Hong Kong West Kowloon Station was a project of scale and complexity never before attempted in the special administrative region.

Covering an 11-hectare site, it is the largest MTR station in Hong Kong by far and serves as the terminus of the express rail link that connects the special administrative region with over 27,000 kilometres of China's national high-speed rail network.

Under a dramatic and irregular three-dimensional roof structure is a vast station that consists of four basement and two above-ground levels, with facilities including nine long-haul and six shuttle train platforms, customs and immigration and numerous retail and food and beverage outlets.

This is the story of the planning, programming, logistics and safety challenges associated with the delivery of a uniquely complex project – a project that brought out the importance of teamwork and innovation as it was steered towards completion.

PROJECT GALLERY

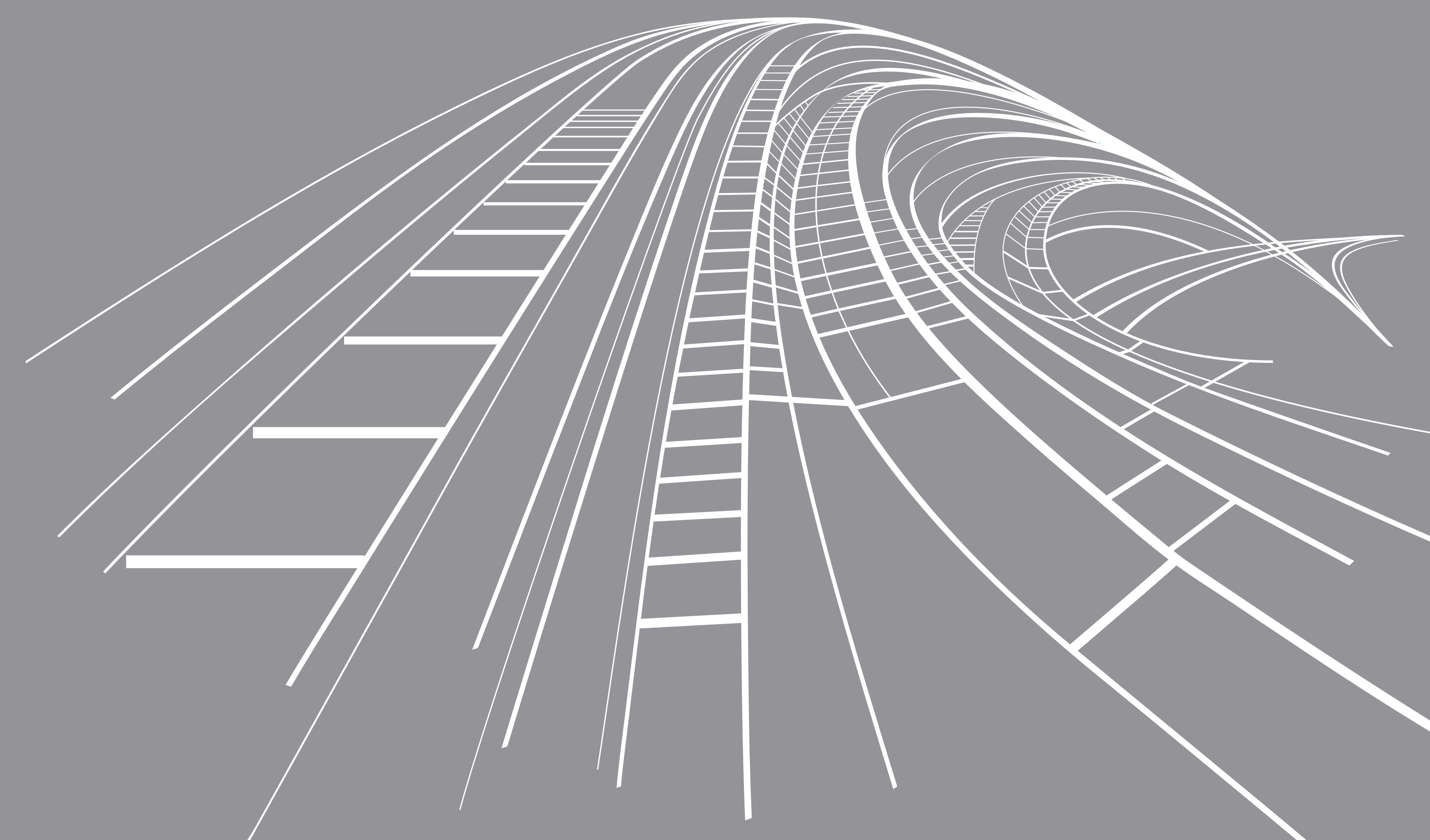
GAMMON CONSTRUCTION LIMITED
Telephone: (852) 2516 8823. www.gammonconstruction.com

ENGINEERING THE VISION 香港西九龍站 HONG KONG WEST KOWLOON STATION

ENGINEERING THE VISION

香港西九龍站

HONG KONG WEST KOWLOON STATION



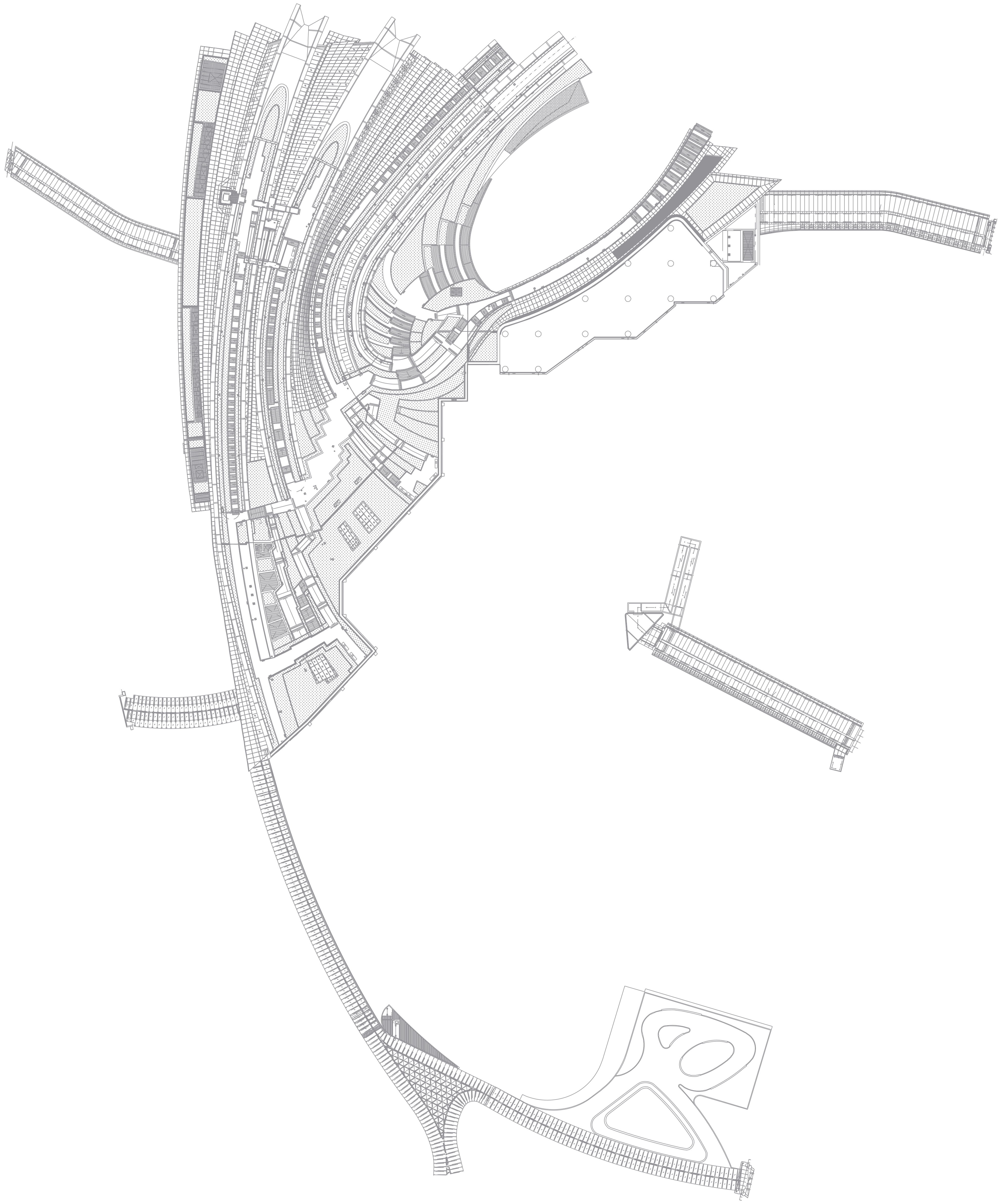
Gammon

香港西九龍站

HONG KONG

WEST KOWLOON STATION

PROJECT GALLERY



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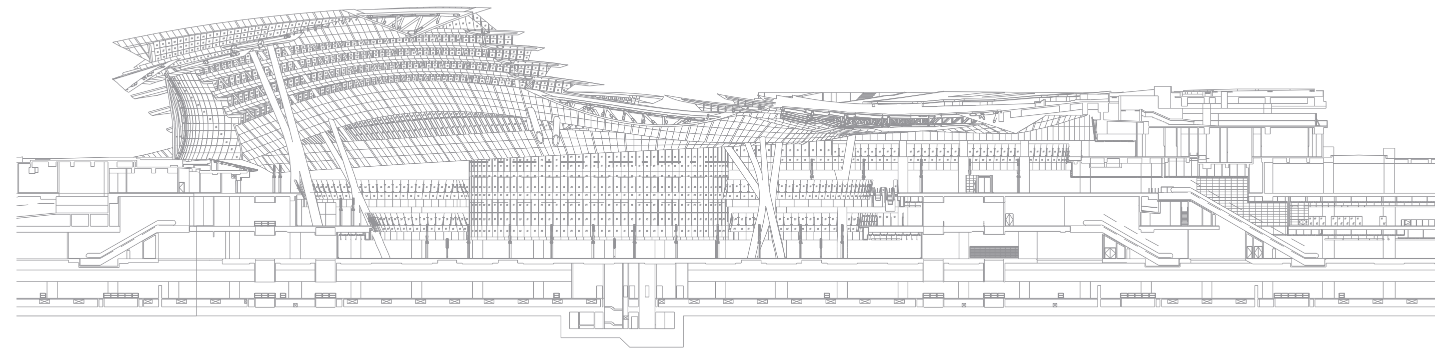
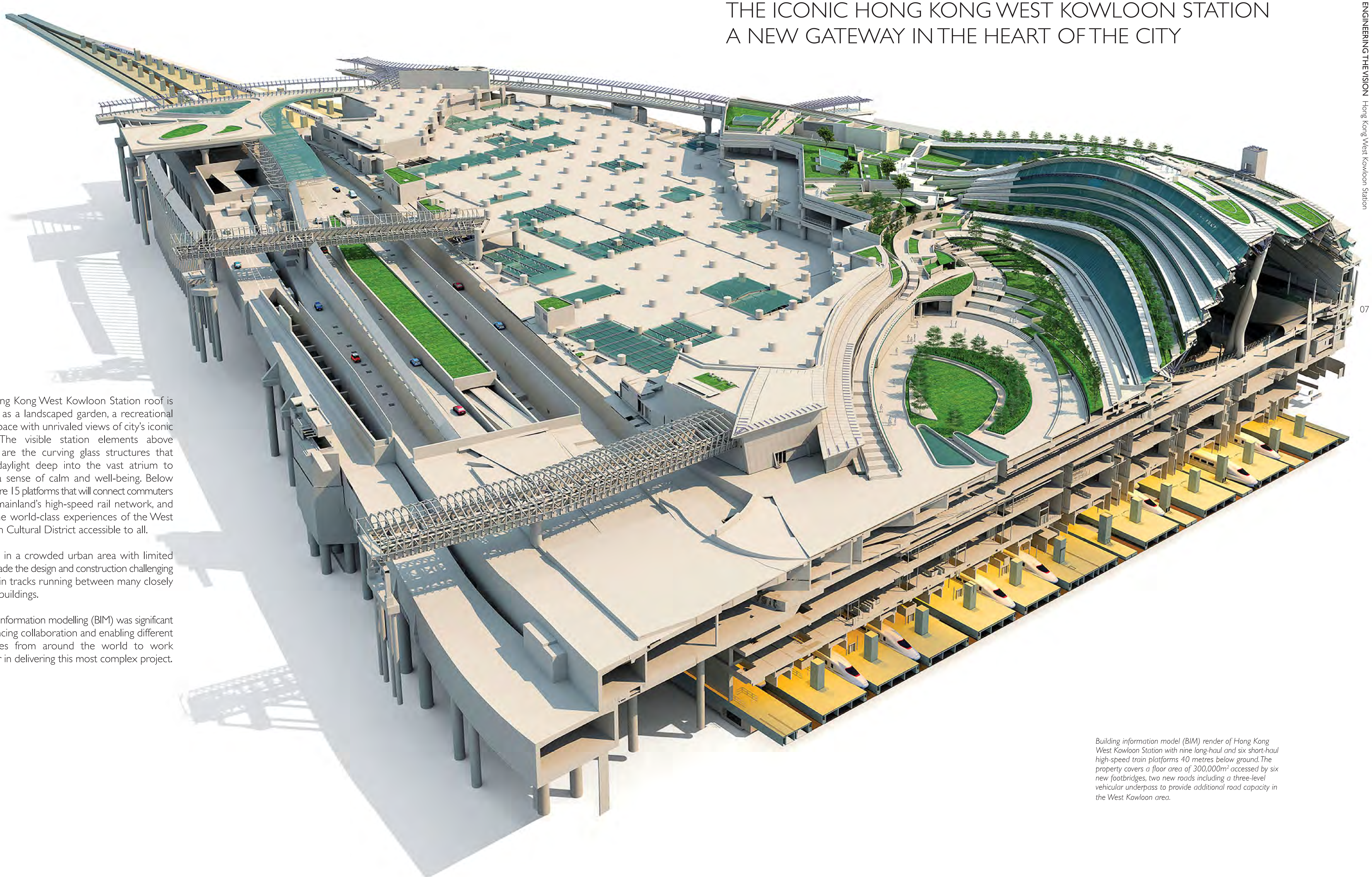


AUTHOR: Angela Tam DESIGN: MAN GREY PHOTOGRAPHY: Kitmin Lee and Oliver Tsang BIM Artist: Jack Cheng Fu, Gammon
GAMMON BOOK COMMITTEE: C.C. Hau, Edmond Lai, Candy Chan, Joey Fan and Emily Macfie.

THE ICONIC HONG KONG WEST KOWLOON STATION A NEW GATEWAY IN THE HEART OF THE CITY



The Hong Kong West Kowloon Station roof is laid out as a landscaped garden, a recreational public space with unrivaled views of city's iconic skyline. The visible station elements above ground are the curving glass structures that draws daylight deep into the vast atrium to create a sense of calm and well-being. Below ground are 15 platforms that will connect commuters to the mainland's high-speed rail network, and make the world-class experiences of the West Kowloon Cultural District accessible to all.

Located in a crowded urban area with limited space made the design and construction challenging with train tracks running between many closely packed buildings.

Building information modelling (BIM) was significant in enhancing collaboration and enabling different disciplines from around the world to work together in delivering this most complex project.

Building information model (BIM) render of Hong Kong West Kowloon Station with nine long-haul and six short-haul high-speed train platforms 40 metres below ground. The property covers a floor area of 300,000m² accessed by six new footbridges, two new roads including a three-level vehicular underpass to provide additional road capacity in the West Kowloon area.

FOREWORD

It is with great pride that I present this book on the Hong Kong West Kowloon Station project, a record of a uniquely challenging project that could not have been delivered without innovation and teamwork. This book is presented in a large format, the better to illustrate the process of delivering a project of such scale and complexity, a project that involved building an iconic roof structure over a large and deep basement almost at the same time.

There were many major challenges on this project. There is the very wide and very deep basement, which required a combination of construction methods to meet the programme. Then there was the roof structure and its 3D geometry, which was complex to get right. There were multiple specialist teams working on multiple levels simultaneously. And on top of it all, the team had to organise numerous large-scale traffic management schemes and ensure the works were carried out safely.

This book lays out these challenges in separate chapters. The descriptions of the works are accompanied by dramatic images of the project, under construction and after completion. The selection of building information modelling (BIM) graphics is a good illustration of the ways in which technologies were deployed to help with the planning and construction of the terminus, as well as to facilitate collaboration and communication among stakeholders.

On the subject of stakeholders, this book makes clear how important teamwork was to the project's delivery. The team, made up of a joint venture between Gammon and Leighton Asia, made a point of communicating with the client, consultants, sub-contractors, foremen and workers, to make sure everyone was on message and committed to the hard work required to meet the challenging programme. It would not have been possible to introduce many of the innovations without everyone sharing the same objectives. In highlighting the teamwork and innovations, this book is a tribute to the people who dedicated so much hard work to the completion of this project. It is also a tribute to all the people without whose patience and understanding the construction work could not proceed. I hope everyone will now enjoy the convenience and connectivity provided by this facility.

Indeed, although Gammon's portfolio contains many public works projects, none interacts with the public at large in quite the same way. Under that iconic roof, hundreds of thousands of people will soon be travelling to and fro, disembarking or catching high-speed trains to Mainland China, or using the pedestrian connections to reach places in West Kowloon and wider Hong Kong. I am grateful to all our partners for sharing this opportunity to deliver a truly historic project. Coming at a time when new technologies made its construction possible, it is a testament to the team's adaptability as well as hard work that the public can now utilise a structure that is so much more than a transport hub.

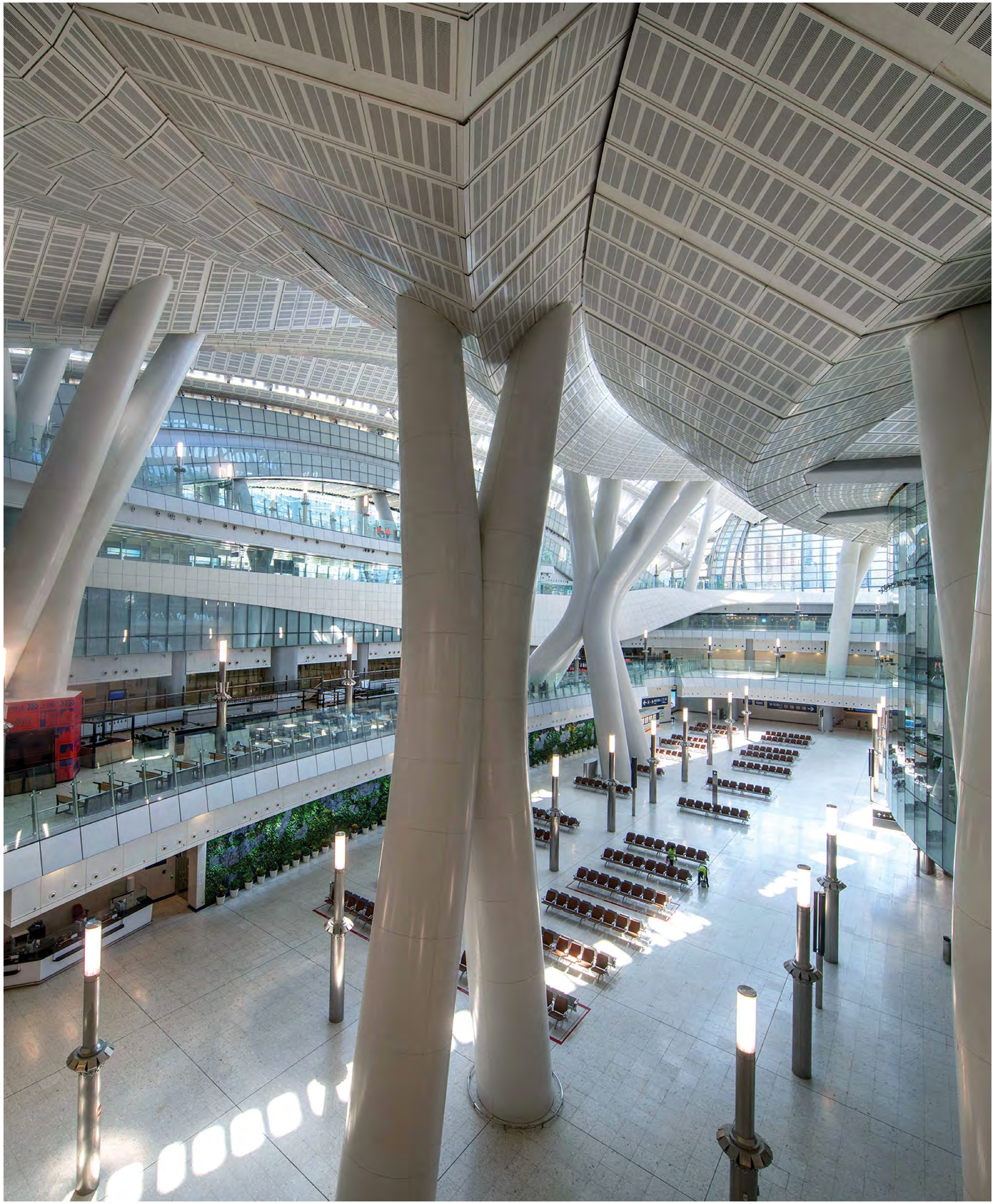
I look forward to seeing you at the terminus, enjoying the services it brings.

Thomas Ho

Chief Executive
Gammon Construction Limited

The largest MTR station by far, it effectively functions like an airport – but with all facilities underground

- 11-HECTARE SITE
- 380,000 METRES SQUARE FLOOR AREA
- 4 BASEMENT LEVELS + 2 ABOVE-GROUND LEVELS
- 9 LONG-HAUL TRAIN PLATFORMS
- 6 SHORT-HAUL TRAIN PLATFORMS
- STATION TUNNELS
- CUSTOMS, IMMIGRATION + QUARANTINE
- ARRIVAL + DEPARTURE HALLS
- DUTY-FREE RETAIL OUTLETS
- FOOD + BEVERAGE OUTLETS
- VEHICLE PARKING + LOADING/UNLOADING
- 2 MAJOR TRUNK ROADS + 3-LEVEL UNDERPASS
- 6 PEDESTRIAN FOOTBRIDGES



新地標、新網絡、新生活

香港的鐵路網絡不斷擴展，方便市民和旅客每日出行，以最便捷的方法到達目的地。建造高速鐵路香港段，就能讓我們在更短的時間內走得更遠。

廣深港高速鐵路是國家策略性高速鐵路網的一部分，全長142公里，香港段長26公里，連接內地福田站、深圳北站，直達廣州南站。高鐵通車後，由香港到廣州只需約50分鐘，即把現時約100分鐘的鐵路旅程時間減半。

香港西九龍站是接通內地高鐵網絡的門戶。它位於香港的中心位置，市民和旅客從香港任何一個角落到香港西九龍站轉乘高鐵都非常便捷，加上車站本身的工程涉及建造多條行人天橋、隧道、公共交通交匯處等，能進一步加強與周邊地區的交通網絡和連繫。

香港西九龍站面積超過380,000平方米，包括四層地庫和兩層地上結構，設有九個長途列車月台、六個短途列車月台、海關、出入境和檢疫設施、抵港和離港大堂、免稅店、零售和餐飲商舖、停車場和上落客貨設施等，是香港迄今面積最大的鐵路車站。

本《工程實錄》闡述合約810A西九龍站(北)及811B連接隧道(南)的建造過程。810A的工程包括外形獨特的車站結構、三層行車隧道系統、道路和公用設施、行人天橋及隧道、隔音屏障和園景工程；811B則涉及以明挖回填方式建造隧道、連續牆、機房大樓、公共運輸交匯處，以及工程期間複雜的公用設施和交通改道，兩項工程均由金門建築和禮頓亞洲攜手合作承造。

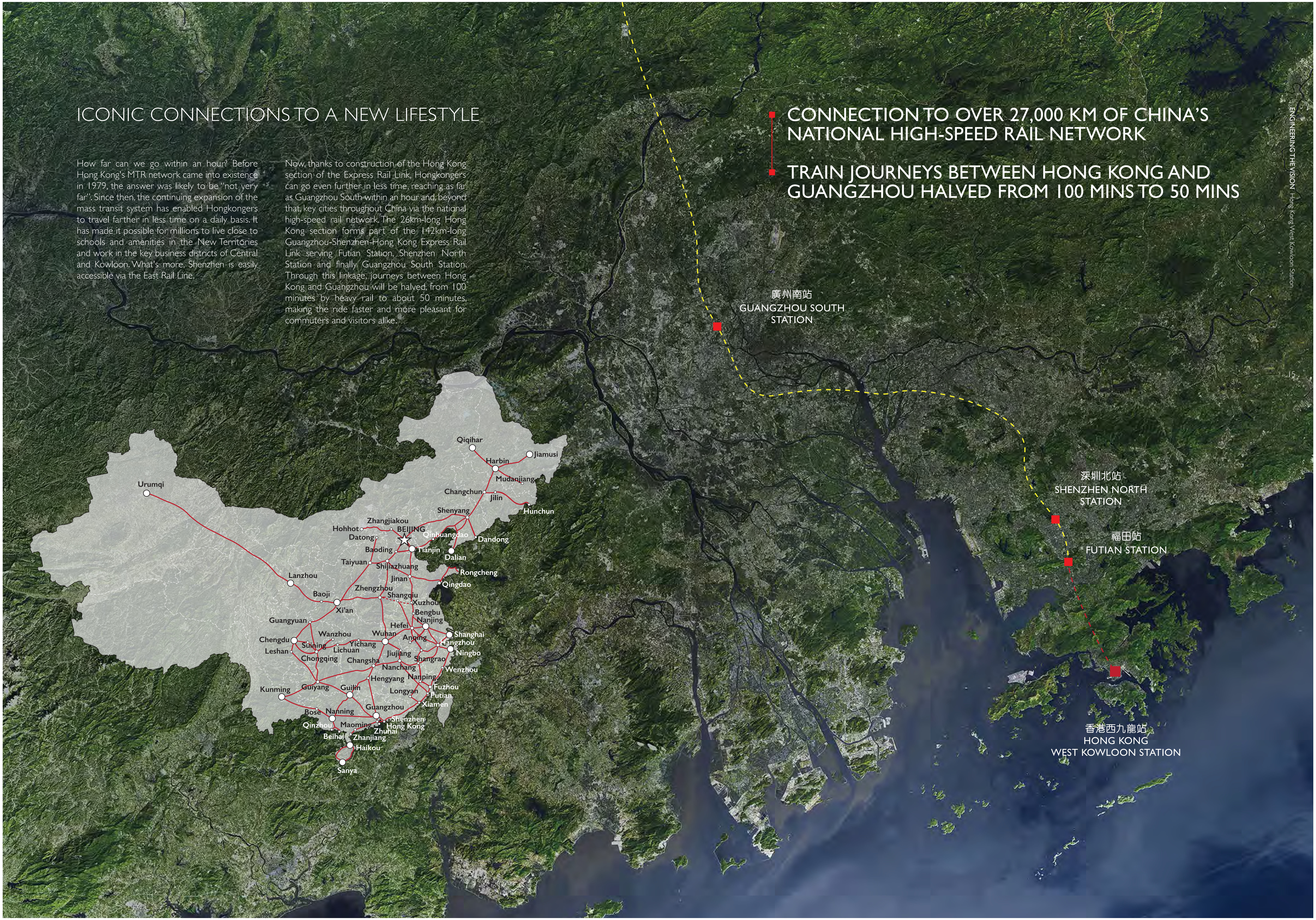
香港西九龍站是一項極具代表性的土木工程，項目能順利完成，全賴團隊的合作、創新，和卓越的工程技術。而最重要的是，它展現了香港人的「獅子山精神」，每一個參與項目的人員都同心同德，以決心、毅力和應變之能，克服建造過程中遇到的種種工程挑戰。

ICONIC CONNECTIONS TO A NEW LIFESTYLE

How far can we go within an hour? Before Hong Kong's MTR network came into existence in 1979, the answer was likely to be "not very far". Since then, the continuing expansion of the mass transit system has enabled Hongkongers to travel farther in less time on a daily basis. It has made it possible for millions to live close to schools and amenities in the New Territories and work in the key business districts of Central and Kowloon. What's more, Shenzhen is easily accessible via the East Rail Line.

Now, thanks to construction of the Hong Kong section of the Express Rail Link, Hongkongers can go even further in less time, reaching as far as Guangzhou South within an hour and, beyond that, key cities throughout China via the national high-speed rail network. The 26km-long Hong Kong section forms part of the 142km-long Guangzhou-Shenzhen-Hong Kong Express Rail Link serving Futian Station, Shenzhen North Station and finally Guangzhou South Station. Through this linkage, journeys between Hong Kong and Guangzhou will be halved, from 100 minutes by heavy rail to about 50 minutes, making the ride faster and more pleasant for commuters and visitors alike.

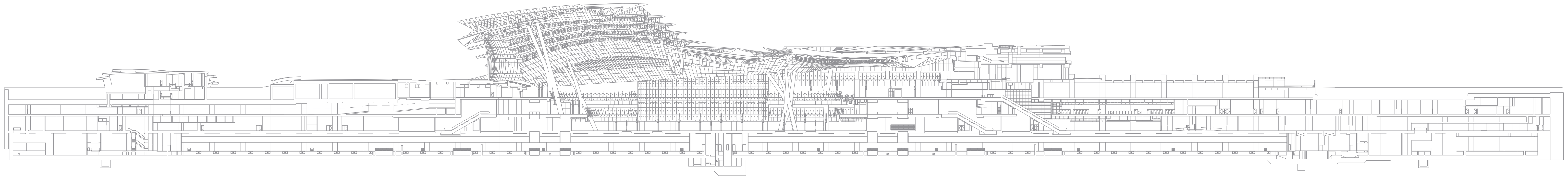
- CONNECTION TO OVER 27,000 KM OF CHINA'S NATIONAL HIGH-SPEED RAIL NETWORK
- TRAIN JOURNEYS BETWEEN HONG KONG AND GUANGZHOU HALVED FROM 100 MINS TO 50 MINS



THE STATION IS LOCATED NEXT TO THE WEST KOWLOON CULTURAL DISTRICT AND ITS WORLD-CLASS CULTURAL EXPERIENCES

The key to this connectivity is Hong Kong West Kowloon Station (HKWKS). Located in the heart of Hong Kong, it promises to make the high-speed rail network accessible to everyone and, through the co-location joint checkpoint arrangement designed to facilitate customs and immigration clearance, convenient for everyone.

At the same time, the station promises to transform West Kowloon and beyond through its extensive local connectivity in the form of footbridges, subways, a public transport interchange and proximity to Austin and Kowloon MTR stations. Located right next to the West Kowloon Cultural District, HKWKS also promises to make world-class cultural experiences accessible to everyone.



