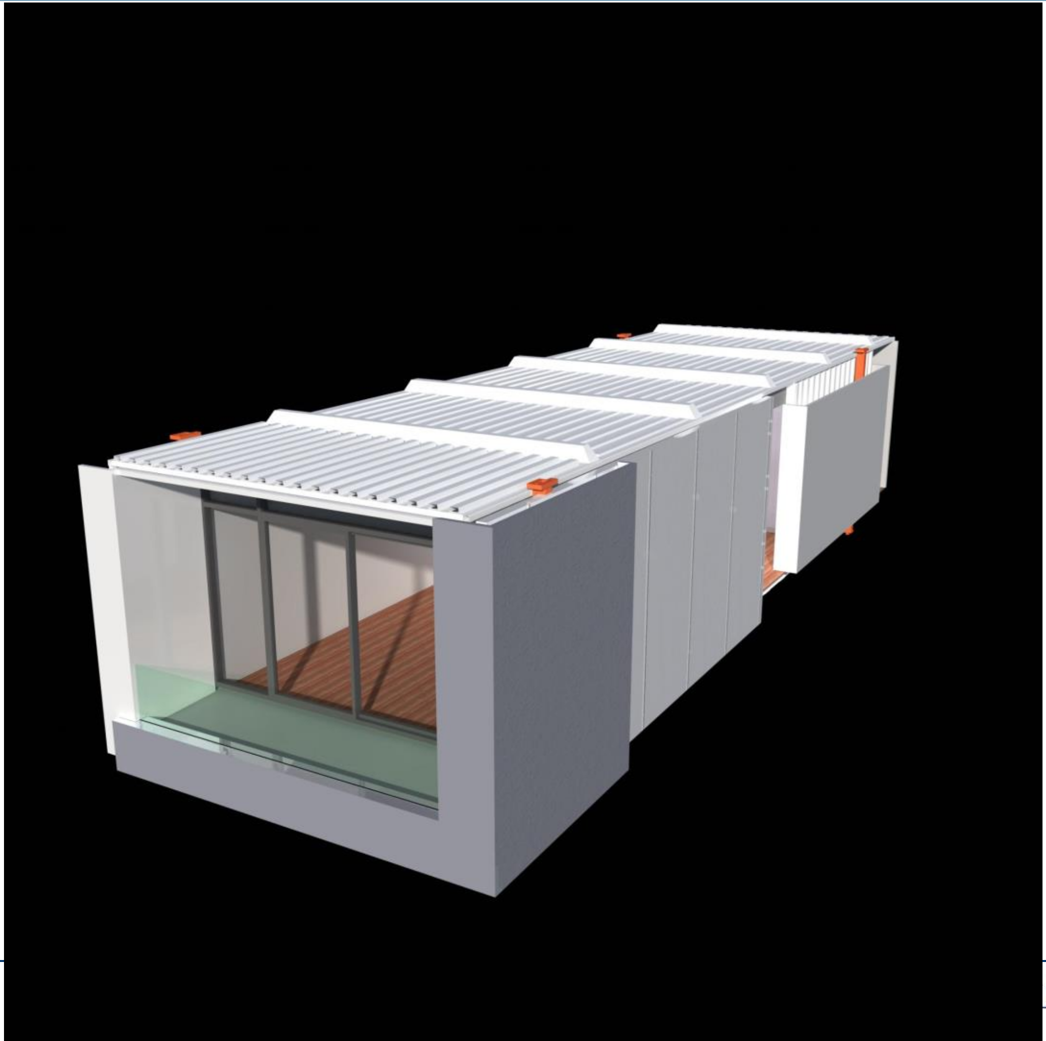

Post-disaster Reconstruction

Case study: from early beginnings…

Little Hero | Fender Katsalidis

- ‘Little Hero’ in Melbourne, Australia
- 58 single-storey apartment modules
- 5 double-storey apartment modules
- The 8 modular stories assembled on site in just 8 days

Modular Construction



Modular buildings （模块结构）

- **Prefabricated** （预配置构件）
- **Normally fully fitted out in manufacture room-sized volumetric units** （规定尺寸的模块会在工厂完全装好）
- **Installed on-site as load-bearing building blocks** （在现场组装并且作为承载力的构件）
- **Used to create varieties of apartment types for high rise buildings** （能搭建出不同类型的高层建筑）
- **Speedy construction** （施工速度快）

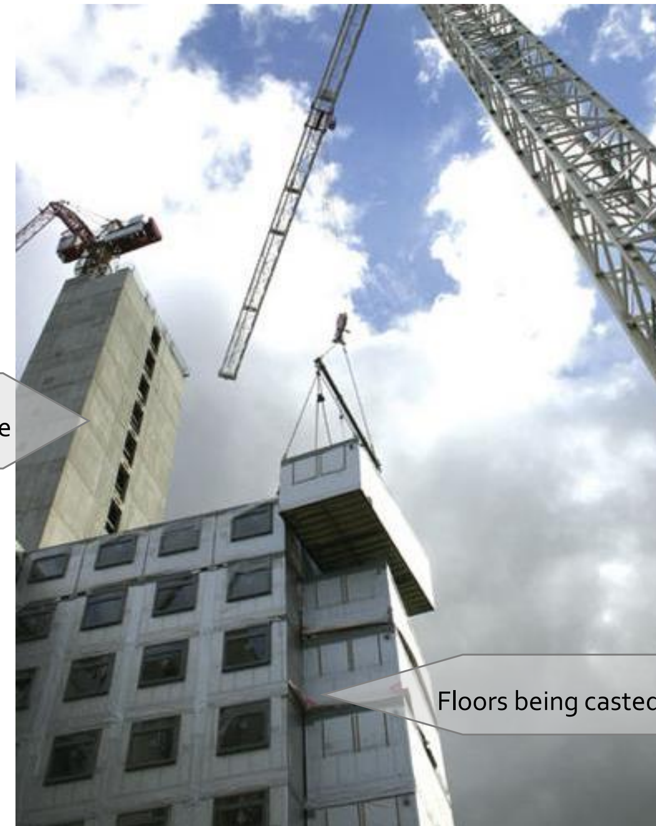
Modular Building Systems currently in use

Unitised Building System (UB)

Modular units with in-situ concrete floors and central RC core

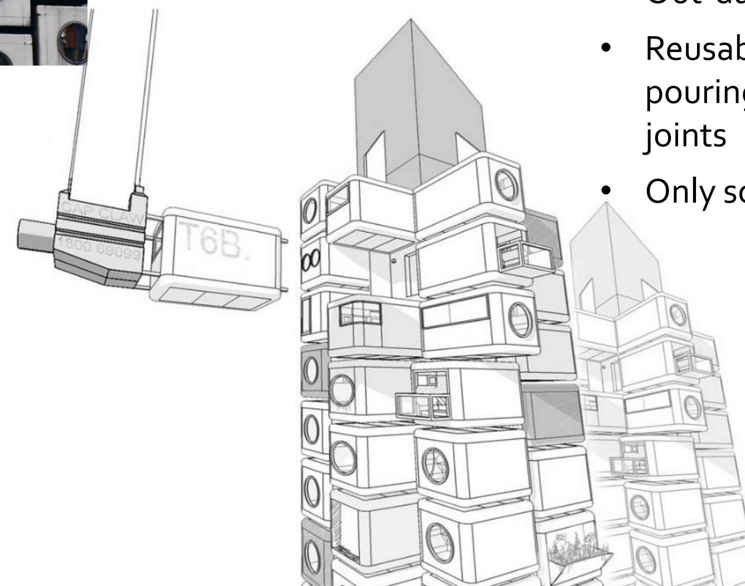
Student Apartments, UK

Cast in-situ concrete core



Floors being casted with in-situ concrete

Modular units with in-situ concrete floors – Early Structures, Japan



<u>Example – Modular gone wrong – Nagakin Capsule Hotel</u>

<u>Tokyo, Japan</u>

- Built in 1972
- Out-dated design today
- Reusability eliminated by pouring concrete into structural joints
- Only solution - Demolition

