

# Modular Tall Buildings



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# The University of Melbourne



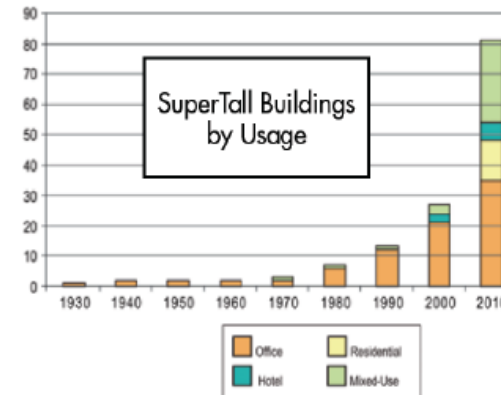
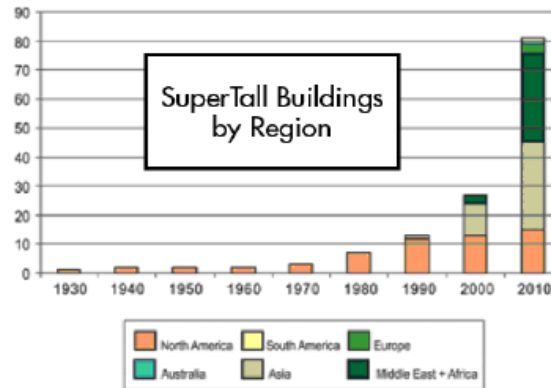


# Some Facts

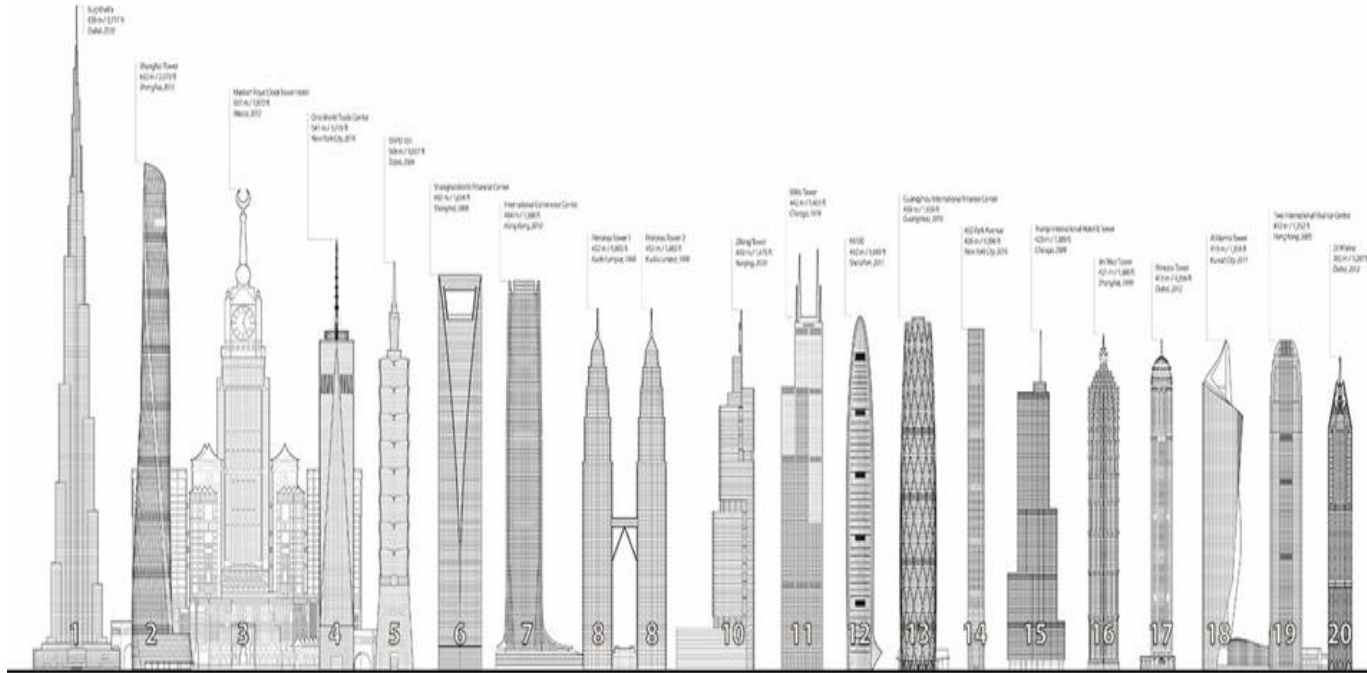
- Number 1 Ranked University in Australia.  
Founded in 1853
- 18 Faculties and Schools
- 8500 + Staff
- 50000+ Students (around 35% International Students)

# 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

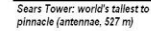






© Council on Tall Buildings and Urban Habitat

© Damien Koh 2006



Taipei 101: world's tallest to roof and highest occupied floor. (roof 449 m)



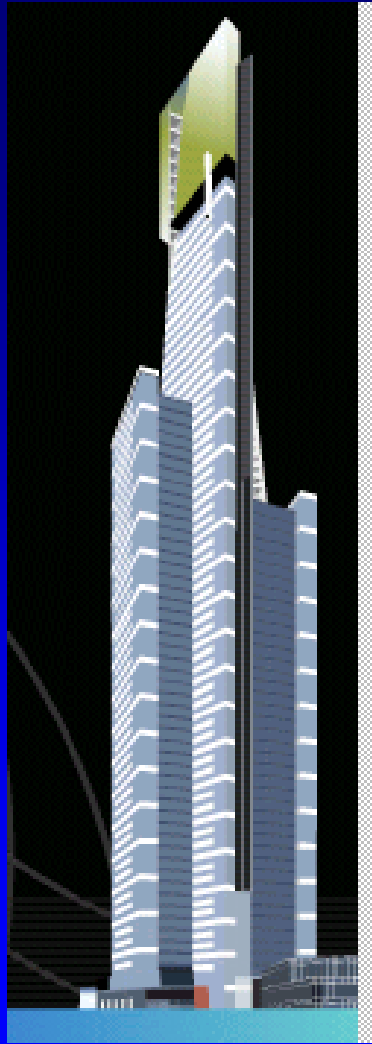
## Hong Kong 1990s



## 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





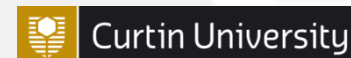
# ARC Training Centre for Advanced Manufacturing of Prefabricated Housing



# Centre overview



THE UNIVERSITY OF  
SYDNEY



PREBUILT.

Fleetwood

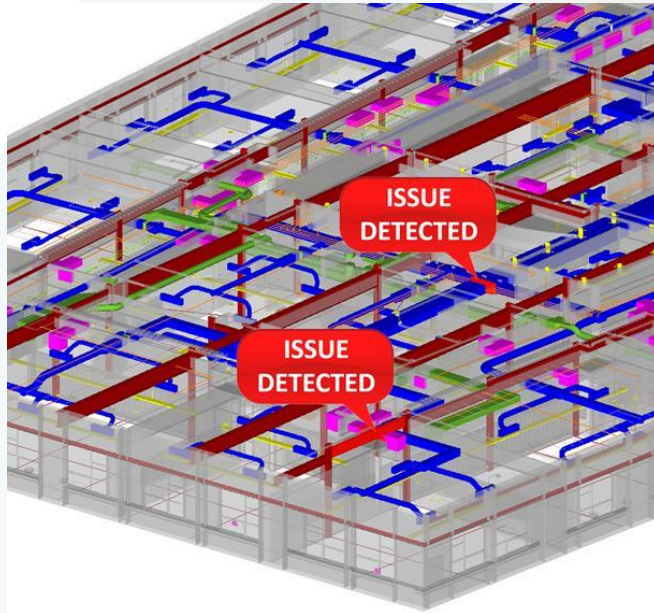






# Four research programs

## Program 1: Innovation in Design for Manufacturing and Assembly



**DfMA**  
**BIM for prefab**

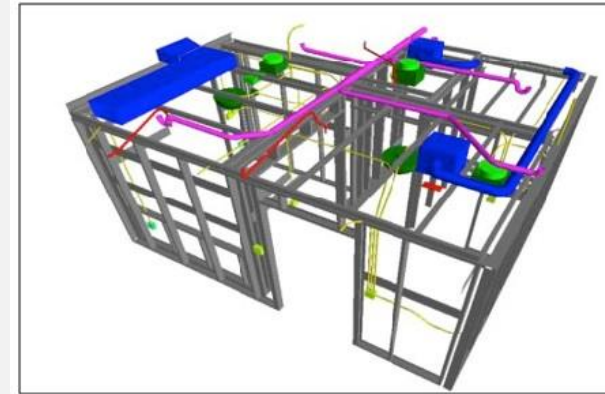
Standardise



Modularise



Mass Customise



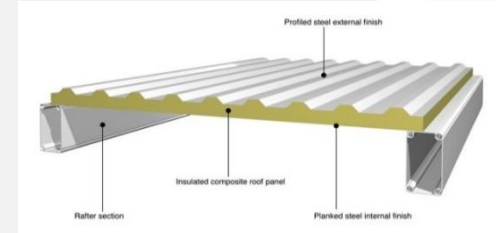


# Four research programs

## Program 2: Advanced building systems and assembly techniques

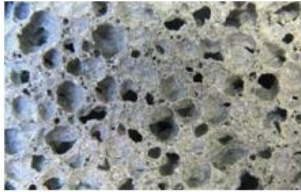
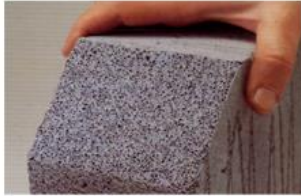


Lightweight Floor Systems  
Framing Systems  
Panel Systems  
Smart MEP Systems  
Connections



# Four research programs

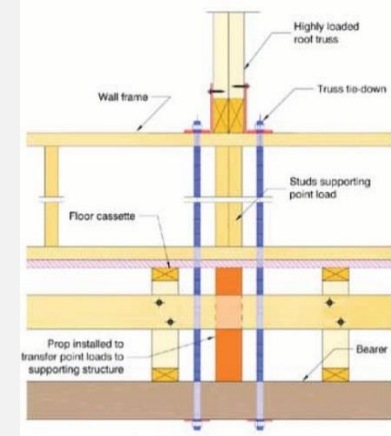
## Program 3: High performance materials



Lightweight

Fire resistant

Affordable



High Strength

Durable

Environmental friendly



## 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



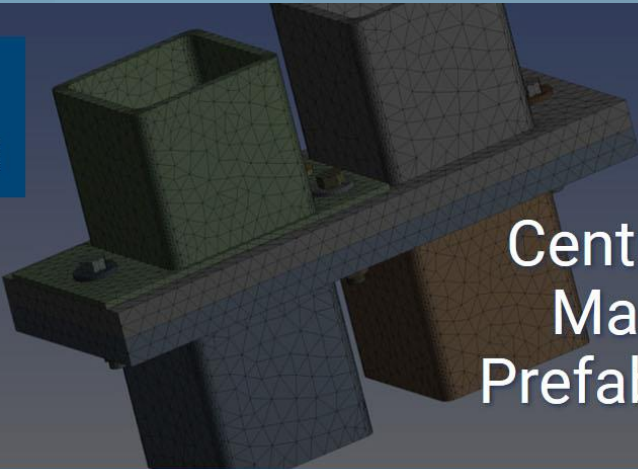
VS



NEW







# Centre for Advanced Manufacturing of Prefabricated Housing

ABOUT THE CENTRE

PARTNERS

RESEARCH

PEOPLE

NEWS AND EVENTS



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

[camph.eng.unimelb.edu.au](http://camph.eng.unimelb.edu.au)



# Prefabricated Homes





**PREBUILT.**

Merrick's Custom Designed House



**PREBUILT.**

Merricks Custom Designed  
House







Retail Facilities





**PREBUILD**  
Stockland The Grove Display Suite



**PREBUILT.**

Stockland Cloverton Display Suite







A modern, single-story building with a glass curtain wall and a flat roof. The building is elevated on a white base. The rooftop terrace is visible, featuring glass railings, white metal tables, and patio heaters. Two people are standing on the terrace. The building is surrounded by a green lawn and a landscaped area with dark mulch and green plants. A large tree is on the left side of the image. The sky is a mix of blue and orange, suggesting sunset or sunrise.