HKWKS

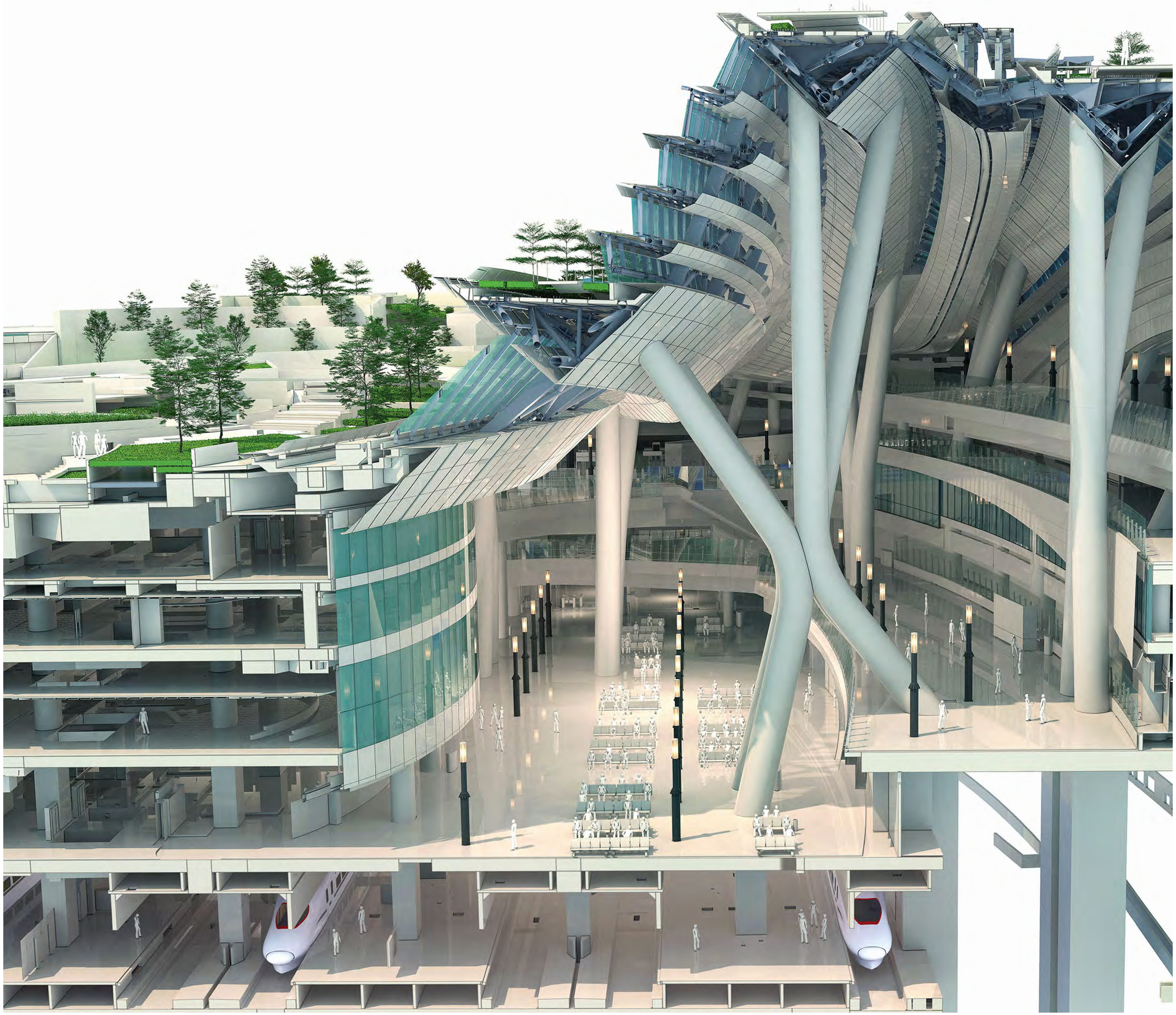
BEGUN IN 2010, HONG KONG WEST KOWLOON STATION IS A PROJECT OF A SCALE AND COMPLEXITY NEVER ATTEMPTED BEFORE IN THE SAR

This is the story of how an iconic civil engineering project came into being through teamwork, innovation, engineering excellence and, most of all, the 'Lion Rock spirit' that gave the project managers, engineers, foremen, workers and sub-contractors the determination and adaptability to work together and see through multiple challenges, to realise the vision for a spectacular structure that only ten years ago would probably have been unbuildable.

It is the story of Contract 810A, which encompassed the northern section of HKWKS and included the iconic terminus structure, as well as a three-level vehicular underpass system, road and utility works, six footbridges, two pedestrian subways, two noise mitigation decks, and landscape works to beautify the station and provide a pleasant area for the public to relax and enjoy the harbour view.

It is also the story of Contract 811B which involved construction of a 430m-long cut-and-cover approach tunnel; a 1.5m-thick, 710m-long diaphragm wall; a ventilation building and associated architectural builders' works and finishes and building services; a public transport interchange with a landscape deck and various traffic and utilities diversion works.

Officially built by Gammon Construction Limited and Leighton Asia Ltd under joint ventures that swapped leading roles, the two contracts were in fact managed under a one-team approach that ensured optimal deployment of resources to tackle the challenges presented by this project.



BIM graphic showing L2 landscaped rooftop Sky Corridor, roof trussing and mega-colums, L1 retail and food outlets, ground level, B1 ticketing concourse, B2 arrival concourse, B3 departures concourse and B4 train platforms.

The challenges were tremendous, explains Gammon Executive Director S.Y. Yu who was involved in the project from the tendering stage.

"The project involved excavation of a 30m-deep basement inside a large diaphragm wall and construction of a visually floating roof structure with complex geometry. And much of this was taking place simultaneously and within a busy transport node where traffic planning became an art in itself."

The most visible part of HKWKS, the roof structure, was designed as a dynamic echo of the station's purpose. Like the multiple train tracks converging in the basement of the station, curved trusses converge southwards, drawing attention towards Victoria Harbour and the vibrant city where the high-speed rail network terminates. To draw natural light into the deep basement, skylights and a large atrium are incorporated into the design. And just as the trusses and the mega-columns that support them posed fabrication and erection challenges, the cladding elements that make up the skylights were equally complex to design, fabricate and install, as no two elements are the same.

Parametric modelling was used to design the many geometrical shapes and forms.

"Without the high-powered computers of today and the support of building information modelling, or BIM, it would be impossible to conceive such a design, let alone build it," says Yu.

Initially set up to facilitate construction planning, the BIM model became an essential tool for identifying spatial clashes, construction coordination and communication among client, contractor and sub-contractors.

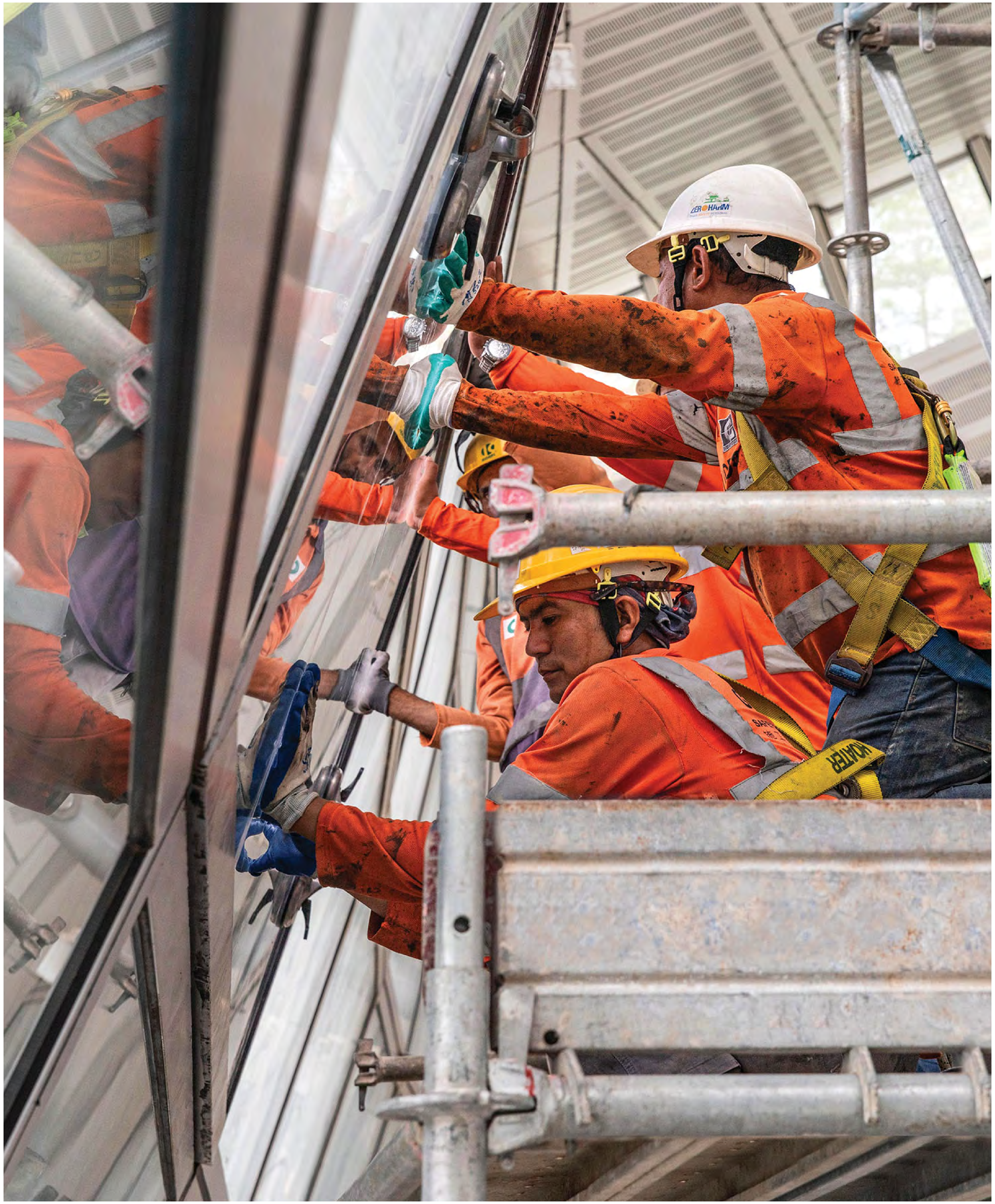
As the Hong Kong SAR Government seeks to drive the city's construction industry towards the adoption of more advanced processes, HKWKS will stand as an example of what can be achieved when all those involved in a project collaborate virtually as well as face-to-face. More than 5,000 workers were on the site at the peak of construction, across multiple levels of the structure, from the roof trusses high above ground to the deepest basement. This is the story of the planning, programming, logistics and safety challenges associated with the delivery of a uniquely complex project – a project that brought out the importance of teamwork and innovation as it was steered towards completion.

Atrium and mega-columns,
B2 food courts and B3 departures concourse.

This civil engineering project came into being through a determination and adaptability to work together and see through multiple challenges to realise the vision for a spectacular structure.

BUILDING THE UNBUILDABLE

More than 5,000 workers were on the site at the peak of construction, across multiple levels of the structure, from the roof trusses high above ground to the deepest basement.



能工巧斧 打造劃時代建築

香港西九龍站的外形設計極富動感，上蓋成流線型不規則曲面形狀，結構中三條主桁架樑只在一端錨定，其餘跨度可自由延伸，並能抵禦風速每小時超過250公里的超級颱風。

為確保結構完成後能承受預期的載荷，工程團隊必須小心計算在安裝構件過程中施加的臨時重量，及建造九組傾斜的巨型支柱時有效地轉移負重。另一方面，這些巨型支柱從地庫不同的樓層崛起，必須仔細協調地庫各樓層的建造流程，這亦大大增添了整個項目的難度和挑戰。

工程團隊把車站的建築設計轉成建築信息模擬(BIM)，在電腦數碼模型內儲存項目各方面的詳盡資料，由屋宇裝備到內部裝修鉅細無遺，並透過三維立體繪圖規劃施工程序，識別潛在的衝突，提高項目的可建造性。

為管理臨時工程之間的銜接、安裝175米長的流線型曲面上蓋、巨型支柱和大量覆面板等工作，就動用了超過300名來自世界各地的BIM技術員一同參與。

上蓋工程進行期間，團隊利用先進的電腦運算程式 — 包括分析階段性安裝情況，及使用三維立體掃描技術，確保上蓋結構符合原定的幾何設計，所有工程能安全和有效率地進行。又用航拍機在上空拍攝，顯示上蓋可能出現變形或移位的位置。

團隊用幾何非線性分析來研究上蓋在安裝期間的負重變化，配合分階段把上蓋從臨時支撐轉移到固定支柱。安裝後，用三維立體掃描檢測上蓋構件的冷縮熱脹變化。在工場製造上蓋構件時亦採用這些技術，確保構件準確無誤。

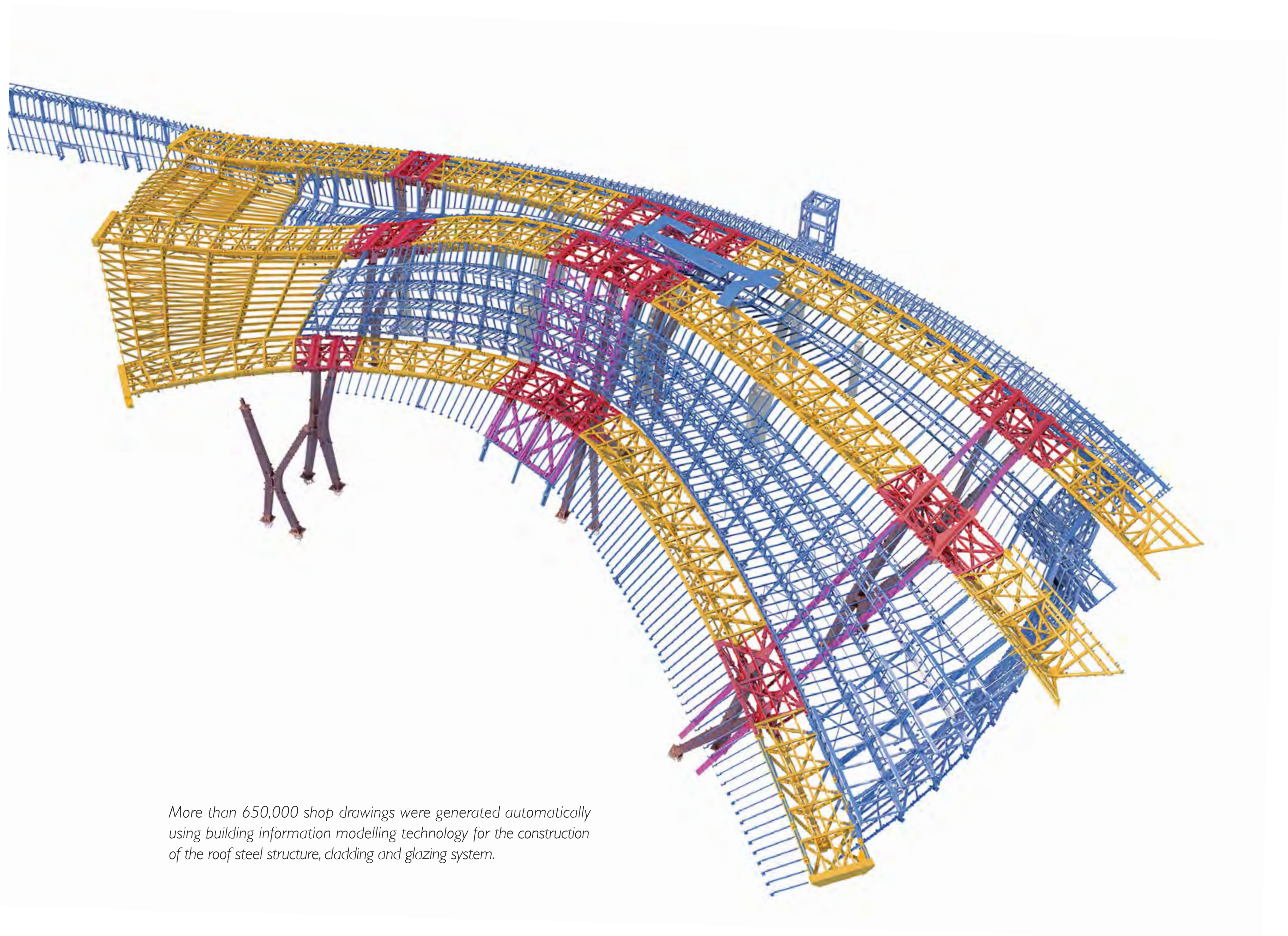
善用一系列電腦軟件進行詳盡的模擬和分析，能建造看似不可能的項目。此外，更能提升工程的可建造性，例如採用同步頂升法，減輕V型橫樑構件的應力；用預製鋁板覆蓋巨型支柱，代替纖維補強石膏板；這項目在培訓BIM技術員方面亦發揮了極大效用，讓他們實戰如何利用這先進技術建構複雜的建築項目。

IMAGINE A BRIDGE WITH A DECK THAT TILTS AND TURNS AS IT FLOWS TOWARDS AN OPEN CANTILEVERED END

You may be able to imagine it, but can it be built? In an area where the building code requires structures to be able to withstand super typhoons carrying winds exceeding speeds of 250km/hour, is it possible to have such an erection without gargantuan supports that take up a big portion of the usable space?

Made of up to 8,000 tonnes of structural steel, the dramatic roof structure has an irregular and three-dimensional curved geometry. Not only are its elements entirely asymmetrical, the three spans that make up the structure are anchored at one end only, making their construction all the more challenging. To ensure it could take the permanent loads as intended, the temporary loads imposed during the erection process needed to be carefully calculated. On top of this was the need to coordinate the erection with construction of the basement levels, where the mega-columns for the steel roof were founded.

The roof structure is supported by nine inclined mega-columns that extend 30m into the basement levels. Again, careful calculations were needed to ensure effective load transfer, which is complicated by the angles at which they extend towards the roof; every degree of deviation from the vertical imposes substantial additional demand on the strength of this support.



More than 650,000 shop drawings were generated automatically using building information modelling technology for the construction of the roof steel structure, cladding and glazing system.

The architect's design was worked out with the help of computer modelling and ultimately translated into a BIM model that incorporated detailed information on all aspects of the terminus, from architectural finishes to building services. On top of the thousands of design drawings issued by the client, thousands more were generated by the construction team for fabrication and planning of the construction phase of the project. These were used to plan the construction sequence, identify potential spatial clashes and improve the project's buildability.

Managing the interface between the temporary works, the erection of the 175m-long curved steel roof and the mega-columns was no easy task, especially since the mega-columns were designed to be slender, raking pillars that depend on V-trusses transversely connected by secondary trusses to form a 3D support structure.

Given the scale and complexity of the project, a total of about 180 modellers were engaged internationally to model the roof structure, generating hundreds of thousands of drawings in the process. This does not include about 150 further modellers employed by the cladding specialist, at locations ranging from Venice in Italy to Dubai and India, to generate thousands of 3D drawings of the cladding panels and frames. Working together, client and contractor ironed out issues in virtual reality, in the process improving communication between the two sides.

BIM modelling was particularly useful for monitoring the load changes during the different phases of construction.

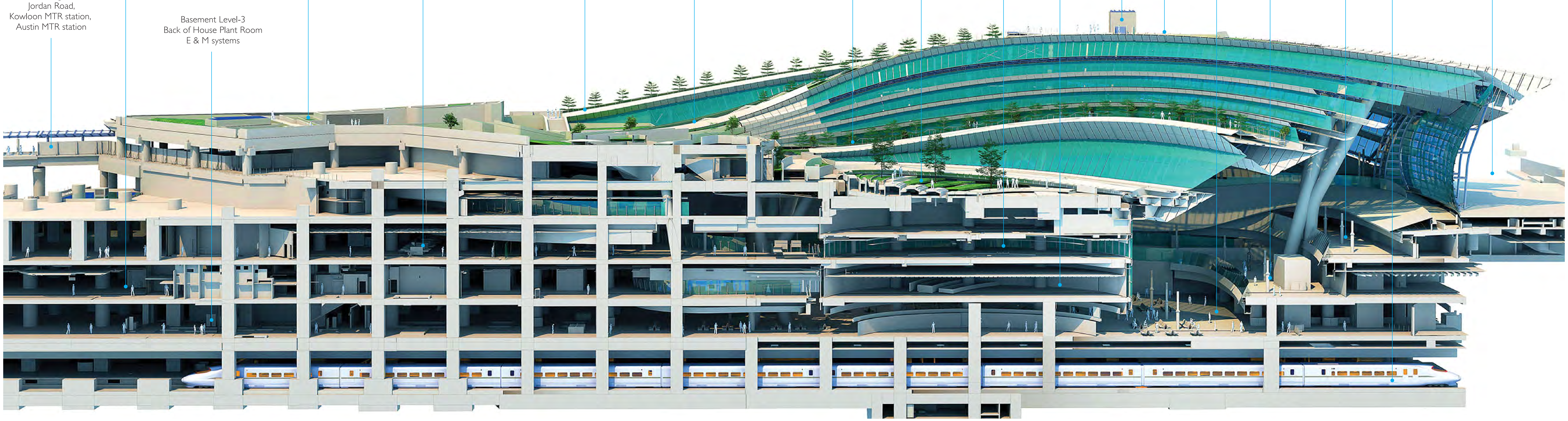
"There were 78 stages of construction and 32 load combinations for the roof alone," said Engineering Manager Mathieu Bessodes. "The roof was built before the foundation was built and we were building both the basement and the roof at the same time. The interface among different trades was incredible."

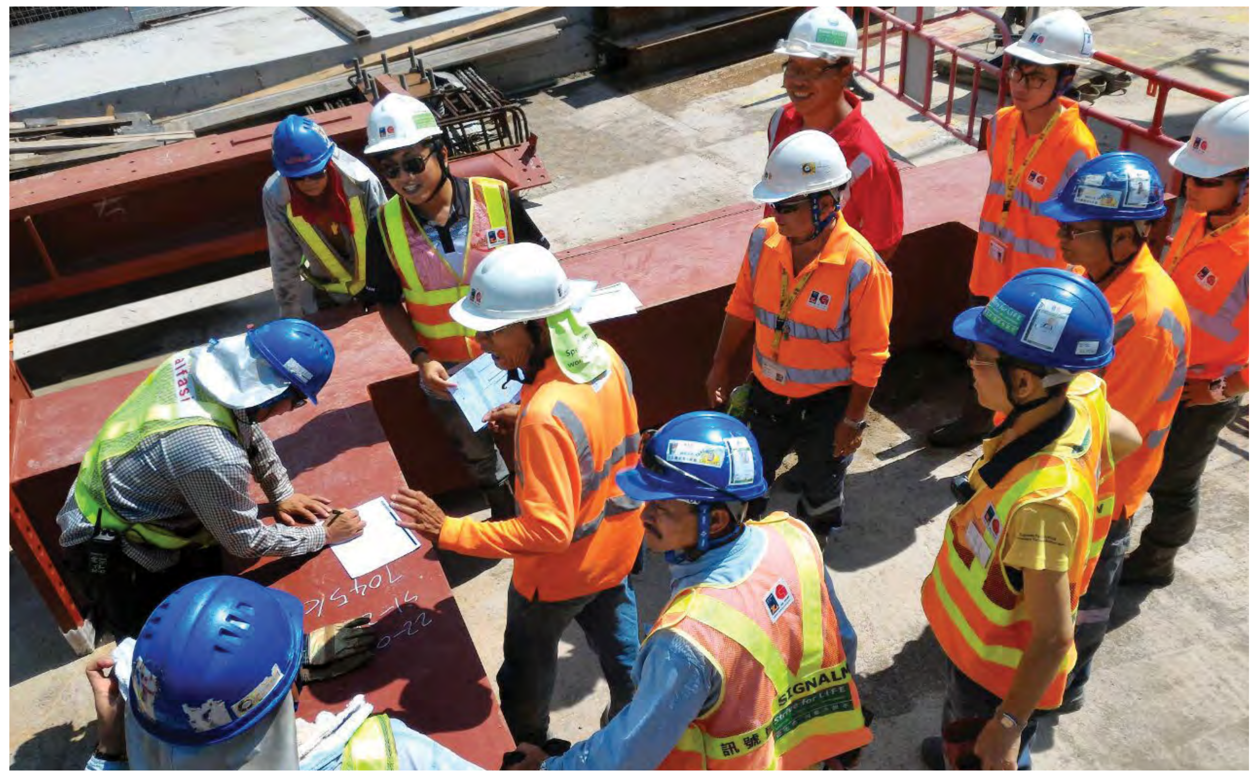
Tackling this planning and construction challenge involved the use of advanced computational methods that included erection phase analysis and 3D scanning to ensure the erected structure conformed with the designed roof geometry.

By modelling the transfer of support for 8,000 tonnes of steel from temporary works to permanent support in stages as the erection progressed, these advanced methods also ensured all works were carried out safely and efficiently. Information from survey points was compared with the 3D model to see if the erected components were within the accepted level of tolerance. As loading conditions changed under different phases of construction, the roof erection phase analysis also provided the project team with a tool for studying alternative erection methods to arrive at the one that would be most effective in handling the changes without causing any drift.

The advanced structural analysis program, Strand7, was used to carry out nonlinear geometric analysis of the changing load conditions during erection. Analysis of the interactions between the roof structure at different stages of erection and the supporting structure revealed locked-in stresses that were mapped onto the permanent roof analysis model to ensure they would not impact on the performance of the completed structure.

3D scanning was also used to check for thermal movement of the roof components after erection and the sets of data points and vertexes generated were processed and compared with the 3D design model. The technique was also employed at the fabrication yard to ensure constructed elements were accurate to +/-3mm. Complex dimensional checks of splice joints were also carried out.





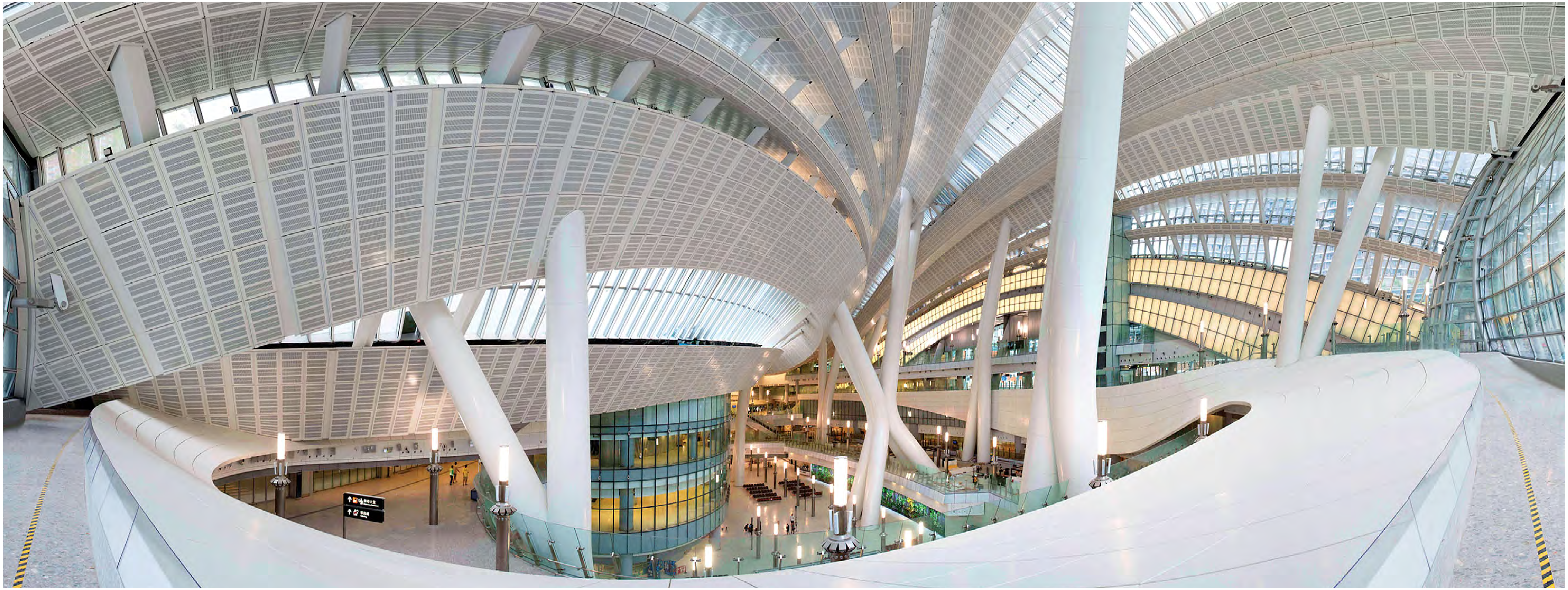
Clockwise from top left: *Customised crane with 60T at 30m lifting capacity; Pre-start morning team briefing; Undulating station atrium ceiling cladding.*

Detailed modelling and analysis using a range of software yielded solutions that made it possible to build what seemed unbuildable. What's more, the buildability was improved as a result.

For example, the roof was treated more like a bridge than a station structure in the way it was constructed and initial plans to use a strand-jacking method for roof erection, which would impose significant stress on the truss members, gave way to a simultaneous jacking method.

At the same time, the joint venture team successfully persuaded the client to switch from fibre-reinforced gypsum to aluminium panels for the surface of the mega-columns, removing an element of work from the critical path and relieving congestion on site, as the panels were fabricated off-site instead.

The team also used BIM to plan and preview construction methods, assess material quantities and study safety issues that might arise. HKWKS has proved to be highly useful for training project staff in the deployment of BIM modelling for complex projects.