General Design Requirements for Modular Buildings

<u>Conceptual Design Formulation</u>

Usage

Importance

Loading

Materials

Arrangement and sizing of structural members

Logistics

Transportation

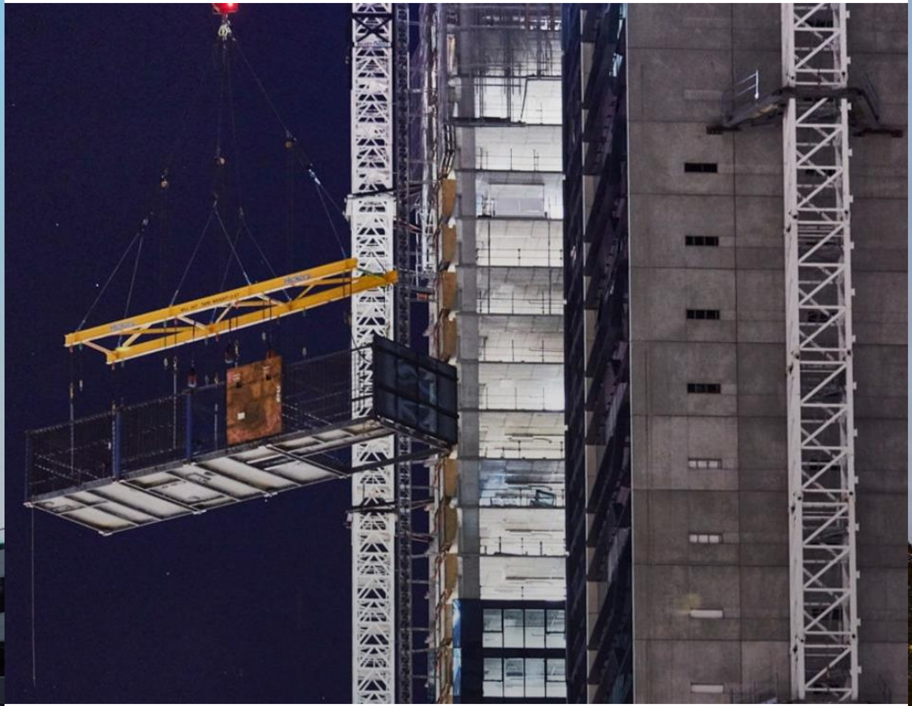
Lifting

Fabrication Process

Assembly Process

Modular High Rises

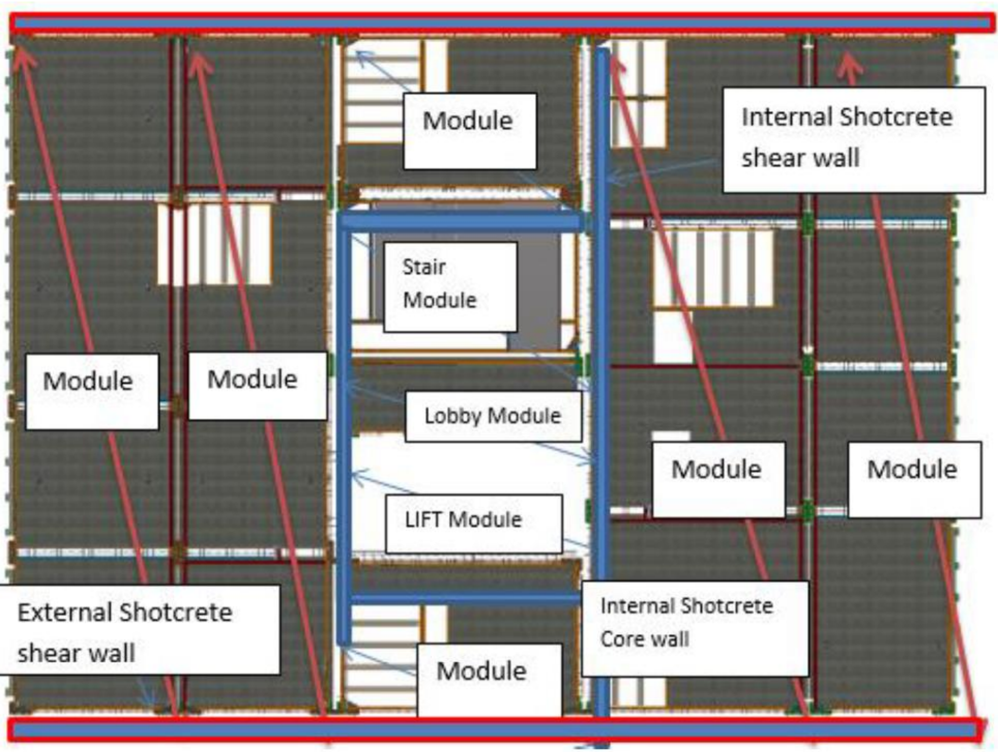
Latrobe Tower, Melbourne

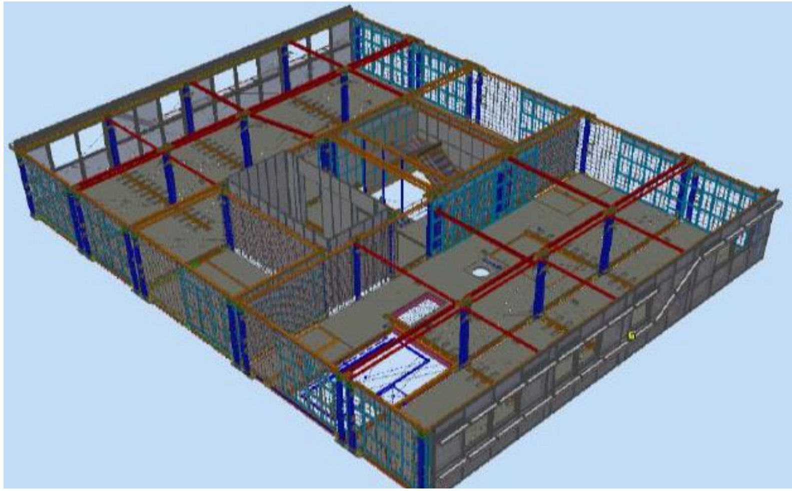


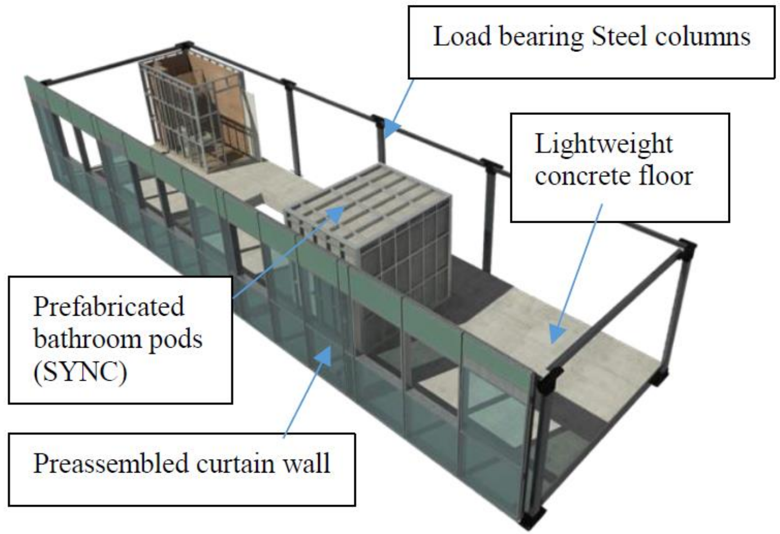
Latrobe Tower – Melbourne, Australia
Hickory Group

- 44 Levels
- 206 Apartments
- 19 months to completion

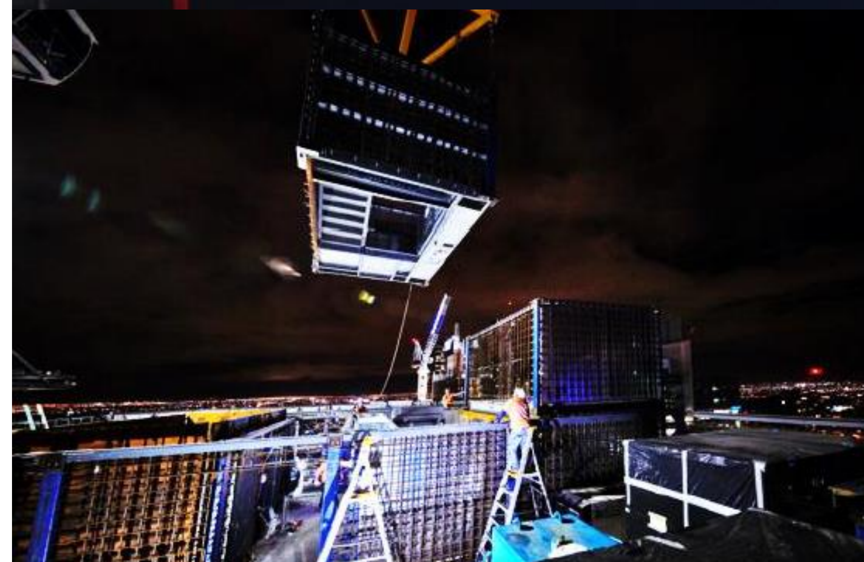
Latrobe Tower – Melbourne, Australia







Latrobe Tower – Melbourne, Australia



Other Forms of Prefabrication

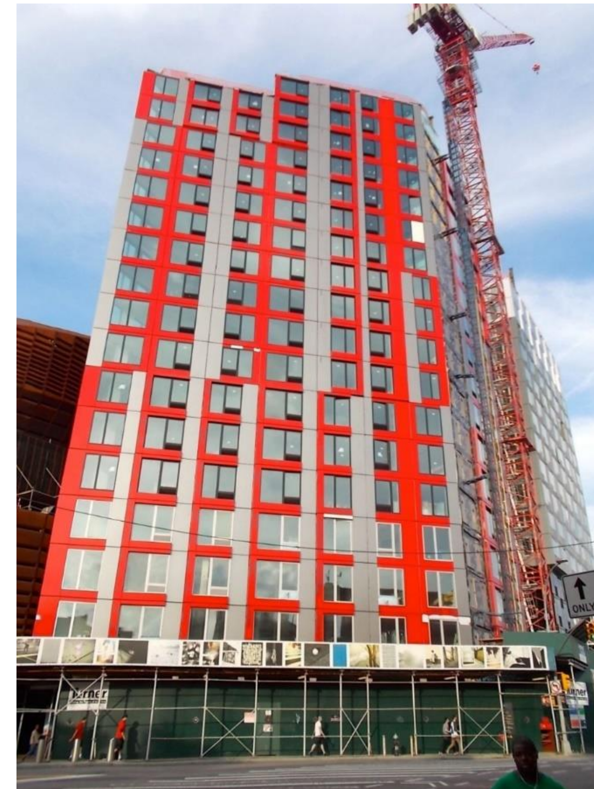
Pods
(Prefabricated units inside conventional buildings)