**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

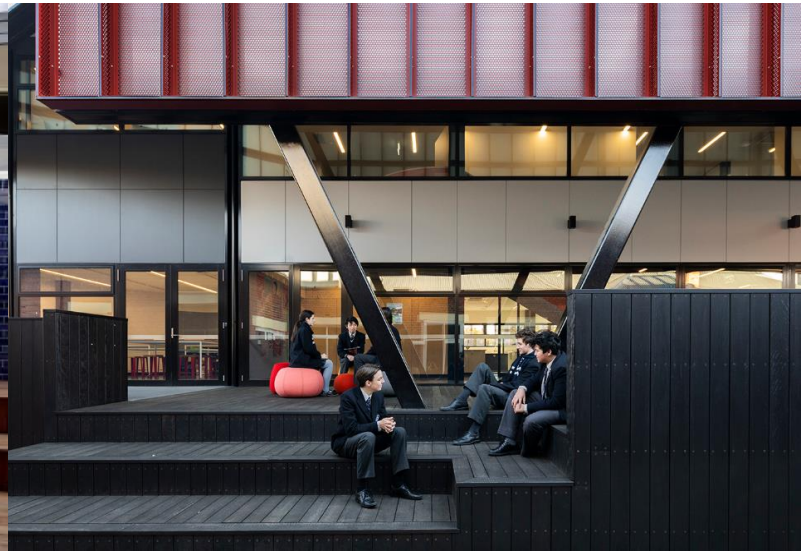


# Schools

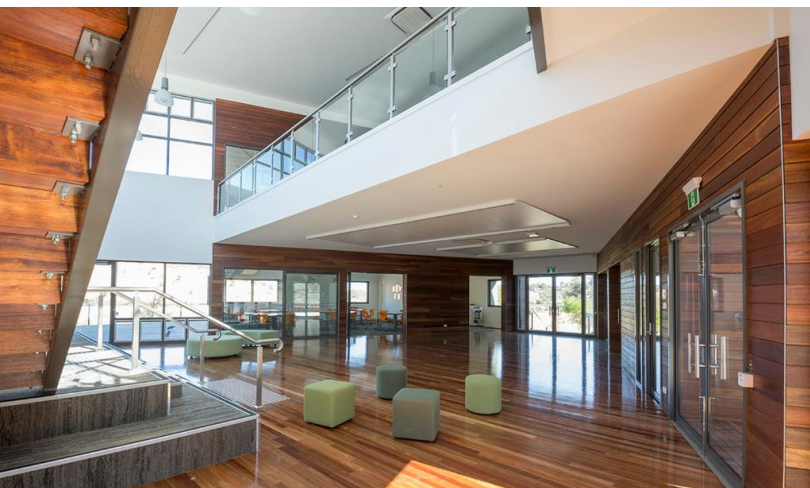




# Schools



# Schools





# Taking Measurements of IEQ Assessment (CO<sub>2</sub>, RH, Temp)

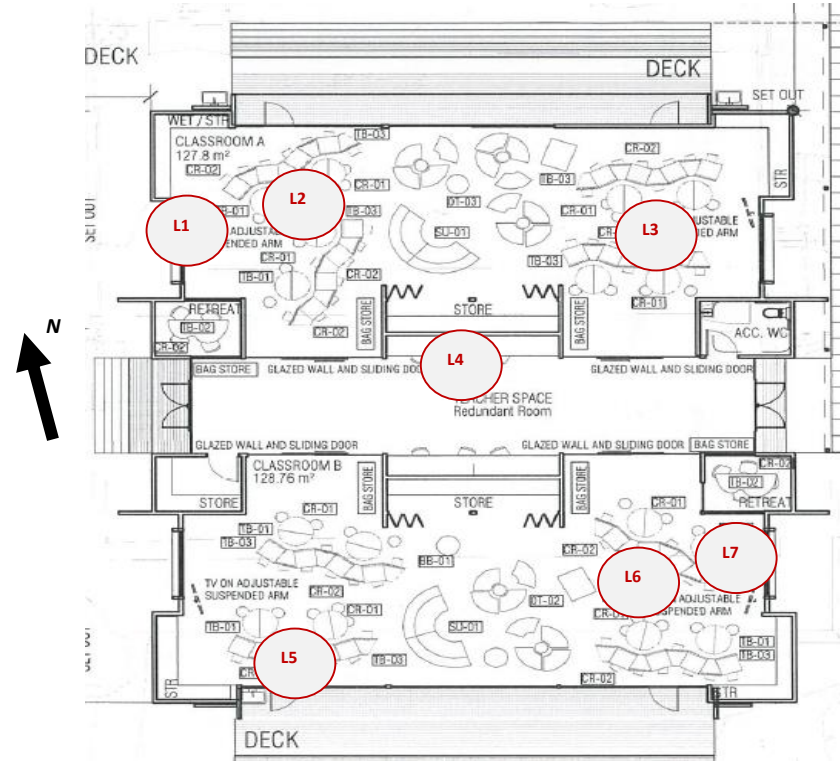
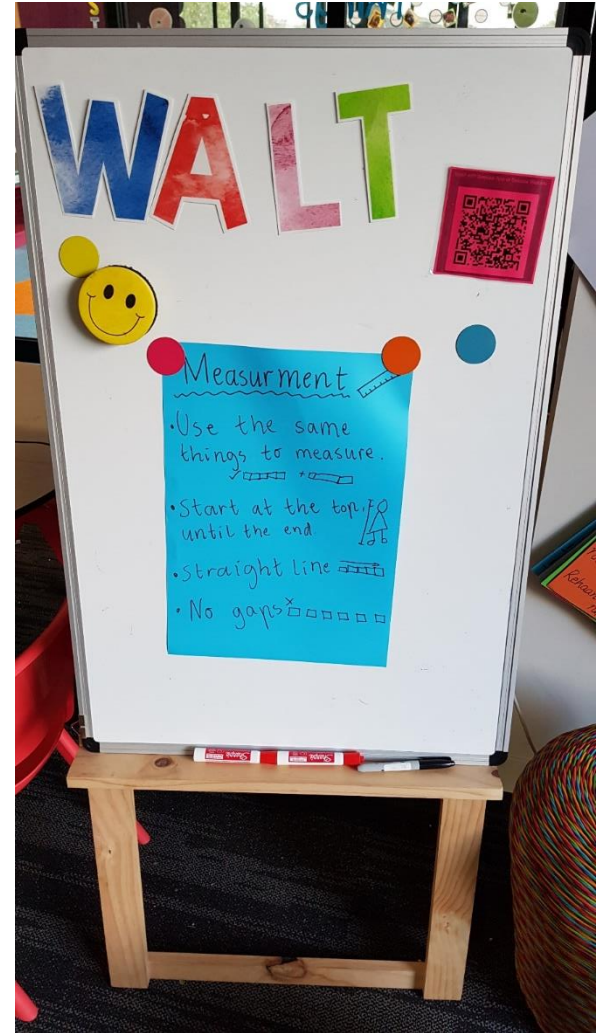


Figure 2: The seven measuring locations (L1 to L7) marked on plan

# Schools





# Railway Stations







# Healthcare



Hospitals built with modular technology in India





## Other Public Facilities – Police Stations



# Modular Correctional Facilities / Prisons





# Post-disaster Reconstruction



## Case study: from early beginnings...



Little Hero | Fender Katsalidis

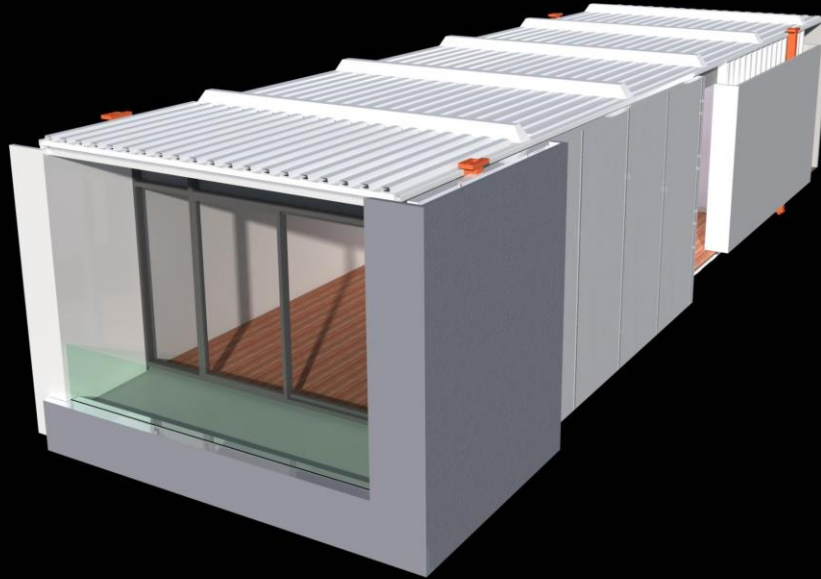
- 'Little Hero' in Melbourne, Australia
- 58 single-storey apartment modules
- 5 double-storey apartment modules
- The 8 modular stories assembled on site in just 8 days