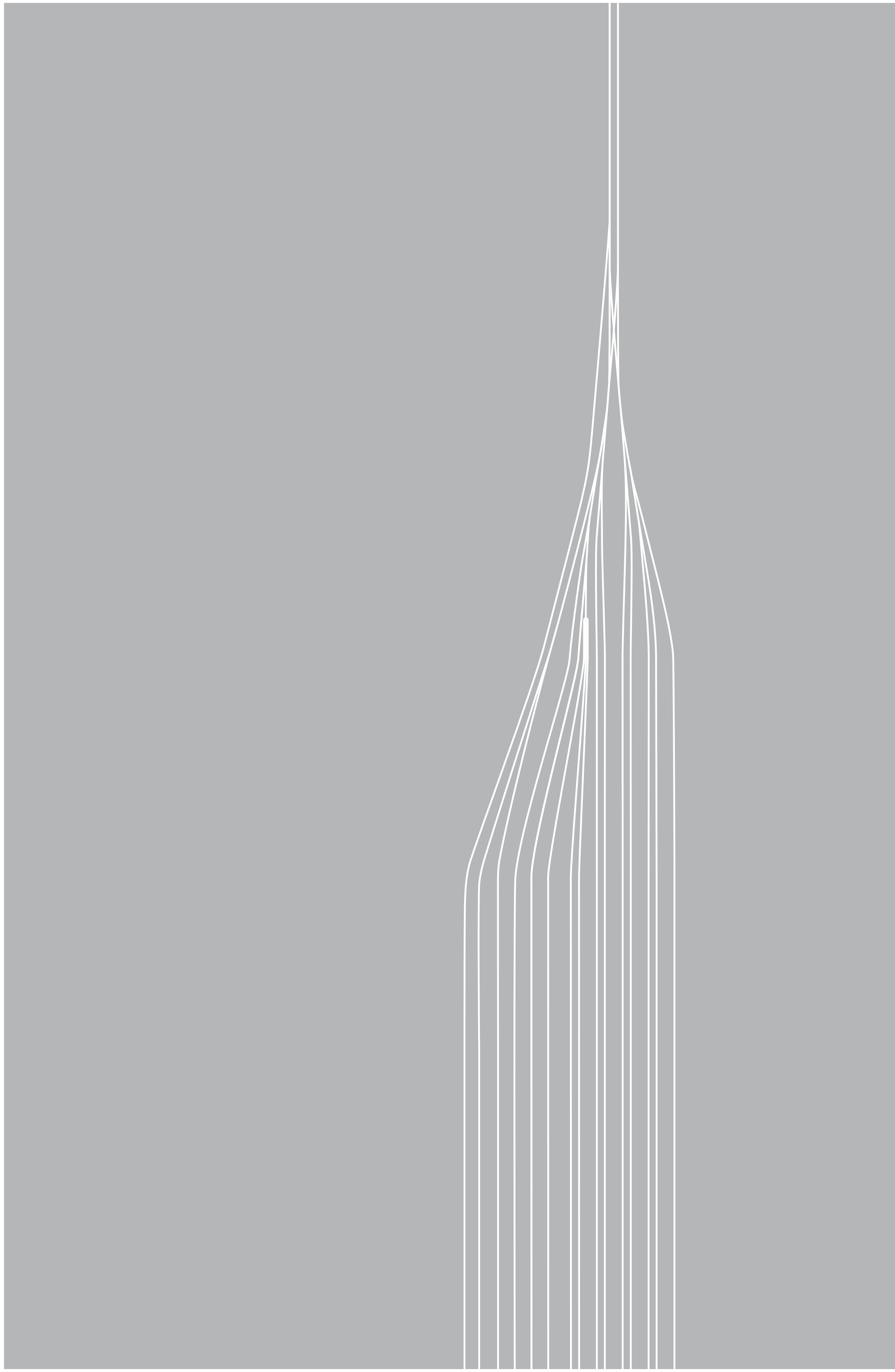
As the Hong Kong SAR Government seeks to drive the city's construction industry towards the adoption of more advanced processes, HKWKS will stand as an example of what can be achieved when all those involved in a project can collaborate virtually as well as face to face.

THE COMPUTER MODELLING AND 3D SCANNING WERE COMPLEMENTED BY DRONE PHOTOGRAPHY

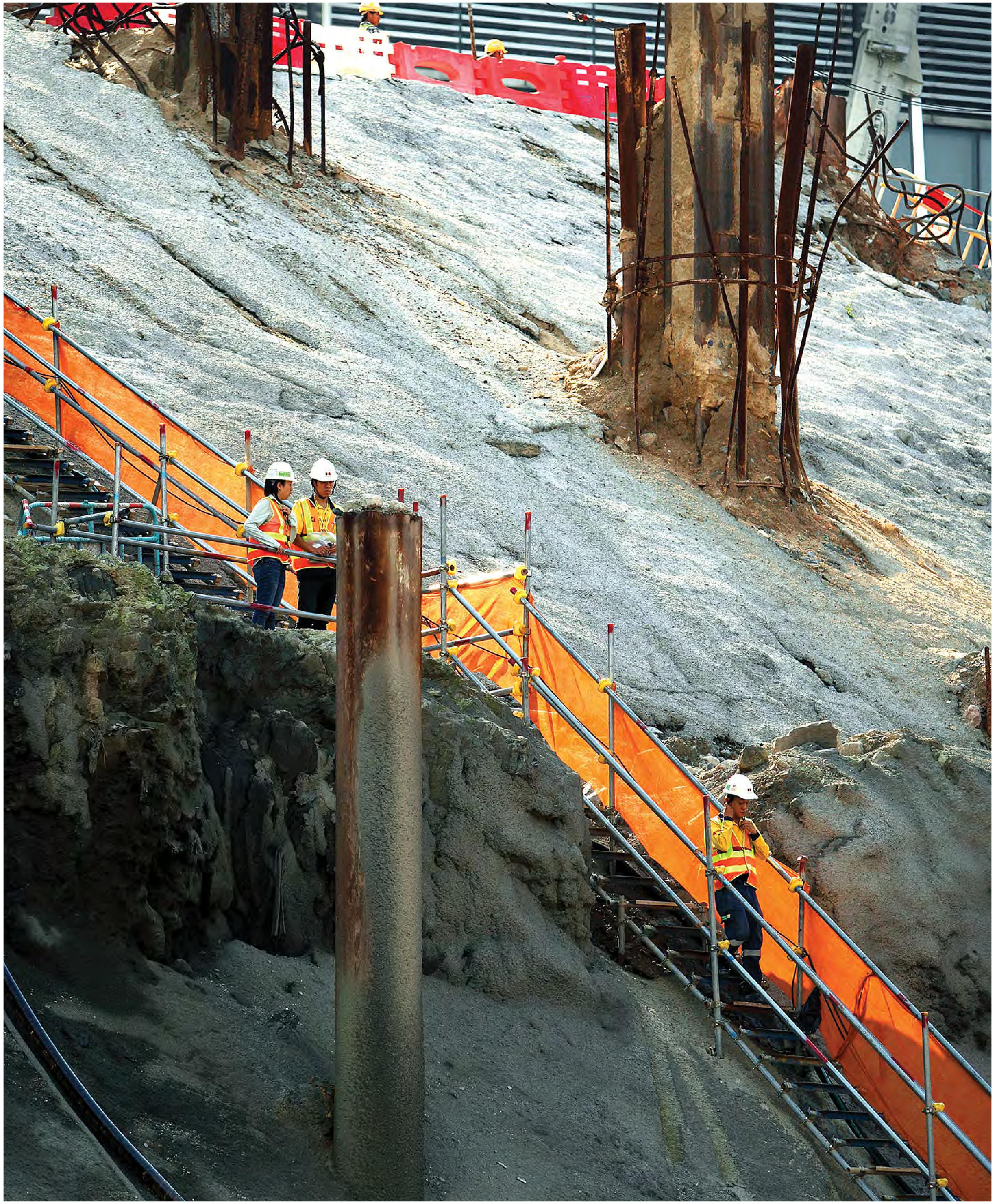
Aerial photos of the roof under construction were taken at weekly intervals to monitor movement. The drone was used to zoom in for photos of individual elements, as well as to zoom out for overall photos of the whole roof. Eighty-two monitoring points were used for the close-range photos and the data gathered was automatically processed to highlight any deflection or movement that might have occurred.

Aerial view of the station rooftop public gardens, pedestrian footbridges, access roads and three-lane vehicular Lin Cheung Road underpass and Austin Road West underpass.

COORDINATING SOLUTIONS UNDERGROUND



Top-down and 'pseudo top-down' construction required excavation inside a diaphragm wall more than 160m wide. The open-mindedness of the team to constantly adapt methods and sequences to suit engineering and physical constraints made a difference to the overall target for completion.



創新方案 理順地庫工程

香港西九龍站的面積與香港國際機場客運大樓相若，但工程的複雜性卻有過之而無不及，因為建造地庫設施時，須同時兼顧巨型上蓋的安裝工程。

工程團隊綜合了多種創新方案來建造地庫。挖掘工程需在兩幅相距160米的連續牆之間進行，北面用「從上而下」方式，中間則用「類上而下」方式。為免在下挖時架設大量重型支架支撐連續牆，團隊先在地盤中間設置插座式工字樁，圍繞樁柱澆注第二層和第三層地庫的部分樓板，再在樓板安裝臨時鋼樑支撐連續牆，讓工隊能在下面繼續進行挖土工程。

開挖地庫時，又改用創新的施工程序，以克服工程局限。團隊從地面開始，用鑽孔樁深入地底，為大型十字柱建造樁洞，再把十字柱組件放平在地面，焊接至既定長度後，用兩台大型起重機豎起，放入樁洞定位，然後才開挖地庫及建造各層樓板。這方案無須在地庫每層為十字柱預留孔洞，又可騰出更多空間方便各樓層施工，更能及早完成多間重要的機房，讓後續相關的承建商提早施工。

整項工程共開掘130,000立方岩石，當挖出15,000立方米之後發現大量岩石，須改用爆破方法挖掘。在禁爆區和靠近連續牆的位置，需同時並用傳統的鑽孔裂石法及爆破法。最後，兩種方法各採用一半，才能完成整項地庫岩石挖掘工程。

這項目本身獨具挑戰性，因為在龐大的地庫內，要同時進行大量挖土和複雜的建造工作。在同一個空間內，有大量工人同時施工，每日要移動大量建材，物流正是團隊要面對的艱巨挑戰之一。為此，他們用鋼鐵建造了18段臨時坡道—每段60米長、10米闊，以方便車輛、工料及人員進出四層地庫。

建造過程須使用大量混凝土，這方面的供應管理亦是一項挑戰。雖然地盤設有石矢攪拌廠，仍需要混凝土車輸送至工地。混凝土泵房設在地面，承建商須設法在地庫各樓層接駁喉管，把混凝土泵送到眾多施工地點。而地庫內又同時進行挖掘工作，工地實在非常擠迫，增加了工作的難度。

因工程有一面積達8,000平方米的石矢氣槽，為免這施工窒礙日間其他關鍵工程的進度，團隊特別設計了一種鋼框，在上面預鑄輕混凝土板面，方便在夜間施工安裝。

團隊同時要協調接連南、北兩面正在進行的其他工程合約，以保持敞大的地庫內，縱橫交錯的通道暢順，及進出的流動方便。項目能順利完成，實有賴全體同仁緊密合作，同心同德尋找最佳的施工方案。

Hong Kong West Kowloon Station is about the size of the Hong Kong International Airport passenger terminal building. Its function is also similar, with space allocated for police, customs clearance, immigration and quarantine. It is a far more complex project, however, by virtue of the fact all the facilities had to be built underground while for much of the time the dynamic roof was also being erected.

The tight programme was made all the more challenging by the discovery of more rock than anticipated, necessitating changes to the foundation and temporary works design. To build the terminus, a combination of methods was used, with top-down construction applied to the northern end and 'pseudo top-down' in the middle – so called because top down was only partially applied in combination with bottom-up construction.

The team commenced work on the contract in two phases, on 19 December 2011 and 16 January 2012 respectively, reflecting the phased handover of the site. At the site boundary with Contract 811B to the north, top-down construction was initially constrained by Jordan Road, which had been diverted south to an area on the site to relieve space for additional work on the diaphragm wall.

"Initially, the plan was to pre-install small socket H-piles on 6m grids then build the slab, leaving a hole for dropping in the critical columns that would support the future property development," recalled Senior Construction Manager John Adams. "But if we did that, it'd take us a long time to close the hole and work back up."

A change of plan was called for and the solution was to alter the construction sequence completely by installing bored piles instead, before starting work on the slab, to create a hole in the ground for the 130-tonne cruciform columns. Originally, the columns were to be installed in sections that were fabricated off-site, but the change meant they were laid out at ground level, welded together to their full length, lifted by two large cranes and lowered into position instead. Eliminating the need to leave openings for columns released space at every level, including the critical plant rooms, which also allowed the rooms to be completed and the designated contractors to commence work earlier.

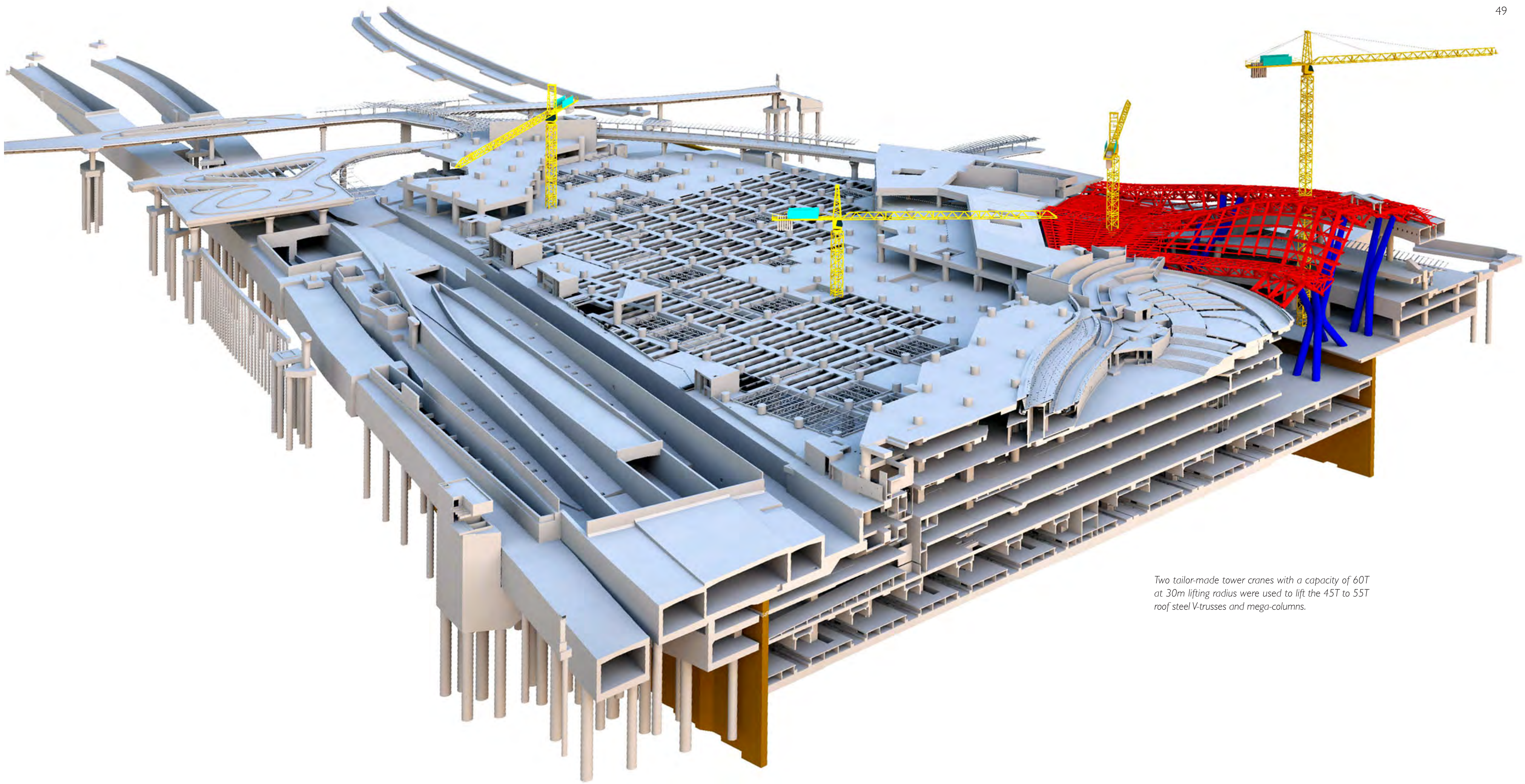
"We were constantly adapting our methods and sequences to suit engineering and physical constraints. It speaks to the open-mindedness of the team, which came up with small changes that made a difference to the overall target for completion," Adams said.

Carrying out top-down and pseudo top-down construction required excavation inside a diaphragm wall that is more than 160m wide. The heavy strutting required for such a large span could easily leave little space for anything else, so to solve the interface between the full top down and the pseudo top down, socket H-piles were installed in the middle portion and part of the final slabs for basement 2, and basement 3 was cast over them. Steel struts were then installed against the slab to create a temporary diaphragm action, thus allowing the remaining excavation to progress.

"There were many challenges because the water pressure on the two sides was not equal, which created different stresses. Lots of engineering work was involved in constantly reviewing the temporary conditions and their effect on the permanent structure," Adams said. "Once diaphragm action was achieved at basement level, we could work down towards basements 3 and 4."

THE STATION IS SIMILAR IN SIZE TO THE HONG KONG INTERNATIONAL AIRPORT TERMINAL BUT BUILT UNDERGROUND

- 175M-LONG CURVED STEEL ROOF
- 50 KILOMETRES OF INTERNAL WALLS
- 4,000 ROOMS
- 77 ESCALATORS + TRAVELATORS + 104 LIFTS



Two tailor-made tower cranes with a capacity of 60T at 30m lifting radius were used to lift the 45T to 55T roof steel V-trusses and mega-columns.

FULL RANGE OF CONSTRUCTION ACTIVITIES ACROSS THE PLATFORMS ONGOING AT THE SAME TIME

Excavation was carried out by mechanical means such as drill-and-split initially, but due to the amount of rock discovered, blasting was also introduced after about 15,000-20,000m^3 of the 130,000m^3 of rock had been removed. As some areas were not suitable for blasting, such as those within 10m of the diaphragm wall and exclusion zones around temporary supports, drill-and-split excavation was carried out in parallel, ultimately achieving a 50:50 division between the two excavation methods.

Some schedule adjustments were made to take into account the use of blasting. Each blast was timed to be carried out between 6:30pm and 7:00pm, after the main construction works for the day had finished. The explosives were delivered around midday, which allowed sufficient time for the team to lay out protective matting and check vibration monitoring and protective measures such as blast nets were in place. Initially, traditional detonators were used but these were later replaced by electronic versions, which could be timed to maintain a sustained period of blasting to reduce vibration.

The commencement of mucking out, which usually occurred at around 7:00am, was moved back to 9:00pm the previous night to allow for a longer period of clean-up. The spoil, which was removed by hydraulic grabs, was either taken away by road or sent to a barging point nearby for removal by sea.

"A lot of the rock was good quality and went to quarries to be broken down into aggregate. Some actually ended up coming back and being used in this project's concrete," Adams said.

The remainder was sent to government fill banks for future reuse.

Most mega projects involve multiple work fronts spread out over a large area. HKWKS was uniquely challenging because the bulk of the work was confined to a big basement. At the peak of construction, there were 500 workers inside the northern portion of the basement alone. Logistics proved one of the project's biggest challenges, given the number of people working within the same space and the amount of materials to be moved.

To cater to these movements, additional openings and cranage were provided to speed up delivery of materials to the track area at the bottom basement. This entailed the construction of 18 steel ramps, each measuring 10m wide and 60m long, to provide access to the four levels of basement. Small cranes were employed to work in the limited headroom and many lifting facilities were cast into the structure to allow for the dismantling of temporary works, to yield more space.

"We also developed a remote-controlled excavator that was modified into a transportation platform for struts so the struts could be driven into position and lifted into their final position," Adams said.

Managing the supply of concrete was a major challenge too, given the volume involved. The basement levels were made of 1.5- to 2m-thick slabs with basement 4 being the thickest. Concrete trucks were brought in to supplement the supply from an on-site batching plant. From concrete pumping stations at ground level, the team also had to find ways to route the pump lines through every level. With excavation continuing underneath, it made for a very congested basement indeed. By the end of the project, however, the team had overcome the learning curve associated with large concrete pours in a confined space and managed to complete up to 2,300m^3 in a single pour.

Above: *Passengers pass through the ticket barrier at Basement Level-3.*
Below: *Departure concourse.*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An important change was also made to the construction of an 8,000m^2 plenum, which took it off the critical path. Hanging below the slab at over 8m high, the erection of falsework to facilitate its construction would have interfered with basement works. There was also concern over the safety of workers given the accumulation of fumes within the confined environment with a very restricted 800mm of headroom.

The team's solution to this conundrum was the development of a steel sub-frame with light, built-in concrete panels that could be precast and installed during the night shift so as not to interfere with the other basement works at daytime.

After platforms 5-8 were handed over to the MTR designated trackwork contractor, both architectural builders' works and finishes and tracklaying works commenced, while rock excavation and concreting works continued on the other tracks to address the programme constraint.

"We had the full range of construction activities across the platforms ongoing at the same time. The central area was finished first; the other works were split into two, west and east, with their separate logistics," said Senior Construction Manager K.W. Lee. "It was also important to coordinate the logistics with adjacent contracts to the north and south because we couldn't rely on our own logistics alone."

As an example, the underpass, which sits on top of the basement 1 slab, was handed over to 811B so they could continue with the excavation underneath. At the same time, three key locations that had minimal impact on other activities were identified and used to continue with 810A works.

"Top-down construction is always a challenge to the completion of the secondary concrete. There's a programme downside to making the work simpler to construct; we adopted the optimum solution but had huge challenges in completing the secondary concrete," Lee said.

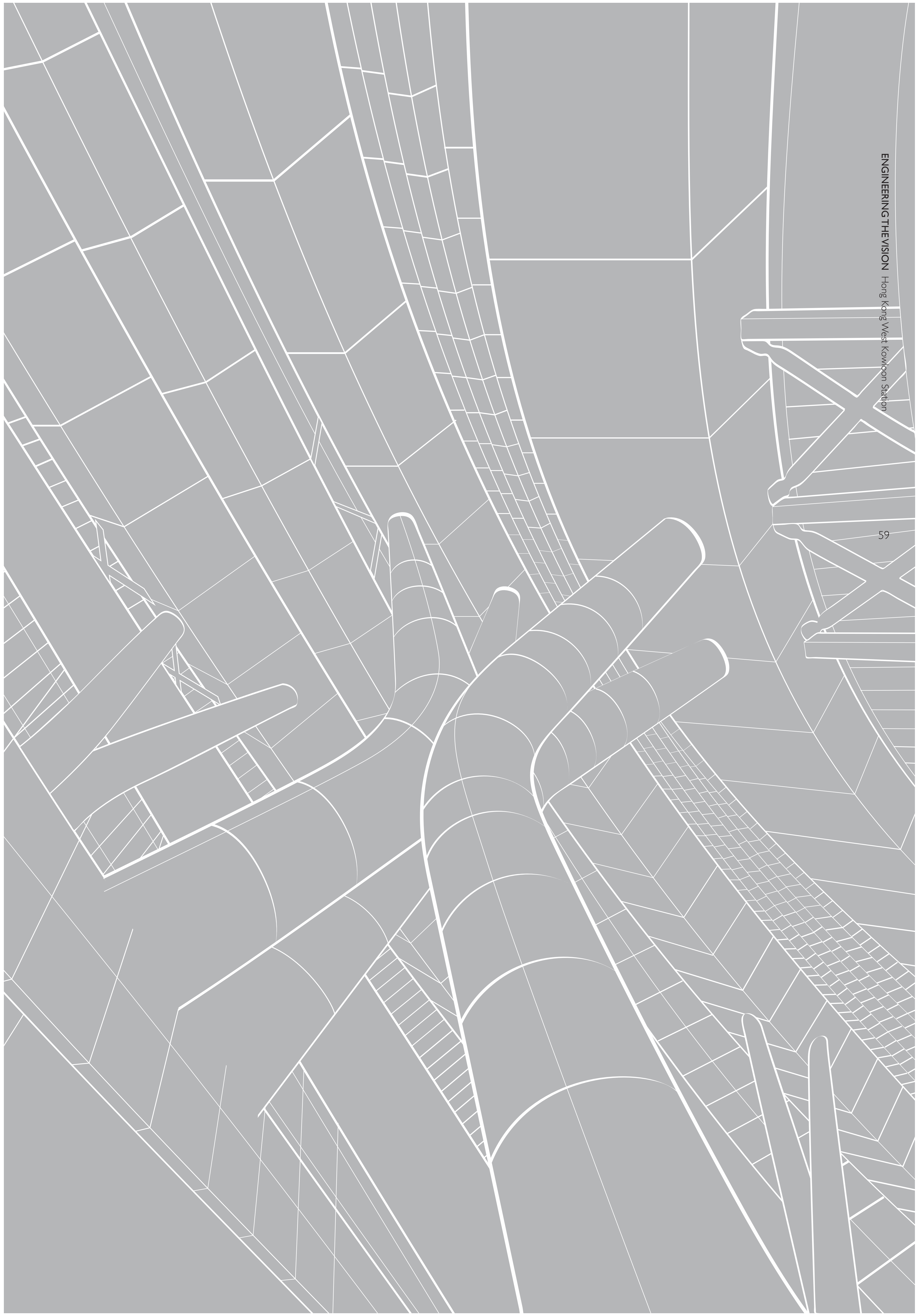
Access to the basement was provided at basement 1 level initially but moved to ground level later. Interface management to coordinate the different activities was essential to maintain horizontal access across the site. For vertical access, the best possible location given the layout was selected for crane openings and the installation of material hoists, to minimise disruption to construction activities.

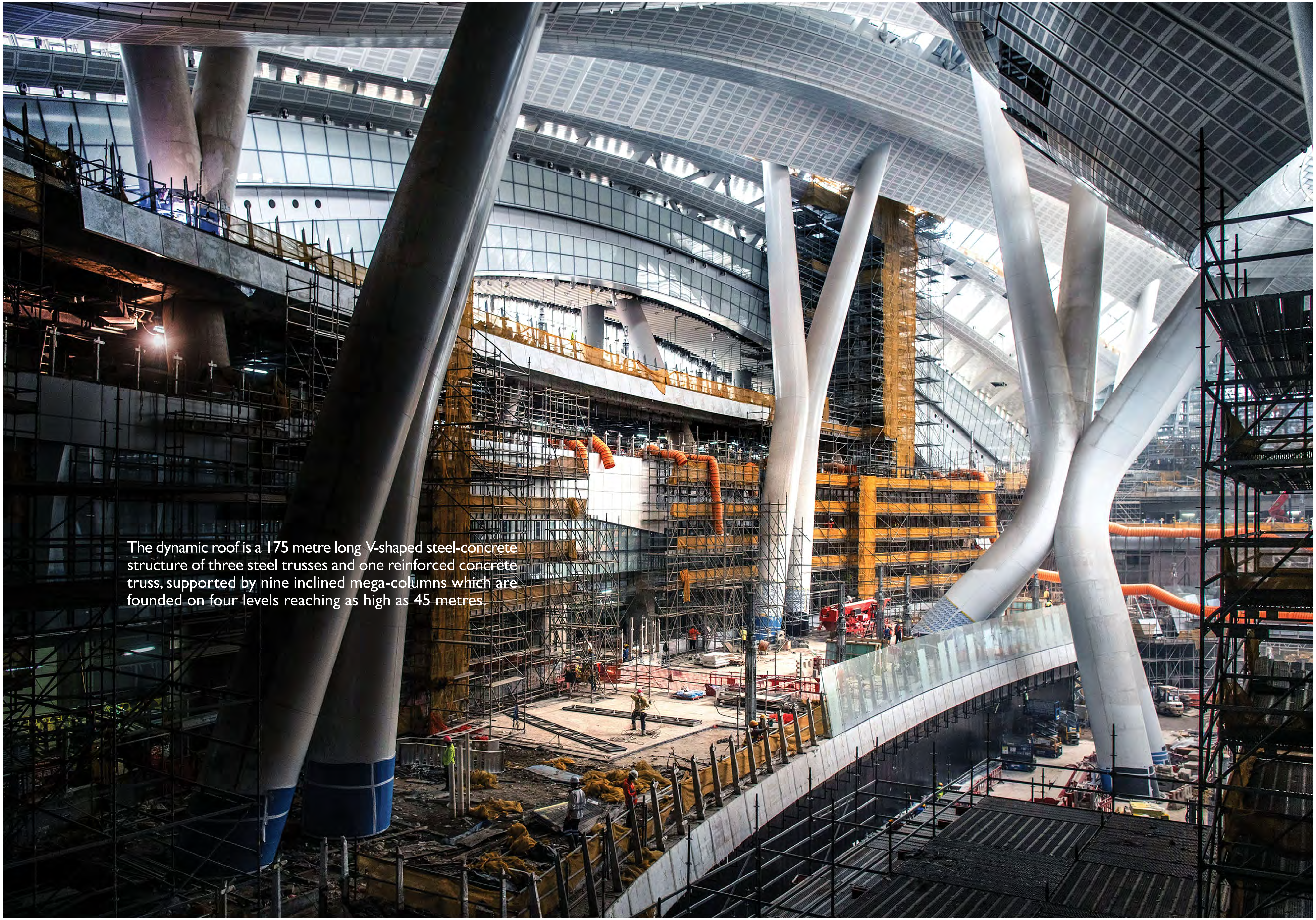
"The project's success has a lot to do with the people who were able to work closely together to coordinate solutions, particularly at basement 4, where there were so many teams working under so many different managers," Lee said. "The key challenge was the logistics of carrying out so much work deep underground while maintaining a safe working environment for the workers and keeping up with progress."

Left to right from top:
Cruciform columns installed for the future development structures above the HKWKS building;
B3 passenger check-in entrance;
Level B4 train platform;
Top-down construction of the atrium;
On-site concrete batching.

The project's success has a lot to do with the people who were able to work closely together to coordinate solutions.

BRIDGING OVER MEGA-COLUMNS





The dynamic roof is a 175 metre long V-shaped steel-concrete structure of three steel trusses and one reinforced concrete truss, supported by nine inclined mega-columns which are founded on four levels reaching as high as 45 metres.

