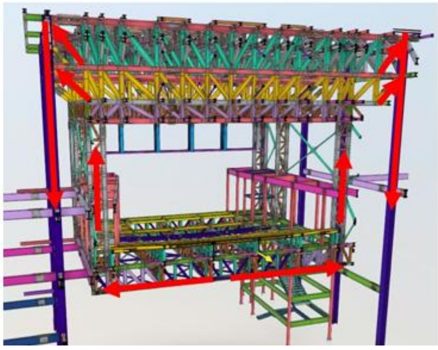
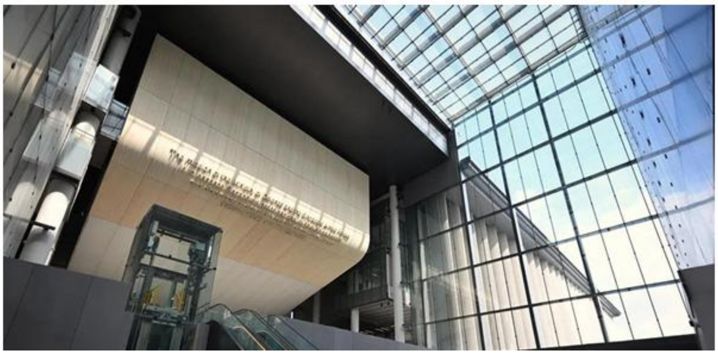
ANNEX A: Er. Clement Chen, Executive Director, Meinhardt (Singapore) Pte Ltd
New Central Manpower Base (CMPB)

Challenge 1: Suspending an auditorium above hall





Picture 1: Singapore's first suspended auditorium. Photo credits: Meinhardt (Singapore) Pte Ltd, The Straits Times

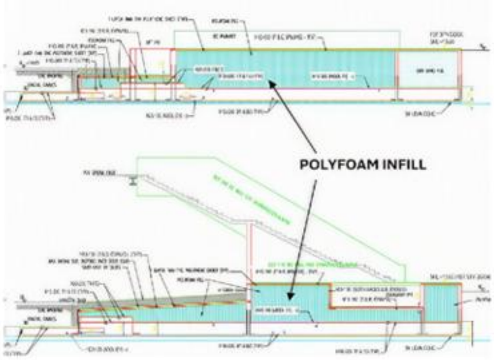
<u>The Challenge</u>

Creating **Singapore's first "floating" auditorium.** Conventionally, an auditorium is supported by beams and columns positioned beneath it. At the New Central Manpower Base (CMPB), this would have introduced multiple columns into the Level 3 Service Connect space which would restrict visitor movement, visibility and flexibility to use the hall for services, ceremonies, training and other events. The engineers therefore devised a solution to support the auditorium without any columns below.

<u>The Engineering Solution</u>

- The auditorium is suspended from large **steel roof trusses**, with its weight channelled upwards and outwards to composite columns at the sides, and down into the building's foundation.
- Steel trusses system was chosen for its ability to (1) incorporate building services within the structural depth, (2) enable quicker assembly by about 30% compared to girder beams, and (3) reduce the need for extensive temporary staging above an active public space.
- Main roof trusses span approximately 30 metres and are supported by six one-metre-diameter steel-concrete composite columns on each side of the auditorium.
- High-strength S460 structural steel was used in selected built-up sections to reduce member sizes and overall structural weight compared to conventional concrete.
- Steel beams and steel decking were used to form the floor slabs. This approach reduced the need for extensive temporary staging and minimised work-at-height works.
- Design for Manufacturing and Assembly (DfMA) was adopted for precast column, beams and slabs to achieve 10% time savings.
- The design was verified through three-dimensional structural analysis and staged construction simulations, covering (1) dead and imposed loads, (2) wind, (3) seismic, (4) load redistribution, (5) structural robustness, (6) temperature (7) movement and vibration. It also included performance-based checks for both seated and walking areas.