# 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



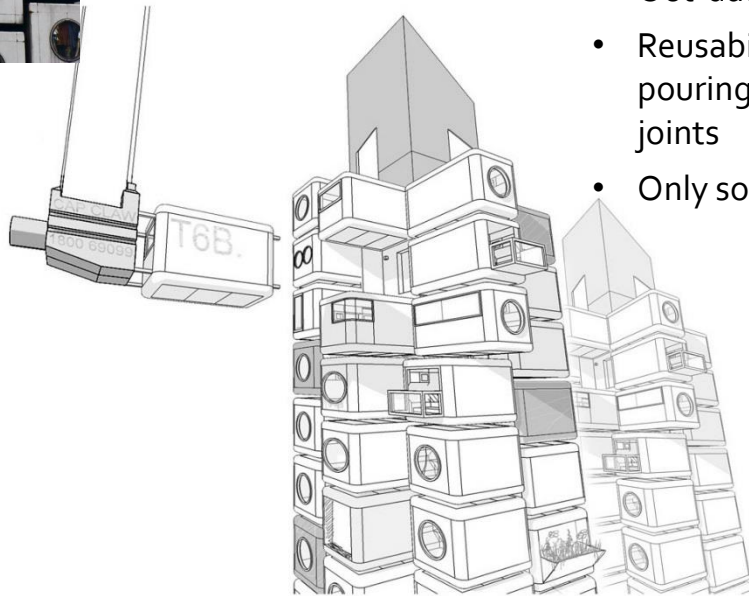
Cast in-situ concrete core



Floors being casted with in-situ concrete



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



Example – Modular gone wrong –  
Nagakin Capsule Hotel

Tokyo, Japan

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

# General Design Requirements for Modular Buildings

## Conceptual Design Formulation

Usage

Importance

Loading

Materials

Arrangement and sizing of structural members

Logistics

Transportation

Lifting

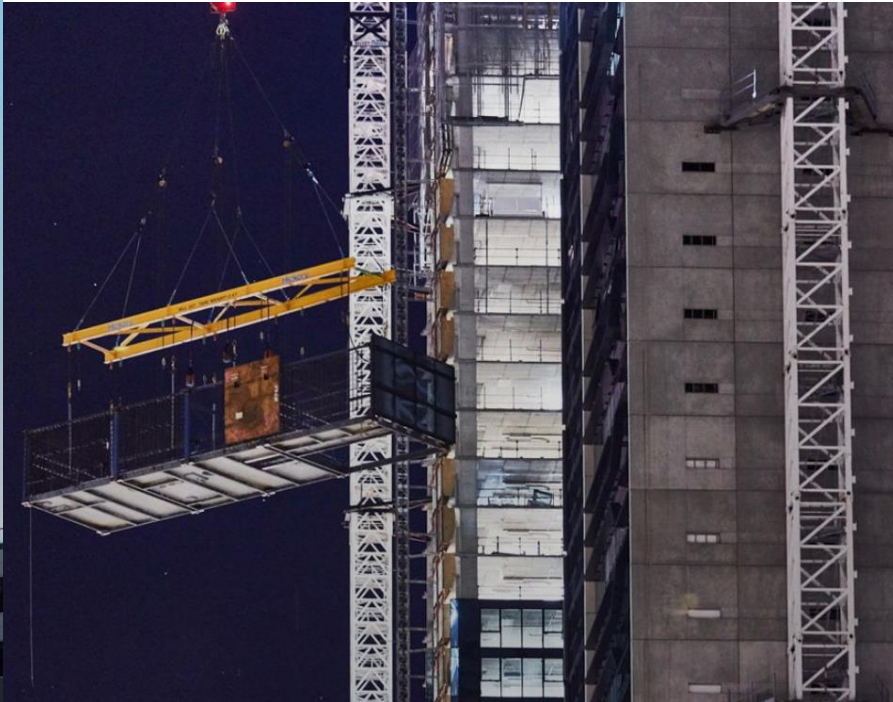
Fabrication Process

Assembly Process



# MODULAR HIGH RISES

Latrobe Tower, Melbourne



# Latrobe Tower – Melbourne, Australia

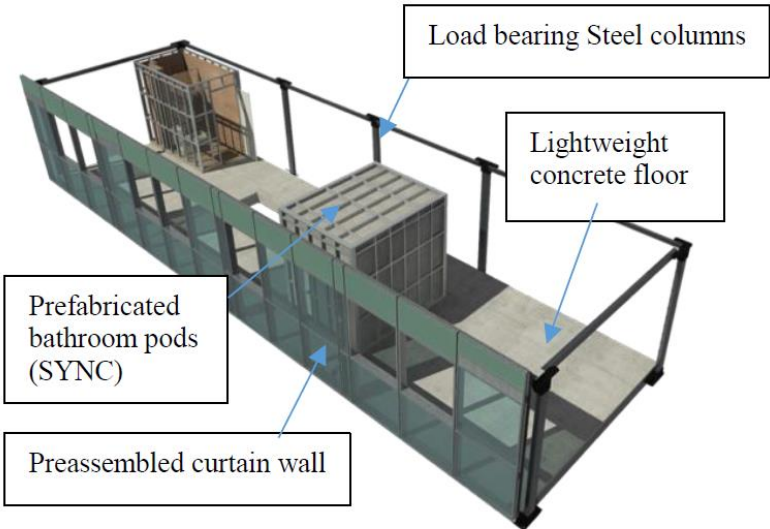
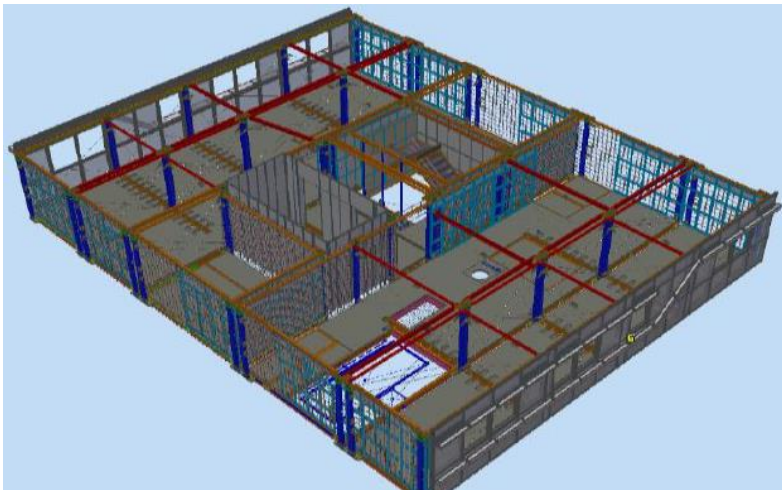
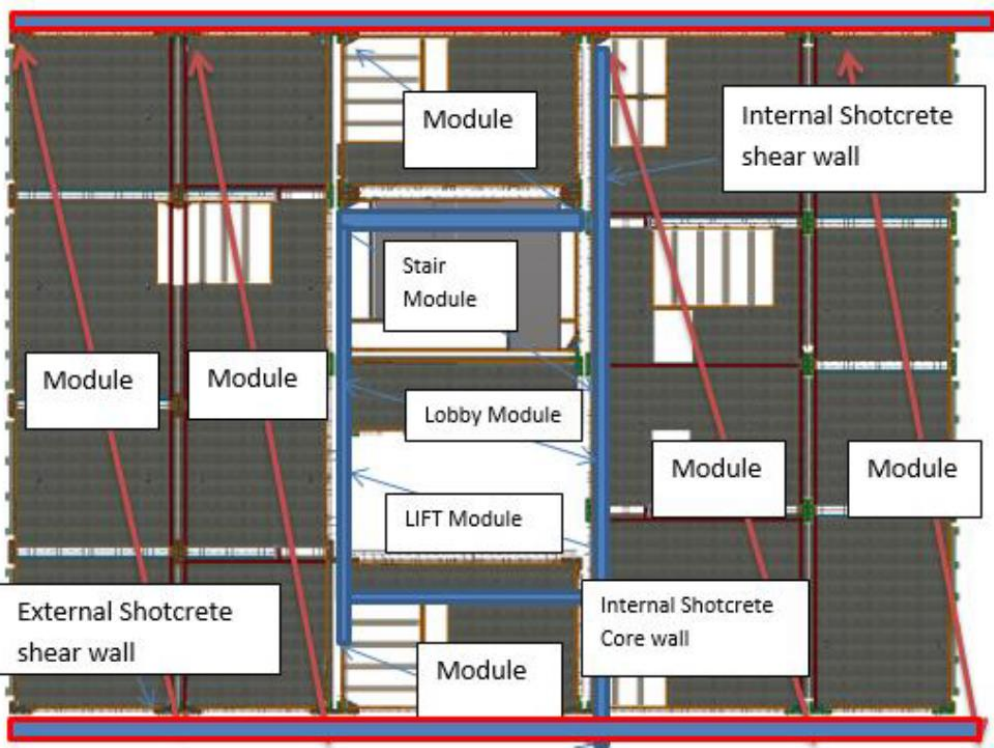
## Hickory Group