彌合支柱與橫樑 呈現流線型上蓋

香港西九龍站已成為西九地區的一個新亮點。車站上蓋是一個175米長的鋼與混凝土複合結構，由三條V形鋼製桁架樑和一條鋼筋混凝土大樑組成。每條鋼製桁架樑濶12米、深6米，從北至南隨上蓋的弧度伸延。九組傾斜的巨型支柱從地庫四個不同樓層崛起，承托整個別具動感的流線型上蓋。

上蓋的中段和南面設有穩定系統連接三條主要桁架樑，以限制結構橫向擺動；三條桁架樑之間設有關節副樑，副樑上再伸出肋片，用以安裝屋頂的鋁板和玻璃板；鋼桁架樑和鋼筋混凝土大樑的北端上面，則澆鑄混凝土樓板，作為園景工程的地台。

地盤面積龐大，地下又同時進行挖土和地庫工程。如果用傳統安裝上蓋的方法需要用上大量通架，亦會與地庫工程發生衝突，所以在此並不可行，因此，團隊重新制訂程序，利用中央穩定系統這個固定結構來支撐安裝上蓋，從而大幅減少臨時承托工程。

團隊參照架設橋樑的方法，用平衡懸臂法從中央穩定系統開始分段安裝鋼桁架。但由於空間有限，未能裝置慣用的大型承重座，團隊於是與瑞士製造商合作，特別設計了兩個並排、體積較小的承重座，來吸收懸臂的擺動，和支撐吊裝桁架的重力。末端錨定的桁架，待其他懸臂分段安裝妥當後才架設。整個上蓋安裝過程分78個階段進行，其中涉及32種不同的負重狀態，過程非常複雜。

為配合緊迫的進度，每條V形桁架被劃分成16段，分別在泰國和中國製造，透過建築信息模擬(BIM)技術進行監控，確保每件構件的尺寸和弧度準確無誤。

此外，團隊建議用預製鋁板替代纖維補強石膏板來覆蓋巨型支柱，這樣可以減少在擠迫的地盤內進行最後修飾的必要。而且鋁板比石膏板更輕、更容易處理，安裝過程亦不受天氣影響，對工程進度大有助益。

上蓋不規則的曲面對製造和安裝面板亦構成重大挑戰。因項目涉及超過17,000塊鋁板和接近4,000塊玻璃板，所有面板大小形狀各異，而且安裝後必須緊貼上蓋的三維立體幾何形狀。由於工作量異常龐大，專家把上蓋覆面劃分成多個區域，分派給300位分佈世界各地的三維模型技術員和繪圖員進行面板設計。

為確保能準確地從倉庫提取特定的組件，團隊用無線射頻辨識標籤(RFID)技術追踪運送到工地和已安裝的面板和構件。又利用航拍機進行立體拍攝，然後把掃描所得的三維數據傳送到建築信息模擬(BIM)進行分析及公差檢查。

地盤內亦架設了一個重2000噸、工程團隊稱之為「鳥籠」的巨型棚架，內有懸掛平台和起重絞車，用以搬運工料，減少對工地天秤的依賴。當工程不斷進展，團隊亦要不斷更改「鳥籠」，以配合安裝各組不同形狀的巨型支柱，所以要與其他隊伍保持緊密聯繫，互相協調。

THE MULTIPURPOSE GREEN ROOF

A commanding presence in West Kowloon, HKWKS's dynamic roof is a 175m-long V-shaped steel-concrete composite structure consisting of three steel trusses and one reinforced concrete truss. They are supported by nine inclined mega-columns founded on four levels – basements 3, 2 and 1 and the ground floor – and reaching as high as 45m. As they reach up towards the roof, they branch out into 12m-wide and 6m-deep trusses that follow the roof's curvature from north to south.

To counter lateral movement, the structure is supported by two stability systems: the central and the south, which are linked to the three primary steel trusses. The former is a rigid frame structure that provides overall lateral stability along with the surrounding concrete structures while the latter provides stability against east-west movement only.

Between the three steel trusses, articulated steel secondary members support tertiary steel fins that in turn support aluminium cladding and the angled glazing that allows natural light to penetrate the deep station. At the north end, concrete slabs cast on top of the steel trusses and planar composite steel trusses provide the base for a landscaped deck.

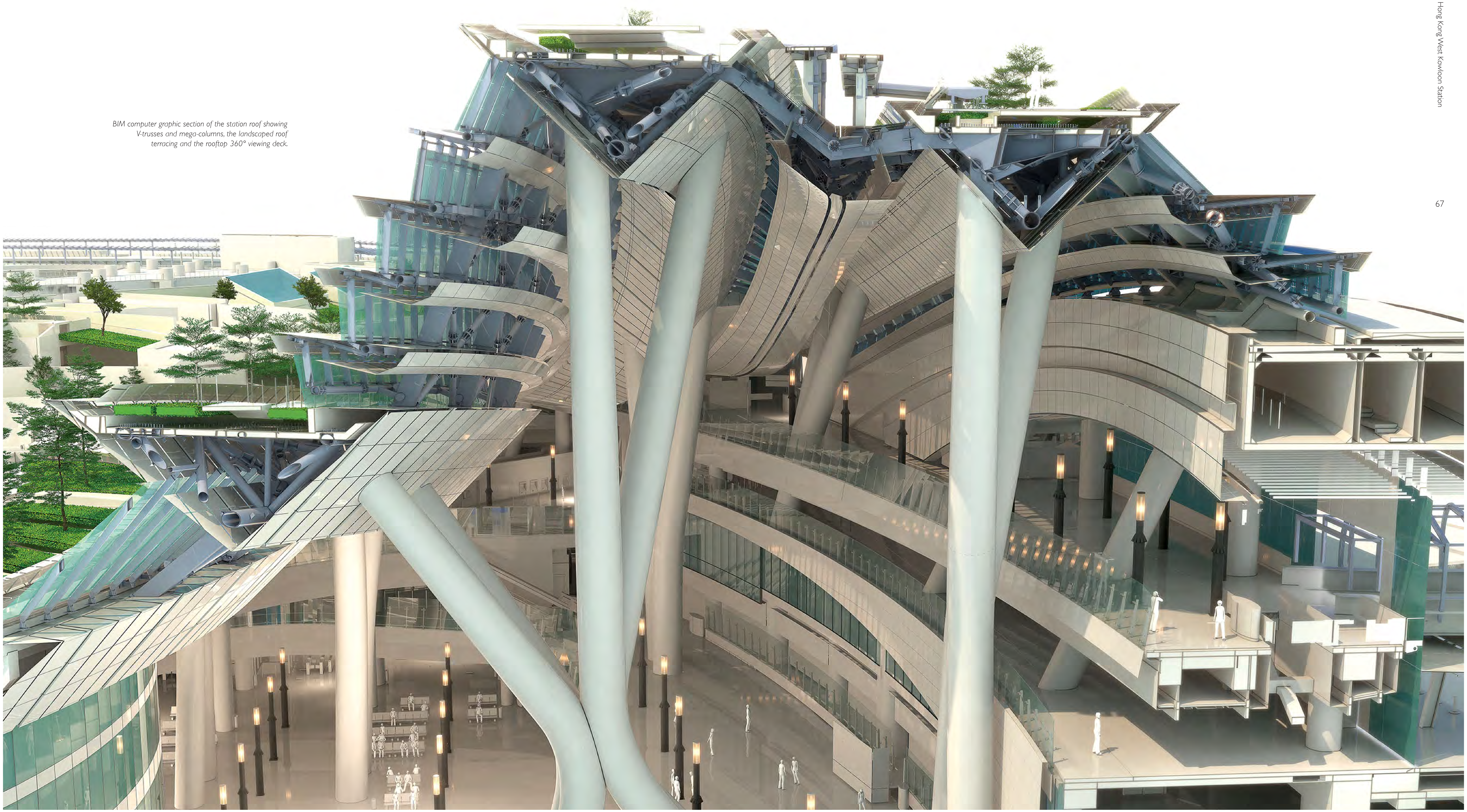
Erecting the 8,000-tonne roof structure required setting up 4,000 tonnes of temporary steelwork. While a conventional approach would have involved installation of sufficient falsework to fully support the entire roof while it was being winched into place, this was clearly not practical with a 30m-high atrium in which so many other construction activities were happening at the same time. So instead of building the roof from north to south, as originally planned, the erection sequence was revised to take advantage of the permanent support structures.

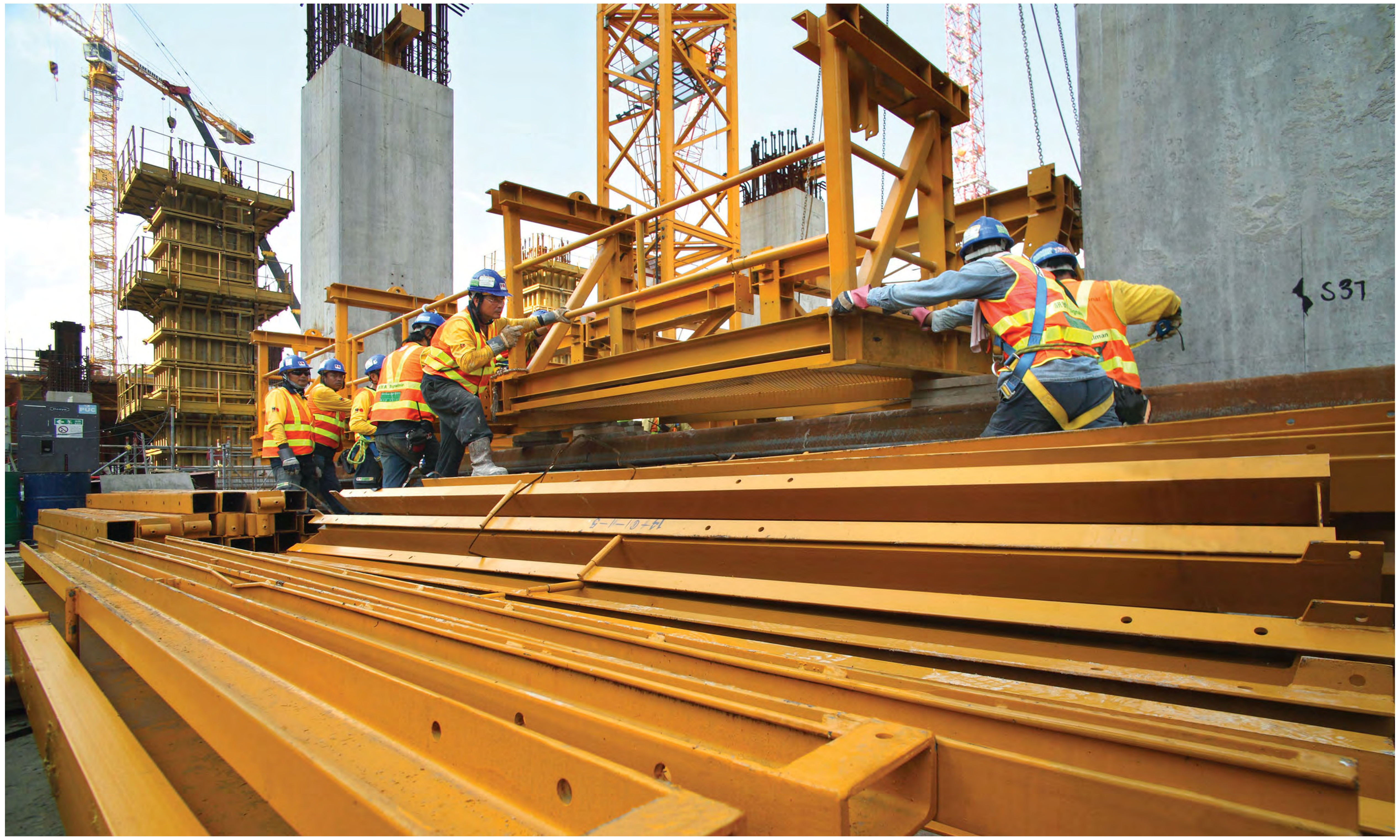
The 3-hectare Hong Kong West Kowloon Station public gardens include the rooftop terrace pathway and greened steps leading to the Sky Corridor and 360° observation deck overlooking Victoria Harbour.

- 16 SECTIONS FOR EACH ROOF TRUSS
- 18,000 ALUMINIUM ROOF PANELS
- 4,000 ROOF GLASS PANELS
- 1,141 ALUMINIUM PANELS PER MEGA-COLUMN

THE 8,000T ASYMMETRICAL + 3-DIMENSIONAL CURVED ROOF STRUCTURE INSPIRED INNOVATIVE FABRICATION TECHNOLOGY + EFFECTIVE LIFTING SCHEMES

BIM computer graphic section of the station roof showing V-trusses and mega-columns, the landscaped roof terracing and the rooftop 360° viewing deck.





"We couldn't fill the whole atrium with falsework so we came up with a better idea," said Engineering Manager Mathieu Bessodes. "The central stability system is the backbone of the roof horizontally so we decided to minimise the amount of temporary works we needed by relying on the permanent works and starting the erection from the central stability system and working concurrently northward and southward."

Starting with the middle span, the steel trusses were erected using the balanced cantilever method – like a bridge. Remote-controlled hydraulic jacks were used to move the V-trusses into position with two jacks installed under each section of a truss. The team had developed a checking system that improved control of the hydraulic jacks, ensuring the pressure they applied was the same and they could be handled incrementally and simultaneously. The need for some of the temporary support was removed as a result of using these jacks. 3D scanning was used to check for thermal movement after erection with the positions of the survey points compared with those in the BIM model to determine if any movement was within the level of tolerance.

"Every load combination went through a series of engineering checks and analyses to make sure the structure would stand up to it," Bessodes said. "Sensitivity studies were also performed with various parameters at different stages of construction to analyse the interactions between the sub- and super-structures. These studies helped us develop the effective erection schemes and ascertain the design parameters and modelling methods simulating most accurately the boundary conditions, properties, erection sequence and construction methods."

The end cantilever was erected after the other sections were in place. Because there was little space for the large conventional bearings to be installed to absorb the forces of uplift and movement at the cantilever, the team worked with a Swiss manufacturer to develop two smaller bearings.

"The bearings are made of elastomeric rubber and have never been used in Hong Kong before," Bessodes said. "They are twice as strong as standard bearings but smaller so you can reduce the space you need to fit them."

Weighing 1.8 tonnes each rather than the 12.5 tonnes of a conventional uplift/guided bearing, the bearings take up much less space. They operate like jacks: injected resin hardens into a rubbery material, effectively preloading them. Care was taken to ensure the load was equally shared between the bearings.

The V-trusses were fabricated in Thailand and China to tie in with the programme. The more complex elements were fabricated in the former, where the expertise was already present, and the different pieces were shipped between the two manufacturing bases for pre-assembly to ensure fit. In fact, the calculations for each section of each truss were sent over to the other factory as soon as the member was fabricated, to confirm their accuracy.

"Each roof truss was separated into 16 different sections of what I'd call 'Toblerones', because of their complex triangular geometry, for fabrication," explained Senior Project Manager W.L. Yeung. "No 2D drawing can express the 3D curvature so we had to rely on the BIM model to ensure each member's length and curvature were correct. I don't think there is another project in Hong Kong that is as reliant on 3D modelling."

Special transport frames were also constructed to bring the sections to site, with each designed to support members with different curvatures. Five to six members were transported to Hong Kong each time.

ROOF ERECTION WENT THROUGH 78 STAGES AND 32 LOAD COMBINATIONS

Above: *Steel formwork for concrete columns.*
Below: *Station front entrance 'eyebrow' external glazing.*

MEGA-COLUMNS

According to the original design, the X-shaped or V-shaped mega-columns were to be clad in glass-reinforced gypsum. However, given the amount of finishing work that would have been required on a congested site and the need to achieve watertightness before the glass-reinforced gypsum surfacing could be applied, the team offered an alternative that was eventually accepted. The glass-reinforced gypsum was replaced with aluminium panels that could be prefabricated off-site, like the mega-columns themselves. The aluminium panels were lighter and therefore easier to handle and, being fabricated in a factory, it was easier to control their curvature and texture. Their installation was also weather-independent, which was a boon for the overall programme. Polishing the glass reinforced gypsum would have required clearing the site of other workers, so its replacement with aluminium panels was advantageous for the programme as well. The fabricator, however, had to pay close attention to the panels' 3D geometry, which needed to conform with that of the columns.

"The columns have 3D geometry so the aluminium panels must be in 3D as well. There is very little deviation tolerance – 3mm horizontally and about 5mm vertically – so to make sure they're fabricated accurately we did 3D scanning of the cladding profile first," said Senior Project Manager Alex Yui. "There are about 1,100 aluminium panels per column and each column was divided into four sections for fabrication. It was quite a learning curve for the draughtsmen who translated our 3D drawings into 2D drawings for the fabrication sub-contractor."

To determine whether the sub-contractor had the ability to make so many 3D aluminium panels, bidders were required to produce mock-ups for assessment before two factories were finally selected.

The mega-columns were pre-assembled at the factory to ensure fit before they were transported to site by flatbed lorries. Erecting the mega-columns involved modifying the falsework set up for the roof works. The sequences of works for the roof and the mega-columns were closely coordinated to avoid disruption and changes were made to ensure, for example, working platforms could be in place for one without getting in the way of the other. Accommodating these changes of sequence meant the factory was sometimes called upon to find extra storage space for column sections that were already fabricated but could not yet be brought to site.

The falsework for the roof works, as well as the scaffolding set up for installing the cladding, were modified to fit installation of the mega-columns, and special 4m x 2m frames were designed for transporting and lifting the column panels into position.

9 SETS OF INCLINED + CURVED MEGA-COLUMNS REACHING UP TO 45M

Above: *Temporary mega-column supporting works.*
Left: *Station roof under construction with temporary central stability system in red supporting the roof trusses.*

CLADDING

INSTALLATION OF 18,000 ALUMINIUM PANELS AND 4,000 GLASS PANELS OF DIFFERENT SHAPES AND SIZES

The roof curvature presented as much of a challenge for those responsible for fabricating and erecting the cladding as for those who worked on the steel trusses and mega-columns. In total, the project involved the installation of about 18,000 aluminium panels and about 4,000 glass panels – all of which had to conform to the 3D geometry and were therefore asymmetrical. There were also more than 100 types of extrusion for the panels' backing frame, considerably more than the 20 or so different types typically needed on a project of such a size. Given the volume of cladding materials required, about nine fabricators were appointed to supply the aluminium panels while subframes were provided by 11 different fabricators. The glass panels, however, were all provided by one supplier with backup to cater for events that might have affected the supply and fabrication. A team of about ten engineers was deployed in mainland China for quality control and logistics management to ensure the products were up to standard and in line with progress requirements.

"Supply chain management was critical. We couldn't use just one or two companies for the work because we had to make sure their productivity could match the installation rate on site," Yui said.

Given the volume of work involved, the cladding specialist divided the panels into different zones and assigned design responsibilities for them to 300 3D modellers and draughtsmen spread across cities around the world. Their design was fed into a combined model and fine-tuned before being sent to a number of manufacturers chosen for their ability to match the installation programme, as well as their experience.

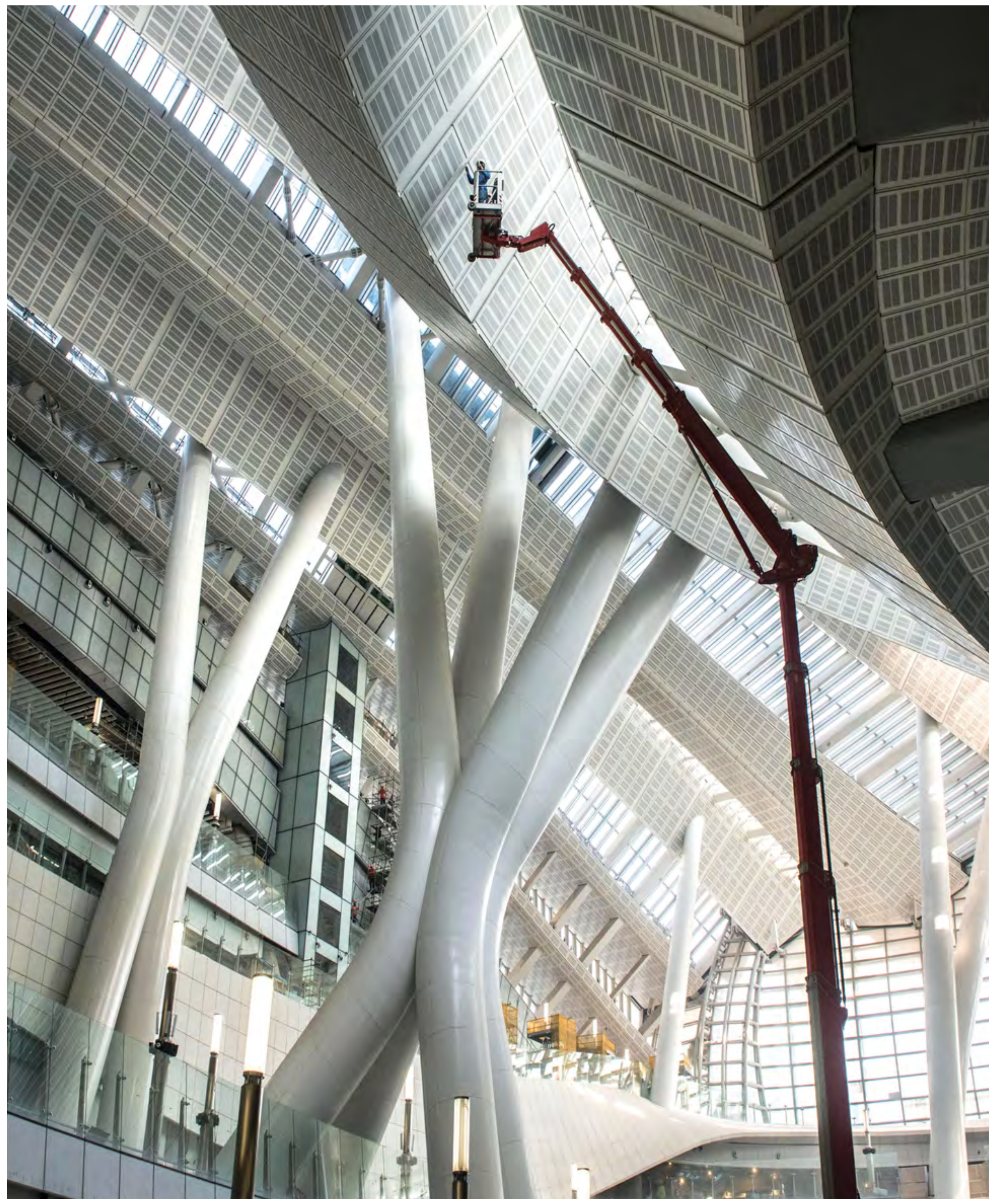
"There were vision glass, spandrel glass, aluminium frames and sub-frames. Each member could involve four factories. There were many non-typical elements, all of which had to be translated into 2D drawings for the factories," Yui said. "There were instances where the drawings were flipped and panels were made the wrong way round."

3D scanning using drone photography was applied to check tolerances, with the scanned data fed into the BIM model.

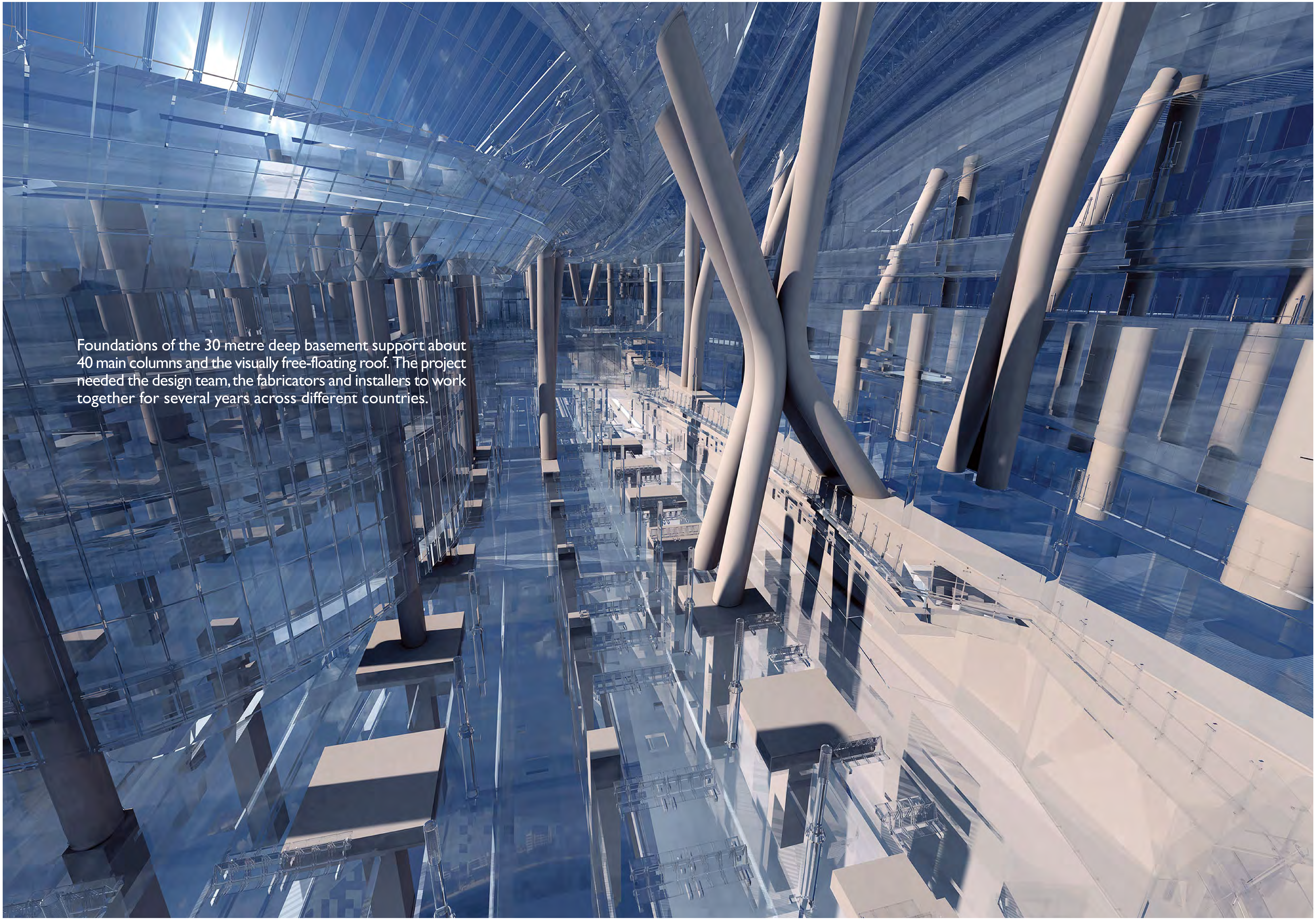
Radio frequency identification was used to keep track of panels and members shipped to site and installed, thereby improving the team's ability to retrieve the correct items from storage.

The 'bird cage', as the 2,000-tonne scaffold was called, was erected by more than 200 scaffolders to provide access for the cladding works. Used for the first time in Hong Kong, the scaffold system was unique in that it came with hanging platforms and a hoist system for materials handling, which reduced reliance on the tower cranes. As the mega-columns were installed concurrently, the bird cage was modified as the works progressed, requiring close coordination between two teams. They were not the only people on site, however, and to avoid delivery trucks for different teams crashing into the scaffold, it was protected by water barriers filled with concrete.

"The bird cage, with its working platforms suspended from the steel roof, was an innovative solution for this project. Hong Kong doesn't have any other place with such a big atrium," Yui said. "The complex roof structure needed the design team, the fabricators and installers to work together for several years across different countries. It was important we partnered with the MTR, the design engineers and the construction team in monitoring progress and planning the schedule."



Top: *Steel mullions to support the glazing.*
Below left: *Installing the roof internal aluminum cladding.*
Below right: *Welding of steel subframe to support aluminium cladding.*



Foundations of the 30 metre deep basement support about 40 main columns and the visually free-floating roof. The project needed the design team, the fabricators and installers to work together for several years across different countries.

CHOREOGRAPHING TRAFFIC DIVERSION + UTILITIES PROTECTION

A key challenge was to protect and divert utilities long buried under a busy road network, a critical element being the construction of a three-level vehicular underpass to provide additional road capacity in the West Kowloon area.

編排交通改道 保護公用設施 有條不紊

香港西九龍站須建造六條行人天橋和兩條行人隧道，接通鄰近的港鐵柯士甸站、九龍站、圓方商場，以至西九龍海旁，令整個地區更加四通八達。

建造車站主體結構和行人通道網絡時，保護公用設施和編排交通改道是工程團隊要面對的重要挑戰。

工程進行期間，無可避免會遇到一些年代久遠的地下公用設施，在某些地方要用類似考古發掘的方式來尋找，然後用大量預防措施保護它們。必要時，甚至要作出遷移。其中一項改動涉及四條處於連續牆兩側的下水道，而且工程受潮汐漲退影響，風險極高。

在連翔道進行建造工程時，發現了一些老舊的公用設施，迫使要更改某些樁柱的設計來遷就。在設施密集的位置種樁時，團隊會先在樁柱位置安裝導向鋼管，並在周圍放置沙包和混凝土，為設施營造保護層。

周邊行人連絡道的建造工程，往往受制於車站結構的施工進度。連接柯士甸站的行人隧道，既要貫通，又不能影響該站的日常運作，工程極富挑戰性。

項目的另一個重點，是興建三層行車隧道網絡，以增加西九龍地區的交通容量。最初的計劃是分階段進行行車隧道工程，以盡量減少對交通的影響，但由於工期緊迫，又要配合地底的工程進度，必須改變計劃，暫時封閉部分連翔道，把交通繞道至雅翔道和廣東道，以加快行車隧道的建造工程。

這些交通改道措施涉及七個區域，共13條三線或四線的行車道，覆蓋範圍長達10公里。又由於改道範圍牽涉810A地盤以外的地方，團隊必須細仔調整施工程序，確保這些改道措施能銜接鄰近工程合約的建築計劃。

整項工程進行期間，曾多次實施交通改道。每次變更臨時行車道時，只能在晚上11時後進行，並須在翌日早上7時前完成。要在這數小時內編排130名工人，遷移大量道路分隔屏障到新定位，這管理計劃和統籌工作本身就是一門藝術。

ARCHAEOLOGICAL EXCAVATION METHODS USED TO UNCOVER AND PROTECT UTILITIES

HKWKS is not just about connecting Hong Kong with the rest of China, but also connecting West Kowloon with wider Hong Kong. Like an octopus, the terminus has tentacles extended towards neighbouring areas in the form of six footbridges and two subways, connecting it to Austin and Kowloon MTR stations, the mixed-use development Elements, and the waterfront. In total, some 55,000m^3 of concrete was poured for the road network alone.

A key challenge associated with construction of these linkages and the station's structure itself was the need to protect and, where necessary, divert utilities long buried under a busy road network. Traffic diversions made up another significant challenge, as the project involved construction of a new underpass and the constant shifting of traffic lanes to facilitate formation of the underground station.

"There are telecommunications cables that feed all the trading desks in the International Commerce Centre, 63 11kV electricity cables, gas pipes, water pipes that supply the whole district and cooling mains that feed the government headquarters in Yau Ma Tei, so we had to be extremely cautious," said Senior Project Manager Andy Barton. "We had to use archaeological excavation methods to uncover the utilities and lots of preparation work was involved in protecting them."

Old utilities were uncovered along Lin Cheung Road and in some cases prompted changes to the pile design with the location of some piles being moved. Where piles were driven in areas dense with utilities, guide rings made up of steel pipes were installed around the pile locations. Protective layers of sandbags and concrete were then placed on top of the utilities before the piling rigs were moved into position. This was a project in its own right, as one footbridge involved the construction of ten columns supported by multiple piles under the pile caps, which could only be constructed once the protective layers of sandbags and concrete were removed.