Challenge 2: Connecting CMPB to Cashew Station



Picture 2:Raft foundation incorporating engineered voids. Photo credits: Meinhardt (Singapore) Pte Ltd

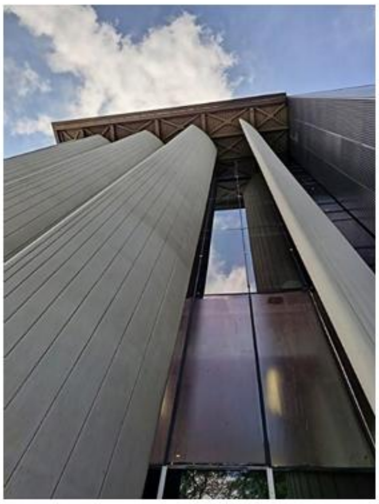
<u>The Challenge</u>

- A sheltered pedestrian bridge was required to provide direct access between CMPB and Cashew MRT station. The bridge is approximately 208 metres long and five metres wide. Its four principal spans range from approximately 35 to 63 metres and cross Upper Bukit Timah Road and a drainage reserve.
- At the Cashew MRT station end, lift structure carrying the POB had to be supported directly above the underground station box. Strict limits therefore applied to the additional permanent load and movement that could be imposed on the existing MRT infrastructure.
- A conventional solid raft foundation would have added substantial weight. Strengthening or modifying the existing station structure would also have caused greater complexity and disruption.

<u>The Engineering Solution</u>

- Engineers designed a calibrated **raft foundation incorporating engineered voids** in carefully selected areas, reducing the foundation's weight while maintaining the strength and stability needed to support the bridge and lift structure.
- Utilise **automated safety controls** set to stringent tolerance to monitor movements of (1) ground, (2) station structure; (3) tunnel of the MRT station.
- **Prefabricated DfMA long steel spans** offsite, to assemble onsite, to reduce number of people working on site. Given that the spans had to be lifted into position above live roads overnight, the operation required careful coordination across multiple agencies, advance notification to residents, nearby schools and management corporations and staged traffic diversions.

Challenge 3: Constructing 68 Reinforced Concrete (RC) Fin Columns, Each 32-metres Tall



Picture 3: 32m aerofoil shaped reinforced concrete. Photo credits: Meinhardt (Singapore) Pte Ltd

<u>The Challenge</u>

The CMPB façade features 68 tapered, 32m aerofoil-shaped reinforced-concrete fins. Aside to contributing to the development's identity, the columns play an important role as passive solar shading at the same time, preserving views between the fins. Due to its height, weight, slender geometry and orientation, alternative installation method is required.

<u>The Engineering Solutions</u>

- Each fin was divided into five precast segments to remain within transportation and crane-lifting limits.
- The segments were joined using grouted splice sleeves to ensure structural continuity between the reinforcement bars.
- A proprietary bracket-fastening system was used to temporarily hold and align the segments during erection eliminating the need for full-height props or scaffolding, reducing work-at-height risks and shortening installation cycles.
- Building Information Modelling (BIM) was used to coordinate the geometry and orientation of each fin prior to fabrication and erection.

<u>Other Notable Engineering and Delivery Innovations</u>

- <u>Higher-Strength Reinforcement, Lower Carbon Footprint</u>: Grade 600 steel rebars has a higher yield strength than conventional Grade 500 steel rebars, meaning less steel is needed to achieve the same structural performance. This reduction in material use translated into sustainability gains of attaining the building's Green Mark Platinum Super Low Energy certification with (1) approximately 10% lower reinforcement tonnage compared with Grade

500 steel rebars; and (2) 10.13% reduction in embodied carbon associated with reinforcement, supported by the use of recycled steel from a local mill.

- <u>Prefabrication and DfMA</u>: Approximately 80% of the superstructure's columns, beams and slabs were precast. This contributes to an overall precast content of approximately 69% by concrete volume leading to reduced on-site labour.
- <u>10 metres retaining wall within tight footprint</u>: (1) A counterfort retaining wall system of approximately 10 metres high was required within a constrained footprint. (2) Compression piles at the toe and tension piles at the heel resist overturning and uplift, allowing a shorter base slab and reducing the wall's required footprint. (3) a hybrid soil-nail and green-bag earth-retaining system stabilised an approximately 11.6-metre-high slope inclined at about 75 degrees. The system combined slope stabilisation with a vegetated finish.
- <u>Dynamic pile load testing (STATRapid method)</u> was adopted in place of conventional kentledge testing, reducing the duration of each test from approximately 12 days to three days.