- 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

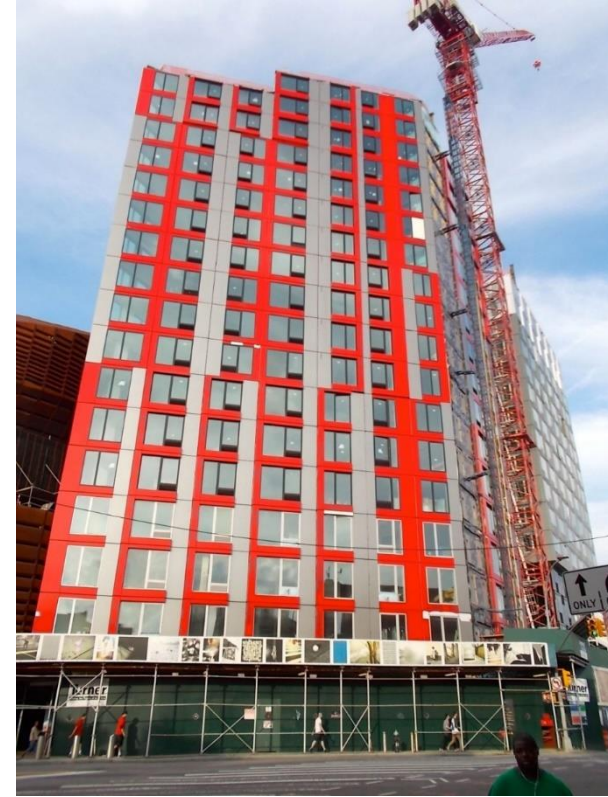
Student Apartments, UK



Public Housing Project, UK



B2 Apartments, USA





# MODULAR HIGH RISES

Collins House, Melbourne





## 461 Dean Street New York





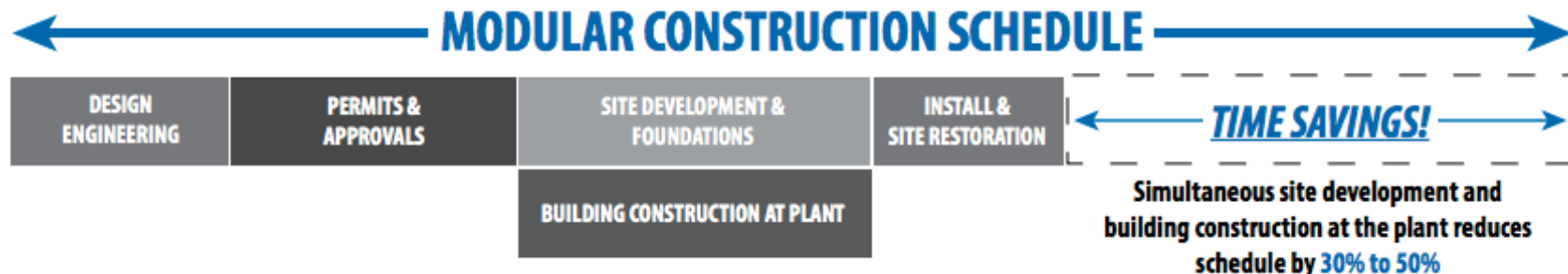


Mini Sky City in Changsha

## Typical traditional project schedule



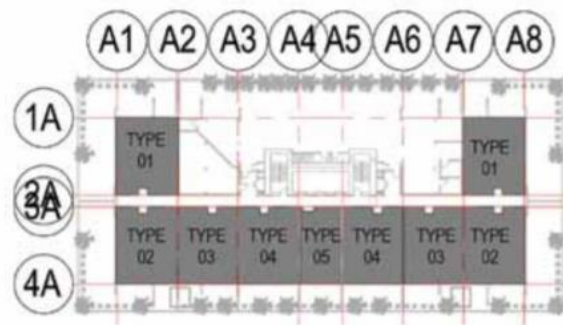
## Typical modular project schedule





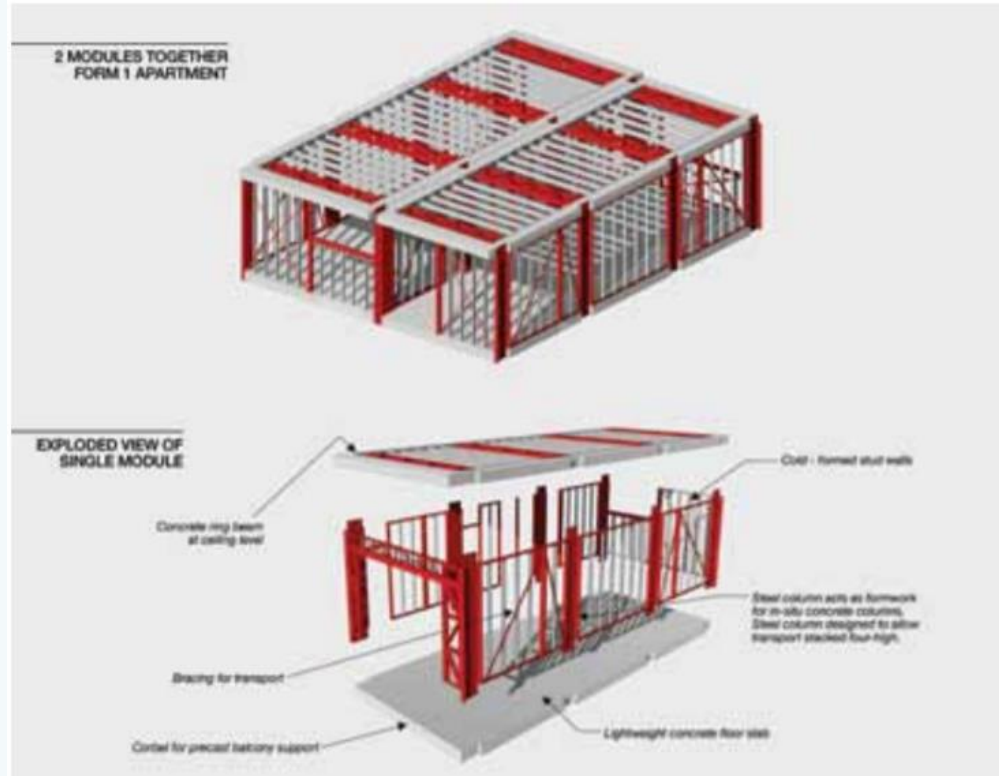
Customisation  
Scalability  
Fabrication  
for construction  
**Challenges**  
Perception  
awareness  
Testing facilities  
Market size

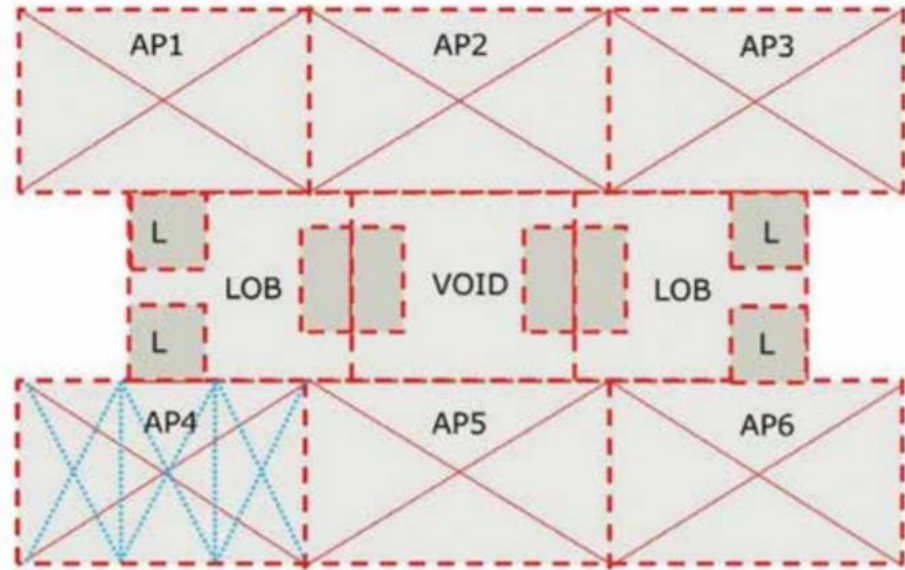
SOHO Tower  
Darwin



LEVEL 6 KEY PLAN







- ..... Rough Scaling – 7m x 4m modules
- Planar bracing or diaphragm action required to transmit lateral loads back to the cores

Figure 14. Prototype module (Source: Ramboll Group)



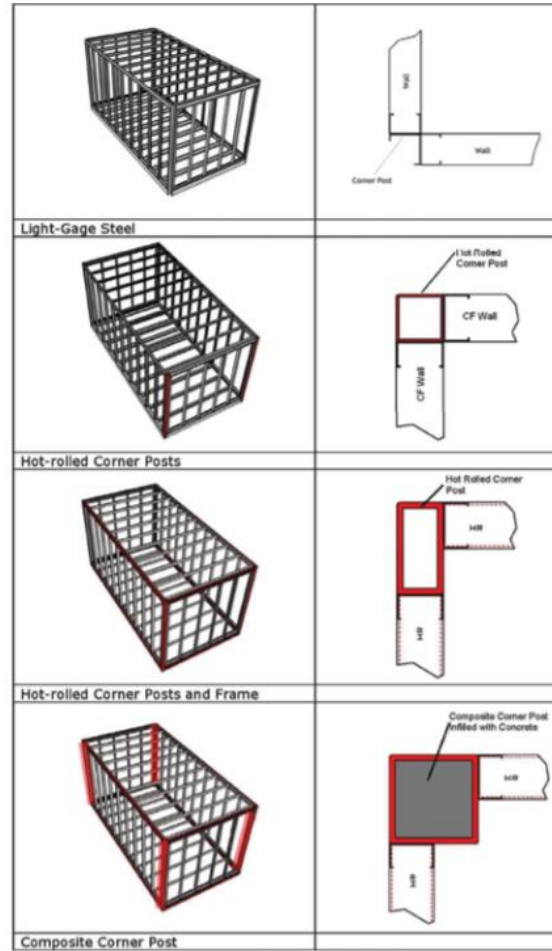


Figure 4. Modular chassis types (Source: Ramboll Group)

No	System	Chassis	Floor Construction	Max Height	Lifting Weight <sup>1</sup>
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





**PREBUILT.**

RAAF East Sale Accommodation



**PREBUILT.**

RAAF East Sale Accommodation





PREBUILT.

PREBUILT.

RAAF East Sale Accommodation

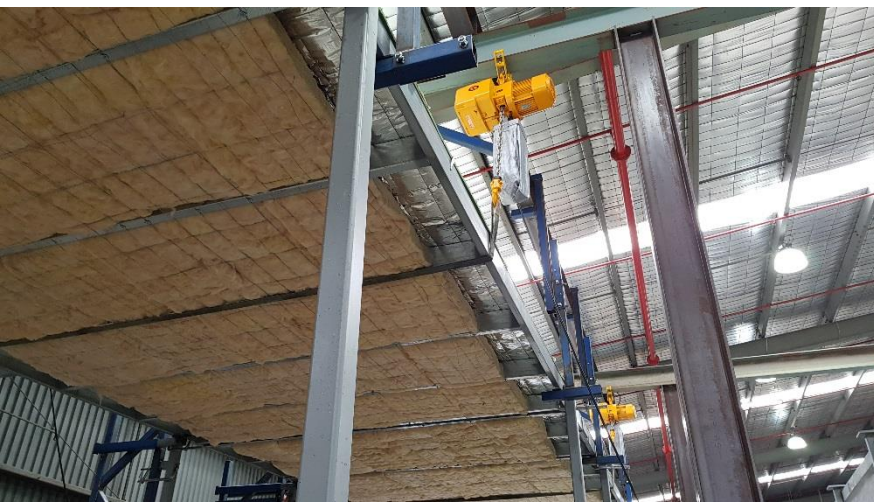


PREBUILT.

RAAF East Sale Accommodation







Factory Jig







# General Design Requirements for Modular Buildings

## Conceptual Design Formulation

Usage

Importance

Loading

Materials

Arrangement and sizing of structural members

Logistics

Transportation

Lifting

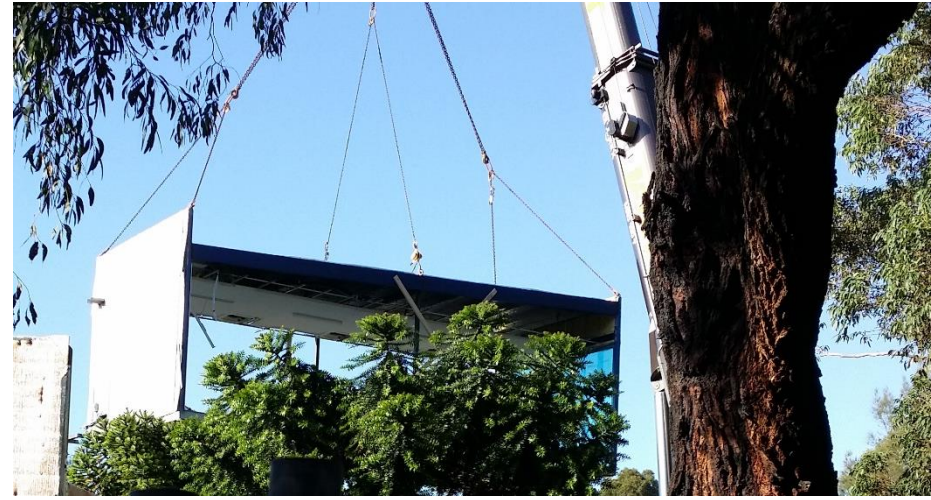
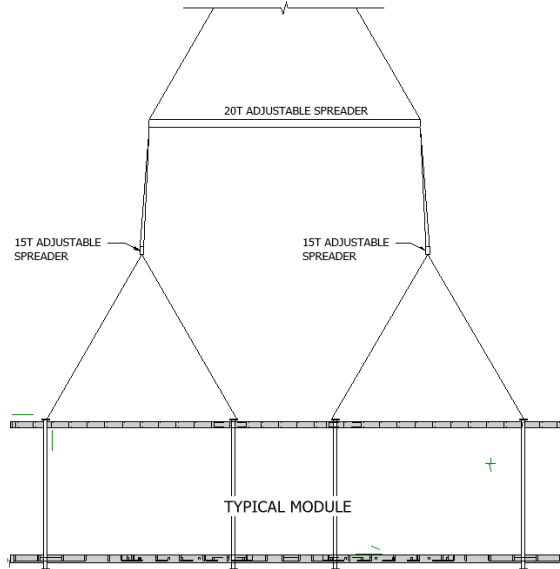
Fabrication Process