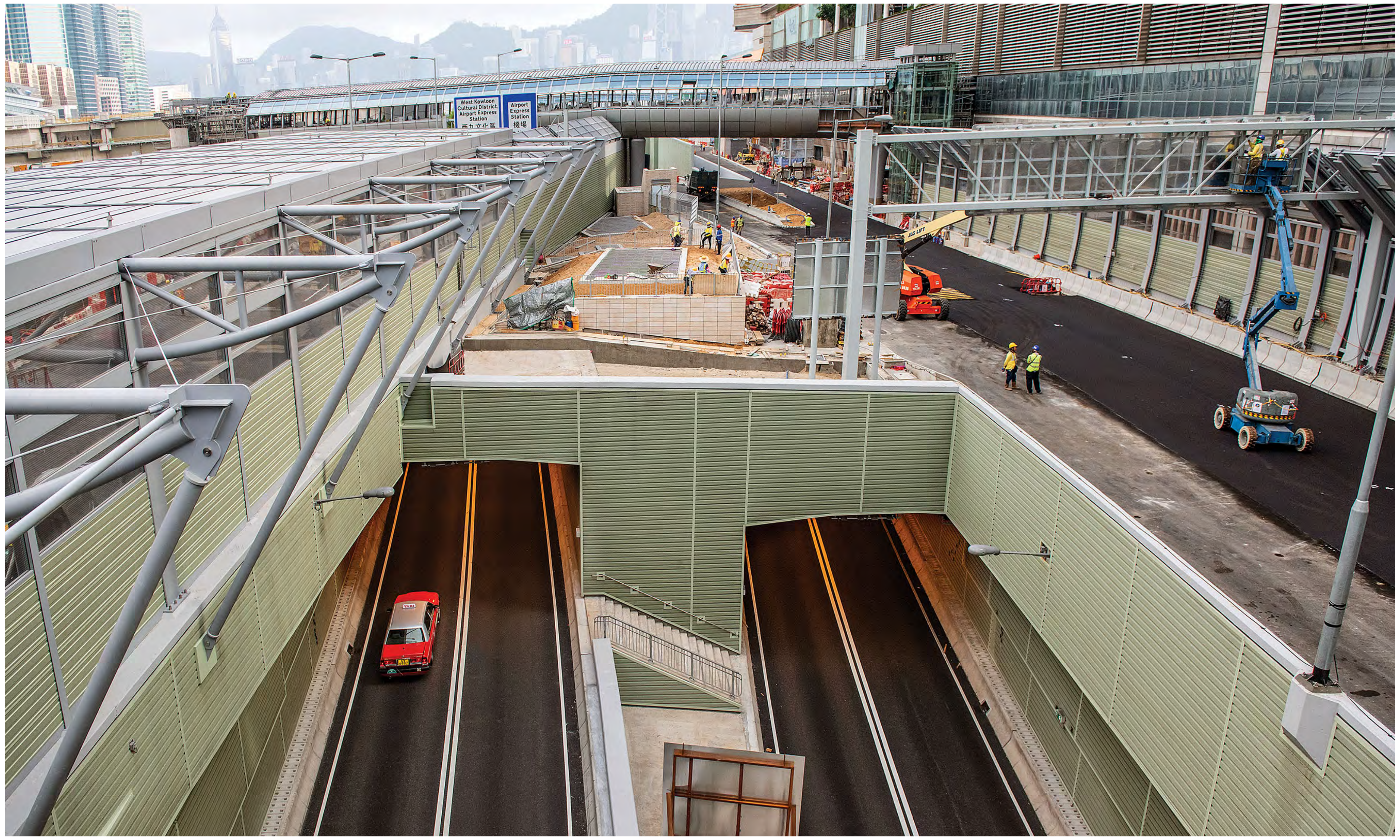
Construction of the footbridges was not only affected by the presence of so many old, unmapped utilities, but also the programme for the station and structures to which they were connected. Programme changes were also made in order to build a temporary roundabout between two Austin MTR station buildings so that Wui Man Road could be closed.

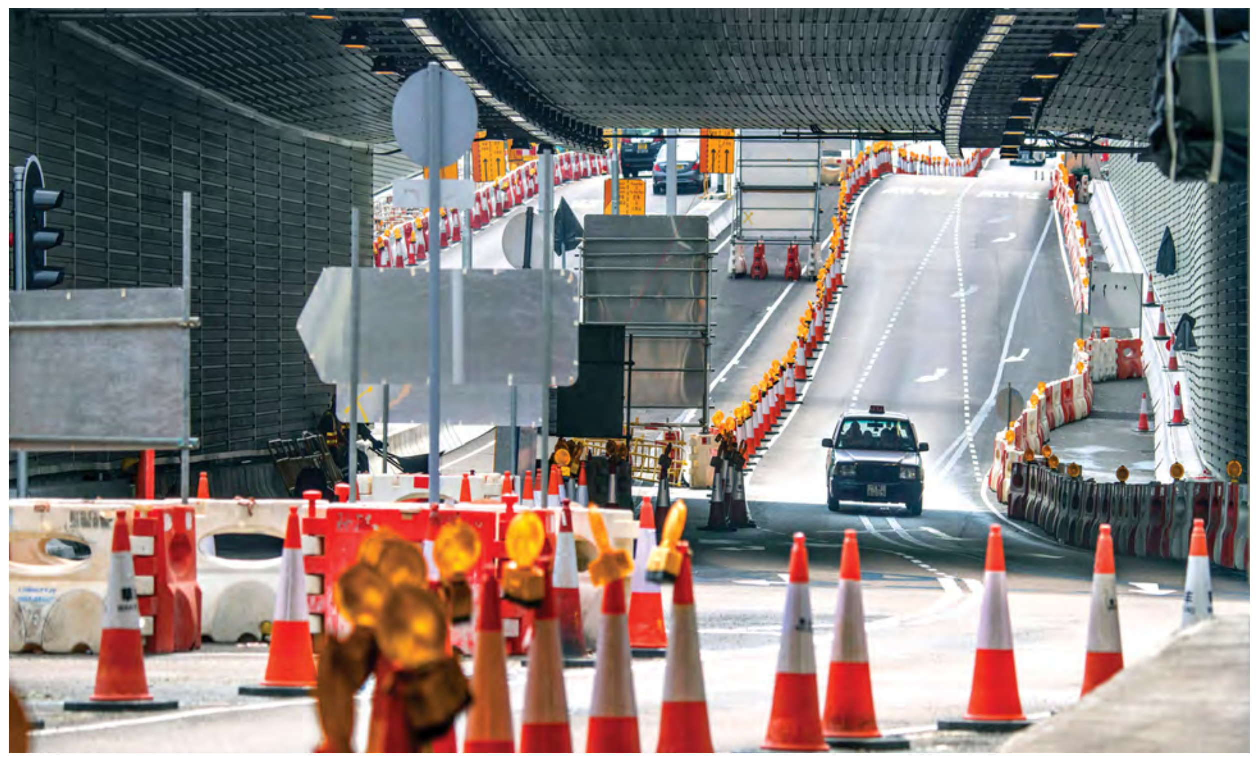
Work on the underpass that links into Austin station was also challenging, as it involved the construction of in-situ connections into an operating station by cutting a hole through the existing diaphragm wall. This entailed the provision of support for the top slab before a hole was punched through the wall. The construction of another footbridge across Jordan Road called for the provision of a temporary footbridge first to maintain access while the permanent one was under construction.

The construction of a three-level vehicular underpass to provide additional road capacity in the West Kowloon area was a critical element of the project. Once completed, two major trunk roads in the area – Lin Cheung Road and Austin Road West – were re-routed through the underpass while a landscaped pedestrian deck was created to provide greenery on top of it.

Initially, the plan called for work on the underpass to be divided into several phases to minimise impact on traffic, with the provision of a temporary traffic deck allowing flow to be maintained while excavation continued underneath. However, it eventually became clear that, given the tight programme, the only way to take this portion of the works off the critical path was to close a section of Lin Cheung Road completely. The transport consultant engaged to study the feasibility of this approach came up with temporary transport management schemes to divert traffic during the construction period. Three to four months of detailed study was presented to the client and the Transport Department before agreement was reached to close the northbound lane of Lin Cheung Road temporarily and divert the traffic to Nga Cheung Road and Canton Road.

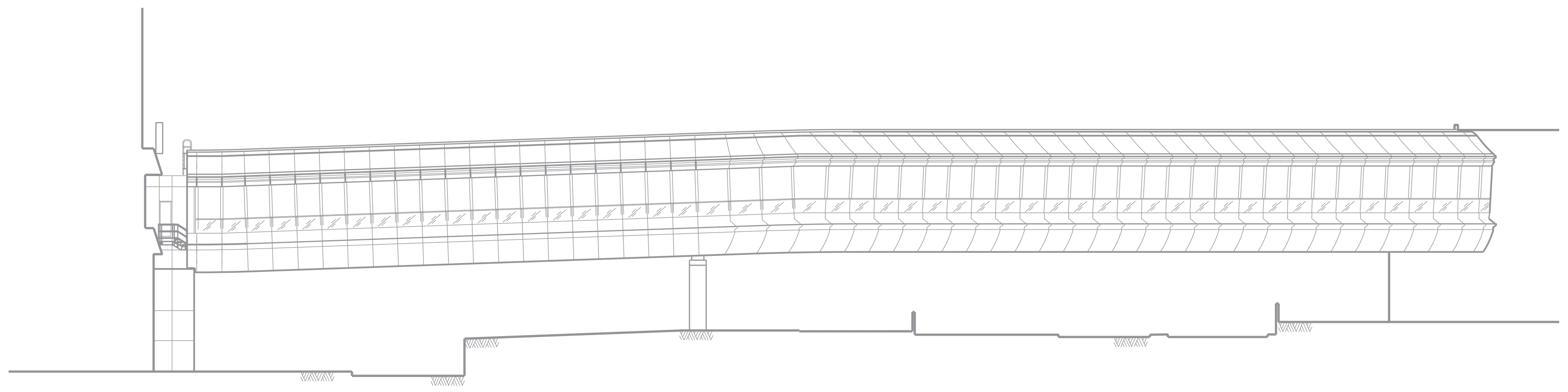
The concern of the authorities was understandable considering the number of public transport routes impacted. Stage 2 of the five-stage temporary traffic management scheme, for example, called for diverting some 15 bus routes to a temporary road. In addition, the closure of Wui Cheung Road meant 11 bus routes that operated from Kowloon station had to be diverted.





Top left to right:
Lin Cheung Road underpass on opening day;
Supporting live utilities to Elements shopping mall;
Tarmac roller and paver Lin Cheung Road;
Temporary traffic management at Austin Road west junction with Lin Cheung Road;
Footbridge-1 steel frame construction over Lin Cheung Road.

- 120 ELECTRICIANS TO LAY ALL CABLES AND INSTALL TRAFFIC SIGNS AND SIGNALS
- 130 WORKERS CHOREOGRAPHED IN THE MOVEMENT OF TRAFFIC BARRIERS ACROSS THE ROAD NETWORK



Before these diversions could be carried out, a temporary road with a new six-lane southbound carriageway was constructed to connect the Western Harbour Crossing slip roads and Jordan Road. A new five-lane southbound carriageway was constructed to connect Jordan Road with Wui Cheung Road and Wui Man Road was upgraded to a four-lane dual carriageway.

"The total length of the underpass northbound is 1km but there are actually 13 different carriageways in seven different areas with three or four lanes covering a total of 10km. The majority of them sit on top of the station box in a box-on-box structure," Barton explained. "We were also responsible for the electrical and mechanical works for the road network."

__Foreground:__ Landscaped deck and underpass ventilation void over the 3-lane Lin Cheung Road and Austin Road.
__Far left:__ Lin Cheung Road Underpass and Footbridges 1, 2, 3.
__Far right:__ Austin Road underpass east ramp.

Since the road network extends well beyond the scope of Contract 810A, the team needed to be particularly nimble in terms of programme adjustments in case the construction programmes of adjacent contracts were out of sync. For example, a temporary road on an adjacent contract was moved to the top of the Contract 810A site but it could not be finished unless the depressed road to be built underneath it was completed, and vice versa.

"We had to spend a lot of time to understand all the dependencies and get the logic right," Barton said.

Finishing the works meant bringing in 120 electricians to lay all the cables and install all the traffic signs and signals, with people put on double shifts. Every time the team moved from one stage of temporary traffic diversions to another, some 130 workers needed to be choreographed in the movement of traffic barriers across the road network, starting at 11:00pm the night before and finishing by 7:00am the next day.

"Even at the tender stage we obtained a traffic study from our consultant to see how many temporary traffic management schemes we'd need but we only foresaw 30% of those that were actually required," Barton said.

With the help of the comprehensive traffic study carried out by the traffic consultant, the team finally managed to persuade all stakeholders it was feasible to close Lin Cheung Road, thus speeding up much critical work, without affecting the traffic capacity of the surrounding road network. Communication and coordination were critical, not least because in addition to maintaining traffic flow, the team had to share site access with others, ensure the integrity of all utilities and essentially keep everybody, from Elements occupants to district councillors, on side.

The diversion of Jordan Road and the uncovering of utilities there were coordinated with Contract 811B. Like the utilities along Lin Cheung Road, the utilities under Jordan Road were critical to the running of large areas, in this case facilities across the harbour, on Hong Kong Island.

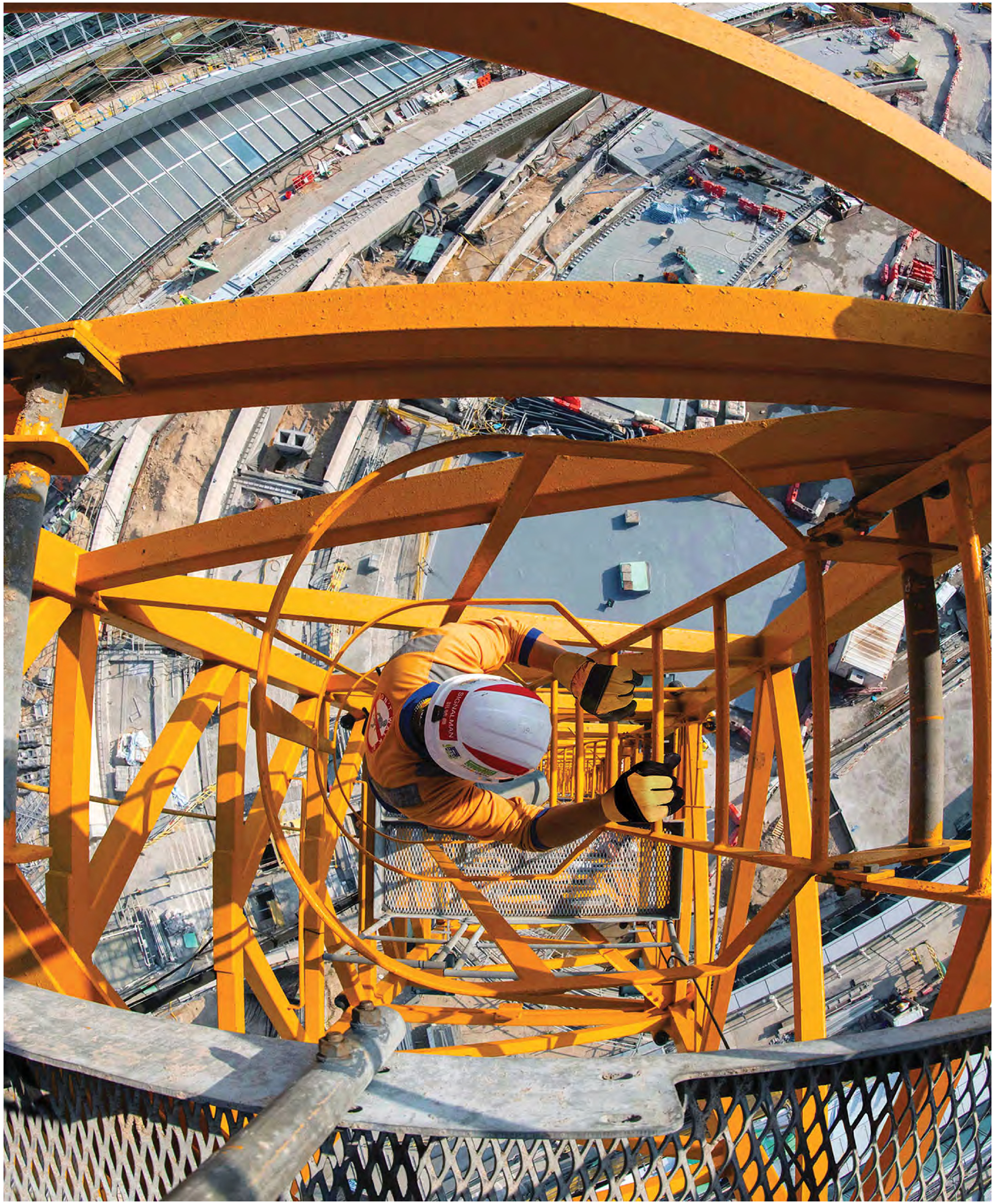
Implementation of the temporary traffic management schemes allowed the team to progressively release more of the site. For example, construction of the temporary road, which was supported on steel columns, released the area beneath for further excavation. The closure of Lin Cheung Road then allowed construction of the underpass to commence.

Right: *Lin Cheung Road slip underpass.*

The station connects with neighbouring areas and wider Hong Kong in the form of six footbridges and two subways, linking it to the Kowloon Station MTR, Elements and the harbour waterfront.

MANAGING PEOPLE + MATERIALS FLOW IN A MINI-CITY

The project employed three made-to-order tower cranes of 60-tonne capacity each and a radius of 25m for lifting the steel trusses for the roof, as well as 45 mobile cranes and 25 crawler cranes.



小城內人來物往 井井有條

香港西九龍站工程繁忙，人流物流絡繹不絕，可說是一個城市的縮影。雖然項目面積與香港國際機場客運大樓相約，但地盤深入地下30多米，要挖掘的土石多達1,700,000立方米，在高峰期，每日澆灌的混凝土超過2,000立方米，5,000工人同時在不同的崗位施工。

經過詳細考量，工程團隊決定由車站大堂的中段位置開始，用「類上而下」建築方式，先建造第一和第二層地庫的部分樓板，再從樓板安裝臨時鋼樑支撐東、西兩側的連續牆，讓工隊可以繼續向下挖掘第三至第五層地庫。

由於需要依賴上述的地庫的結構，來支撐上蓋安裝工程的臨時及永久負重，團隊必須爭分奪秒，準時完成大部分地下結構，讓上蓋可以及早施工。但在這階段，工程車只能到達第二層地庫，物流成為了項目的重大挑戰。

地盤實在非常繁忙，每天有400架次重型泥頭車，把挖出的土石搬離工地；又有60架次大型貨車，每車盛載10噸鋼架和鋼筋送入地盤。雖然工地設有混凝土攪拌廠，仍需依賴混凝土車補充供應，增加了地盤的物流壓力。處理混凝土方面，最初只在地面設置輸送泵，隨後為方便施工，亦要在第二及第三層地庫加設新泵，把混凝土送到更遠的地點。在工程的高峰期，曾錄得每天澆灌2,500立方米混凝土的紀錄。

按照原訂設計，車站需現場裝嵌200支十字柱，每支全長40米，重160噸。但鑑於工地太過擠迫，最後改為在工場預製，然後放入樁洞進行定位和安裝。

起重設備方面，項目特別訂製了三台吊升力高達65噸的天秤，用以安裝上蓋的鋼桁架。還有六台常規天秤、45台移動式起重機，和25台履帶式起重機等。

良好的決策對整個建造流程至關重要。地庫所有樓層的總面積達21,500平方米，包括超過4,000間房間，和100條不同規格的樓梯，全部均須盡快進行室內裝修工程。為此，團隊特別為每一層地庫委派一位項目經理，專責協調相關的工程，例如更改牆身和樁柱的施工順序，就成功縮短幾個月的工期。

隨著工程進展，臨時的出入坡道逐一被拆除，運送工料的工作需逐漸轉由天秤、起重絞車及伸縮平台等處理。此外，團隊又要顧及地盤內七個臨時存放建材的倉庫。管理地盤內大量的工料和物流，實在是一大學問。

"AT THE PEAK OF CONSTRUCTION WE HAD 5,000 WORKERS ON 810A. WE WERE EFFECTIVELY RUNNING A MINI-CITY."

Picture a site the size of the Hong Kong International Airport passenger terminal building and also 30m deep, where 1,700,000m^3 of spoil is removed and 2,300m^3 of concrete is poured a day at the peak of construction; where 5,000 workers operate at multiple work fronts as the construction of the two sets of customs, immigration and quarantine facilities, plant rooms and offices for five government departments and the like is carried out concurrently.

The construction of HKWKS was complicated by the handover of the site in two phases, in December 2011 and January 2012 respectively, as well as the different construction methods adopted for different sections of the structure. Using what was described as a 'pseudo top-down' method, structural work was carried out from the bottom up in the central portion while the perimeter was built from the top down utilising the completed slabs in the middle as part of the excavation and lateral support. In this way, a combination of temporary and permanent works held up the 220m-wide site, allowing excavation to be carried out around the sides.

Programme considerations drove this sequence, which saw construction of the central portion from the bottom up completed first. The basement 1 and basement 2 slabs were cast across the east and west diaphragm walls to act like struts that allowed the diaphragm action to pass through them. Once this support was in place, excavation was able to continue downwards to basements 3-5. The top-down construction was supported by 52 punch columns weighing 4 tonnes each and large dog-bone- shaped struts were used to prop up the diaphragm wall. Due to movement in the diaphragm wall surrounding the site, installation of temporary works also became part of the daily activities.

There was pressure to complete much of the below-ground structure in time for the erection of the roof structure to commence, as the temporary and permanent loads imposed by the steel roof were to be supported by the former. Access for material deliveries was a major challenge, as construction vehicles could go only as far as basements 1 and 2, where the permanent car park and taxi pick-up/drop-off areas are located.

"That means the permanent road only reached basements 1 and 2, but the station goes as far down as basements 4 and 5 and we had no vehicular access to them," explained Senior Construction Manager K.W. Lee. "We had to build 18 steel ramps, each about 10m wide and 60m long, to get to the bottom because each basement has a headroom of about 6m."

The top-down excavation yielded about 2,500-3,000m^3 of mud, which was removed by a fleet of lorries winding their way up and down the ramps. About 400 lorry trips were made on a daily basis; in addition, another 60 lorry trips were made for steel delivery with each lorry carrying 10 tonnes of steel frames and rebar. Concrete was delivered by mixers as well as an on-site batching plant that supplied 100m^3 per hour, allowing workers to pour on average 900m^3 of concrete per day. The team had three concrete pumps at the ground-floor level capable of sending 400m^3 of concrete to the basement. When access to basements 2 and 3 became available, concrete pumps were also set up at those levels, allowing the team to achieve a record 2,500m^2 of concrete poured per day using a total of up to 12 pumps.

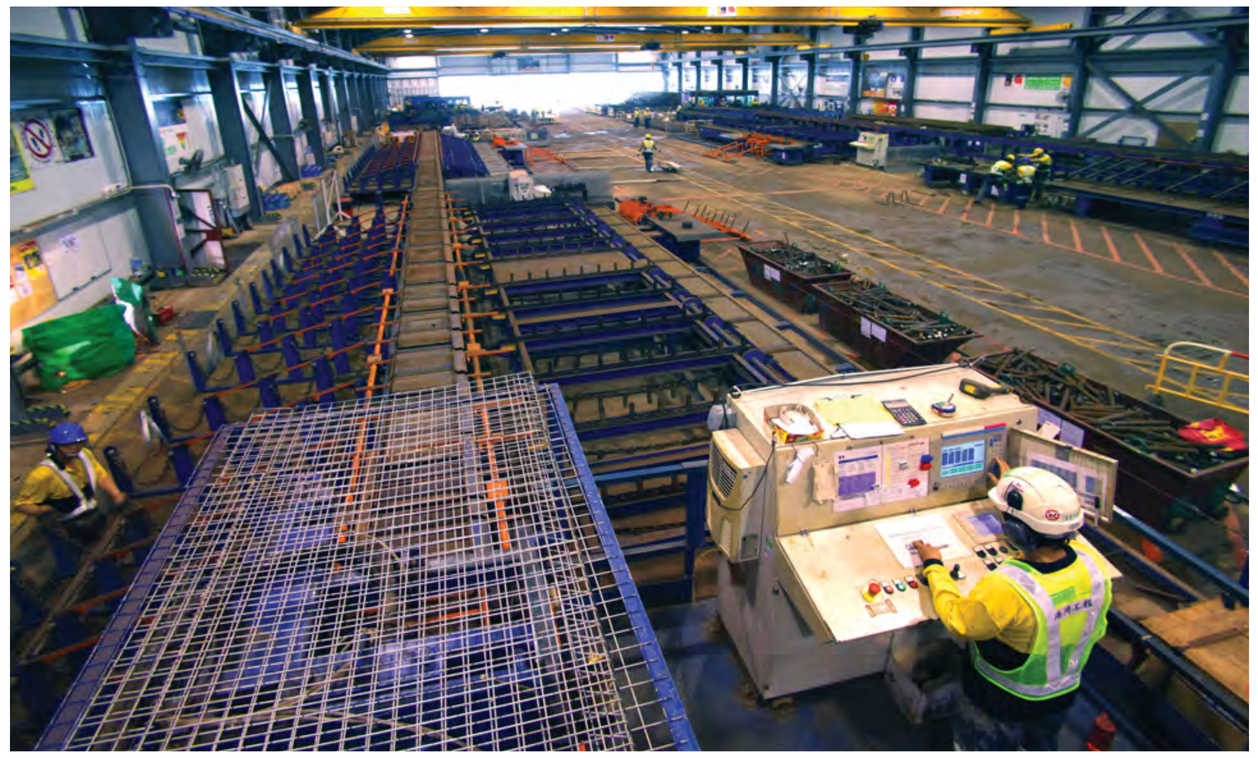
According to the conforming design, the station would be supported by 200 cruciform columns to be installed in-situ. However, with the site already busy with other works, the team developed an alternative installation method whereby each column, which measures 40m in length and weighs 160 tonnes, was prefabricated off site and dropped into position. They were transported to site in 12m sections and lowered using a 400-tonne capacity crane.

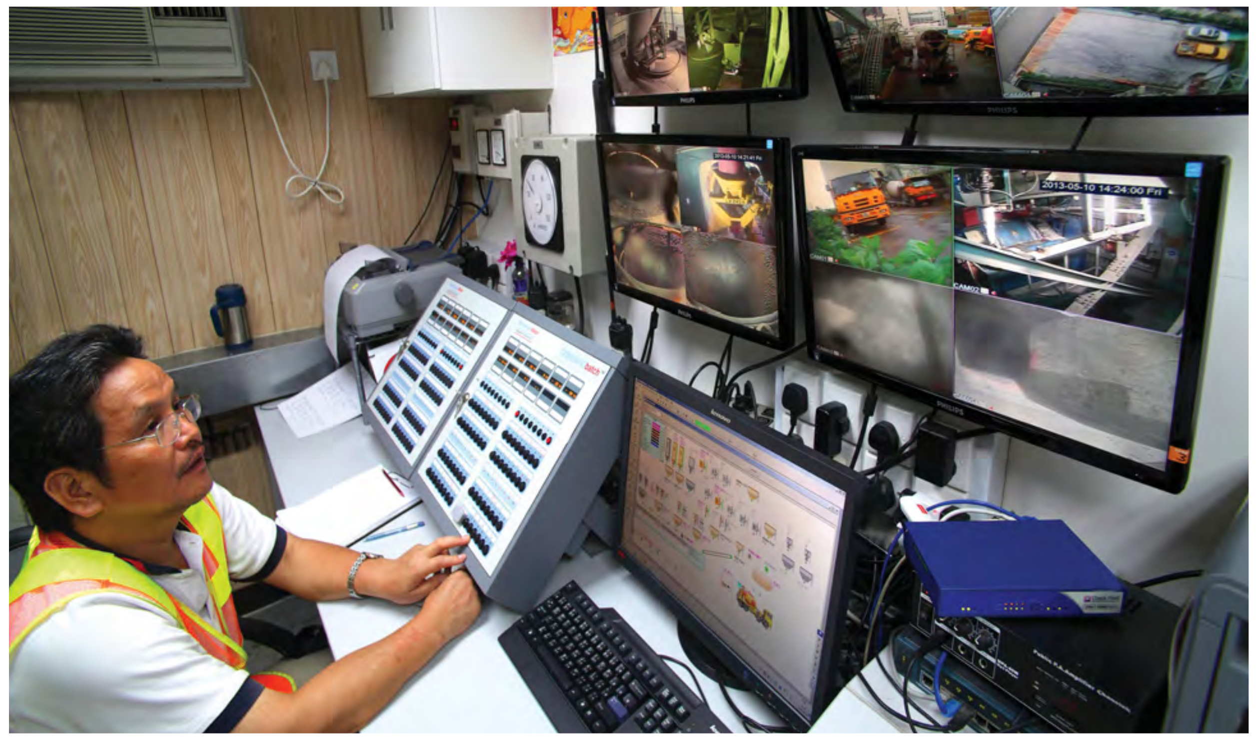
The project also employed three made-to-order tower cranes of 60-tonne capacity each and a radius of 25m to lift the steel trusses for the roof. Other material-handling equipment included six conventional tower cranes, 45 mobile cranes and 25 crawler cranes.