<u>Quote</u>

Er. Clement Chen

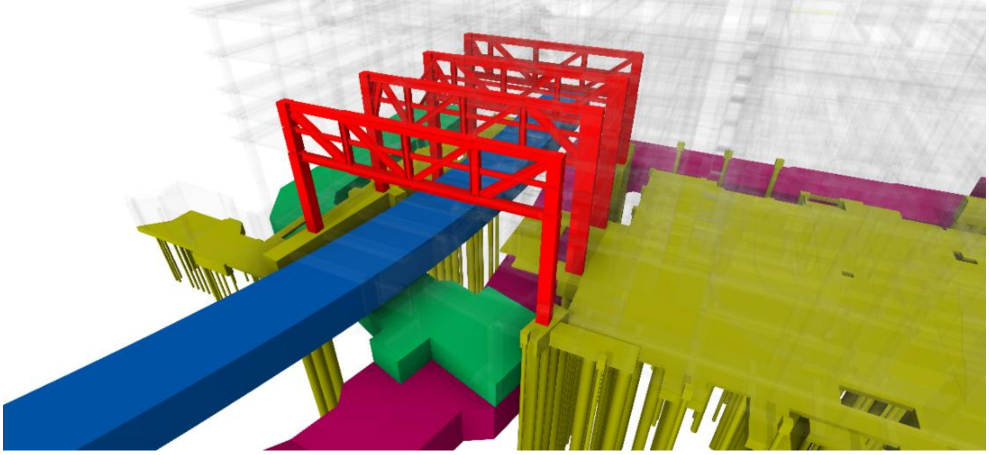
Executive Director, Meinhardt (Singapore) Pte Ltd

"This project shows that what appears effortless architecturally is often the result of considerable engineering complexity behind the scenes. Through meticulous planning, close collaboration and a clear understanding of users' needs, we transformed ambitious ideas (from the 'floating' auditorium to the direct MRT connection) into safe, practical solutions. That is the value of civil engineering: creating lasting infrastructure that improves connectivity, amenities and quality of life for generations."

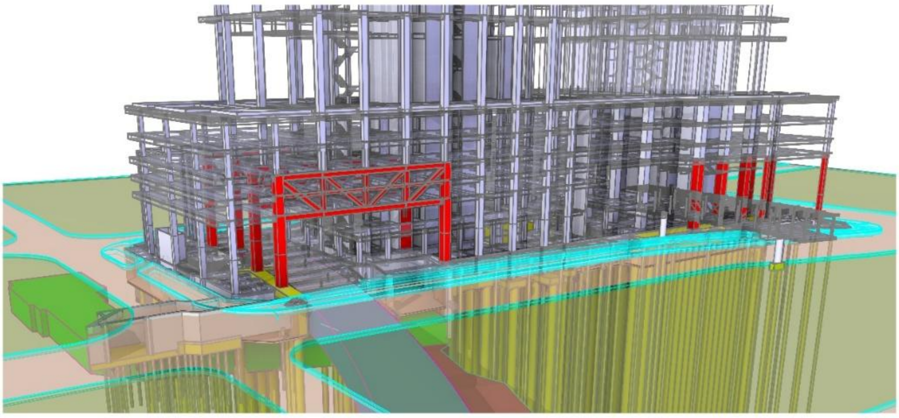
ANNEX B: Er. Aaron Foong, Senior Executive Director, KTP Consultants a member company of Surbana Jurong (SJ Group)