Assembly Process

# Design for Lifting – Lifting Strategy

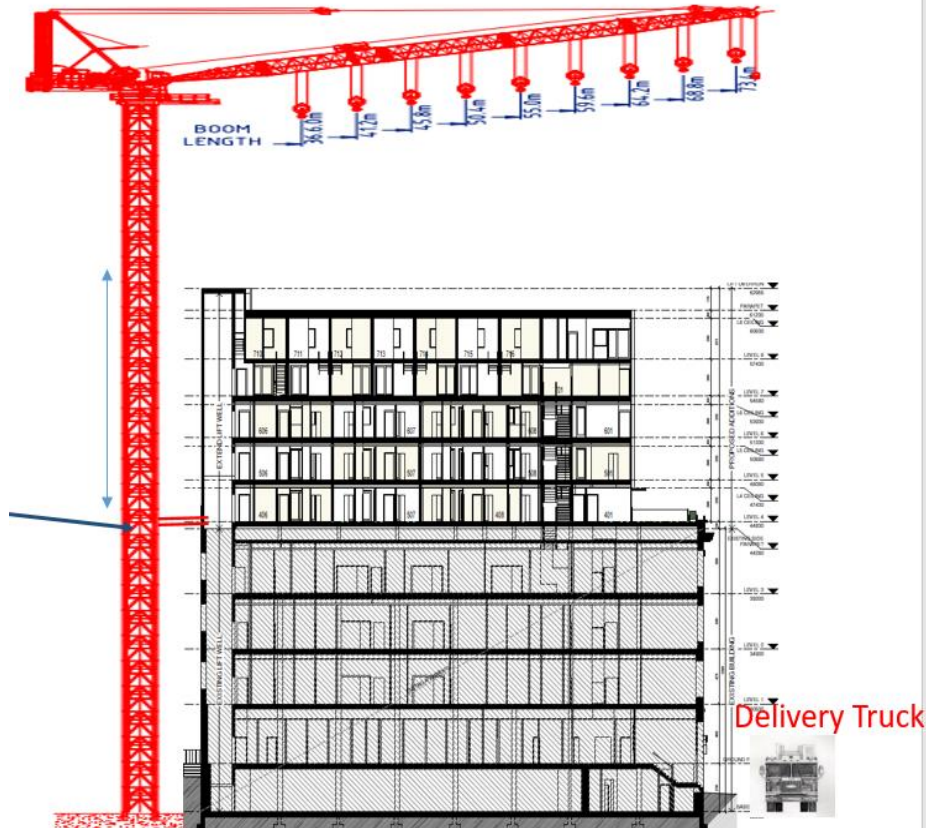
Methodology for lifting from the module

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





# Design for Lifting – Lifting Strategy



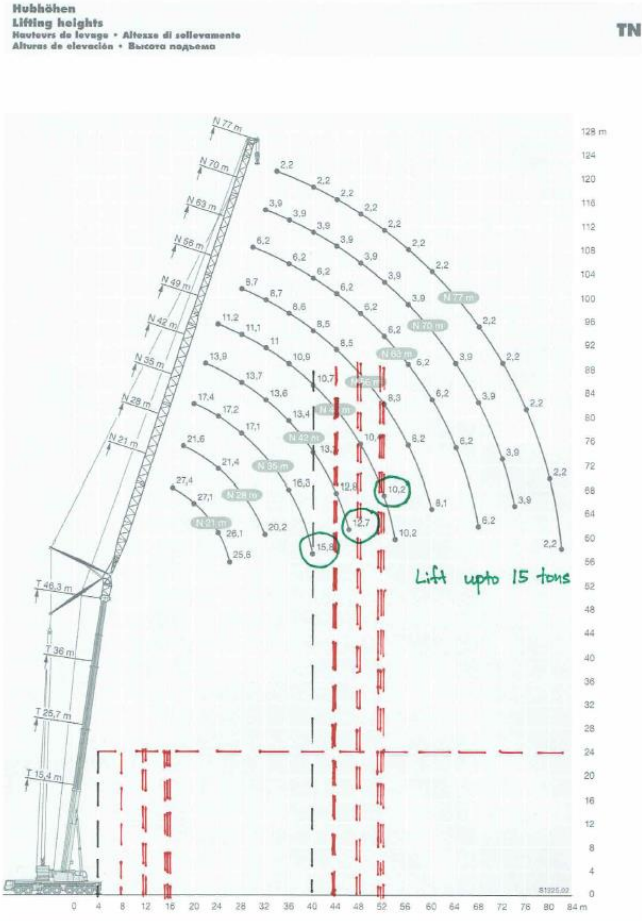
## Lifting With Tower Cranes

- 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

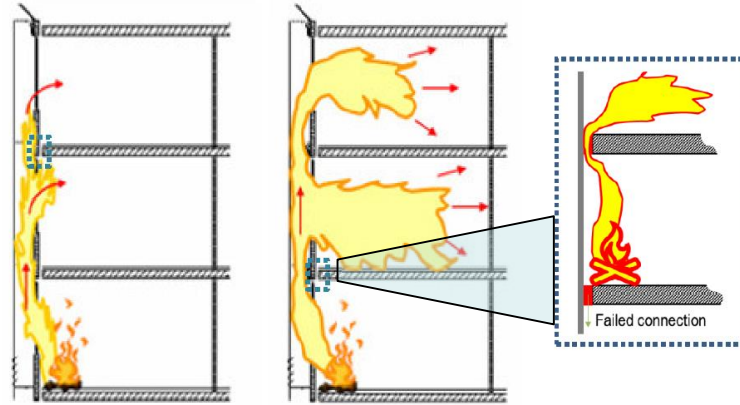
- Temporary bracing
- Temporary columns







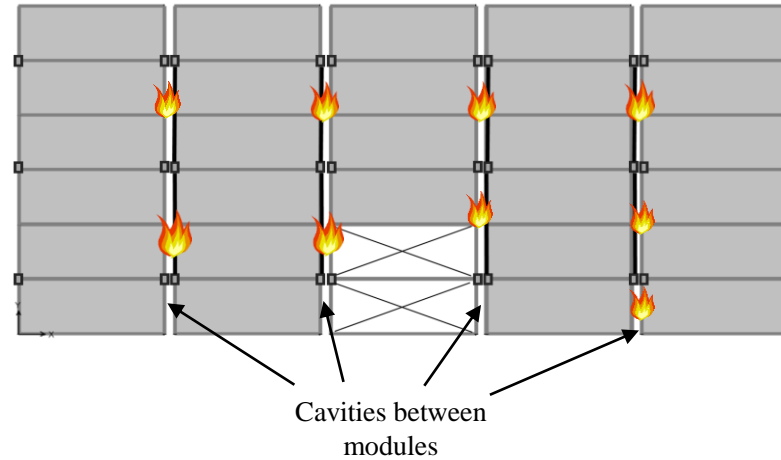
## Advantages of prefabrication for fire resistance



- 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.



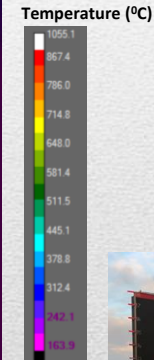
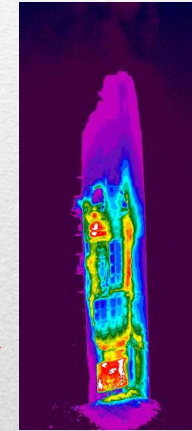
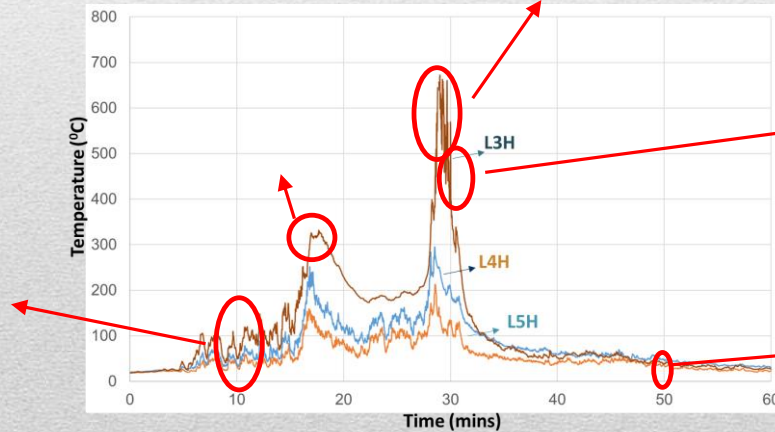
## Major Concern



- 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.

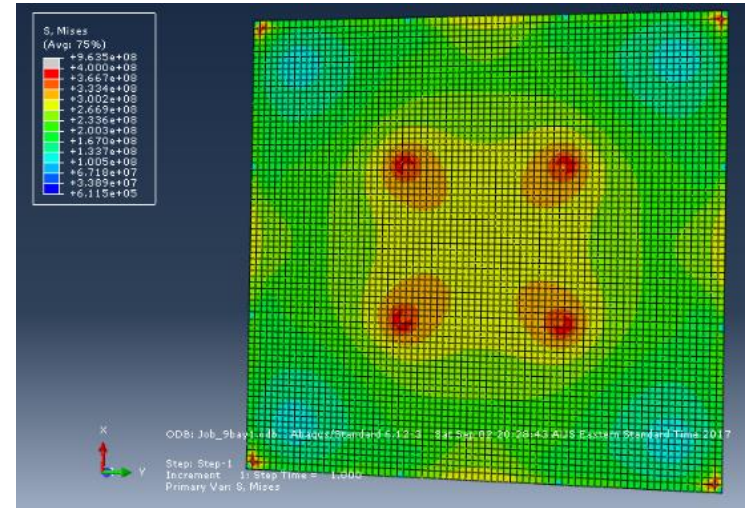
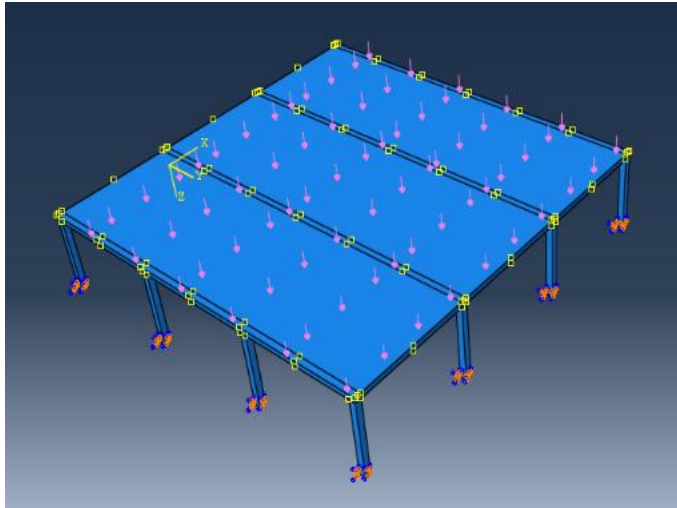
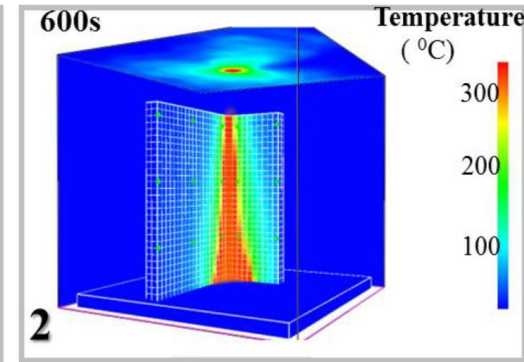
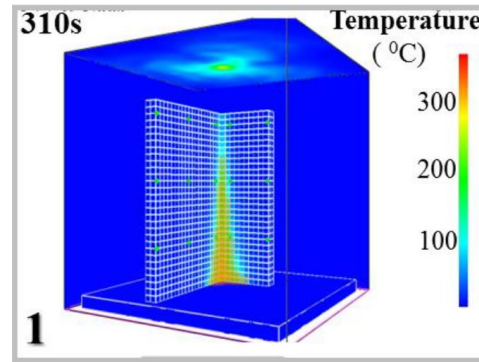