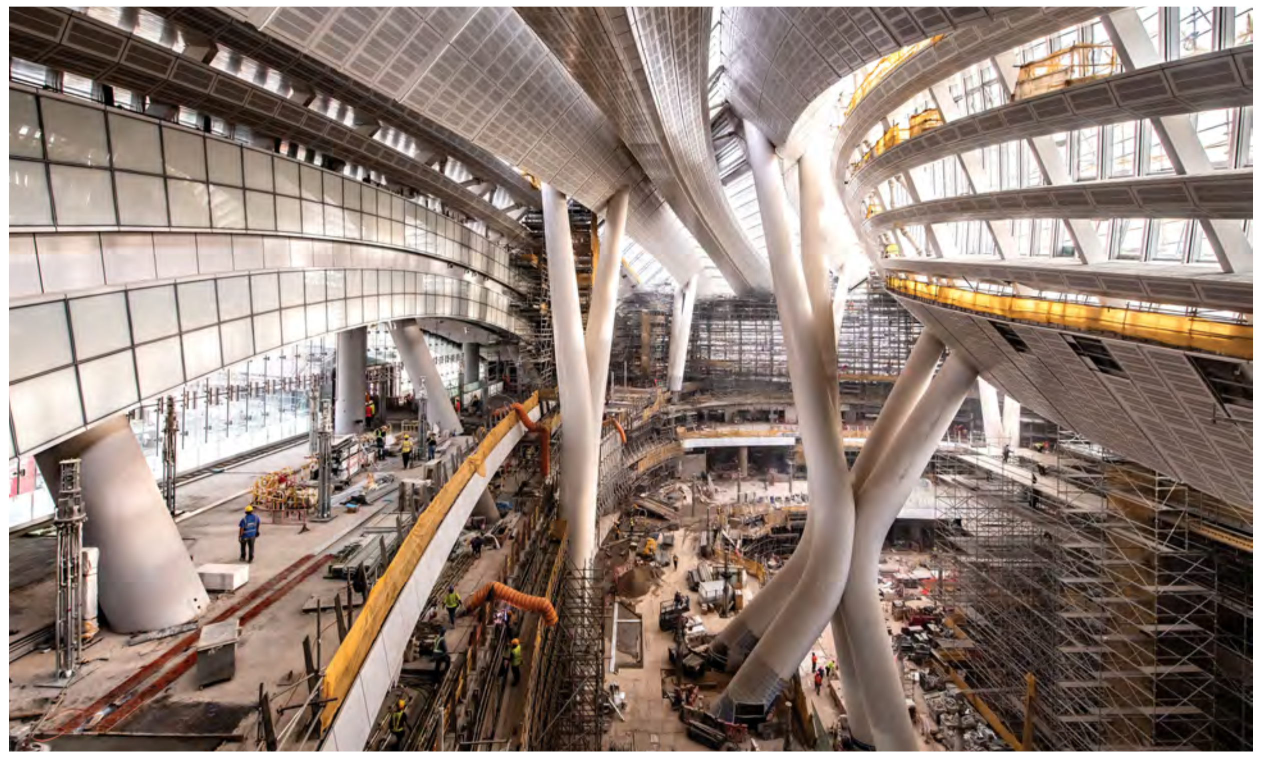
The team also deployed a 12m x 15m travelling form for initial construction of 800mm-thick flat slabs before adapting to the congested nature of the site and switching to traditional formwork.

"There were too many interfaces; traditional methods gave us more flexibility once we had the access roads for materials delivery," Lee said.

Because progress on the basement and the roof structure was mutually dependent, the central stability system designed to support the former was built independently and tied back to the concrete structure to support the balanced cantilever construction of the roof trusses.







Top left to right:
Steel stanchions and columns in the basement;
On-site rebar rigging warehouse;
Control room of on-site concrete batching plant;
On-site concrete batching plant;
Tree planting;
Decorative station wall art;
Atrium and basement works;
Basement 4 train platform.

Having the support structure ready for roof erection was only part of the story; the station also contains 4,000 plus rooms and 100 staircases of different dimensions. The architectural builders' works and finishes cover some 21,500m^2 and, stretched from end to end, the 600,000m^2 of walls built for the rooms would run for 50km. The need for formworkers alone was such that the team had to engage seven formwork sub-contractors. There were a number of other reasons for calling upon so many formworkers, including the curved geometry of the station's architecture, the varying layouts and functions of the rooms on each floor which call for different finishing details, and the need to meet critical dates for handing over different zones to designated contractors.

The architectural builders' works and finishes were carried out across all the basement levels at once. At basement 4, the platform level, works started from the middle and progressed both southward and northward. At basements 3, 2 and 1, works started from the north and west and progressed towards the large atrium at the station entrance to the east. Works at the entrance void began after construction of the roof structure was substantially completed, ensuring the work space was watertight.

A project manager was assigned to each floor for better coordination. Good decision-making was critical to the overall programme; changing the construction sequence for the walls and columns, for example, saved months of time.

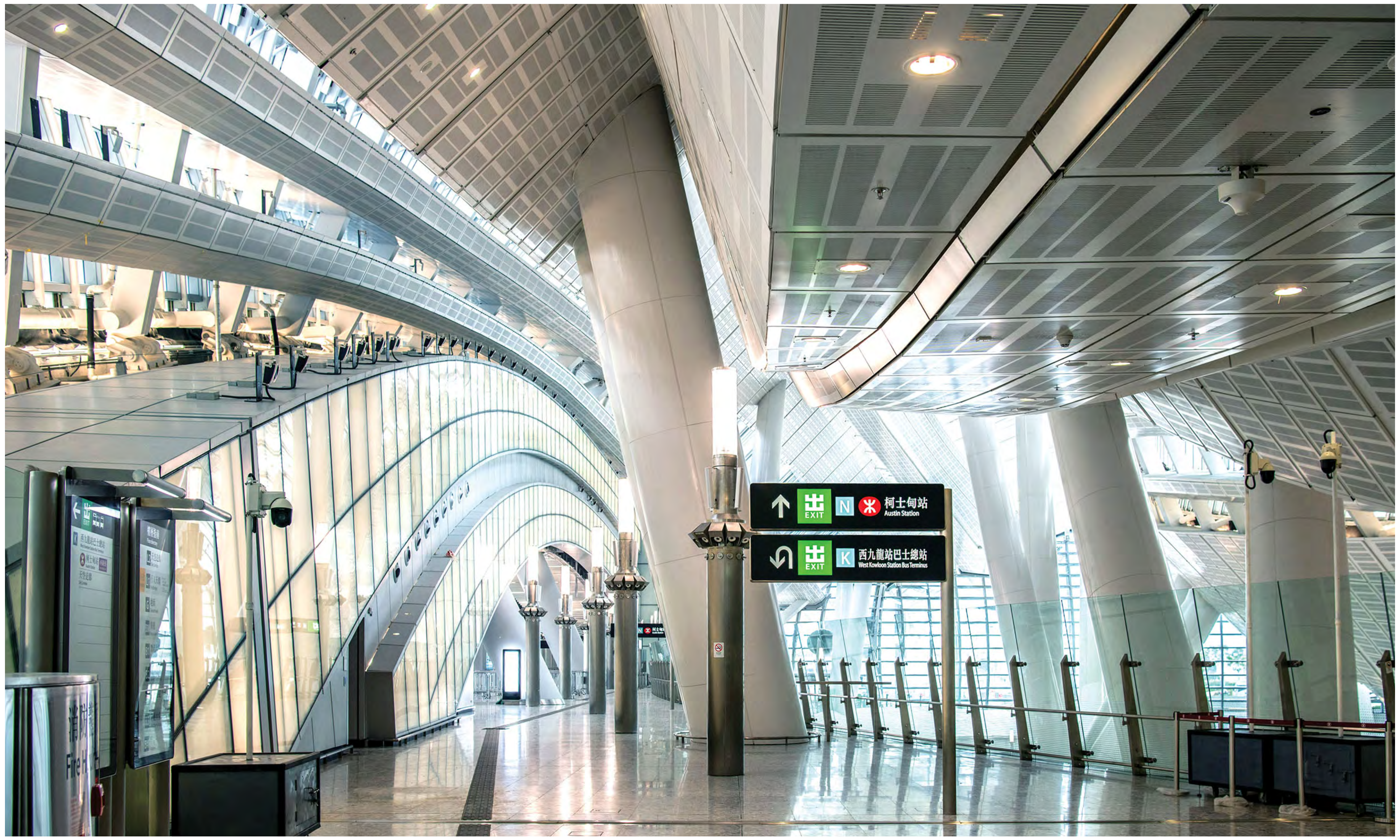
"According to the conforming design, all columns had to be in place before the walls could be built. However, after calculations confirmed the temporary support was good enough to support permanent loading, we began wall construction while column construction was still ongoing. That allowed the team to move on to finishing works by the time column construction was completed," Lee said.

The project involved the use of a lot of materials, including 135,000m^3 of stones for walls and floors, 14km of bumper rails, 3,000 doors, 4,000 advertising panels and 7km of guard rails. The access ramps were initially used to move these materials into the basement levels but as the ramps were progressively removed, materials handling was taken over by a combination of tower cranes and material hoists. Three tower cranes were used along with four material hoists distributed across the central portion of the structure. Retractable platforms with a 5-tonne capacity each were used to take delivery of the materials at each floor for local storage or installation. Having both Contract 810A and Contract 811B under one team offered a logistical advantage, as the latter provided access to a combined works area under the same management whose aim was to benefit the project as a whole.

Due to the large volume of materials required, seven stores were established on site for temporary storage. Some methods of construction were changed in part to reduce site traffic which was already congested, as the contract had only one sole access and other accesses were controlled by adjoining contracts. The switch from the use of 12m x 15m travelling form for slab construction to traditional formwork, for example, was driven by changes to the construction sequence, as well as the pressure on road traffic and vertical transport systems if the 2,000 forms that would have been required were to be brought to site and lifted down to the basement.

"At the peak of construction we had 5,000 workers on 810A. We were effectively running a mini-city. Logistics was a very important issue," Lee said.

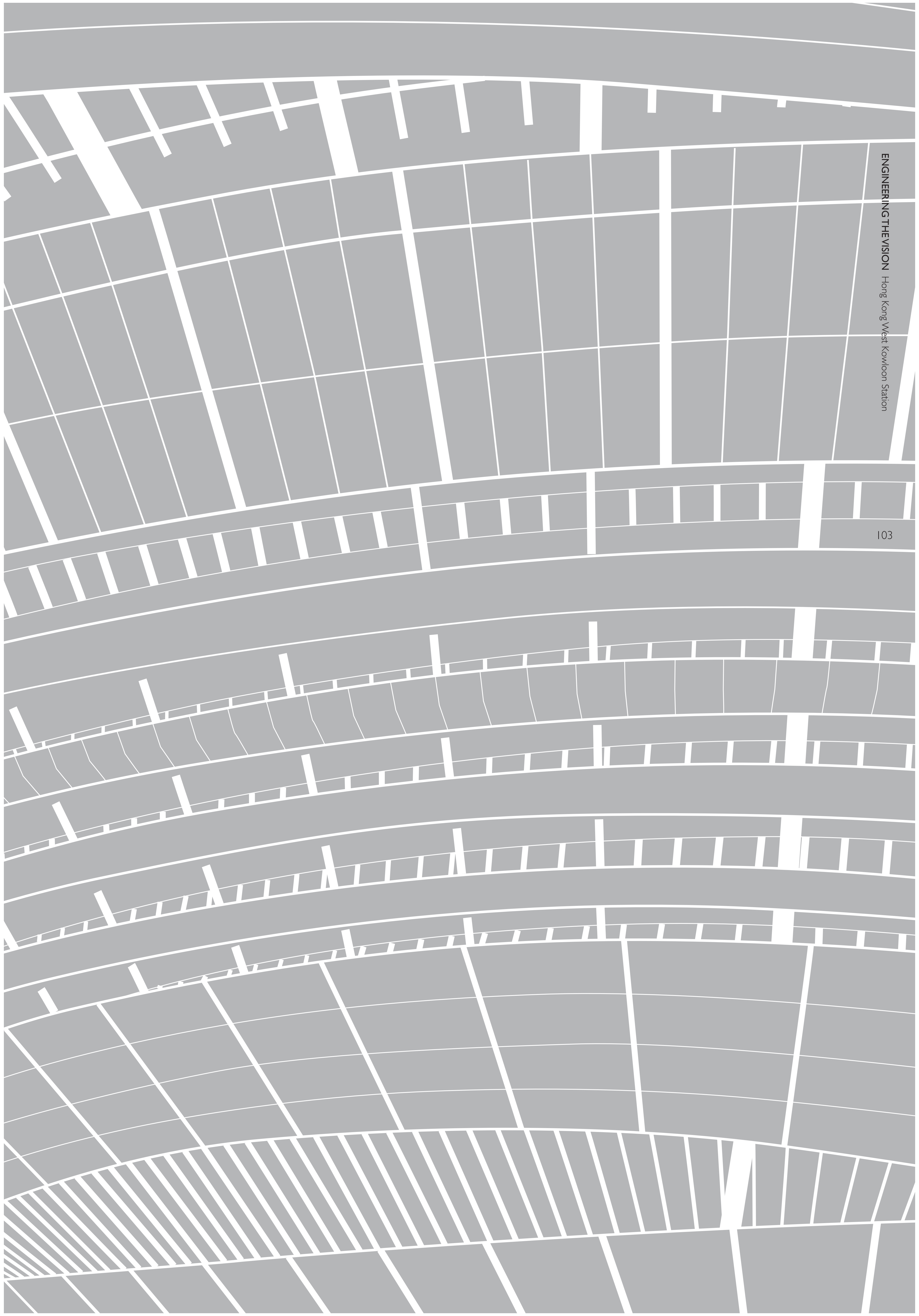
PROJECT MATERIALS INCLUDE 135,000M^3 OF STONES, 14KM OF BUMPER RAILS, 3,000 DOORS, 4,000 ADVERTISING PANELS AND 7KM OF GUARD RAILS



Above: *Lorries access ramp for basement open cut excavation.*
Below: *Level-1 concrete eastern 'lightbox' arch with above steel double-pin articulated roof joints.*

An urban oasis in the heart of Hong Kong, where the planting of 700 trees and shrubs surrounding the station create a welcoming green environment.

SAFE PERCHES ON A LARGE BIRD CAGE



The new scaffolding system, referred to as the bird cage, arrived in 200 containers, weighed 2,000 tonnes, took three months to build and at the peak of construction involved 250 scaffolders.

鳥籠堅固 棲木安全 工程順利完成

地盤內有數千名工人同時在不同地點施工，要確保整個工地安全，本身就是一項挑戰。鑑於工程緊迫，團隊採用了一個嶄新的模組棚架系統，可以為安裝覆面板的工人提供安全的架空通道，同時能釋放空間，讓地面的工人鋪設地台。

這套全新系統被稱為「鳥籠」，由輕質鋁框組成。組件交貨期短，並具備多項安全特性，又容易架設。標準組件可以用作支撐、搭建樓梯、加固棚架和工作平台。此外，這棚架系統每平方米可負重400公斤，對安裝巨型支柱的重型覆面板發揮極大作用，因為九組巨型支柱各以不同角度傾斜，不能用起重機協助安裝。

「鳥籠」設有13組懸吊式工作平台，每組長30米、濶10米，設有完備的安全圍欄和踢腳板。工作平台在第三層地庫組裝後，利用頂部懸垂的鋼纜吊升，讓工人可以在地庫至上蓋之間任何高度進行工作。

工程團隊除了為棚架工人舉辦安全講座之外，又利用午餐時段深化解釋「鳥籠」的特性，增進工人對這新系統的認識。同時為來自不同種族的工人準備切合他們民族特性的餐盒，有效建立工隊的溝通和互信。

最初，棚架工人對這新系統感到陌生，因為不同的接合組件有特定的用途，只有一種裝配方法，不可隨意安裝。但當他們熟習後就非常欣賞，認同新系統更加安全，值得推介。

搭建這「鳥籠」需時三個月，高峰期參與架設的工人多達250人。「鳥籠」體積龐大，對室內工程非常重要，必須小心保護。由於每日有大量重型運輸車輛進出地盤，在棚架旁邊川流不息，形成了多條運輸通道，所以要用灌滿混凝土的水馬，放在棚架旁邊分隔車輛，並作為保護「鳥籠」的屏障。

一年後拆卸「鳥籠」，安全亦是首要的考量。當時地面樓層已經完成地台工程，禁止剷車內進，工人要用人手逐一拆除和搬運組件離開，過程有條不紊。

利用「鳥籠」進行的工程，錄得「零意外」紀錄，反映這嶄新的棚架系統對施工大有助益，而且堅固安全。

THE TEAM TURNED IT INTO SOMETHING OF A REAL BIRD CAGE – WITH HIGH PERCHES WHERE WORKERS COULD WORK, REST AND EAT WITHOUT EVER COMING DOWN

With thousands of workers operating at multiple levels, ensuring everyone's safety is no easy task. At HKWKS, this was made even more challenging by a tight programme which meant that, instead of setting up falsework that covered the whole void in the station, the team had to opt for a system that could provide access for all the cladding work high above while releasing space for tiling works down below.

"There were more than 11,000 pieces of cladding and we had to put them on temporary platforms and fix them one by one. We were asked to provide platforms 15m up in the air for up to 300 people to work on for one year; it was extremely high risk," said William Robinette, Principal Engineer of Lambeth Associates, Gammon's in-house engineering consultancy.

Using a 3D virtual structural model of HKWKS, Lambeth began planning for an access scaffold system a year before construction began. The model was critical to the design of the falsework system because it allowed the engineer to identify the critical areas that must be left open for other works. The most important of these were the mega-columns and the floor of the atrium void, where tiling works were to be carried out. The model also allowed the engineer to plan the flow of people, as well as the vertical movement of materials from basement 3 to +15m and the horizontal movement of vehicles such as forklift trucks. To enhance safety, designated areas were also established where there were people working at height, to avoid injuries due to materials falling on anyone working below. Given that the winches weighed 2 tonnes without load, all hoists were also fitted with flashing red lights to warn people of deliveries, to ensure no one was working in the areas above.

After reviewing available options, the team selected a scaffold system consisting of lightweight aluminium frames that the manufacturer could deliver within a short time and which was efficient to set up. The company also happened to be the only one in town that could insert its system into the 3D model to check for clashes, which made the planning easier.

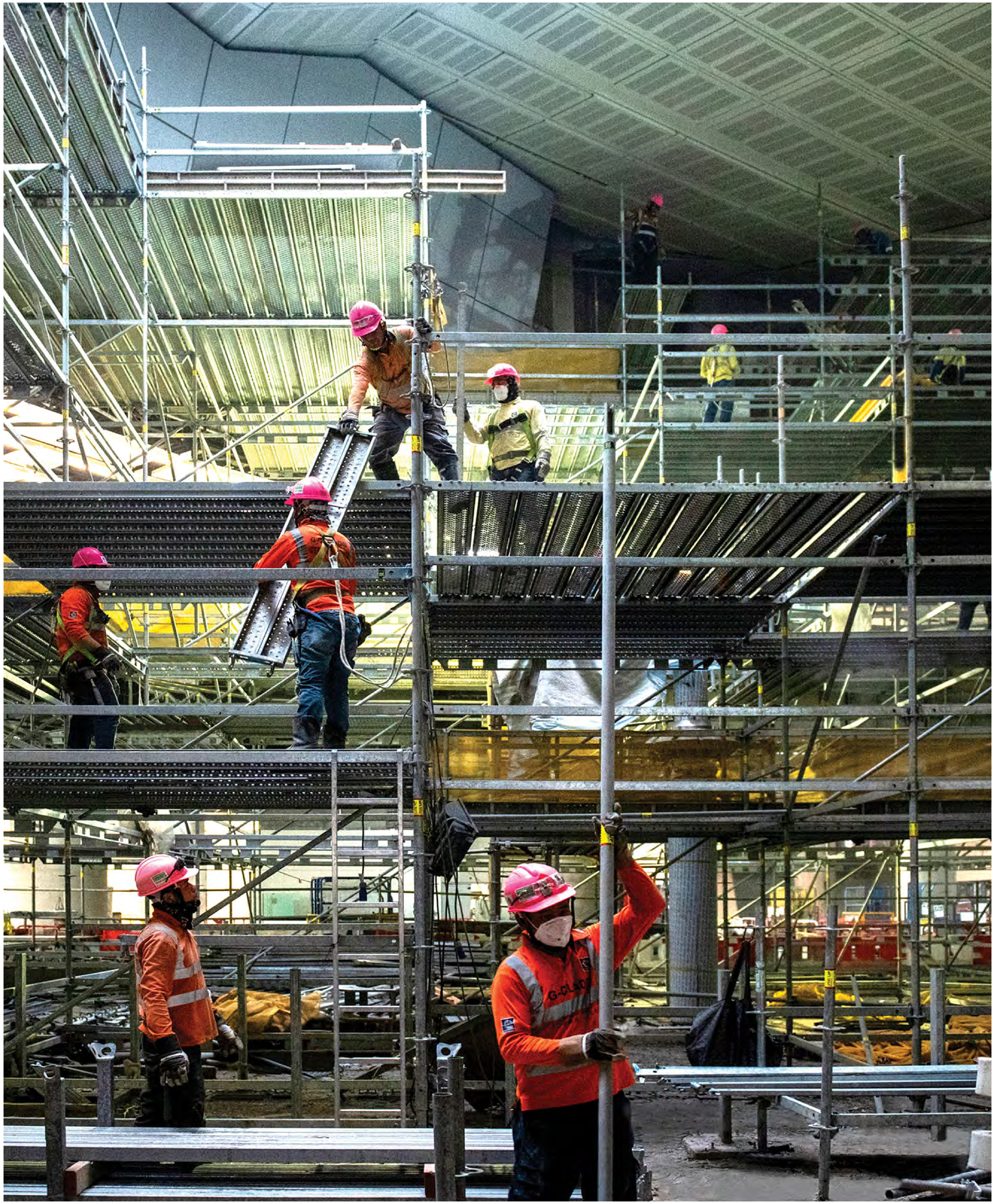
The modular system comes with integrated safety features and is efficient to set up because the same components are used for shoring, stair towers, reinforcement scaffold and work platforms. It has a 400kg/m^2 capacity, which was essential for handling the heavy cladding panels of the mega-columns which weighed 200kg each and could not be installed by crane because the columns were set at an incline. It also boasts the largest grid of any scaffolding system in Hong Kong at 3m x 3m between supports, compared with 2.5m x 2.5m for other scaffolding systems on the market.

Delivered in 200 containers from Japan, the Philippines, Singapore, Germany and the Middle East, the system weighed about 2,000 tonnes and was set up to hold 13 platforms hung from the roof using steel cables. The 10m-wide, 30m-long platforms were delivered to basement 3 where they were assembled complete with handrails and toeboards then fixed to the lowered steel cables and lifted into position under the roof.

"When we started building the scaffolding we had one main issue, which was that the system was new to Hong Kong; we had 200 highly trained scaffolders but none had experience with it," Robinette recounted.

To familiarise the scaffolders with the new system, commonly referred to as the 'bird cage', the team instituted lunchtime training sessions over and above the standard toolbox talks. All senior scaffolders and managers responsible for the bird cage and roof works were invited to attend the half-hour sessions and raise any questions or issues they might have. The team's approach was to also offer, along with the talks, lunch boxes that were everybody's favourite, whatever their nationality. The opportunity to communicate was good for teamwork and helped build trust, as everyone from project managers to scaffolders got to talk face-to-face on a weekly basis and came to know each other. The approach was so successful in drawing attention to the issues of the day and improving productivity that it was embraced by the joint venture as a way of improving teamwork throughout the project.

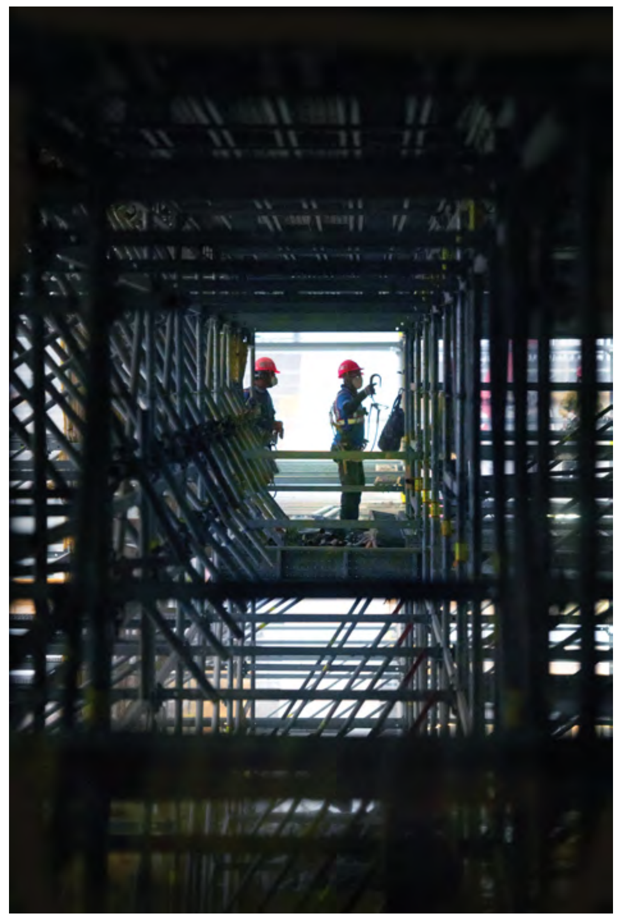
***Above:** BIM rendering of departure concourse.*
***Below:** Scaffolding system used to install more than 11,000 pieces of cladding.*



The scaffolders took a couple of weeks to get over their learning curve. They were initially uncomfortable with the system because there was only one way for its proprietary components to fit together so they could not improvise the assembly. For example, ordinary scaffolds would allow them to combine systems and components according to what are needed, like attaching steel tubes to platforms to make handrails. The selected system, on the other hand, is deliberately different from other systems so scaffolders can only assemble the components correctly even when they come across awkward areas. This ensures the system is safely set up.

"The scaffolders didn't like it at first but once they got familiar with it they liked it and converted," Robinette said.

Taking advantage of the comfortable environment created by the system, which comes with wide stairs for easy access, the team turned it into something of a real bird cage – with high perches where the workers could work, rest and eat without coming down. Rest areas with fans were set up on top of the scaffolding, as well as cold and hot water drinking systems. Lunches could be delivered by a hoist. There were even some real birds there, as pigeons and other species eventually took up residence on the scaffolding as well.



Left: *Disassembly of the maze of safety scaffolding in the 30m station basement atrium.*
Above: *There were zero accidents throughout the use of the safety scaffolding system.*

Some modifications were made to the scaffolding to accommodate programme changes, as the installation of information and ticketing desks in the ticketing area became critical. Part of the scaffolding was removed after some challenging calculations were made and confirmed that it was safe to do so.

The bird cage took three months to build, with 250 scaffolders involved at the peak. Water barriers filled with concrete rather than water were set up to protect the scaffolding from large vehicles transporting materials and concrete to site on what was effectively an indoor haul road. Six full-time traffic wardens patrolled the site round the clock, using flashing lights to alert everyone of oncoming vehicles. Over the course of the year, an average of 50 scaffolders remained on site to modify it in line with project progress. Because it left large areas of the structure free, work on laying the marble flooring, installing the lighting posts and glass walls and the like could be carried out at the same time as the cladding works, thus saving some three months from the programme.

Safety was also the top priority when the bird cage was dismantled after one year. As there was restricted access for forklifts on the ground floor, once the tiling works were completed, every component was removed by hand and taken out of the building by hand, in a controlled and methodical way.

"We had a chain of workers lined up to hand each piece out. We moved 200,000 pieces out that way. We did that to stop workers just throwing any pieces down so we avoided damaging the marble flooring," Robinette explained.

The success of the system is reflected in the record of zero accidents throughout its use. The efforts to ensure workers' safety also won the team the Best Safety Enhancement Programme for Working at Height Golden Award at the Construction Safety Forum in 2014.

Although the falsework sub-contractors initially disliked the system, they were converted to such an extent after working on HKWKS they have become ambassadors for the safer system of scaffolds. While its components are more expensive when compared with traditional scaffolding systems, its overall cost is attractive because it takes much less time to set up, so the labour cost is lower.

"It is now the sub-contractors' preferred system," said Robinette. "They can now drive the use of this system in Hong Kong and that is important because they tend to work to a higher standard of safety and like to get it right the first time. The safety culture we established on 810A will as a result carry on in Hong Kong."

The success of the modular scaffold system is reflected in the record of zero accidents throughout its use. The efforts to ensure workers' safety also won the team the Best Safety Enhancement Programme for Working at Height Gold Award at the Construction Safety Forum in 2014.

DISSOLVING WORK BOUNDARIES

A 311 metre-long approach tunnel and a track fan tunnel was one of the critical components requiring different teams to apply the same principle of collaboration and innovation to successfully complete this major project.

融合兩個工程項目

香港西九龍站810A工程毗鄰811B工程，811B早於2010年8月已開始動工，工程涉及四個主要部分，包括建造連續牆和地基、連接隧道和軌道扇形隧道、一幢機房大樓、公共運輸交匯處及遷移和重置一條人行天橋和四條暗渠。兩項合約一併管理，更方便融合工程。

在項目進行期間，為保持佐敦道的車輛和行人通道暢須，須進行大規模交通改道，並架設一條619米長的臨時鋼橋，和拆除一條鋼筋混凝土人行天橋，所有工程必須在夜間分階段進行。道路網絡完成後，須再建造一條全新的永久行人天橋及拆除臨時鋼橋。在此，工程團隊創新地採用滑軌方案拆除一條頂部空間只有500毫米的橫樑，無需設置臨時支撐進行提吊，贏得了一項創意大獎。

團隊為佐敦道進行交通改道，才能建造連續牆和挖掘連接隧道。得810A項目的同事配合，把交通繞道向南，811B團隊才得以及早啟動連續牆的建造工程。

項目的另一關鍵是遷移和重置四條跨越連續牆兩側的暗渠，而其中一段臨時暗渠必須加蓋，以保持地面交通暢順，地下則繼續進行大規模挖掘工程。

連接隧道大部分工程在圍堰內以傳統的下而上方法建造，但其中一段120米長的部分需以上而下方法施工。機房大樓的地下結構亦是依賴臨時支柱和延伸拉力樁連接的樓板，以上而下方法建成。

團隊持守創新和環保精神，致力改善項目的施工和安全。他們使用循環再造的鑽孔樁建造了一條長24米的臨時隧道，為工人提供安全的通道。為公共運輸交匯處進行鑽探工作時，亦為安全和減輕工人體力勞動，主動採購零重力機械臂輔助工人施工。這設備以外骨骼系統支撐身體，有效減輕勞損和提升施工效率。

為避免建造機房大樓時出現工程衝突，團隊以三維模型研究施工、物流，及完工後拆除臨時支撐的順序。又特別設計了一個平衡吊架，安全地拆除和搬運位於地庫的6000噸撐干和支架。

811B項目在建造高峰期僱用約500名工人。項目團隊其後進駐810A項目的地盤辦公室，把原本用作地盤辦公室的用地歸還政府，過程中不但鞏固兩支團隊的合作，更加強兩個項目的融合和管理。

MANAGEMENT OF CONTRACT INTERFACES A CRITICAL ELEMENT OF ALL MAJOR PROJECTS

The management of contract interfaces is a critical element of all major projects involving multiple contracts and all the more so on a mega project such as Hong Kong West Kowloon Station. This was, however, made easier when the adjoining Contract 811B also came under Gammon's purview through another joint venture with Leighton Asia. Commenced in August 2010, Contract 811B had four main components: construction of a diaphragm wall and foundations, a 311m-long approach tunnel and a track fan tunnel, a plant building, public transport interchange and the diversion and reinstatement of a footbridge, and four culverts. Many elements called for staff on both contracts to collaborate with each other, as highlighted in this book. There were also many elements that required the staff on 811B to apply the same principles of teamwork and innovation, to complete the connections that would enable the station to function efficiently for years to come.