PREFABRICATED MODULAR BUILDINGS AROUND THE WORLD

Student Apartments, UK

Public Housing Project, UK

B2 Apartments, USA



Modular High Rises

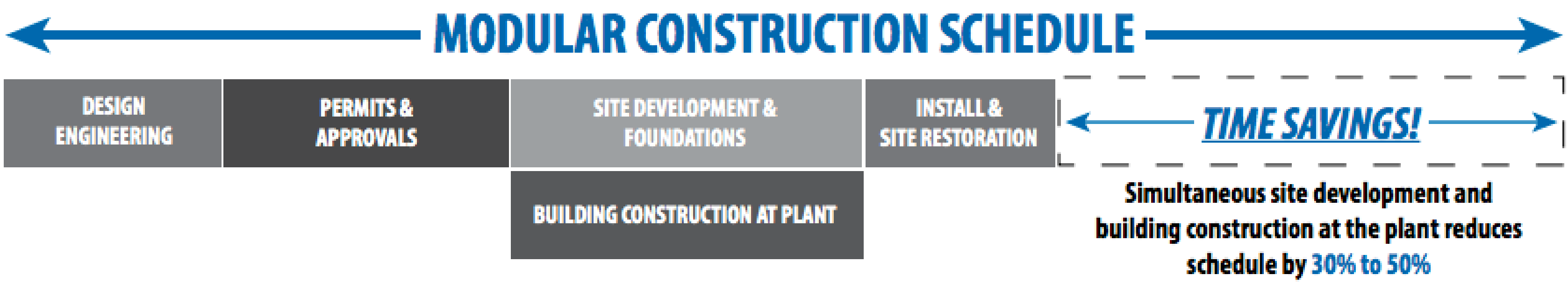
Collins House, Melbourne

461 Dean Street New York

Mini Sky City in Changsha

Typical traditional project schedule

Typical modular project schedule



Customisation

Scalability

Fabrication
for construction

Challenges

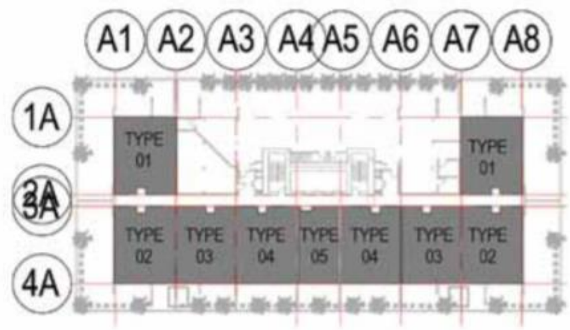
Perception

awareness

Testing facilities

Market size

SOHO Tower
Darwin



LEVEL 6 KEY PLAN

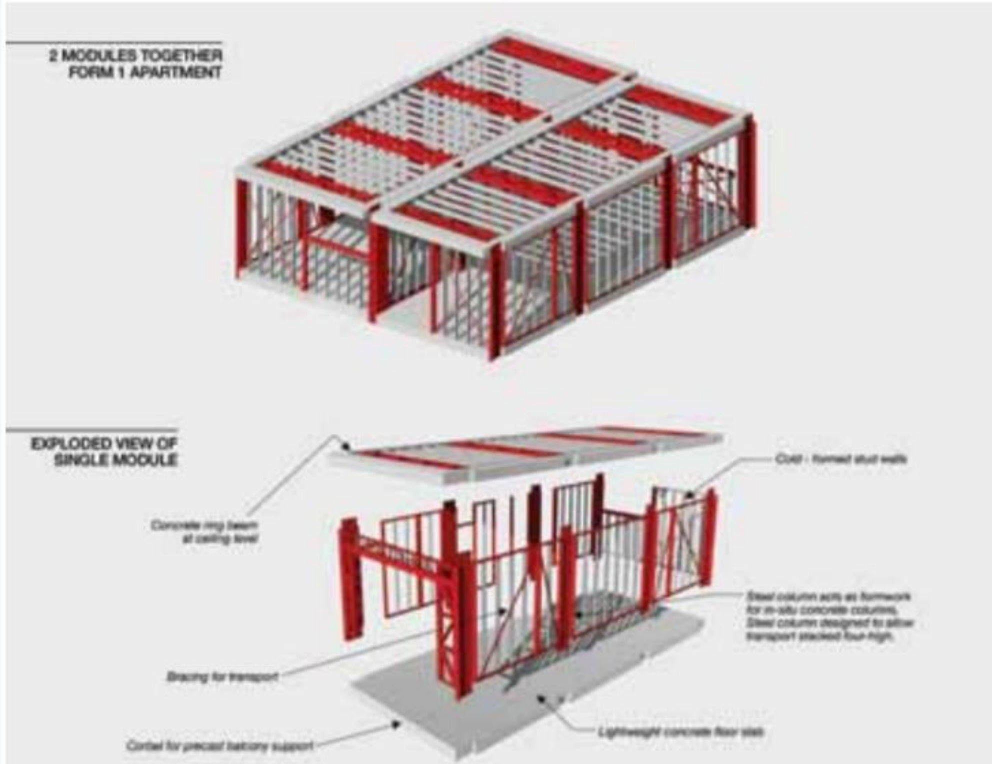
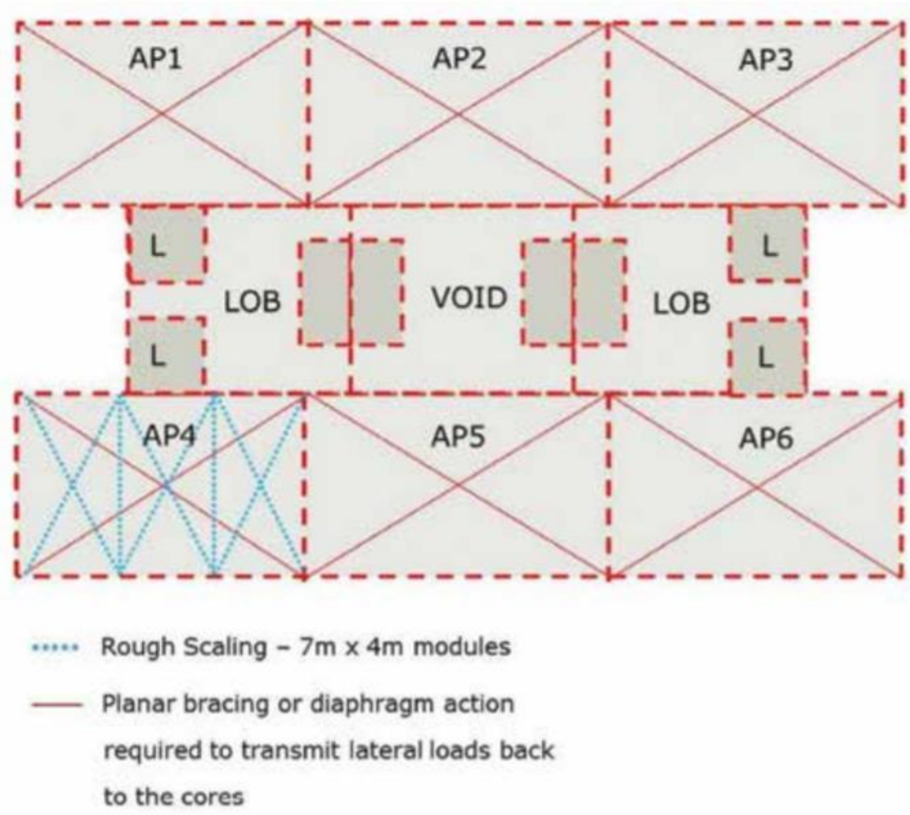

2 MODULES TOGETHER
FORM 1 APARTMENT
EXPLODED VIEW OF
SINGLE MODULE
Concrete ring beam
at ceiling level
Cold - formed stud walls
Steel column acts as formwork
for in-situ concrete columns.
Steel column designed to allow
transport stacked four-high.
Bracing for transport
Lightweight concrete floor slab
Corbel for precast balcony support

Figure 14. Prototype module (Source: Ramboll Group)



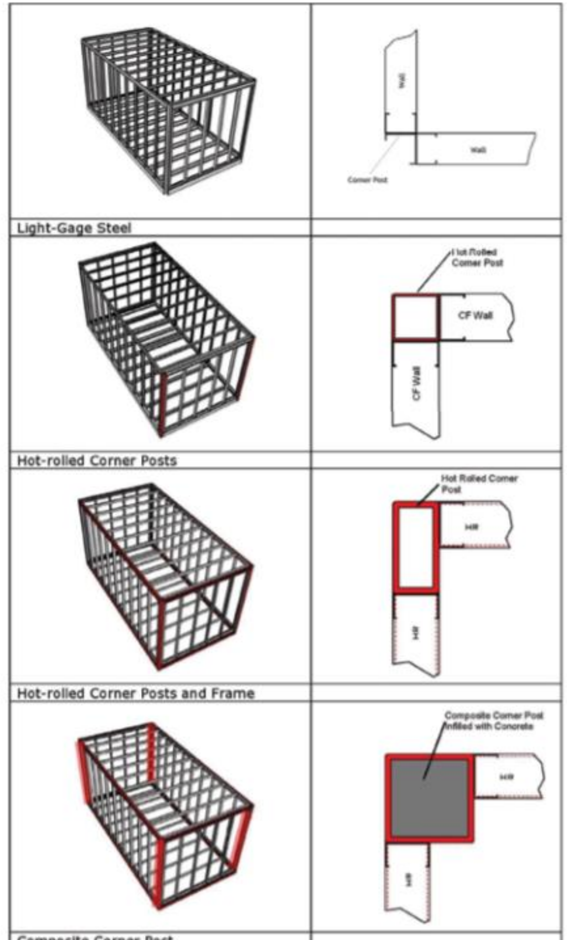


Figure 4. Modular chassis types (Source: Ramboll Group)