# Fire performance of façades





- 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

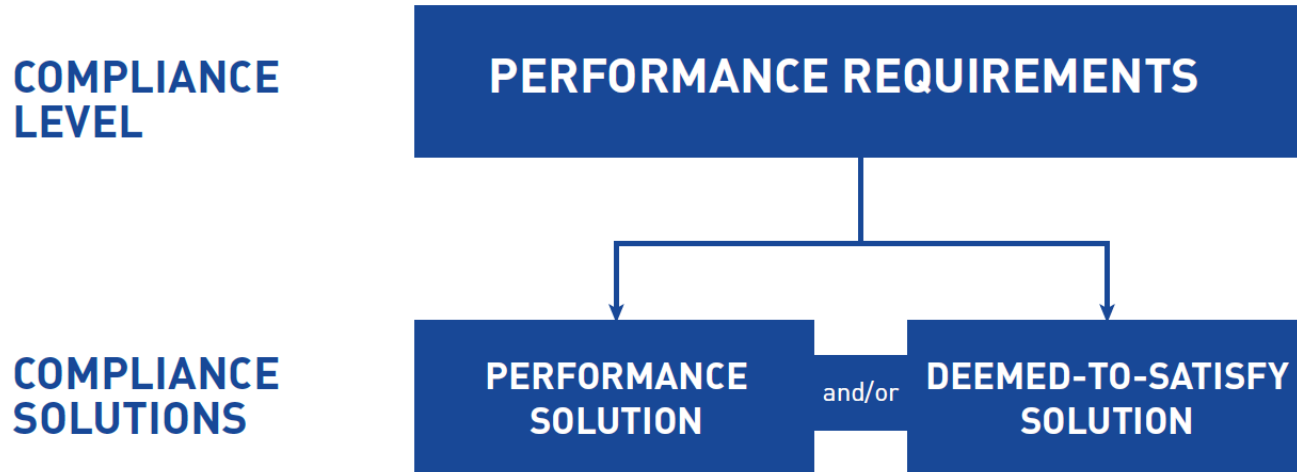


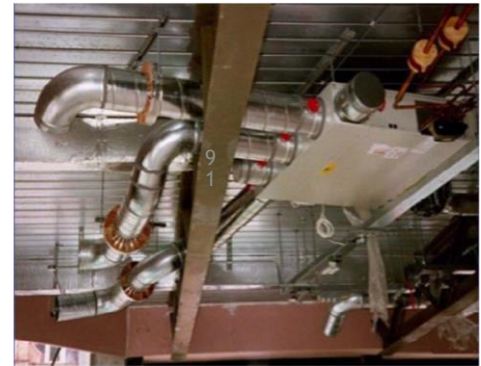
Figure: NCC Compliance Structure



## MECHANICAL & ELECTRICAL SYSTEMS



# FORMS OF MEP PREFABRICATION





## MODULAR MEP PROJECTS

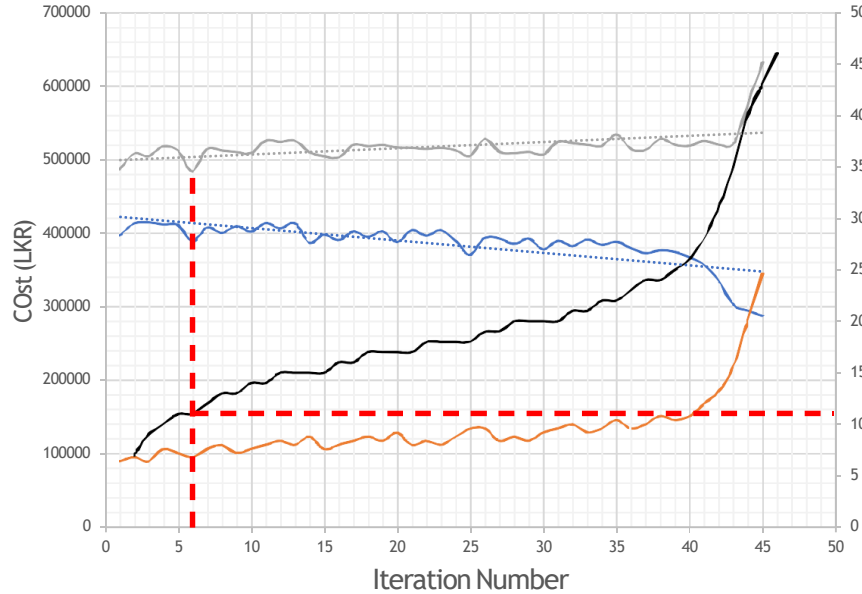


North Core and services integrated bench at The Leadenhall Building (Source: Davies 2013)

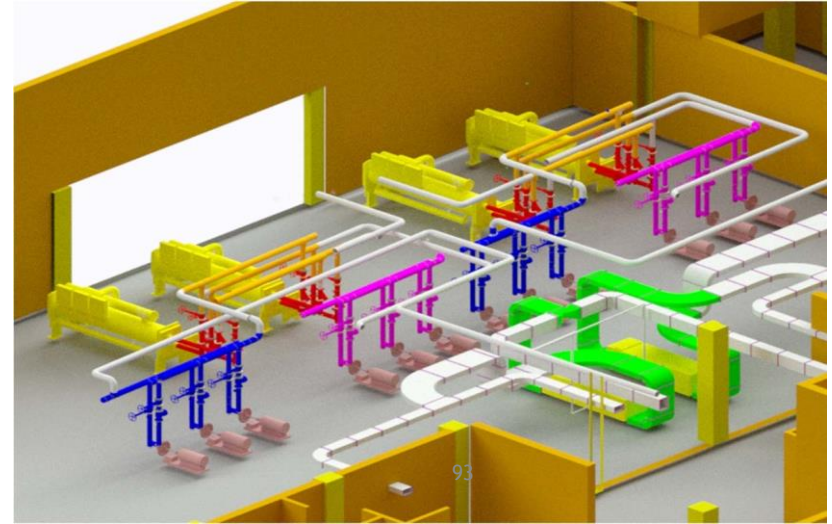


Modular Hotel Room Construction London (Image courtesy: Amoveo (Pty) Ltd.)

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



$m = 12$  (iteration 6)







## 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<sup>25</sup> 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)**

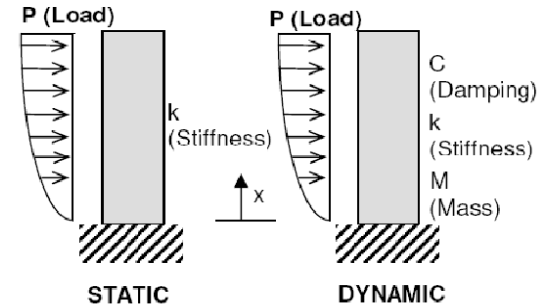
Samarasinghe, T., Mendis, P., Ngo, T., & Fernando, W. (2015). *BIM Software Framework for Prefabricated Construction: Case Study Demonstrating BIM Implementation on a Modular House*. Paper presented at the 6th International Conference On Structural Engineering And Construction Management. **(Published)**



# Wind Design



## Static vs Dynamic



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

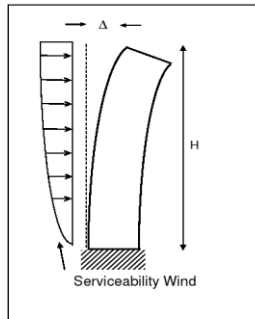
Where  $M$ ,  $C$ ,  $k$  are mass, damping and stiffness characteristics as a function of height.

# 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- $\Delta$  or secondary loading effects.

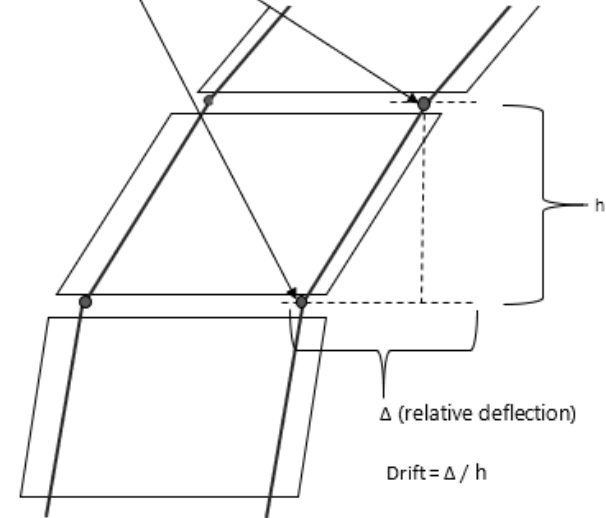
### Total Lateral Deflection



**TOTAL DEFLECTION**  
(Control for P-  $\Delta$   
effect)

$$H/\Delta < 500 \text{ to } 1000$$

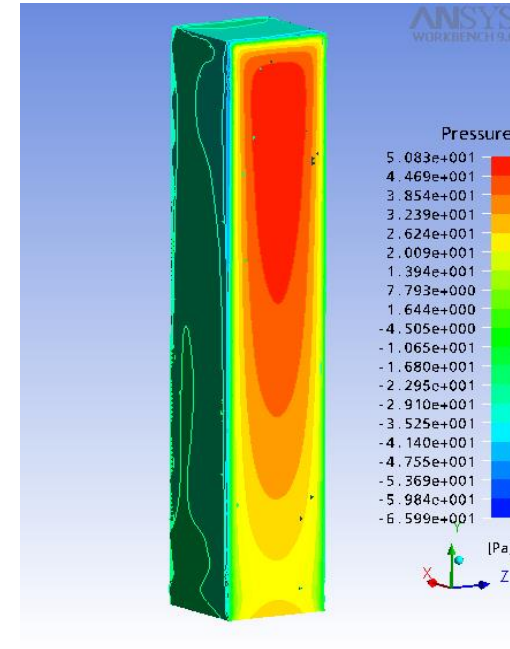
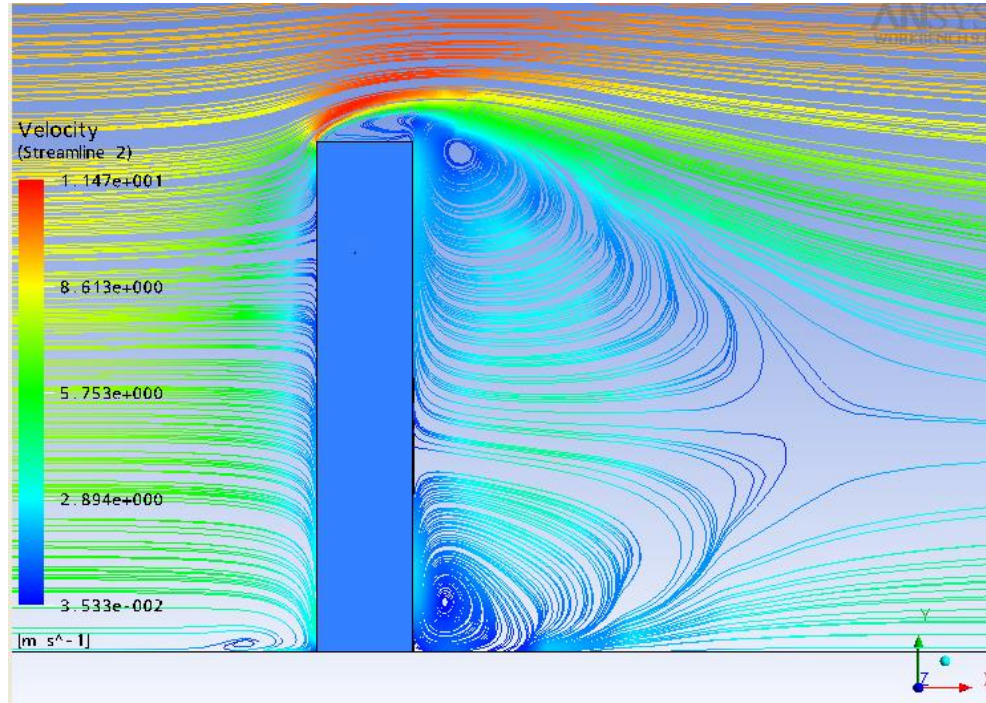
Module to module connections