In order to maintain pedestrian connections along the diverted Jordan Road throughout the construction period, a 619m-long temporary steel bridge was erected. It replaced an existing footbridge that was removed in stages at night. Cut sections were lifted away by a 500-tonne mobile crane and driven off by a trailer.

"We dismantled the original reinforced concrete footbridge at night, with the road closed. We had three and a half hours to do it each night using wire cutting," said Project Director Brian Gowran.

Once the road was reinstated, a new permanent footbridge was built to provide pedestrian access to the north side of the road. The temporary bridge, which weighed 1,087 tonnes and was fabricated in segments off-site, was also removed in segments. The team won an innovation award for using a ski rail to dismantle portal beams with just 500mm of headroom, thereby eliminating the need to set up temporary works to support a heavy lift.

Diversion of Jordan Road allowed the team to build the 1.2m-thick, 400m-long diaphragm wall and excavate for the approach tunnel. Having teammates on Contract 810A meant the road could be flipped to the south to facilitate an early start to diaphragm wall construction.

Another critical element of the contract involved the diversion and reinstatement of four 3-4m wide, twin-cell/single-cell box culverts that spanned both sides of the diaphragm wall. Construction of the diaphragm wall was coordinated with the culverts' diversion in the early stage of the project. Temporary steel sheet pile cofferdams spanning 29.8m were used to support bulk excavation for the approach tunnel. Once the tunnel was completed, the existing culverts were reinstated and the temporary diversion channels backfilled. As water flow was subject to tidal changes, the diversion eventually took two years to complete.

A section of one temporary culvert was decked over to facilitate traffic flow over the diverted Lin Cheung Road above ground and bulk excavation for the approach tunnel underground.

The approach tunnel was constructed from the bottom up inside a cofferdam that required six layers of shoring. Extra care was taken to ensure the struts could support the excavation due to the proximity of West Rail inside a floating box. A 120m section was constructed using the top-down method, to facilitate the early diversion of Jordan Road so that excavation works to a depth of 30m could be carried out underneath. The underground structure of the West Kowloon Plant Building was also built using the top-down method, with support for the floor slabs provided by temporary stanchions and extended tension piles.

"We used top-down construction so Jordan Road could run on top of the slab," explained Gowran. "Lambeth developed a system of temporary support for the upper slab that used the permanent pre-bored socketed H-piles at founding level in the bottom slab. The columns were put in between the piles. It was a clever and environmental solution that used the client's original material for the permanent works as temporary works."

The team combined an innovative spirit with environmental protection to improve project execution, as well as safety. A notable item of temporary works was a 24m-long subway built to help workers get to site safely and quickly. Due to the distance between the construction site and site offices, walking from one to the other took 30 minutes and involved crossing busy traffic lanes. To build the temporary subway, the team used recycled 2,000mm-diameter bored piles as the core of the tunnel. The steel casing was lifted into place by mobile crane and concrete blocks were placed either side before the shallow excavation was backfilled, ensuring the subway could take the load from a live carriageway.

Top left to right:
Austin Road footbridge;
Temporary footbridge dismantling;
Concrete pour;
Constant management of temporary road diversions;
Jordan Road approach tunnel construction.

Embracing new, safer methods of work, ZeroG Arm was procured for workers so they could manipulate equipment such as heavy drills without strain. The device applies mechanical principles to provide support via a mounted exoskeletal system to enable tasks to be executed with complete freedom of movement. It was used for drilling holes for ductwork on the public transport interchange.

"We used it mainly for Postfix drilling on the landscape deck. The workers had to drill upwards using a heavy tool so fatigue was an issue. With this system the cherry picker took the strain and the ZeroG arm provided an extra push-up force through a spring mechanism. It reduced fatigue and improved efficiency. We ordered it because we had positive feedback from the workers during a trial," said Senior Engineering Manager Stanley Cheng.

The team built a new vehicular deck, footbridge, diaphragm wall and box culverts concurrently on an extremely congested site. To avoid clashes during construction of the critical plant building, a 3D model was set up to study the sequence of construction and logistics as well as falsework removal after completion.

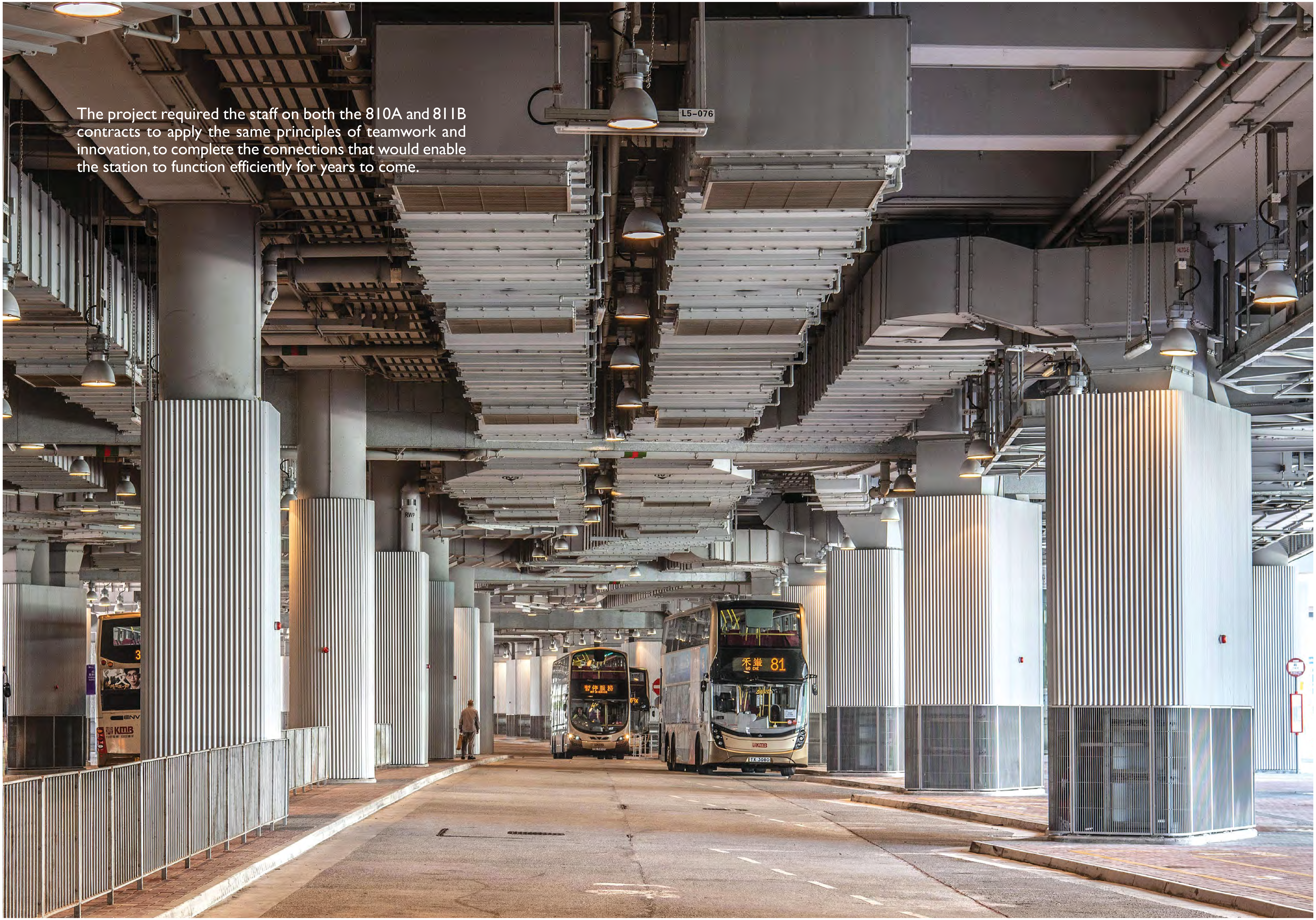
Taking lessons learnt on other projects that involved deep basements, the team opted for a specially designed horizontal lifting frame to remove the 6,000 tonnes of walers and struts safely. Struts that support basement construction are typically installed from the top to the bottom as excavation progresses, but have to be removed in the reverse order. This poses a risk as the upper struts may get in the way of the removal of the structural steel from the lower levels. To address this problem, Lambeth helped the team design a lifting frame to secure each member after it was disconnected before lowering it to the ground for safe removal by crane.

"The frame was wider at the top to ensure stability when a member was lifted but its four chains came down at an angle so they wouldn't hit the steel at the higher levels. It was an additional procedure and took a bit more time, but we put safety first, and eventually safety leads us to the overall efficiency," Cheng said.

The contract employed about 500 workers at the peak of construction. As the time came to hand back the land occupied by the 811B site office to the government, the team simply moved into the 810A site office, in the process cementing the teamwork that had facilitated management of both contracts.

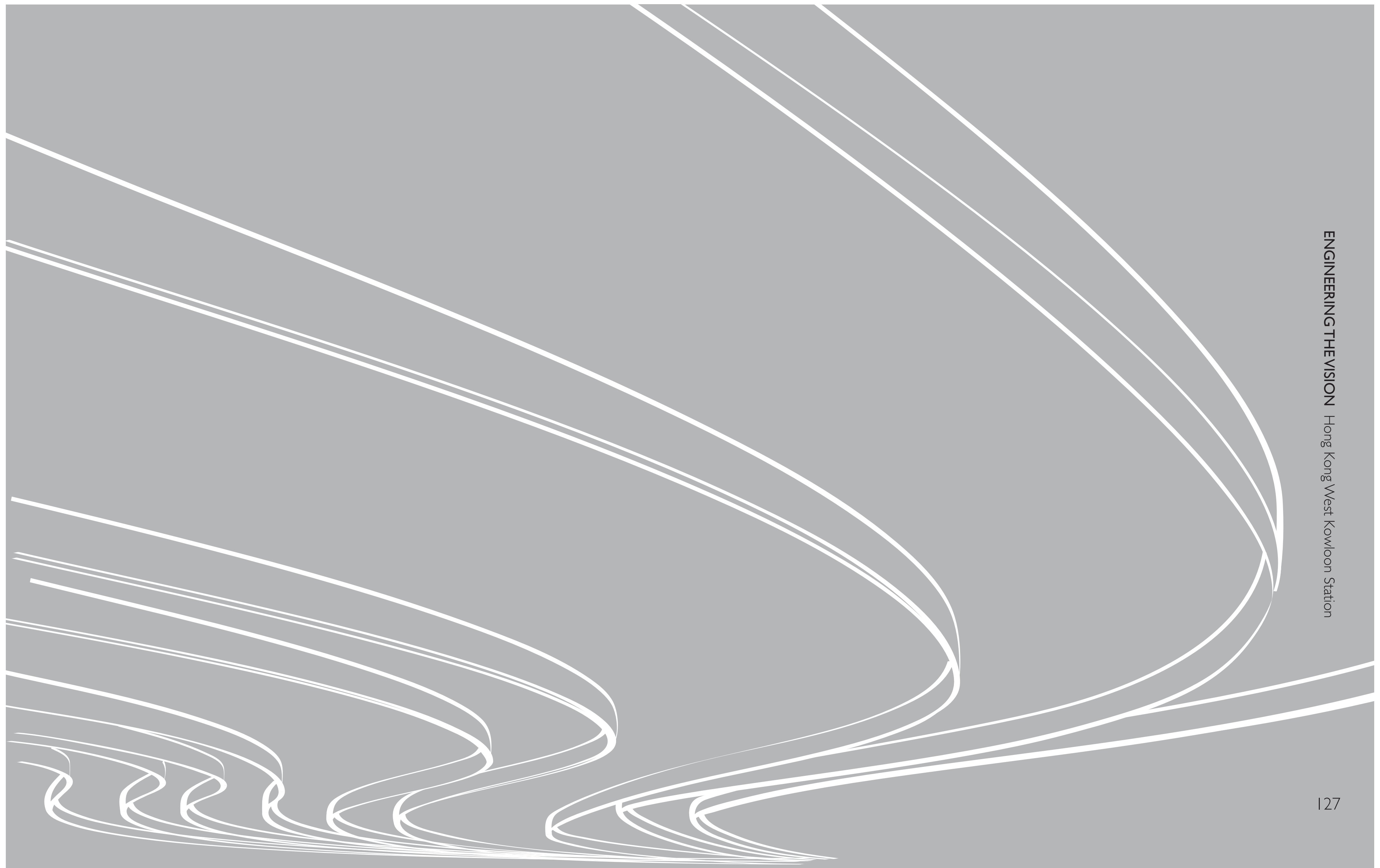
"I'm proud of the whole team, including the gangers. They controlled safety and preserved our values; the frontline people deserve a lot of credit," Gowran said.

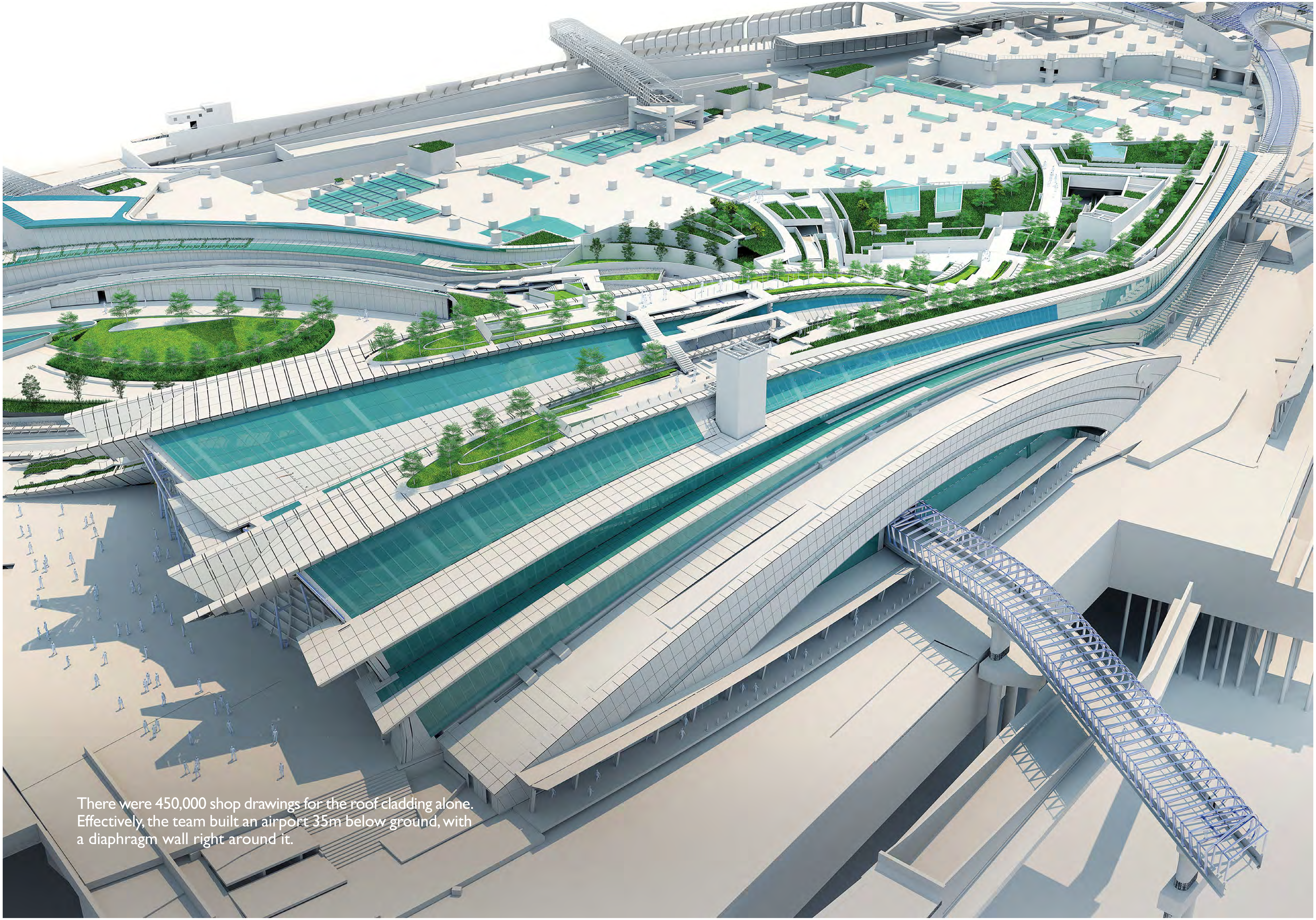
***Below:** There are 3 hectares of public space outside the station including the Green Plaza and Sky Corridor.*



The project required the staff on both the 810A and 811B contracts to apply the same principles of teamwork and innovation, to complete the connections that would enable the station to function efficiently for years to come.

INNOVATION ADAPTABILITY + TEAMWORK





There were 450,000 shop drawings for the roof cladding alone. Effectively, the team built an airport 35m below ground, with a diaphragm wall right around it.

創新思維

創新的思維方式、團隊的靈活應變和衷誠合作，是順利完成香港西九龍站項目的成功關鍵。

建造上蓋時，工程團隊以創新思維，先把中段結構安裝在固定支柱上，然後用懸臂施工法向兩端伸延桁架，大量減少了臨時支撐。此外，又引進香港建造工程有史以來最大型的天秤，協助吊裝上蓋的重型鋼桁架，以及把各種巨型預鑄/預製組件吊運到地庫的指定位置。

建造地基時，團隊因應工程變動，採取了兩項新措施。先是取消建造4米深的井洞地基，省卻了大量挖掘工作；其次是用預製板區間一個敞大的空間，代替現場建造，這不但節省工時，對工人的健康亦更加有利。另一項應變措施是，因應工程團隊同時承造810A和811B工程，方便取消原本分隔兩個毗鄰地盤的一堵板樁牆和相關的臨時支撐。而且，更可讓團隊能夠在佐敦道，分三個階段進行大規模的「大轉身」交通改道。

其他提高工程效率的措施包括，在地盤增設wifi 無線網路，方便傳送和審批臨時工程的資料；採用在香港已標準化及廣泛使用的PVC排水管，代替原本計劃採用的不銹鋼管；平整地台時，用更優勝、可更快速地在更大範圍使用的K-Screed砂漿層，代替標準的地台批盪層。

經過多翻改良，團隊最終成功應用一種創新、不易堵塞泵管的高性能混凝土，以便泵送到遠距離的施工地點；又設計了一款新索具，在裝置固定大型複合柱時，能夠把它們分段豎起，以便逐一接駁和安裝。

工程團隊更充分利用多項金門為整體業務而開發的創新技術，例如用自動化發薪系統處理工人的工資、使用無線射頻辨識(RFID)標籤幫助追踪數量龐大、形狀各異的覆板面組件。

THE KEY TO A SUCCESSFUL OUTCOME IS AN INNOVATIVE MINDSET, ADAPTABILITY AND TEAMWORK

"The best laid plans of mice and men, often go awry," so the saying goes. On a project as vast as HKWKS, it is inevitable that the best laid plans for how to build it would turn out to be quite different from what eventually transpired. The key to a successful outcome then, is an innovative mindset, adaptability and teamwork.

Some of the innovations have already been mentioned earlier, including the use of the balanced cantilever method of construction to erect the roof structure on permanent support, thus reducing the amount of temporary works required.

Minimising the amount of temporary support depended on accurate calculations of the load permanent works could effectively support. At the same time, careful estimates of the movements and deflections affecting the roof structure as well as the associated locked-in stresses enabled the team to avoid any undesirable overstress and strengthening. In this way depropping could be carried out safely and earlier, releasing space for other works.

The layout of the temporary support towers were also adjusted to accommodate some low-level truss members and to release room for the setting up of three made-to-order tower cranes. To cope with much of the heavy lifting on such a deep site, the team procured what were the biggest tower cranes ever used in Hong Kong, which allowed them to lift heavy steel sections for the roof as well as various large precast and prefabricated components destined for the basement levels. An even bigger capacity crane was procured once it was decided that the punch columns would be preassembled and dropped into position rather than built from the basement levels up.

Above: *Temporary access bridge used to erect the roof's 58 tonne, 75mm-150mm thick steel plate V-trusses.*

"Imagine building a 100m steel bridge three times. After erecting the middle truss we still had to erect the upper and lower trusses." Principal Project Director C.C. Hau.

Two of the most significant innovations involve foundation works. One was the deletion of the pocket foundations originally designed for the north area, where top-down construction of a ventilation plenum was planned. The original design called for 4m-deep excavations into rock to create pocket foundations to support columns in an 8,000m^2 area where the plenum is located.

"After additional testing of actual ground conditions, which turned out to be more favourable, we were able to reanalyse the pocket foundations and raise the level so they weren't so deep," said Senior Construction Manager John Adams. "The foundations were to support about 40 main columns so the amount of excavations saved was significant. We probably saved a couple of months' time as a result."

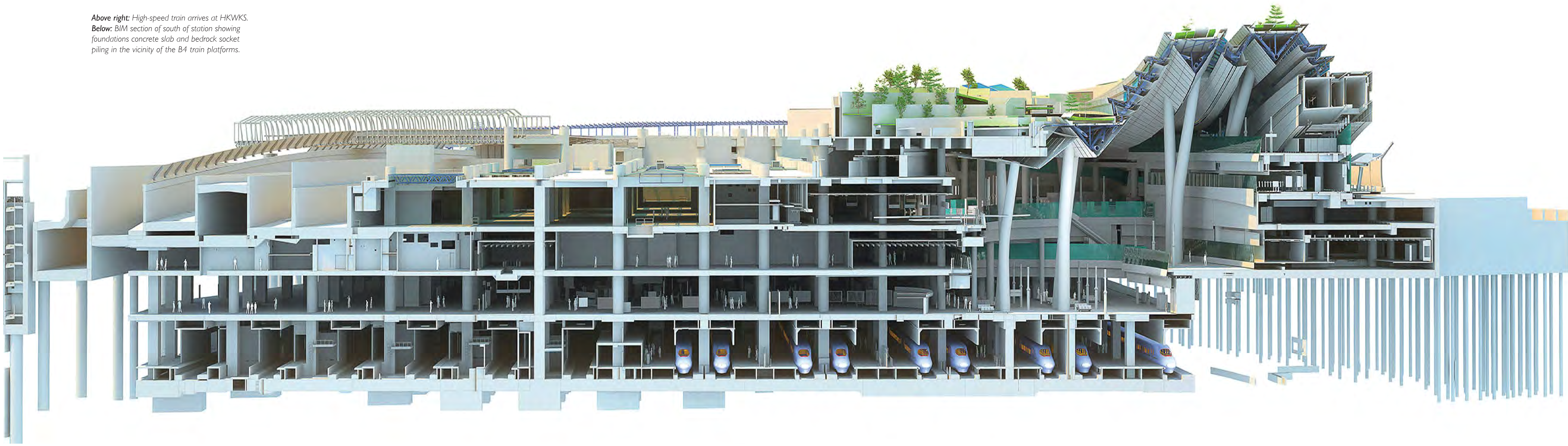
The change to precast panels for the plenum instead of in-situ construction also saved time and safeguarded the health of workers who would otherwise have to work in a poorly ventilated and tight 800mm-deep space. The change won the team the Bronze Award from the Lighthouse Club International Design for Safety Awards.

The other innovation involved the deletion of struts originally required to support a wall separating Contract 810A from the adjacent Contract 811B. According to the original design, a separation wall consisting of sheet piles driven to 24m below ground was to be installed as a demarcation between the two contracts. When the team secured Contract 811B as well, it offered the client savings in terms of cost and programme by removing the separation wall. As ground conditions would have made it difficult to drive so many struts to the required depth, the deletion of the requirement is estimated to have saved two to three months from the programme.

Winning the tender for 811B also enabled the team to implement 'the big flip', the large-scale diversion of traffic on Jordan Road, in three stages. Top-down construction on 811B meant a traffic slab could be installed to accommodate traffic diverted from Jordan Road, enabling construction of the three-level underpass to proceed. In-house design consultant Lambeth developed a system of temporary support for the slab using pre-bored socket H-piles which were part of the permanent works – an efficient and environmentally friendly solution that saved materials, as well as time.

- 1,700,000M^3 OF EXCAVATIONS
- 124,000M^3 OF ROCK BLASTED MATERIAL
- 573,000M^3 STRUCTURAL CONCRETE
- OVER 20,000T CRUCIFORM STANCHIONS IN BASEMENT

Above right: *High-speed train arrives at HKWKS.*
Below: *BIM section of south of station showing foundations concrete slab and bedrock socket piling in the vicinity of the B4 train platforms.*



Technology came into play when the team carried out E&M work under the deck of the public transport interchange. After on-site tests proved its efficiency, a robotic arm was used to drill the holes for the ductwork, thus speeding up the installation of fixings.

Bringing construction into the 21st century, the team also decided to install wi-fi on the underground site in order to access the Gammon Engineering Management System.

"The Gammon Engineering Management System is an online system that allows us to control temporary works. If you are underground with wi-fi, you can use that to approve an item of temporary works without having to come back up to the office to allow it to happen. We've also installed chargers around the site for our workers, so they can charge their devices because that's how people choose to communicate now," said 811B Project Director Brian Gowran.

Since the station and the emergency escape assembly building are both irregularly shaped, the design and dismantling of temporary works needed to be carefully reviewed; the communication system was important in facilitating that process.

Other innovative measures were adopted to improve the efficiency of various works. For example, the team persuaded the client to install PVC drainage pipes, which are standard and widely available in Hong Kong, instead of stainless steel per the original design, which would have taken time to weld together. Another example was the switch from a standard type of screed to K-Screed for the tiling works. Its relatively higher cost was made up for by the improved efficiency it brought.

"It could be applied to a much larger area a lot quicker, which gave us more continuity of work in laying the floor tiles. As a consequence, we were able to lay all the floor tiles before the high-level building services were done. It was done out of sequence, but by the time the building services contractors came in, the floor was already protected," said Senior Commercial Manager Martin Webster. "If we hadn't done that, the project might have been six to eight months behind."

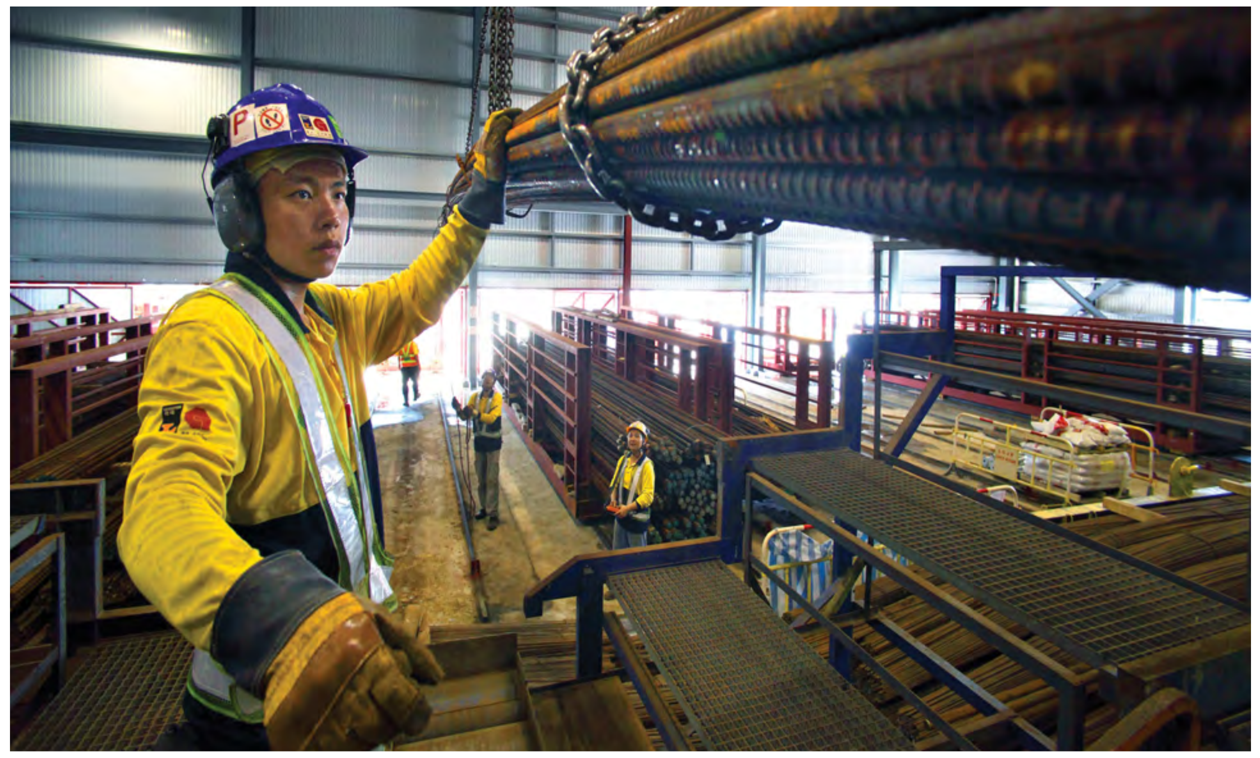
While changes were made to meet the demands of the project, there were also innovations that were successfully applied as originally planned, notably the use of a high-performance concrete that could be pumped over long distances, as well as cut rebar cost. Due to the depth of the basement and the amount of reinforcement required for the slabs, the team needed a concrete mix that could be pumped over a distance of as much as 600m and, once poured, would shrink less, so that less rebar would be needed to control shrinkage. With less rebar to cut and bend, this in turn reduced labour cost and time.