IOI CENTRAL BOULEVARD TOWERS

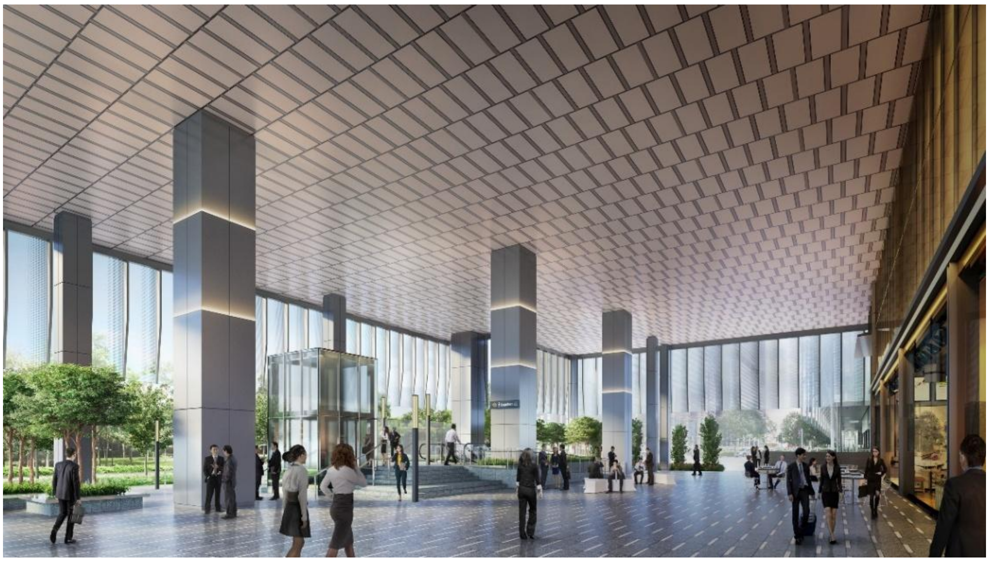
Challenge 1: Constructing a High-Rise Development Across Live Infrastructure



Picture 4: Transfer truss over public infrastructure corridor. Photo credits: KTP Consultants



Picture 5: Inter-storey transfer truss integrated within functional building zones. Photo credits: KTP Consultants



Picture 6: Artist impression of large, open, column-free areas. Photo credits: IOI Properties Singapore.

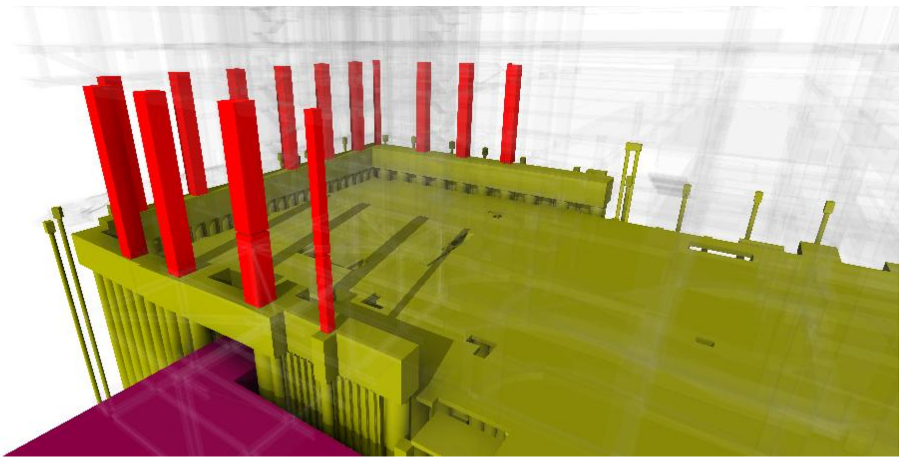
The Challenge

- In a conventional high-rise building, columns and core walls transfer structural loads vertically into foundations located directly beneath them. At IOI Central Boulevard Towers, this was not possible within the strict no-pile zones occupied by the Common Services Tunnel (CST), monsoon drain and other protected infrastructure.