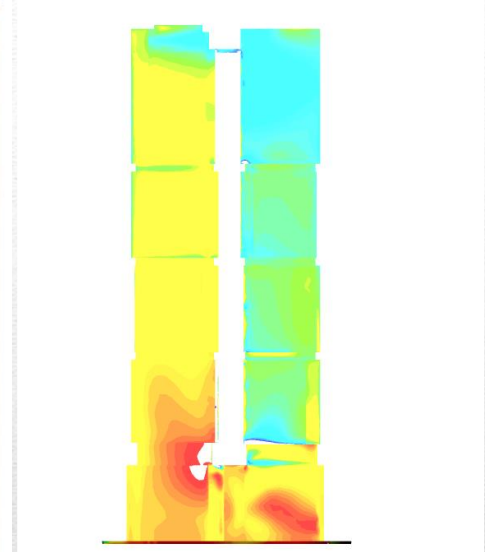


# Wind Design - CFD for Wind Analysis

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



## Capitol Twin Peaks Wind Tunnel Model

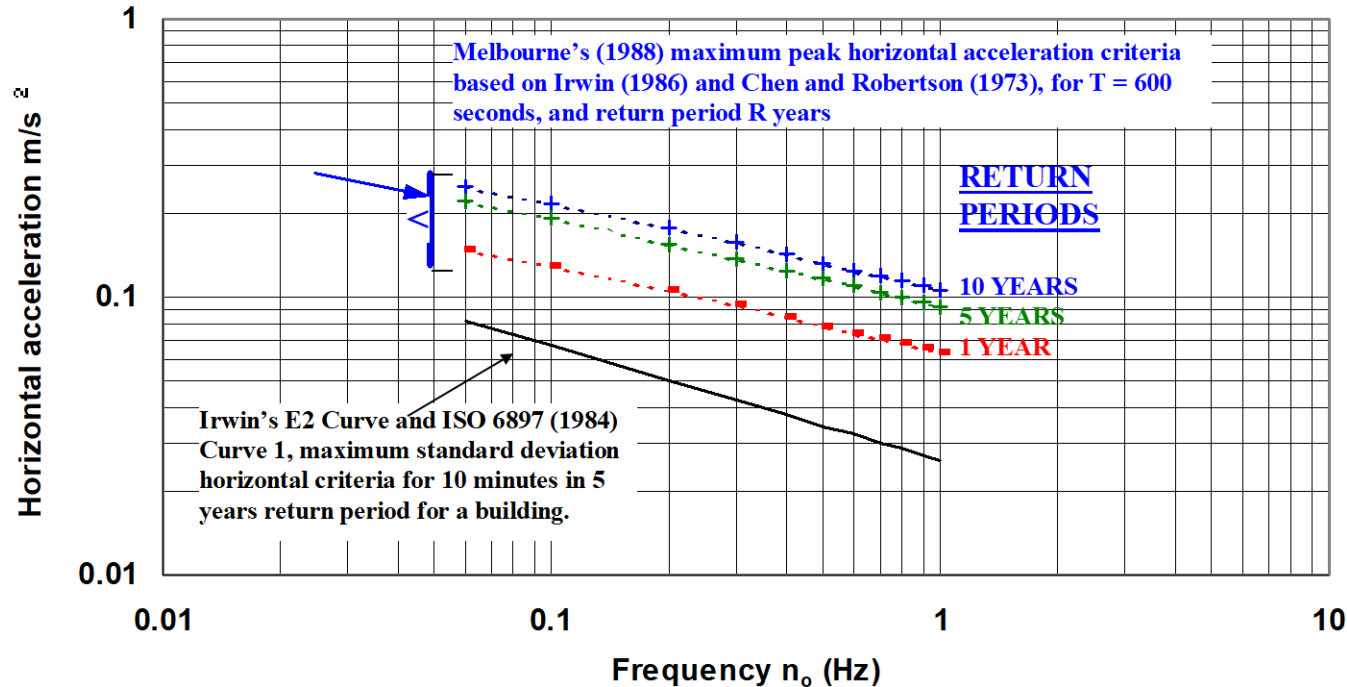


**CFD Model analysis  
by CSEC Sri Lanka**

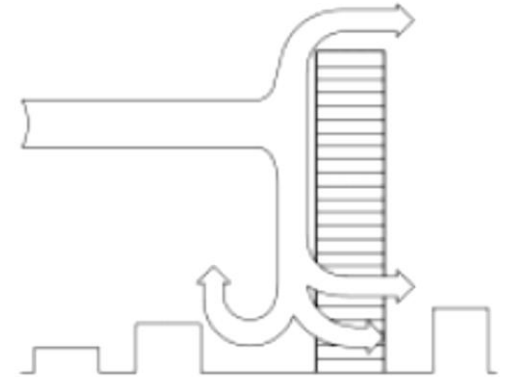
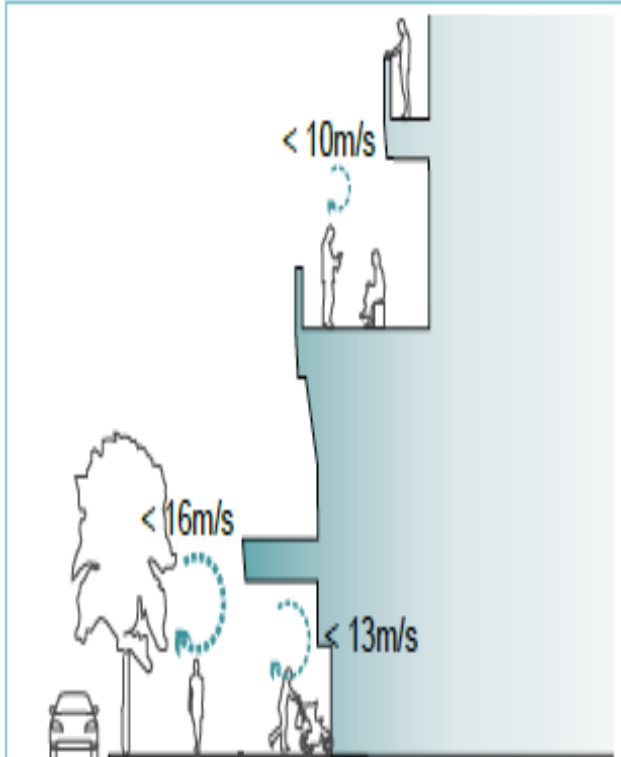


# Wind Design - Wind Accelerations (Ref: Mendis et al., EJSE, 2007)

Human perception of motion (Allowable accelerations)

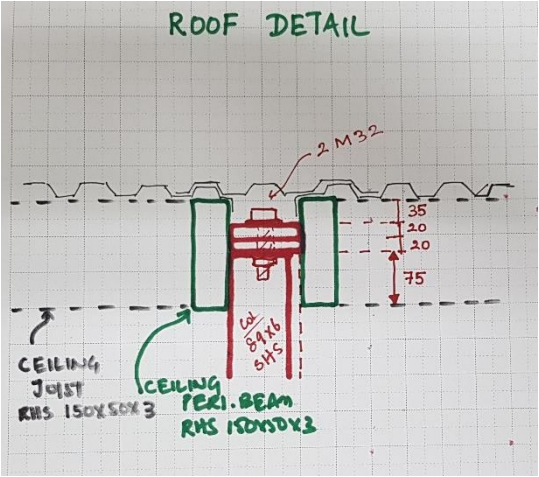
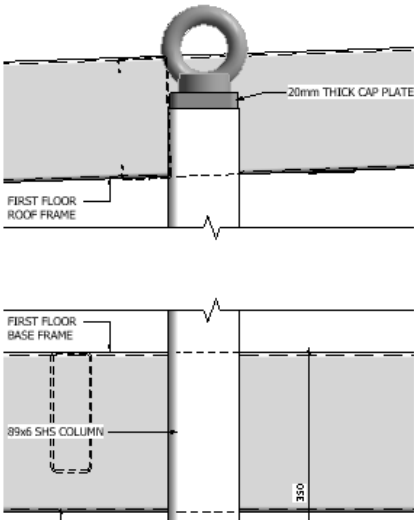


# Wind Design - Pedestrian Comfort





# Multi-purpose Systems



# Latest Research on Modular Construction

PREFABRICATED CONCRETE CONSTRUCTION — GUEST EDITORIAL

## 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 challenges including the fact that prefabrication 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 the 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 the 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 has also drawn 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 prefabricated 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 of the connection of elements to concrete members. Comprehensive guidance on fastening design is currently available via Standards Australia publications including AS 3550.1 to cover lifting and assembly and AS 3550.2 to cover shackle fittings for permanent safety-critical fastenings. However, innovative material technologies are

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

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INNOVATION AND R&D, VICORY BUILDING SYSTEMS

Prefabricated modules are increasingly becoming popular in the construction industry as they result in achieving cost-effective buildings in very short time. This increasing demand for modular construction has expanded to multi-story applications, where the effect of lateral loads, such as earthquake loads, becomes critical. However, there is a shortage of detailed engineering research on the performance of modular structural systems subjected to earthquake loads. This paper evaluates a modified center supported modular structural system that was rigid concrete walls to enhance its lateral stiffness. The performance of the overall structural system against earthquake loads and the contribution of modular concrete infill concrete walls to the overall lateral load resisting system is discussed in this paper.

### 1.0 INTRODUCTION

Prefabrication and modularization have both featured in building construction for many years in various forms. Examples of such forms are dry wall systems, structural insulated panels (SIPs), roof trusses, precast beams, other cages, modularized furniture, modularized plumbing systems etc. The demand for achieving short building construction times while continuing to improve the quality of the final product is a critical performance criterion in the Architectural, Engineering and Construction (AEC) industry. The concept of prefabricated modular structures has gained popularity in recent times as an effective solution to the aforementioned AEC performance criterion.

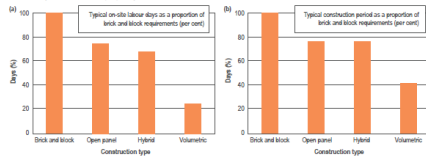
A modular building is, by definition, an entire building that is assembled on-site from self-contained modular units that are complete with services and finished, and are mass-produced in a factory prior to being transported to the site. Most manufacturers will nowadays cater for any type of architectural design with modules of innovative geometry and finished interior systems. These building modules are mass produced in factories such that the significant labor force which would have otherwise been required at a conventional building site is replaced with specialist workmanship and automated manufacturing in a production facility.

As more innovative and unconventional designs are generated through modern architecture, prefabricated modules with different shapes and sizes will be increasing in demand. A building designer is free to lay out a building in the conventional manner to suit clients and the market requirements. The building would then be adjusted and divided into units by a width and length that is suitable for transportation and lifting by a crane on site.