No	System	Chassis	Floor Construction	Max Height	Lifting Weight[1]
1	Cold-formed Posts	All CF Steel Galvanised	Steel with gypsum board	G+3	5-6 tonnes
2	CF Walls	Double CF Steel	Steel with light weight screed	G+10	6.5-8.0
3	Hot Rolled corner post	Hot rolled Steel corner Posts/ CF Sections for walls and ceiling	Steel with gypsum board	G+12	5.5-6.5 tonnes
			Steel with light weight screed		7.0 - 8.5
4	Full Hot rolled frame	HR Posts and Beams CF Sections infill to walls and ceiling	Steel with gypsum board	G+35	6-7 tonnes
			Steel with light weight screed		7.5 - 9.0
5	Pre-cast Concrete	All sections in precast concrete	Pre cast concrete	G + 40	30-40 tonnes

Table 2. Summary of PPVC Technology (Source: Ramboll Group)


PREBUILT
RAAF East Sale Accommodation


PREBUILT
RAAF East Sale Accommodation

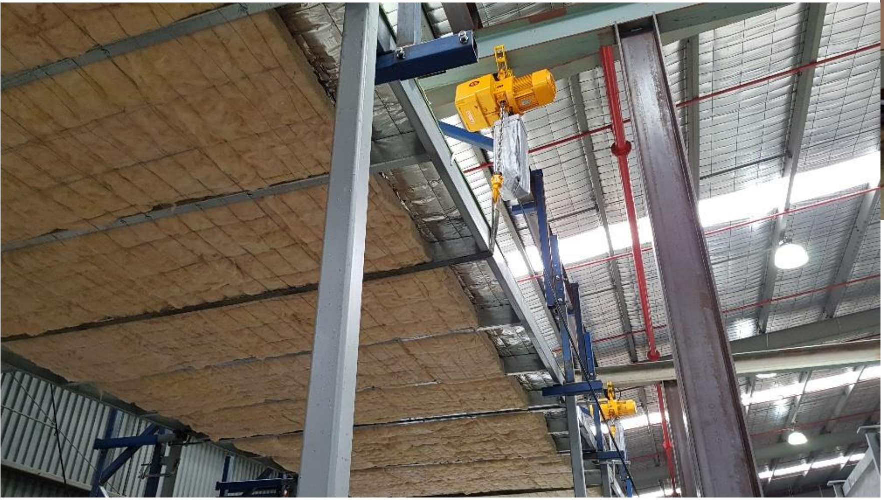

MANITOU
A
B
C
PREBUILT
RAAF East Sale Accommodation

PREBUILT.

RAAF East Sale Accommodation


PREBUILT.
PREBUILT.
RAAF East Sale Accommodation


PREBUILT
RAAF East Sale Accommodation
TOILET
STAR 6 AC
UNITED



Factory Jig


UNITED
Haulotte
STAR 6
AC

General Design Requirements for Modular Buildings

Conceptual Design Formulation

Usage

Importance

Loading

Materials

Arrangement and sizing of structural members

Logistics

Transportation

Lifting

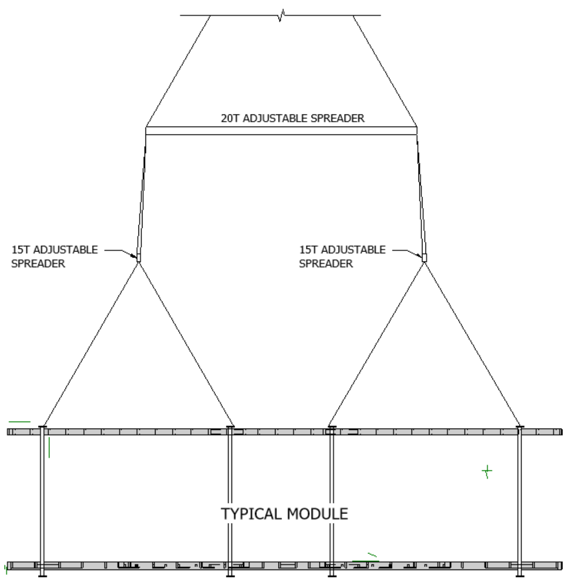
Fabrication Process

Assembly Process

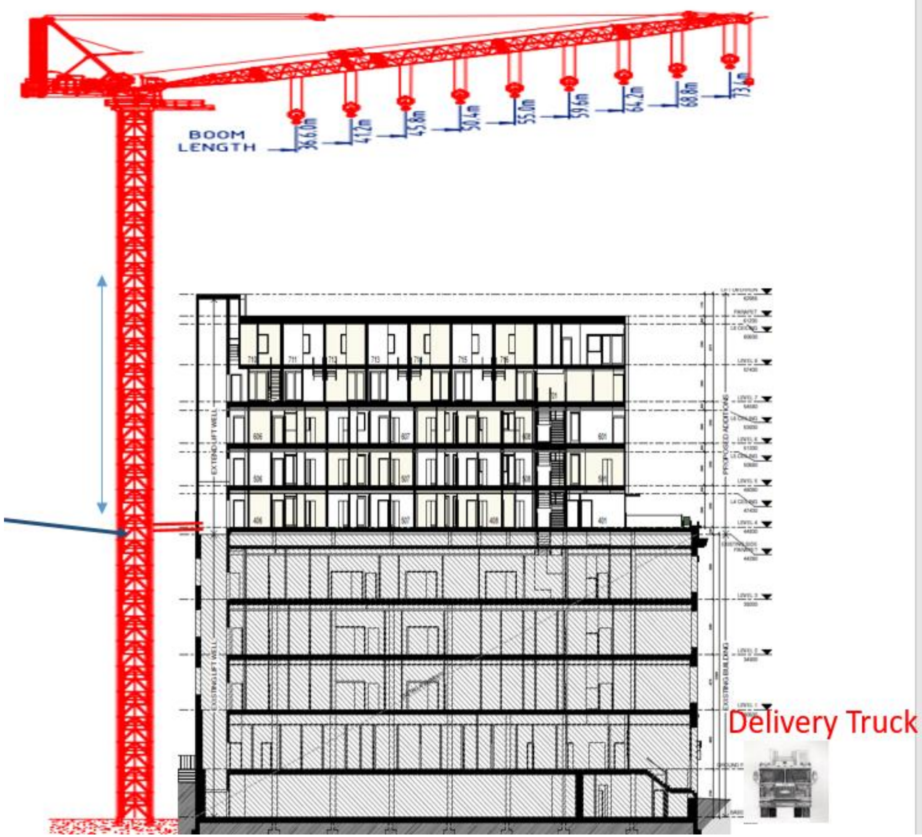
Design for Lifting – Lifting Strategy

Methodology for lifting from the module

- Top lift or bottom (strapped) lift?
- With or without spreaders?



Design for Lifting – Lifting Strategy



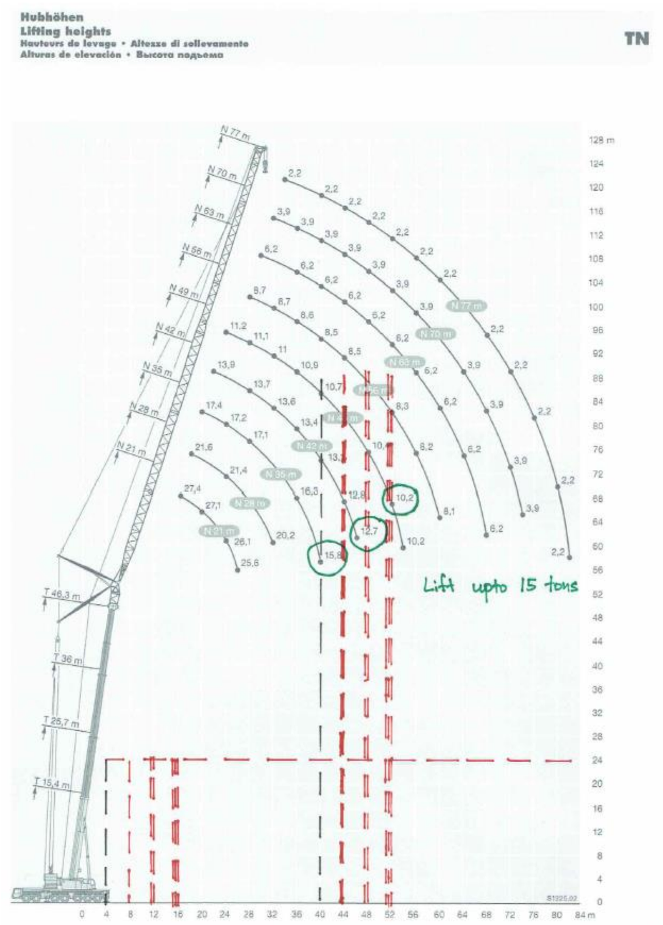
Lifting With Tower Cranes

- For medium to high rise buildings

Considerations

- Crane capacity
- Boom angle – access to delivery truck
- Crane ties (having concrete walls is an advantage)

Design for Lifting – Lifting Strategy



Lifting With Mobile Cranes

- For low to medium rise buildings

Considerations
- Crane capacity
- Boom angle – access availability
- Site-specific obstacles

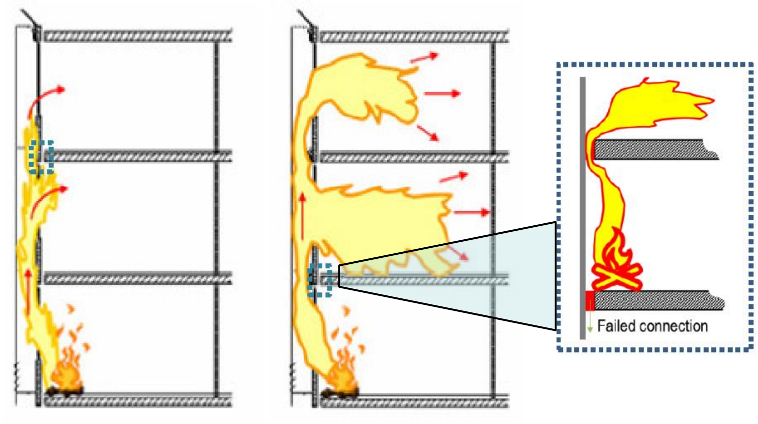
Design for Transportation

- Temporary Cantilevers (not there in the final structure)