The Engineering Solution

- Interstitial long-span transfer trusses: The engineers developed **interstitial long-span transfer trusses** that span across the restricted zones. These trusses collect structural loads from the building above and redirect them to columns and foundations positioned outside the no-pile zones. This allows co-existence between the development and existing public infrastructure. Similar to the role of bridges, transfer trusses of a structural depth of 7 metres were integrated within functional building zones rather than added as a separate transfer floor. By integrating as part of the building, it does not impact floor space nor height. This reduced the need for additional building height and allowed the transfer structure to coexist with car-park, circulation or service requirements.
- Precambering: The transfer trusses did not receive their full load at once. As each new floor was constructed, additional weight was progressively transferred into them. Engineers therefore had to calculate how much the trusses would deflect at different stages of construction. An intentional upward curvature (precamber) was introduced during fabrication. As the permanent building loads were added, the trusses gradually settled towards their intended final position. This was important because movement could affect areas such as finished floor levels, façade, internal finishes etc. This required both structural calculation and engineering judgement throughout design and construction.

Challenge 2: Combining Excavation Support and Permanent Foundations



Picture 7: Dual-function secant bored piles. Photo credits: KTP Consultants.

The Challenge

The project required a deep basement to be constructed in ground underlain by up to 40 metres of soft marine clay, while maintaining strict movement limits to protect the operational Downtown MRT and nearby public infrastructure. The high-rise tower's commercial floor plate is formed by perimeter columns close to the site boundary, leaving very limited space below ground. Conventional construction would have required separate temporary earth-retaining walls for excavation and permanent foundations to support the completed building. Accommodating both systems within the constrained site would have been highly challenging, consuming valuable underground space and increasing construction complexity.

The Engineering Solutions

- Dual-function Secant Bored Pile System: A secant bored pile wall is formed by constructing overlapping bored piles so that adjacent piles intersect and create a continuous wall. Piles were designed to: (1) retain soil and groundwater during excavation; and (2) become part of the permanent foundation system supporting the completed development. This (1) simplifies construction sequencing, (2) improves spatial efficiency; and (3) saves approximately 10,000 m^3 of concrete and 1000 tonnes of steel reinforcement, significantly reducing the project's embodied carbon.
- Observational Method: This is the first project in Singapore to apply Observational Method to an Earth Retaining and Stabilising Structure (ERSS). Engineers developed both a conventional code-based excavation design and a Performance-Based design before construction began. As excavation progressed, a network of sensors continuously measured how the ground and retaining walls were actually performing. The real-world data was compared against the design predictions and pre-agreed safety limits. When readings confirmed that the excavation was performing better than the code-based assumptions and remained within pre-agreed safety limits, the team adopted the two-strut scheme. Omitting the third strut cleared space for a major pile cap, improved access and headroom at the lowest basement level. This saved approximately three months on the basement programme. Both schemes, together with their safety limits and contingency measures, had been fully assessed before excavation began.

Quote

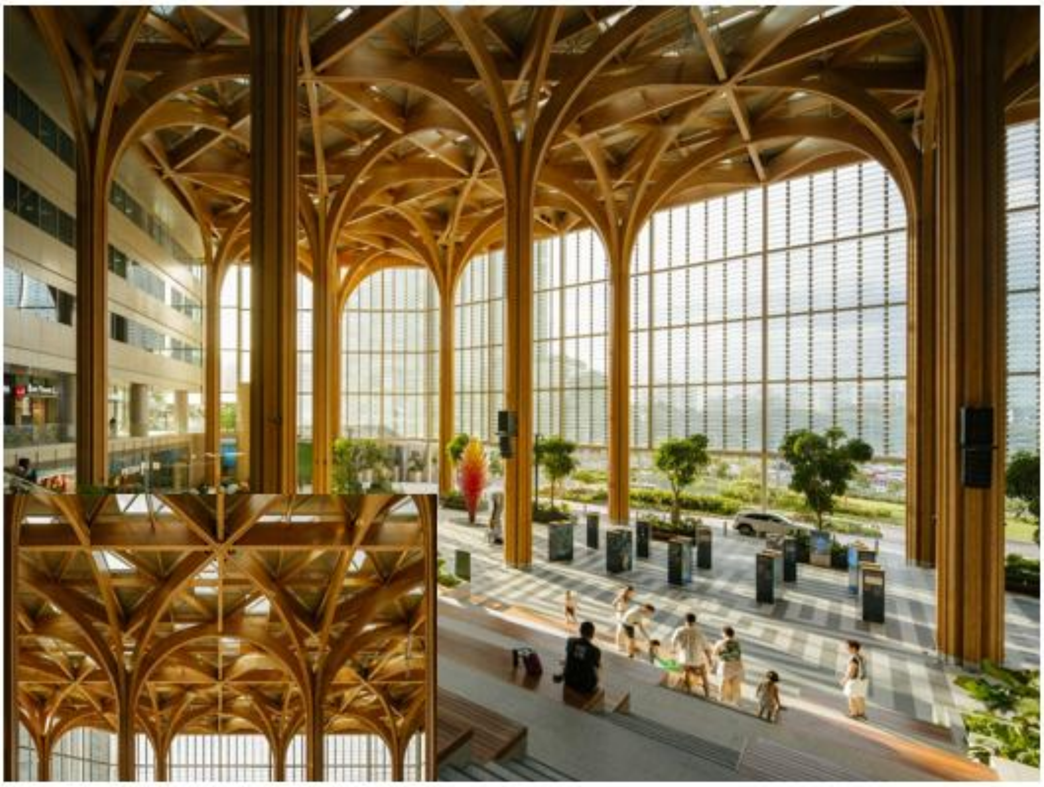
Er. Aaron Foong Kit Kuen, Senior Executive Director, KTP Consultants (a member company of Surbana Jurong (SJ Group)