Figure 1 highlights the two main benefits of volumetric (modular) construction in the form of reduced labor and reduced construction time compared to other conventional and modern methods of construction. Some of the other benefits and features of prefabricated construction are listed as follows:

- The modules can incorporate all components of a building including stairs, lift shafts, facilities, and services.
- The modules are mass produced in a quality controlled production facility. A unit's length, width and height may vary from project to project.
- There is minimal work on site to complete the building as the facade and interiors themselves form parts of modules. This enables the construction process to become a more process-oriented manufacturing and assembly process, resulting in building sites with less congestion and pollution.

FIGURE 1: (a) On-site labor requirement and (b) construction duration of volumetric (modular) construction compared to other types of construction (Based on Oke, 1998).



Concrete in Australia | Vol 43 No 5 |

PERFORMANCE OF PREFABRICATED MODULAR BUILDINGS

## CHARACTERISATION TESTS AND DESIGN OF FOAM CONCRETE FOR PREFABRICATED MODULAR CONSTRUCTION

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Circular concrete or foam concrete has been recently utilized for prefabricated modular construction. The application of high-pore concrete in prefabricated modules brings some advantages to the construction industry, such as improving the fire resistance, thermal and acoustic insulation properties, construction efficiency and lowering efflorescence. In order to control the properties of foam concrete and predict their performance for various precast applications, it is necessary to understand and measure their characteristics. In this effort, some advances in concrete foam technology and their applications for prefabricated modular construction have been explored. With a combination of advanced characterization techniques, the properties of foam concrete can be examined for specific construction applications. Knowledge on effective techniques for manipulating the characteristics of foam concrete facilitates the application of novel materials and the development of high-performance prefabricated modules.

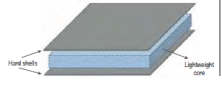
### 1.0 INTRODUCTION

Structural insulated panels (SIP) or insulated sandwich panels are usually three-layer panels that are made of two outer shells of high-strength materials with a lightweight, low-density core material separating them (Figure 1). SIPs are ideal for prefabricated construction. Forest Products Laboratory (FPL) introduced SIP in 1957 and the first commercial SIP was produced in 1957. This development spurred growing interest in developing and advancing SIPs in terms of improving their properties, reducing costs and exploiting environmentally friendly options.

In substituting a soft core between strong thin facers, the combined properties of the sandwich panel possess many advantages over in monolithic construction, such as high strength and toughness, rapid assembly from cost-effective and lightweight building materials, and so on. The lightweight nature of SIP panels is particularly attractive because this permits ease of handling and assembly. This special design of these panels facilitates a significant reduction in construction time, effective acoustic and thermal performance, utilization of recyclable materials, reduction of the maintenance cost of building and extension of their design life. The application of SIPs in construction can also improve housing affordability.

Carbon or glass fibre reinforced polymer composites (CFRP/GFRP) have been used from the mid 1980s as the stiff skin of SIPs, together with a lightweight and softer core typically made of polymeric foams such as PVC or PE. RFP sandwich panels have limited applications due to their relatively high cost. Steel shell sandwich panels with polymeric infill core was developed later to expand the application of SIPs by increasing the stiffness of the panels. However, the durability of the panels is decreased.

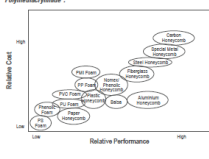
FIGURE 1: SIP with two hard shells that sandwich a lightweight foam core.



temperatures was still a concern in these panels. The core of SIPs is generally made of lightweight materials such as polystyrene foam (PS), expanded polystyrene (EPS) and polyurethane foam (PUF). EPS is still the most common core in the market and is widely used in Australia. One of the drawbacks of the polymeric core in SIPs is its susceptibility to elevated temperatures, as most of these foams are combustible. In the 1990s, while most SIPs were introduced, a ribbed metal structure (e.g. honeycomb) replaced the lightweight core, and the metal skins were welded to the core by laser welding technology. While the efficiency, consistency and accuracy of the SIP design were massively improved by this technique, the project resistance of SIP was still not suitable and they could be perforated. Various materials have been introduced to be used in SIPs (Figure 2). The honeycomb cores usually offered superior performance compared to foam cores but their price was also significantly higher, which limited their adoption in practice.

Concrete was later used in prefabricated modules as an alternative core material for SIPs with improved properties. Concrete has relatively low cost, high durability and a long service life, which makes it ideal for precast modular construction. Lightweight concrete has been used in the core of SIPs with PUF or metal skins (Figure 3) and

FIGURE 2: Core types performance of some lightweight core materials (Based on Oke, 1998). PS: Polystyrene, PE: Polyethylene, PUF: Polyurethane, RFB: Reinforced Fibre Board.



Concrete in Australia | Vol 43 No 5 | 43

DESIGN OF FASTENINGS

## DESIGN OF FASTENINGS TO CONCRETE FOR PREFABRICATED CONSTRUCTION

DAVID HEATH, TUAN NGO, PRYAN MENDES, UNIVERSITY OF MELBOURNE, VICTORIA, AUSTRALIA

Prefabricated construction is an emerging industry in Australia and is expected to significantly contribute towards growth in the construction industry's capacity to deliver an improved standard of buildings. Large research projects are in progress at the University of Melbourne such as the ABC Centre for Advanced Manufacturing of Prefabricated Buildings that are developing new materials and systems to which precast in Australia construction industry. Prefabricated construction encompasses various concrete-based systems in a range of various research avenues. One of the on-site assembly of these systems is of permanent importance and careful design of fastenings to concrete is required. Australian concrete industry design guidelines covering safety-critical fastenings to concrete in recent years including SA 3550.1 (2015) for transport and assembly, and SA 3550.2 (2015) for the performance during the design life of the structure. This paper reviews some of the key considerations for the design of safety-critical fastenings to concrete for prefabricated concrete structures.

### 1.0 INTRODUCTION

The precast industry in Australia is very mature and includes myriad different types of configurations from linear elements, panelised systems, volumetric and more complex. Concrete has long been favoured in building design for its inherent resistance to fire, thermal capacity and acoustic insulation capabilities. While these systems are typically cast in factories and assembled on-site, new types of prefabricated systems are being developed such as those used on a Lytle Tower in Melbourne. Australia's tallest modular building. A key advantage of off-site manufacture is the ability to consistently undertake site-based activities such as site preparation, footing installation, basement and podium construction, then deliver the prefabricated components "just in time" to compress the overall project schedule enabling earlier occupancy. In certain circumstances prefabricated solutions also bypass the need for external scaffolding, leaving a stable material storage for the high-rise project.

Due to weight limitations imposed by craning and transport a hybrid approach may be required that combines a large portion of off-site manufacture of the system with site-based activities such as in-situ concrete pour and/or the application of concrete (refer to Figure 1). Careful attention should be given to the specification of fastenings in these concrete systems for on-site assembly as well as in-situ. Guidelines are now available for the reliable design of both anchors

lifting applications as well as fasteners for permanent connections between members.

Steel and timber elements are frequently connected to concrete members via post-tensioned or cast-in-place. Non-structural fasteners are widely used for systems such as utility racks, suspended ceilings, internal and external cladding, and many others in conventional and prefabricated construction. The facade industry has long used curtain wall systems involving prefabricated panels systems requiring cast-in fastenings solutions. Curtain wall facade systems are typically prefabricated and fixed on-site to cast-in-place walls via cast-in channels systems that permit adjustment for correct alignment.

The design of appropriate lifting anchors and fasteners for use during transport and assembly is covered in AS 3580.1 for lifting anchors and bearing inserts including design provisions and testing and verification procedures for the determination of design capacity. The prefabrication and design requirements for safety-critical fastenings to concrete that are included in SA 3550.1 were developed by the Australian Engineers' Association and Architects' Council (AEAC) as relevant during the service life of the structure. SA 3550.1 is a primary reference in the National Construction Code Volume 1 and Volume 2.

1.1 CONSIDERATIONS FOR PREFABRICATED CONCRETE CONSTRUCTION

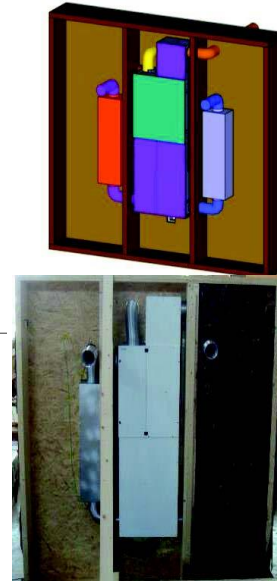
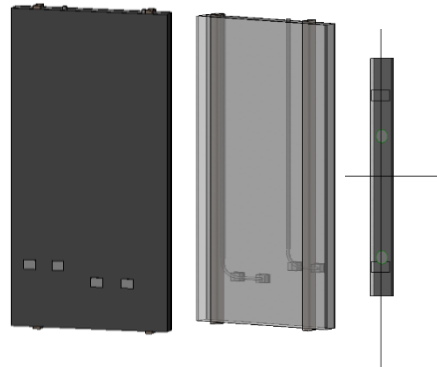
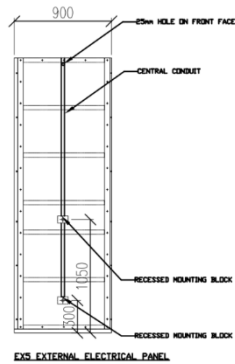
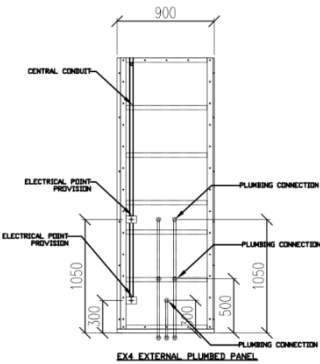
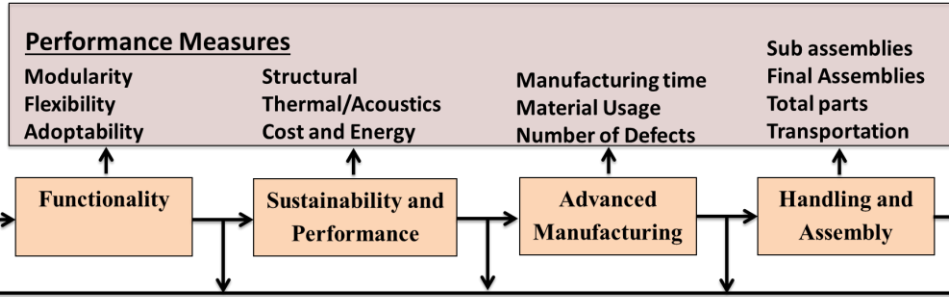
Relative to site-based construction prefabricated systems offer greater efficiency, reduced requirements for formwork and scaffolding, reduced on-site construction time, improved safety, improved reduction in project schedule, improved sustainability, and higher quality and finish. From a sustainability perspective, relative to lightweight systems such as floors, concrete systems are advantageous since they are far less responsible for excitation from traffic, and are less prone to requiring intervention to dampen vibrations in most vibration criteria.

In terms of fastening elements to concrete members there are two main families of fasteners: post-tensioned (mechanical and chemical) and cast-in. The selection of a suitable system will depend on a number of factors such as the nature of the elements, assembly requirements and performance requirements throughout the service life of the structure. Positional accuracy is often determined by the fastening system on-site. This can influence the choice of fastener adopted to secure the system. The accuracy of fastening locations in facades that employ cast-in channels such as those shown in Figure 2 is critical for proper assembly. Shallow anchor systems adopted in conventional

36 Concrete in Australia | Vol 43 No 5



**Design for Manufacture and Assembly process  
developed by ARC CAMPH**

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