Design for Transportation

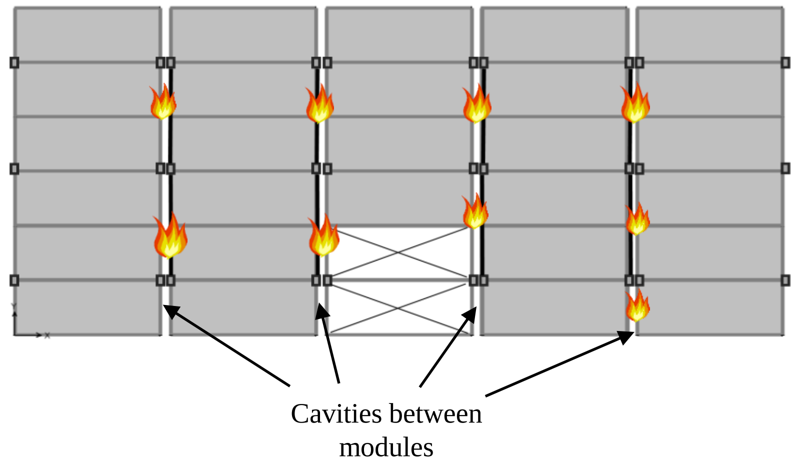
- Temporary bracing
- Temporary columns

Advantages of prefabrication for fire resistance



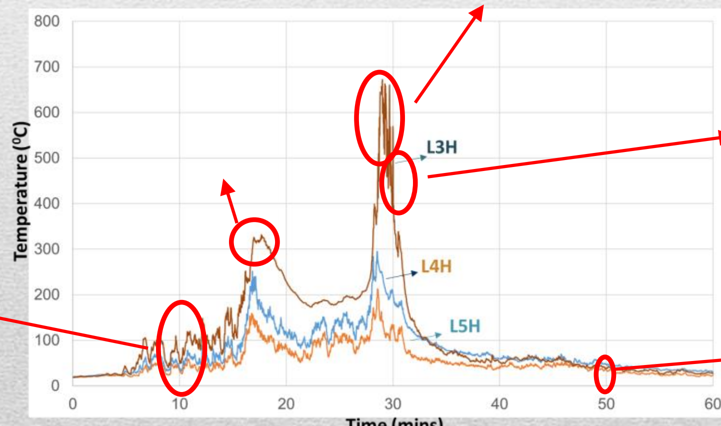
- Off site manufacturing in a quality controlled factory environment allows careful detailing of fire resisting components.
- Eg: Fire stops – Provided in external cladding to act as a barrier against fire spread. Installing them inside a factory rather than on-site allows quality workmanship which enhances the fire resistance.

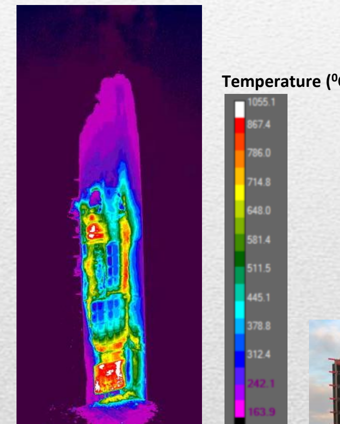
Major Concern



- Voids between adjacent modules could increase the risk of vertical and horizontal fire spread
- Address this issue before installing the modules, as after modules are assembled together it is difficult to reach these voids to carry out any remedial work.

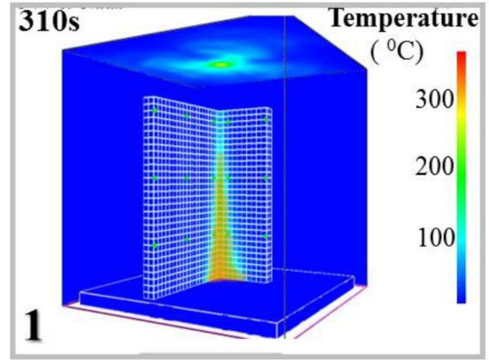
IFE Fire performance of façades

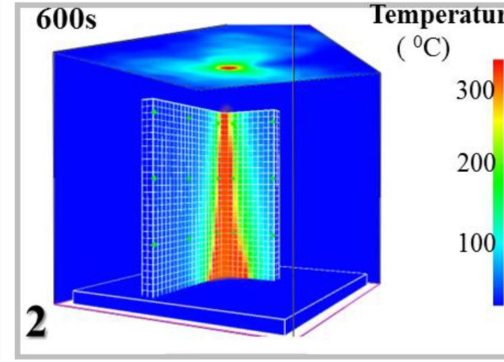


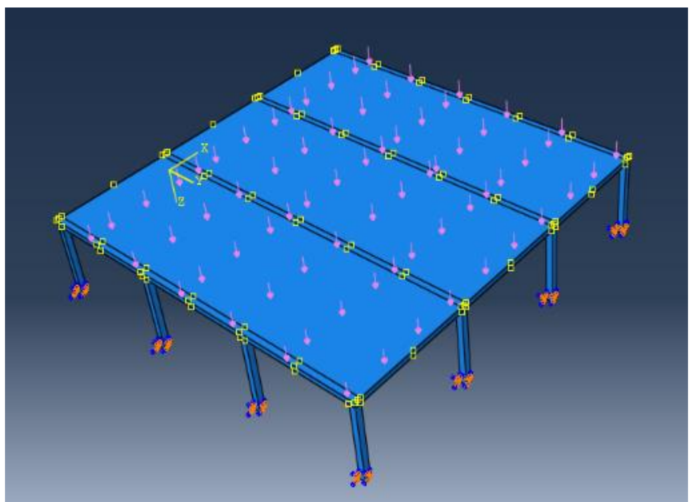


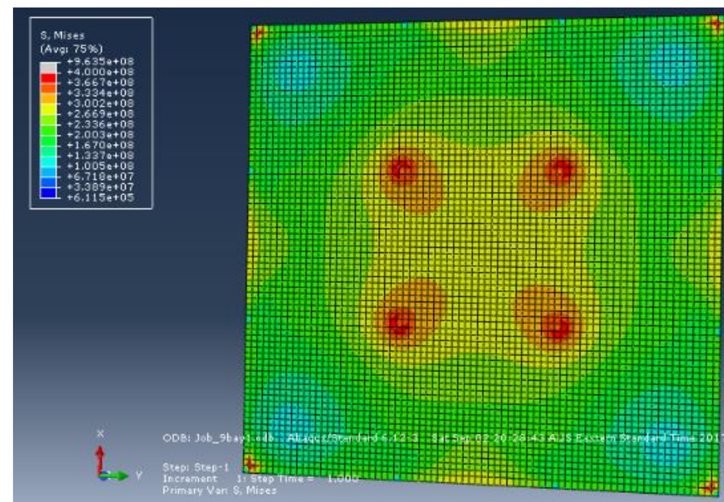
Kate Nguyen (kate.nguyen@rmit.edu.au)

- Off-site manufacturing can enhance the fire resistance
- Cavities between modules could increase the risk of fire spread
- Fire modelling will be carried out using;
  - CFD programs – thermal behaviour
  - FE programs – structural behaviour









Performance based code NCC 2019

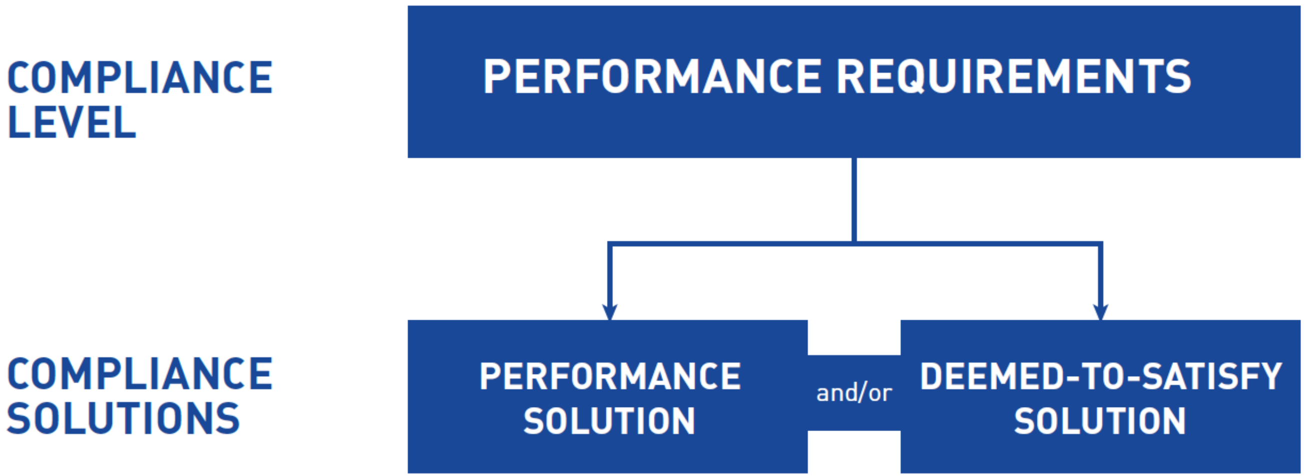


Figure: NCC Compliance Structure

MECHANICAL & ELECTRICAL SYSTEMS

FORMS OF MEP PREFABRICATION

Source :https://sourceable.net/prefab-services-riser-technology-resets-industry-standards/