"This project reminded us that good engineering is rarely about finding a single technically feasible answer. It requires us to challenge conventional assumptions, understand competing priorities and work closely with all stakeholders to arrive at the solution that best serves the project and the city. Much of that work may remain unseen, but its impact is felt in the safety, resilience and functionality of the places people use every day."

ANNEX C: GENEO AT SINGAPORE SCIENCE PARK

Challenge 1: Creating Singapore's First 27-metre Mass Engineered Timber (MET) Arched Canopy Structure

Picture 8: Analysis model and construction of Singapore's tallest arched MET canopy structure. Photo credits: CapitaLand, Ronnie and Koh Consultants Pte Ltd



Picture 9: Artist Impression on Singapore's tallest arched MET canopy structure. Photo credit: CapitaLand

The Challenge

The development required a large sheltered public plaza that would serve as a welcoming gathering space at the centre of the innovation hub. The approximately 3,000-square-metre plaza is covered by a timber canopy rising 27 metres – the tallest in Singapore. Its columns and arched beams function as both the canopy's primary structural supports and its defining architectural elements. Compared with a more regular straight-beam structure, the canopy's long spans, complex geometry and limited number of supporting columns created additional challenges involving: structure behaviour, complex connection design and integration with surrounding buildings.

The Engineering Solution

- Prefabricated off-site: The principal timber elements were manufactured under factory-controlled conditions. As the long-span arches could not be transported as complete elements, each arch was delivered in two sections and on-site assembled for installation. Off-site prefabrication provided: (1) tighter dimension control; (2) reduced on-site cutting and adjustment; (3) improved fabrication quality; and (4) reduced work at height.
- Concealing Structural Connections: Bespoke steel connectors were designed to join the timber elements while remaining concealed. The connections had to transfer structural forces safely while accommodating manufacturing and installation tolerances. The steel brackets were designed to allow movement in the direction that they were designed for. This connection allows the timber structure to be safely braced to the adjacent building structure while allowing a certain degree of movement.
- Precision and stability during construction via Building Information and Modelling (BIM): The arch reaches full structural stability once all its sections are assembled and working together. Engineers therefore analysed each major stage of the assembly sequence, including lifting, temporary support, connection of arch sections, transfer of loads to permanent support etc. Building Information and Modelling (BIM) was utilised to create four-dimensional construction simulations and virtual construction. Through early coordination and careful planning of the assembly sequence, the installation was successfully carried out using only localised shoring. Compared with the conventional approach of erecting full shoring beneath the structure, this resulted in labour savings of approximately 780 man-days.

Challenge 2: Designing adaptable, vibration-controlled laboratories

The Challenge

Research and laboratory tenants may have substantially different requirements. The space may require accommodating to changes in laboratory planning, different equipment layouts, sensitive instruments, heavier floorboards. A conventional floor structure with a dense column grid would restrict how laboratories could be arranged or reconfigured with changing research requirements. At the same time, highly sensitive scientific equipment may be affected by floor movement that building occupants may not perceive. The structural system therefore had to provide both flexibility and stringent vibration performance.