THE UNIVERSITY OF MELBOURNE

MODULAR MEP PROJECTS

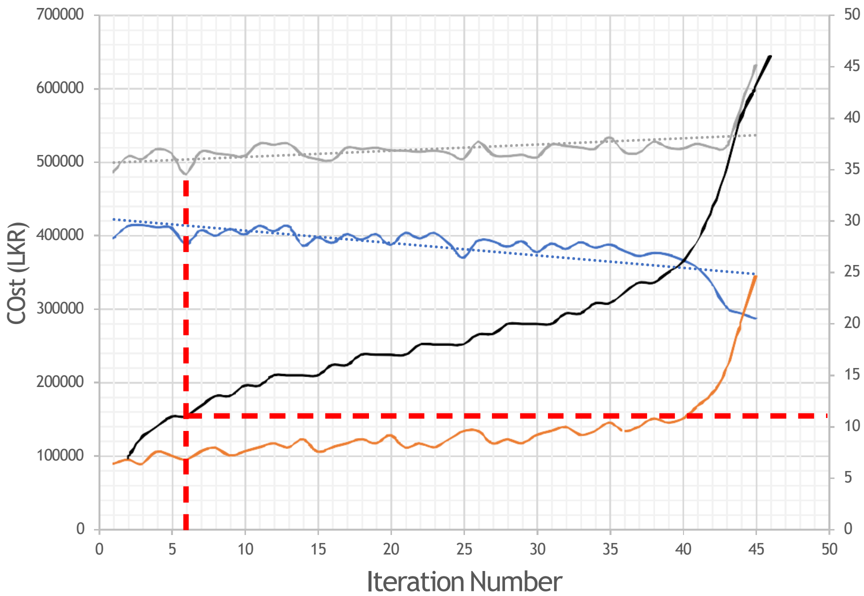
North Core and services integrated bench at The Leadenhall Building (Source: Davies 2013)

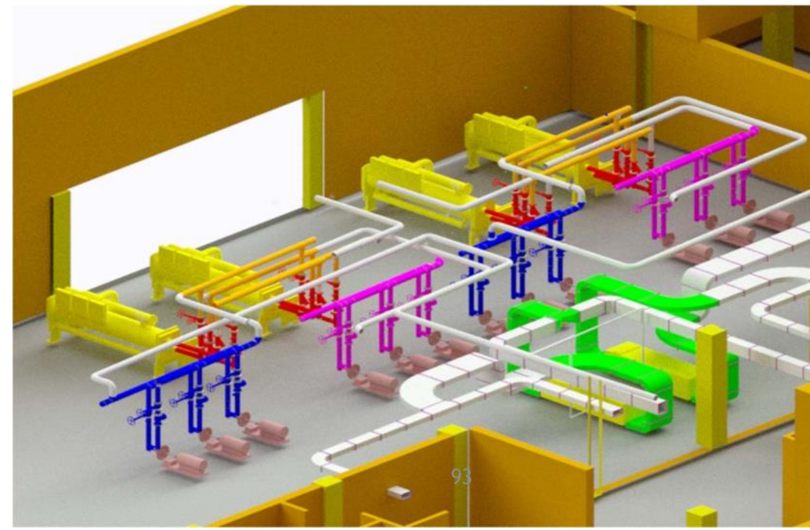
Modular Hotel Room Construction London (Image courtesy: Amoveo (Pty) Ltd.)

MELBOURNE SCHOOL OF GRADUATE RESEARCH

THE UNIVERSITY OF MELBOURNE

Use of AI -OPTIMUM SOLUTION FOR PROJECT A - 12 MODULES





m = 12 (iteration 6)

PUBLICATIONS

Journal papers

Samarasinghe, T., Gunawardene, T., Mendis, P., Aye, L., Sofi, M., (2018) Hierarchical Clustering based algorithm for optimum module identification in MEP Systems (**Accepted with comments - Automation in Construction**)

Samarasinghe, T., Gunawardene, T., Mendis, P., Aye, L., Sofi, M., (2018) Hybrid offsite construction strategy for MEP systems to achieve minimum installation cost (**To be Submitted to Journal of Construction Engineering and Management (ASCE)**)

Samarasinghe, T., Mendis, P., Fernando, S., (2018) Advancements in BIM for modular MEP construction in high-rise buildings in Sri Lanka (**Submitted to Journal of Construction Engineering and Management (ASCE)**)

Articles

Samarasinghe, T., Heath, D., (2018) CAMPH BIM Initiatives: Modularisation and Standardisation of MEP, *Built Offsite (Issue 10)*, 8 August , pp 37 **(Published)**

Conference papers

Samarasinghe , T., Mendis, P., Aye, L., (2018) An Optimization method for MEP plant room Modularization. *Proceedings of ZEMCH2018 International Conference*, Melbourne, 29 January–1 February 2018. **(Published)**

Weerasinghe, P., Samarasinghe, T., Gunawardena, T., Nguyen, K., Mendis, P., Ngo, T., & Aye, L. (2018). AN OPTIMUM CONSTRUCTION STRATEGY FOR MULTI-STORY RESIDENTIAL PREFABRICATED MODULAR BUILDINGS. . *Proceedings of ZEMCH2018 International Conference*, Melbourne, 29 January–1 February 2018. **(Published)**

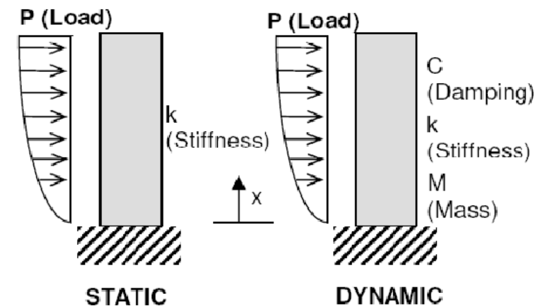
Samarasinghe, T., Mendis, P., Aye, L., Gunawardena, T., Fernando, S., & Karunaratne, R. (2017). BIM and modular MEP for Super-Tall and Mega-Tall Buildings. Paper presented at the 8th International Conference on Structural Engineering and Construction Management. **(Published)**

Samarasinghe, T., Mendis, P., Aye, L., & Vassos, T. (2016). Applications of design for excellence in prefabricated building services systems. (7th International Conference On Structural Engineering And Construction Management, Kandy, Sri Lanka**(Published)**

Samarasinghe, T., Mendis, P., Ngo, T., & Fernando, W. (2015). *BIM Software Framework for Prefabricated Construction: Case Study Demonstrating BIM Implementation on a Modular House*. Paper presented at the 6th International Conference On Structural Engineering And Construction Management. **(Published)**

Wind Design

Static vs Dynamic



Static $Force = k(x)$

Dynamic $Force = M(x'') + C(x') + k(x)$

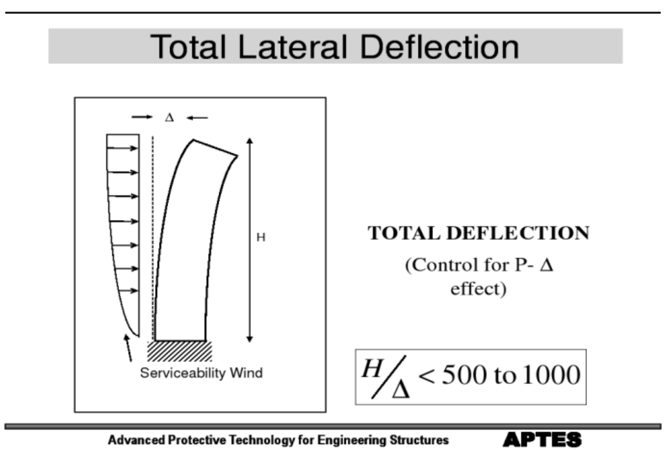
Where M, C, k are mass, damping and stiffness characteristics as a function of height.

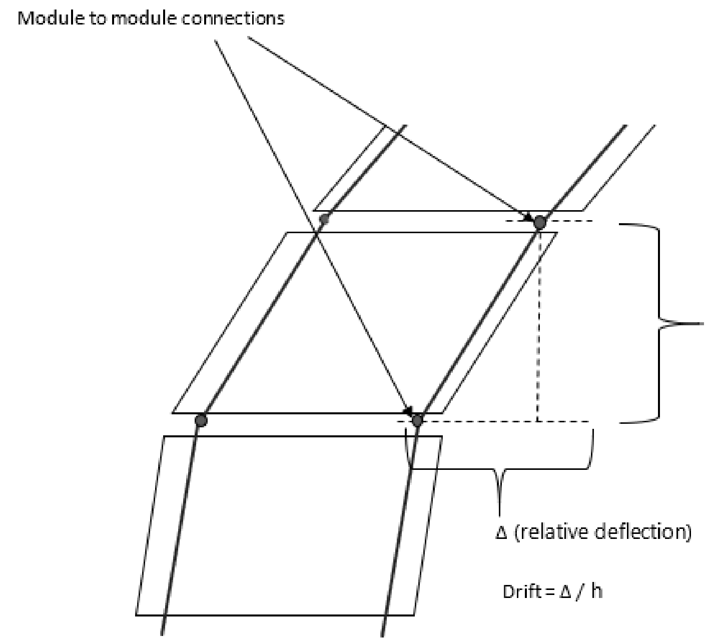
Advanced Protective Technology for Engineering Structures **APTES**