The Engineering Solutions

- Post tension reinforced concrete system: The engineers developed a hybrid post-tensioned and reinforced-concrete structural system. Post-tensioning uses tensioned steel tendons to place the concrete floor into compression. In suitable applications, it allows longer spans with fewer columns while controlling structural deflection and cracking. The system enabled: (1) Long spans of up to 19.2 m, enabling column-free, highly flexible floor plates; (2) zoned structural design to achieve stringent laboratory vibration criteria (4,000 MIPS) allowing for both stringent vibration performance and greater flexibility for future use.

What the Engineering Enabled

The structural strategy created large, flexible floor plates while maintaining the environmental stability required for sensitive laboratory operations. Future occupants can reconfigure: (1) laboratory layouts; (2) equipment positions; (3) internal partitions; (4) tenant spaces etc.

Challenge 3: Designing the Basement Around the Natural Terrain

The Challenge

The site has a substantial change in elevation between Science Park Drive and the Ayer Rajah Expressway. A conventional approach would establish a relatively uniform development platform by excavating the higher ground and constructing extensive retaining structures. This would have required greater excavation and soil removal; more permanent earth retaining structures and greater embodied carbon.

The Engineering Solutions

- Basement levels to follow natural terrain: Instead of extensively reshaping the site, engineers profiled the basement levels to follow the natural terrain. This includes retaining the higher ground near Science Park Drive without introducing unnecessary basement construction beneath it.
- Managing groundwater without pumping: The basement was positioned largely above the existing groundwater table. A drainage blanket beneath the base slab was designed to: (1) allow groundwater to continue flowing from the higher to the lower parts of the site; (2) channel water in a controlled manner towards external drains; and (3) discharge the water by gravity rather than relying on permanent pumping.

Other Notable Engineering and Delivery Innovations

- Digital Design and Construction: The project used full-lifecycle BIM and Integrated Digital Delivery (IDD) to coordinate design, construction sequencing, building services and cost information. Applications included (1) weekly clash-detection and coordination reviews; (2) virtual construction; (3) four-dimensional installation simulations; (4) digital mock-ups and BIM walkthroughs; and (5) a common data environment for project records and collaboration.
- Off-site Manufacturing and Lean Construction: DfMA was adopted for: (1) prefabricated timber components; (2) precast staircases; (3) modular precast linkway beams etc. These approaches reduced on-site work and improved installation consistency.
- Construction Robotics: Rebar-tying robots were used for selected reinforcement works with speeds of 2.7 seconds tie per second. An automated overhead-drilling robot was also deployed to reduce manual work at height which translated to 30% improvement in drilling productivity.
- Sustainability Outcomes: The project has been certified with BCA Green Mark Platinum Super Low Energy and WELL Core Gold Certification. The use of Mass Engineered Timber as a lower-carbon structural material; distributed district cooling and photovoltaic integration; construction materials certified under the Singapore Green Building Product scheme are some areas the project has committed to sustainability outcomes.

Quotes

Er. Teoh Eng Sin, Technical Director (Structural), Mott MacDonald Singapore Pte Limited

"This project reinforced that the best engineering solutions often emerge when we are prepared to rethink conventional approaches. By working closely with the architect, client and project team, we reshaped the basement to follow the natural terrain, reducing excavation and protecting nearby MRT infrastructure. Good engineering is about understanding the site holistically, balancing competing priorities and creating safe, sustainable solutions that will serve society for generations."

Er. Ponnampalam Thusiyanthan, Technical Director, Ronnie & Koh Consultants Pte Ltd

"Many visitors will admire the timber canopy without realising the engineering precision behind it. Every prefabricated component had to fit within extremely tight tolerances, accommodate structural movement and connect seamlessly with the surrounding buildings. Delivering the canopy required close collaboration across design, fabrication and construction to transform an ambitious vision into a safe, buildable and enduring structure.