Wind Design - Deflection and Drift

Design Criteria

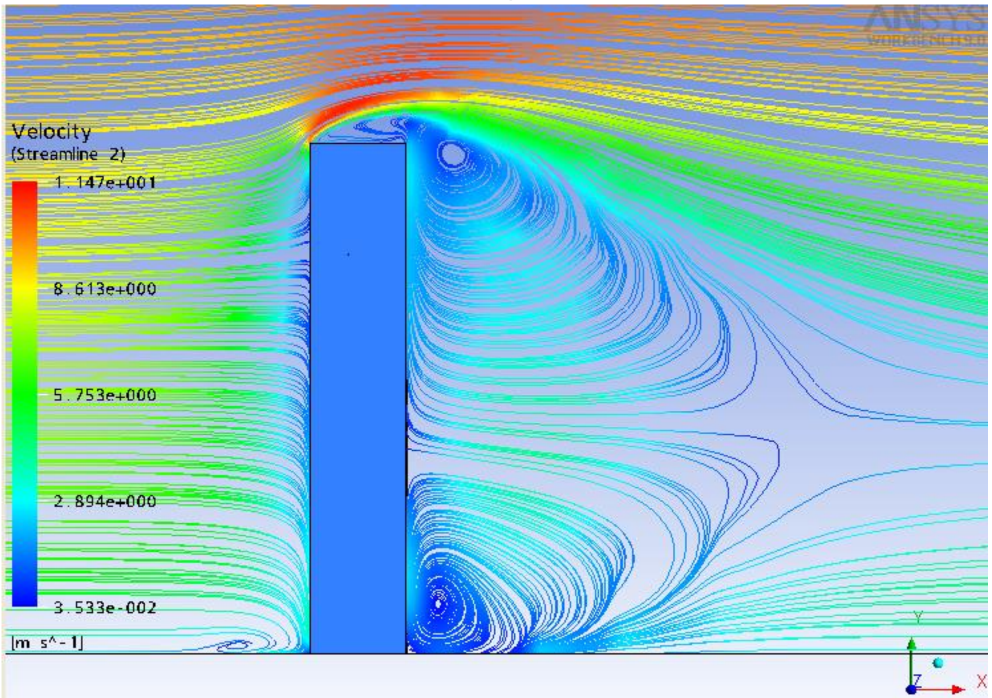
(a) To limit damage to the cladding on the building facade and to partitions and interior finishes;
(b) To reduce the effects of motion perceptibility;
(c)To limit the P-Δ or secondary loading effects.

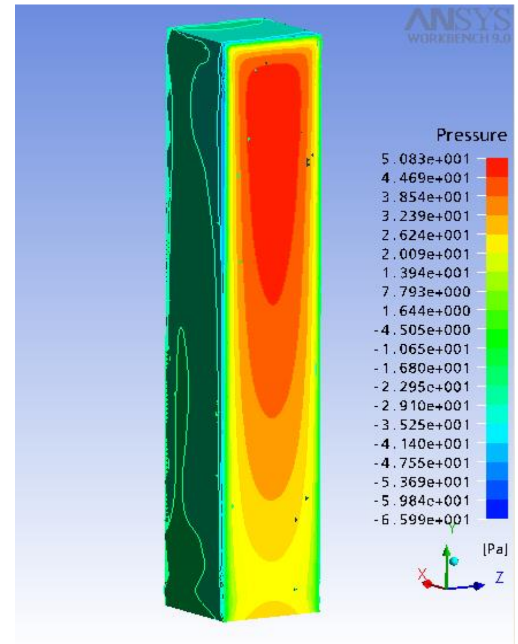




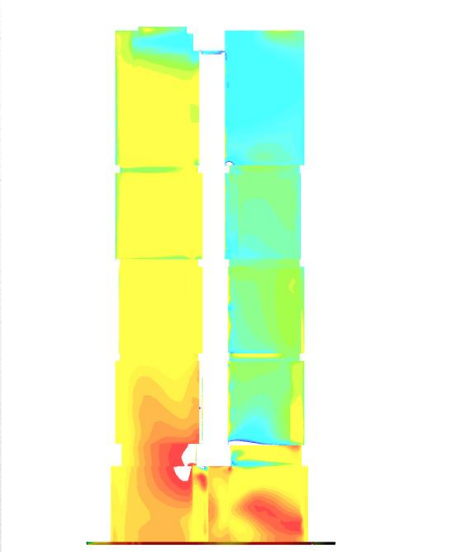
Wind Design - CFD for Wind Analysis

Stream line of a flow over a building model – Vertical view & Pressure distribution





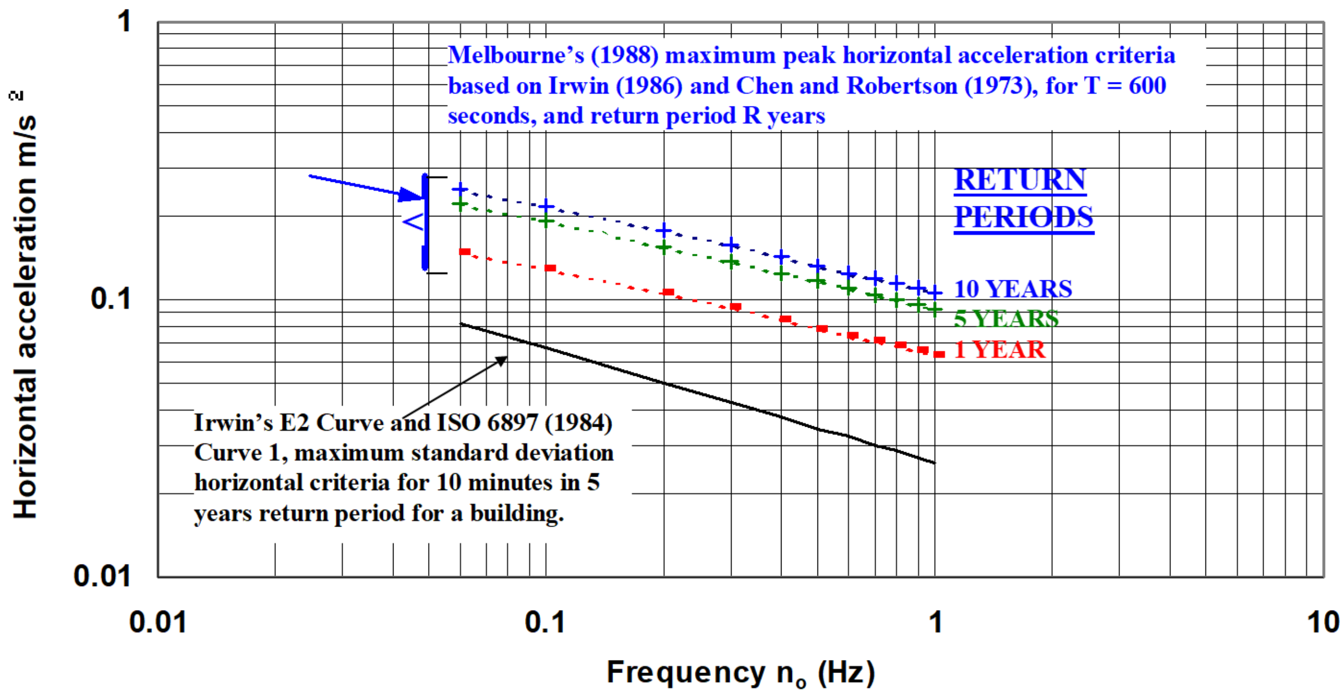
Capitol Twin Peaks Wind Tunnel Model



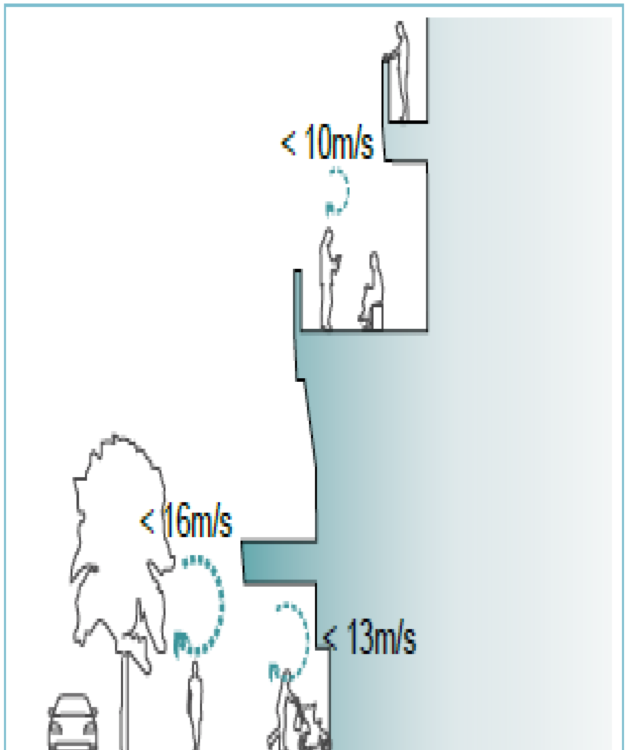
CFD Model analysis by CSEC Sri Lanka

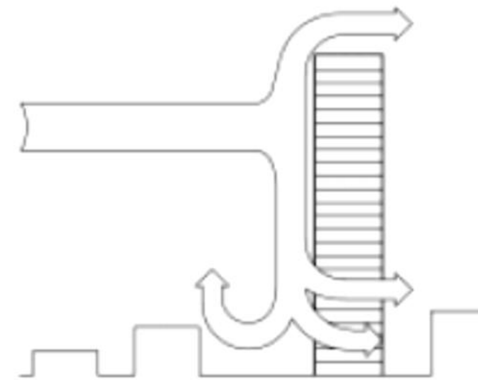
Wind Design - Wind Accelerations (Ref: Mendis et al., EJSE, 2007)

Human perception of motion (Allowable accelerations)

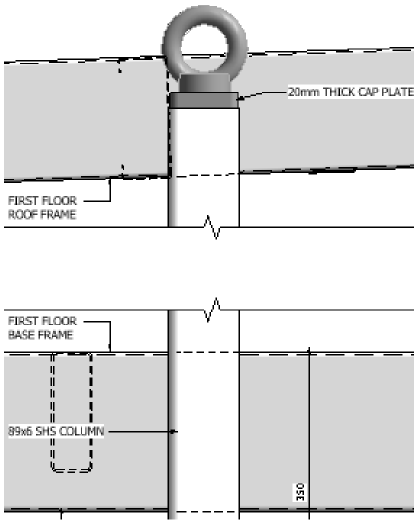


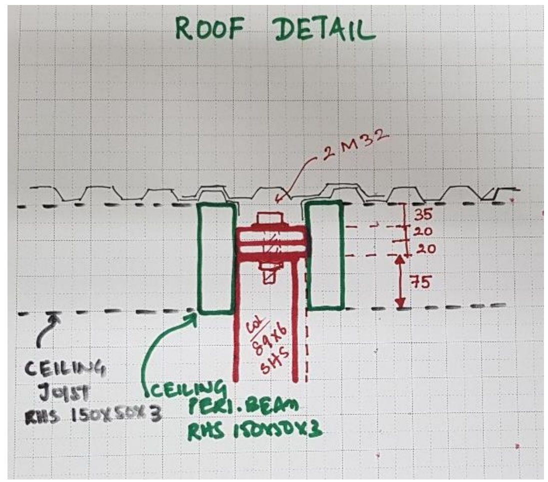
Wind Design - Pedestrian Comfort





Multi-purpose Systems





Latest Research on Modular Construction

INNOVATIONS IN MODERN PREFABRICATED CONCRETE CONSTRUCTION

BY ASSOCIATE PROFESSOR TUAN NGO

Prefabricated construction is an emerging industry in Australia and is considered a key mechanism to unlock existing potential and boosting productivity in our $200 billion construction industry. However, this is not without its challenges including overcoming the stigma that prefab is a lower quality offering. The long history and proliferation of precast concrete projects in Australia today is a testament to the merits of off-site manufacture relative to conventional site-based construction.

Moreover, benefits of prefabricated construction are many: greater speed, reduced waste, improved safety, higher quality and improved productivity, among others. Nonetheless, embracing this new thinking into an industry that is historically slow at uptake of new technologies is not without its challenges. The new paradigm influences all aspects of work including the supply chain, manufacture, transport and assembly, operation, maintenance, decommissioning, and even re-use requiring cradle-to-cradle thinking.

The new generation of buildings also bring new challenges and research opportunities. The prefabricated construction group within the Melbourne School of Engineering at the University of Melbourne have secured a number of large projects specifically related to prefabricated construction that are expected to significantly contribute towards the transformation of the construction industry.

This research hub also draws upon strong research networks with other academic institutions and industry partners throughout Australia and abroad. New and innovative materials as well as advanced structural systems are central themes to the prefab research platform. This edition showcases three papers from the work that is being conducted by the large research team based at the University of Melbourne.

The first paper considers the importance of proper design for the connection of elements to concrete members. Comprehensive guidance on fastening design is currently available via Standards Australia publications including *AS 3850.1* to cover lifting and assembly and *TS 101* to cover shallow fixings for permanent safety-critical fastenings. However, innovative material technologies are

PERFORMANCE OF MULTI-STOREY PREFABRICATED MODULAR BUILDINGS WITH INFILL CONCRETE WALLS SUBJECTED TO EARTHQUAKE LOADS

THARAKA GUNAWARDENA[1], TUAN NGO[1], PRIYAN MENDIS[1], SHAN KUMAR[2]
[1]DEPARTMENT OF INFRASTRUCTURE ENGINEERING, THE UNIVERSITY OF MELBOURNE
[2]INNOVATION AND R&D, HICKORY BUILDING SYSTEMS

1.0 INTRODUCTION

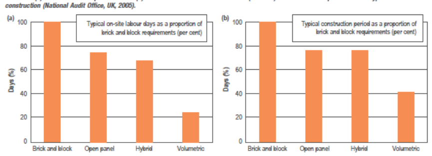


FIGURE 1: (a) On-site labour requirement and (b) construction duration of volumetric (modular) construction compared to other types of construction (National Audit Office, UK, 2005).

CHARACTERISATION TESTS AND DESIGN OF FOAM CONCRETE FOR PREFABRICATED MODULAR CONSTRUCTION

TUAN NGO[1], AILAR HAJIMOHAMMADI[1], JAY SANJAYAN[2], PRIYAN MENDIS[1]
[1]DEPARTMENT OF INFRASTRUCTURE ENGINEERING, UNIVERSITY OF MELBOURNE, VICTORIA 3010, AUSTRALIA
[2]FACULTY OF SCIENCE, ENGINEERING AND TECHNOLOGY, SWINBURNE UNIVERSITY OF TECHNOLOGY, VICTORIA 3122, AUSTRALIA

1.0 INTRODUCTION

FIGURE 1: SIP with two hard shells that sandwich a lightweight foam core.

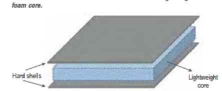
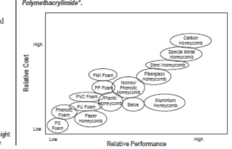


FIGURE 2: Cost versus performance of some lightweight core materials in SIPs, PS: Polystyrene, PU: Polyurethane, PP: Polypropylene, PMI: Polymethacrylimide.



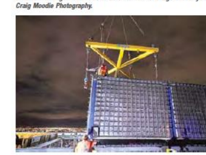
DESIGN OF FASTENINGS TO CONCRETE FOR PREFABRICATED CONSTRUCTION

DAVID HEATH, TUAN NGO, PRIYAN MENDIS, UNIVERSITY OF MELBOURNE, VICTORIA AUSTRALIA

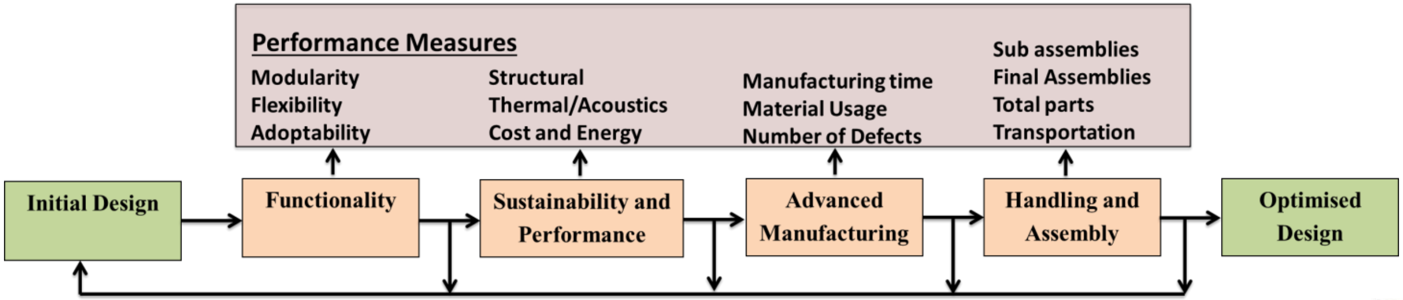
1.0 INTRODUCTION

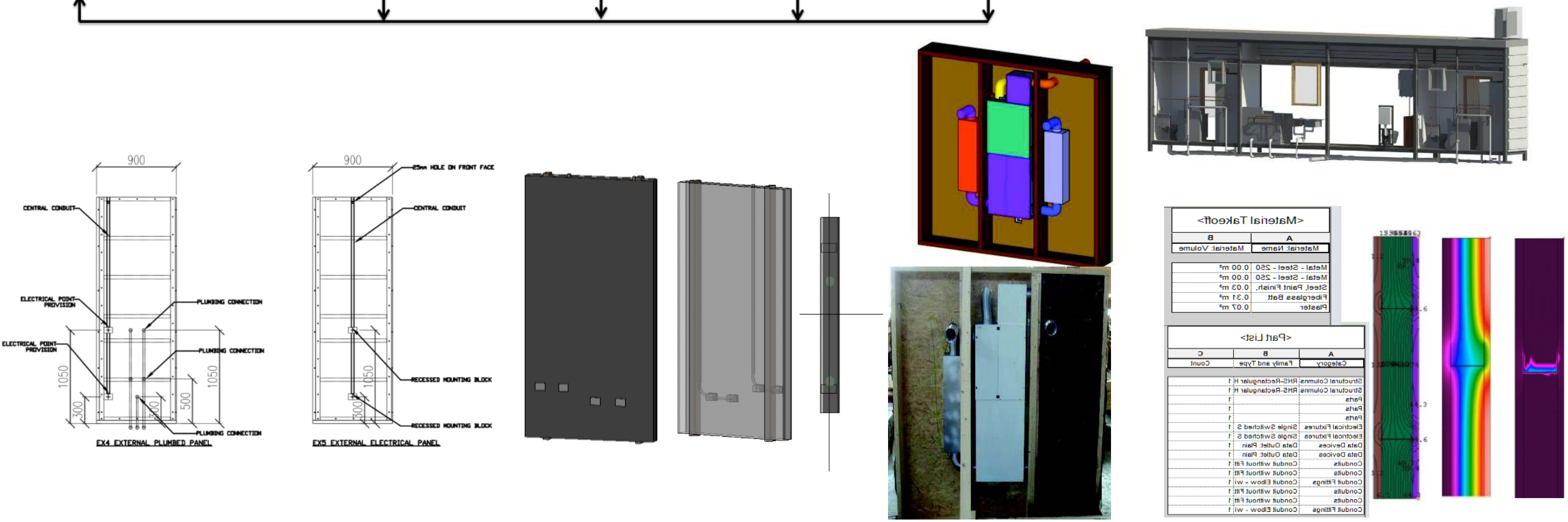
1.1 CONSIDERATIONS FOR PREFABRICATED CONCRETE CONSTRUCTION

FIGURE 1: Module being craned into place prior to application of shotcrete during the erection of La Trobe Tower. Image courtesy of Craig Moodie Photography.



Design for Manufacture and Assembly process developed by ARC CAMPH





BIM & Prefab Process developed by ARC CAMPH