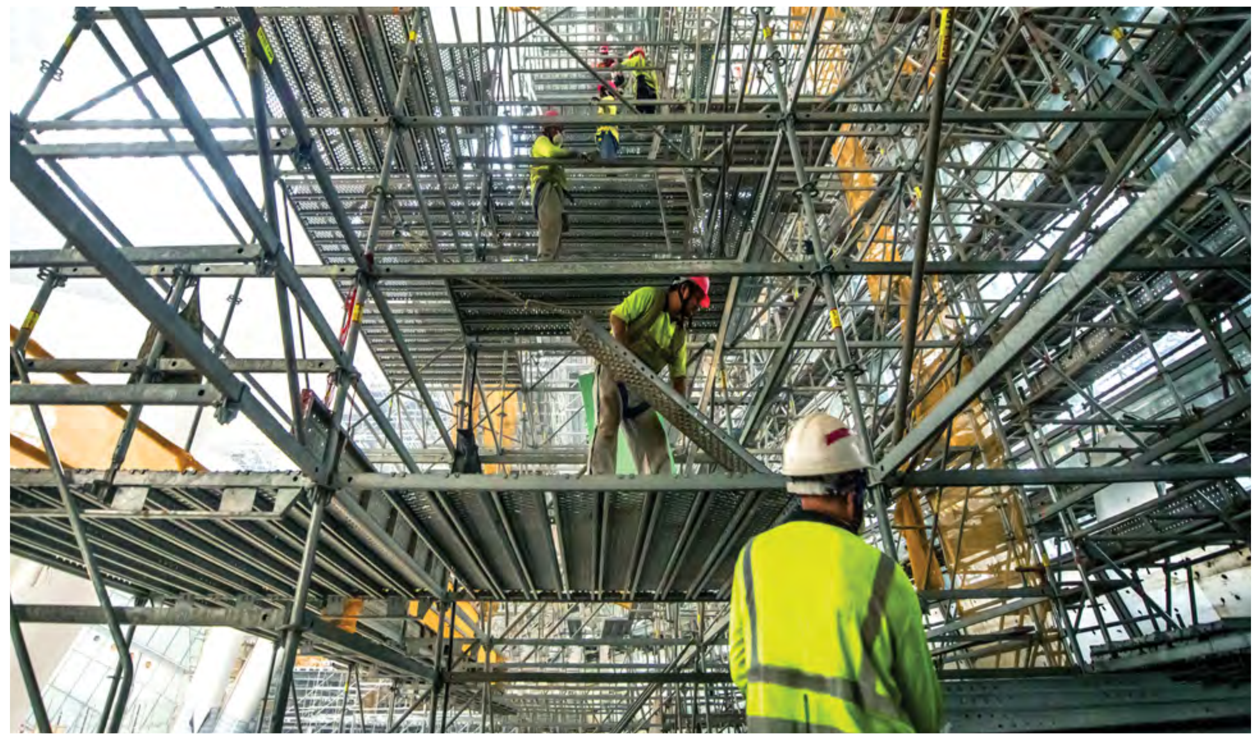
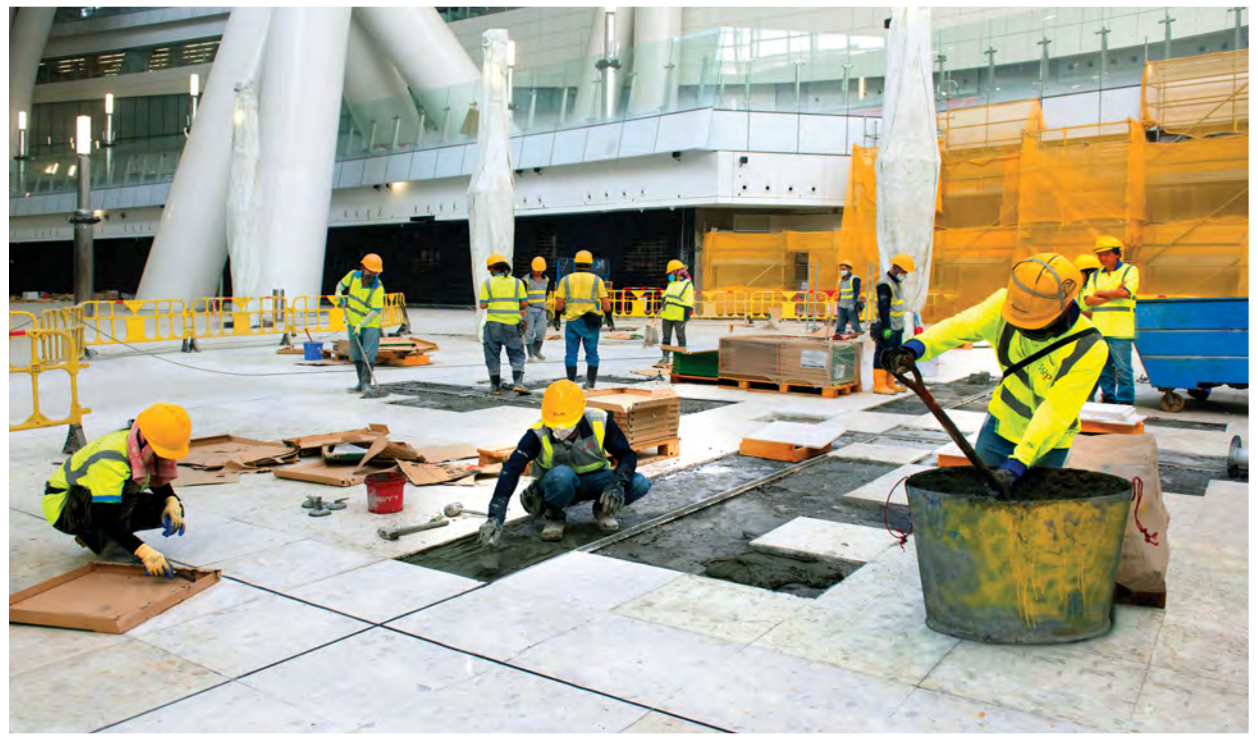
In-house designers developed a concrete that complied with Buildings Department requirements and could be pumped to location from the on-site batching plant without blocking the pipe halfway. The plant was able to supply 950m^3 of flowing concrete per day, thus drastically reducing the number of concrete truck movements that would have increased the project's impact on road traffic and the environment. The use of the high-performance concrete also meant that 20 per cent less rebar was needed for the basement slabs, which translated into significant labour and cost savings.

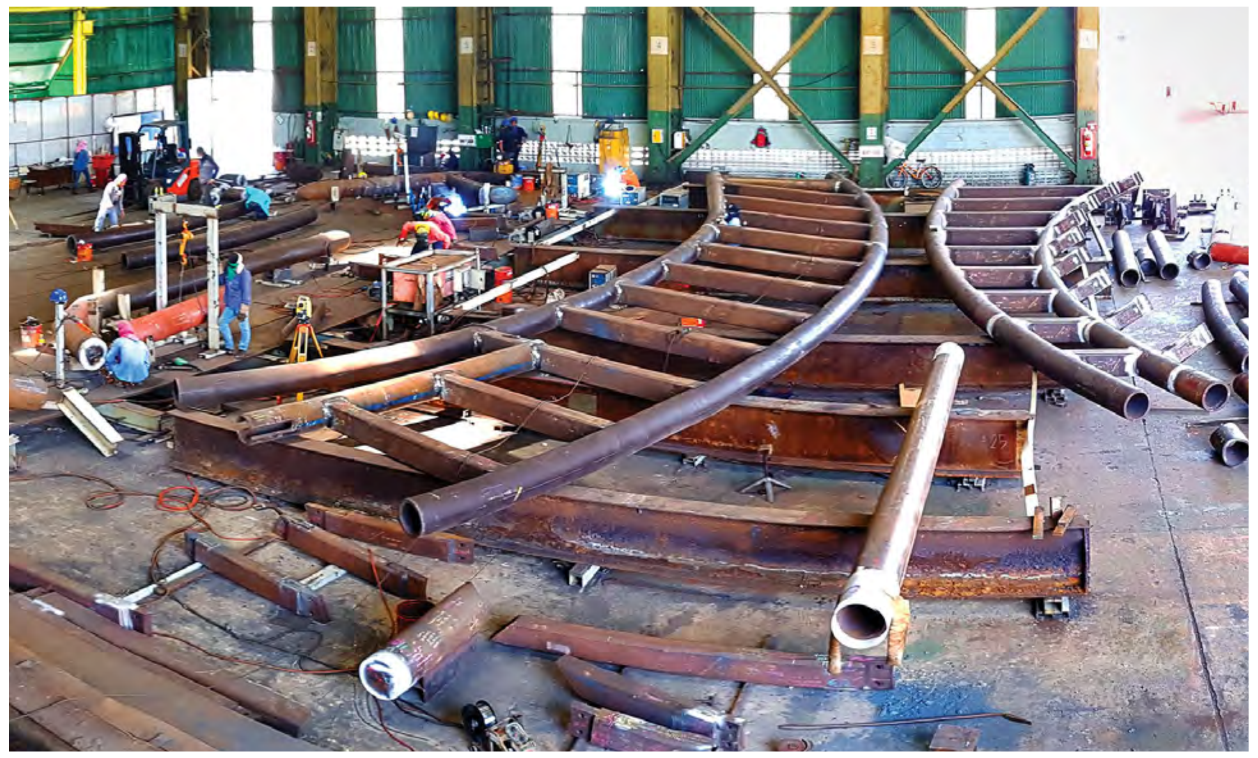
Another innovation was the design of a lifting device to secure the 345 composite columns – which weigh 27-72-tonnes each – during installation, allowing a column to be flipped upside down for the attachment of a second section.

The team also took advantage of innovations developed for Gammon's overall business, automating its payroll system, for example, and using radio frequency identification tags to facilitate the handling of cladding components.

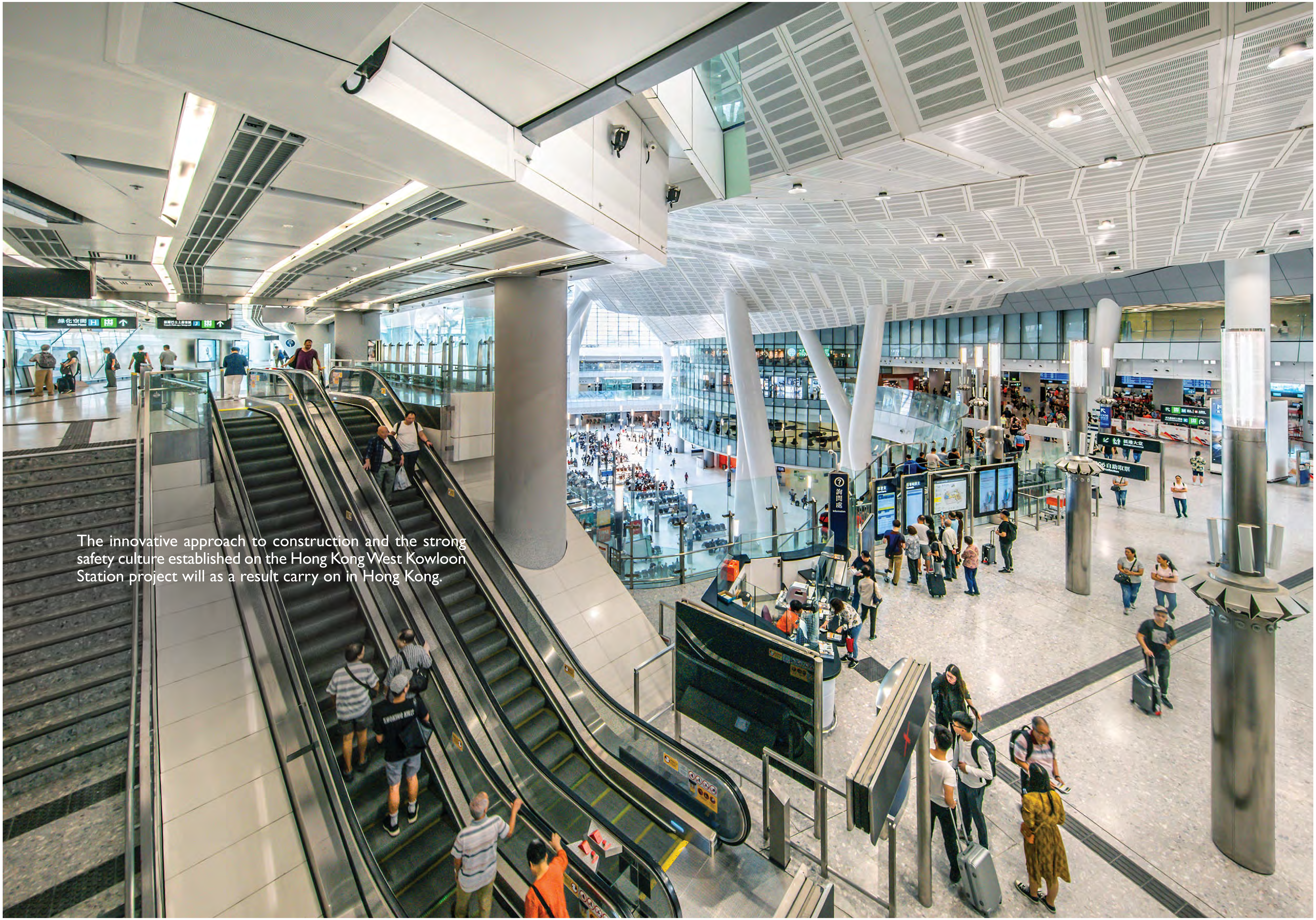
"Effectively we built an airport 35m below sea level with a diaphragm wall right around it. There were 450,000 shop drawings for the roof cladding alone. Few people in the world could have grasped the enormity of it," said Webster. "We applied a lot of innovation to the construction; the team put a lot of effort into the project and some have gone on to lead other projects. We've learnt a lot from this project and benefited from it as well."



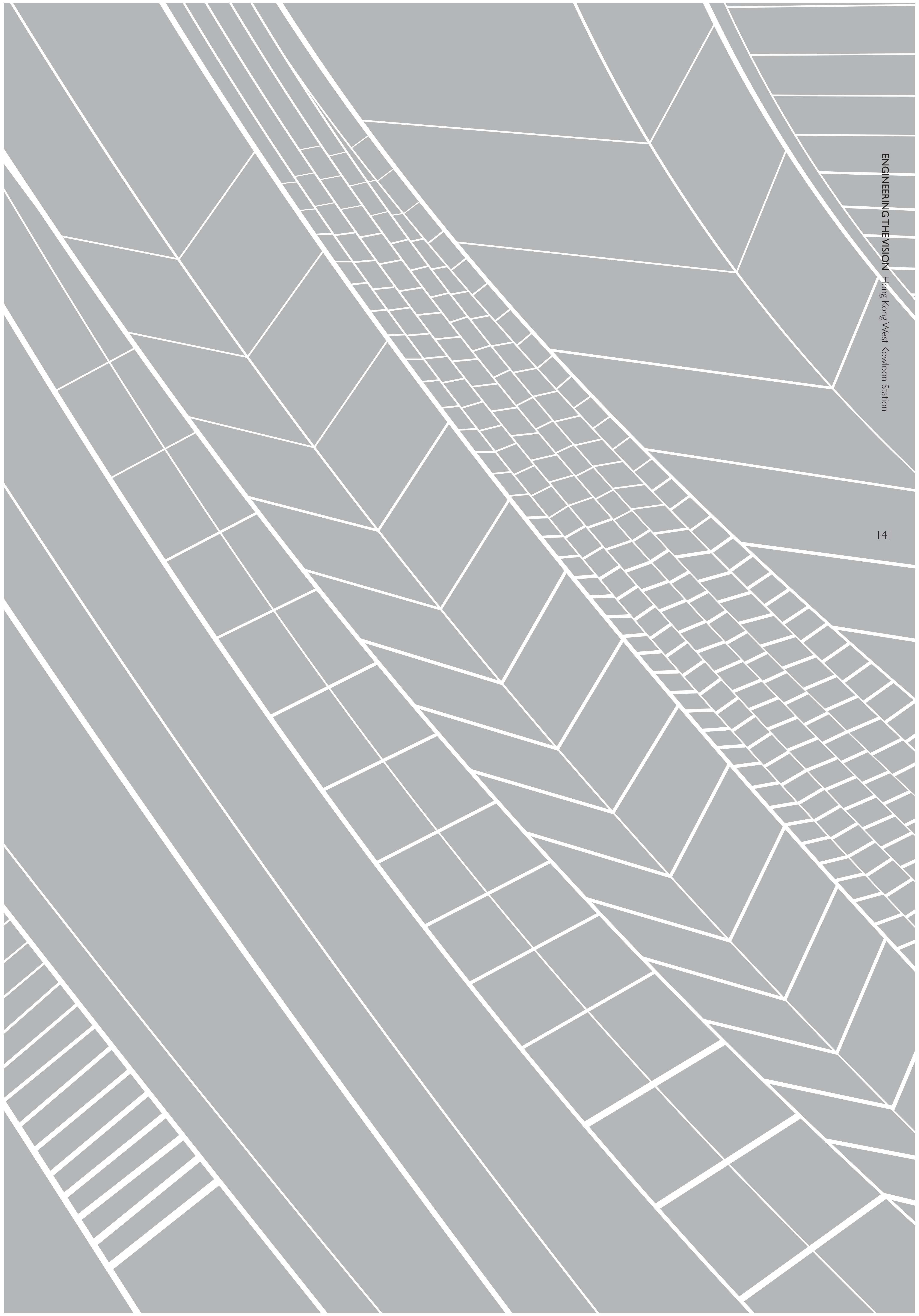




Top left to right:
Concrete pour;
On-site rebar warehouse facility;
On-site concrete batching plant;
Atrium 'bird cage' scaffolding modular system;
Floor tiling at Level-3 Departures Concourse;
HKWKS cross-boundary area;
Bow truss workshop, Thailand;
BIM engineer.



The innovative approach to construction and the strong safety culture established on the Hong Kong West Kowloon Station project will as a result carry on in Hong Kong.

BRINGING TEAMWORK + LEADERSHIP TO BEAR



One team undertaking the entire project, whether a frontline worker or a designer, all dedicated to problem-solving together.

團隊合作和非凡領導

香港西九龍站的工程雖然複雜，但團隊憑著創新和香港人的獅子山精神，排除萬難，最終把香港西九龍站簇立眼前。

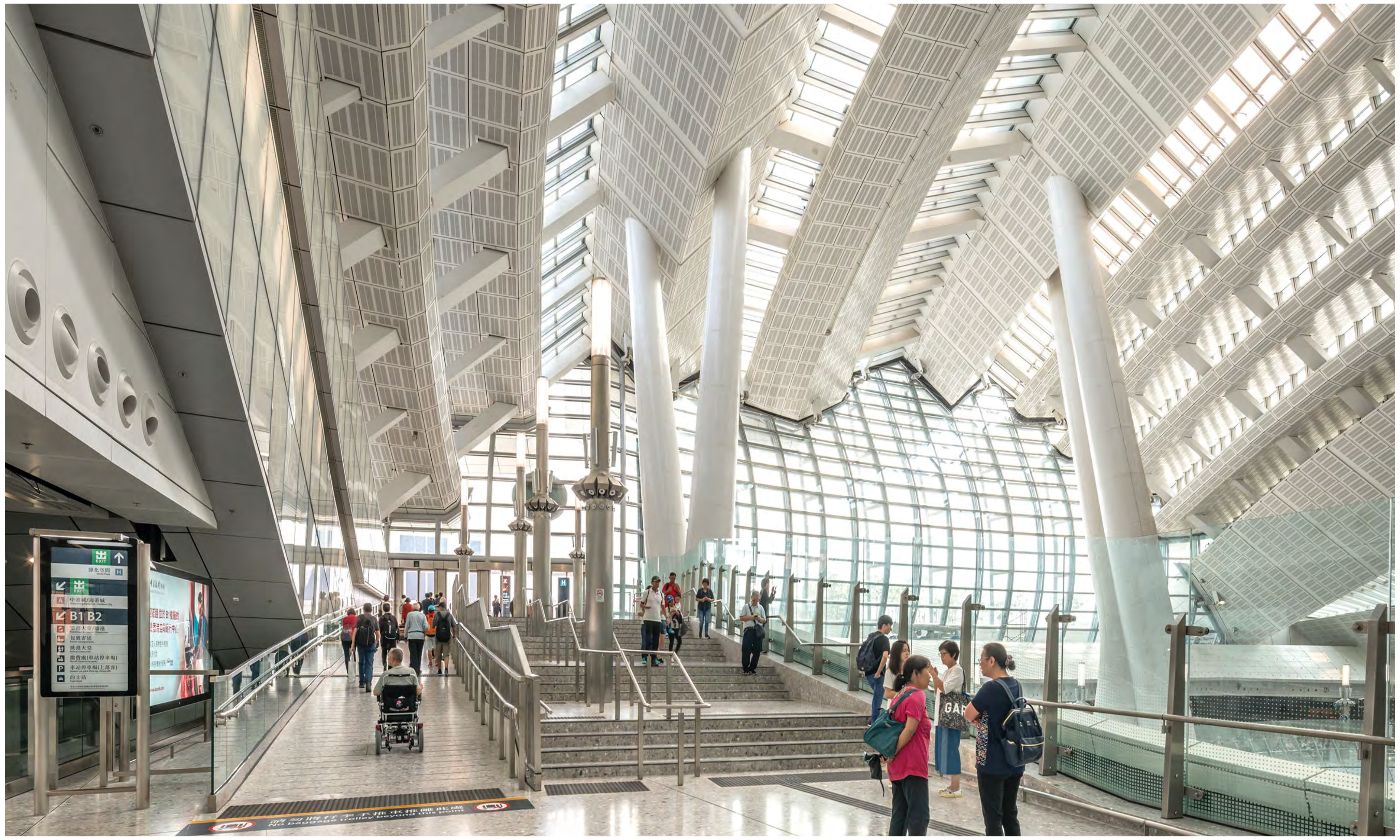
在啟動項目初期，從未預計會遇上重重挑戰。然而困難無法阻撓一群團結、擁有共同目標和卓越領導的團隊。每一位成員都明白，他們不能狹隘地只著眼於自身眼前的職務，而是要互相配合，衷誠合作，每一個施工細節都要以項目整體的最佳利益為依歸。

項目能順利完成，一個全新修訂的合約模式至為關鍵，它為整個工程計劃制定實際的關鍵績效指標，把實力聚焦。工程人員並向供應鏈內所有分判商介紹這新計劃，確保所有參與的同仁達致互相關顧、有效溝通、增進聯繫、鞏固承諾，一起為共同的目標努力。

總括而言，順利交付香港西九龍站項目，關鍵在於凝聚了合適的工程人員，按實際情況作出了正確的判斷和決定。首席項目總監侯志超總結從建造過程中汲取的經驗指出：

- 規劃、編訂程序，及供應鏈的管理至關重要
- 要與客戶和顧問緊密合作，凝聚團隊精神
- 必須明確界定責任和目標
- 勇於面對挑戰，作出果斷決定和承擔
- 團結就是力量，所有工程人員同心同德，一起向共同目標邁進

這項目成功培育了大批建造人才。香港西九龍站落成後，多位工程經理從中累積到寶貴經驗，繼續領導其他建造項目；多家分判商因參與項目建立了良好商譽，繼續落實其他工程合約。從建造中學習，汲取經驗，同時跨越困難，呈現劃時代建築，人才培育與建造項目相得益彰。



"WE'RE ALL COLLEAGUES SO WE WORKED TOGETHER TO OVERCOME ISSUES."

Raising an iconic roof, excavating a deep basement, setting up multiple stages of traffic diversions and building the many facilities required of the MTR's biggest train station in Hong Kong called for innovation and the Lion Rock spirit that made the impossible possible. Most of all, these often concurrent challenges called for teamwork and decisive leadership to drive the project forward safely, regardless of the circumstances.

At the beginning of the project, no one could foresee how complex it would be and how different ground conditions would turn out to be. However, no issue was too hard for a team united by common objectives and led by decisive leaders.

"Sometimes you have to make painful decisions and give up original ideas to make things work," said Principal Project Director C.C. Hau. "The project is so big – we had 580 staff – that it was a challenge to give everyone clear objectives and deliverables."

While every member of the team was assigned responsibility for an area, it was made clear they must not regard their areas as silos. Do your job well, but don't just mind your own business; work with everybody else to smooth interfaces and improve the programme. The logistics of the project, for example, benefited from cooperation with the team on Contract 811B, which provided a combined works area that allowed the 810A team to store materials and carry out piling works.

"The person responsible for controlling the combined works area must think in terms of what's best for the project as a whole rather than the contracts," said Project Director Brian Gowran, who headed the 811B team.

The large-scale traffic diversion schemes implemented also demonstrated the importance of this teamwork. The underpass on Lin Cheung Road had sections that came under the two different contracts so when the traffic management schemes were implemented, the two teams worked together to make them happen.

"One contract was responsible for the fitting-out and the other was responsible for the structure, but we're all colleagues so we worked together to overcome issues," Gowran said. "Also, there's a footbridge across Jordan Road that was done by the 810A team but which came under our contract. There was a period when they needed to get their people on site and the most efficient way to do that was to get them to use the footbridge, so we let them do that. It probably saved half an hour each way."

For those on the project, the word 'team' did not refer to those working in the same areas; instead, it meant the one team undertaking the entire project, whether one was a frontline worker or a designer, dedicated to problem-solving together.

Bringing the project to a successful outcome was down to the development of a revised contract model that provided realistic key performance indicators for the programme that helped every member of the team see clearly what the objectives were and how they could be met.

"We had a team that brought a fresh perspective on delivery, programme management and planning. It was a confluence of the right people coming in at the same time and within six months we were all heading in one direction," said Senior Commercial Manager Martin Webster. "Teamwork and having the right senior management were important. We changed the 'street of irrelevance' culture that was there before."

The team took care to bring on board the entire supply chain, to make sure the sub-contractors also bought into the new programme. Providing free lunchboxes that catered to the culinary tastes of people from different ethnic backgrounds was a good way to attract attendance at technical talks. Opportunities were also provided for managers and consultants to talk directly to frontline workers so that, for example, a designer could better understand how a reinforcement detail could or could not be realised by speaking to an experienced steel fixer face-to-face.

Making sure everyone was looked after and able to communicate fostered commitment and a positive relationship that everyone was then keen to maintain.

Ultimately, the successful delivery of HKWKS was down to getting the right people to make the right decisions according to their practised judgement. "The decisions made involved tens of millions of dollars; they had cost implications and with authority comes responsibility. We must know how to use that authority to make the best decision for the moment," said Hau.

***Above:** Light-filled entrance with curved bow truss and glass wall panels.*
***Below:** Gammon, Leighton and MTR completion team, September 2018.*

THE LESSONS LEARNT WERE JUST AS IMPORTANT AS THE DELIVERY OF THE PROJECT

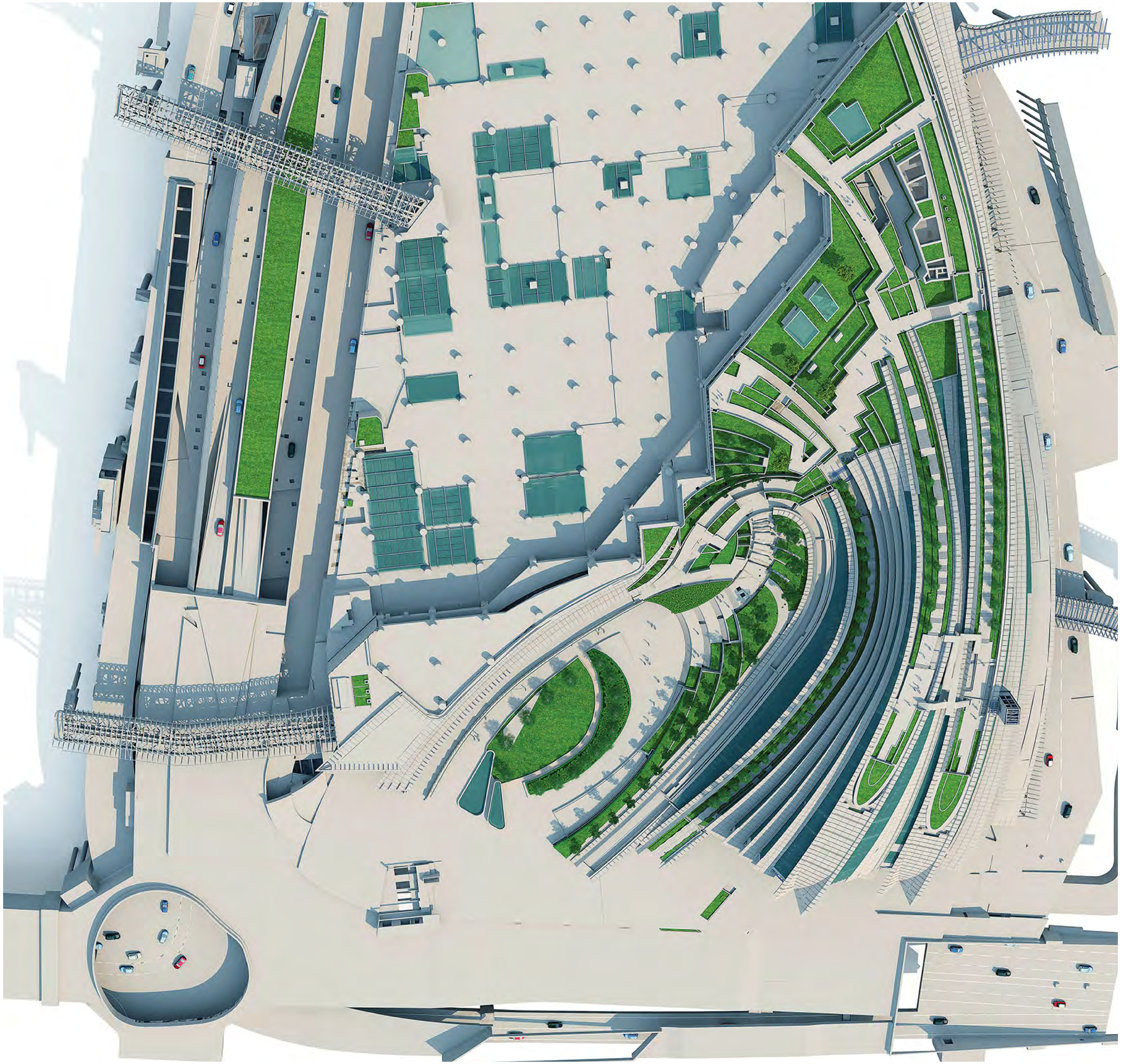
If there are lessons to be learnt from the execution of the HKWKS project, they are, according to C.C. Hau, the following:

The importance of planning and programming and the management of the supply chain. The need to work with the client and consultant, all as a team. Clarity with regards to responsibilities and objectives. The courage to take hard decisions. The importance of team building and a one-team approach.

"Building a team and getting everyone to buy in takes a lot of effort; it's not easy to change the typical contract culture," he said. "I gave myself the task of drawing up a new programme that would meet the client's expectation. If someone felt they couldn't handle the responsibility, I'd say, fine, let me handle it."

With that kind of determination, the staff were finally persuaded to commit to the project's delivery. Many design refinements were issued to overcome the site constraints after the new programme came into effect, but the benefit of the new programme was apparent because the team was able to manage the changes and focus on delivery. Staff development on the project reflects its success; a number of managers have gone on to lead other projects and even sub-contractors, such as those who erected the bird cage, have gone on to secure other jobs after building experience on HKWKS.

"The project started November 2011 and so much has changed in terms of how technology affects business. We now have a digital concrete reconciliation system, WhatsApp and a paperless labour pay-roll system, none of which came out of this project but this project has benefited from them," said Webster.



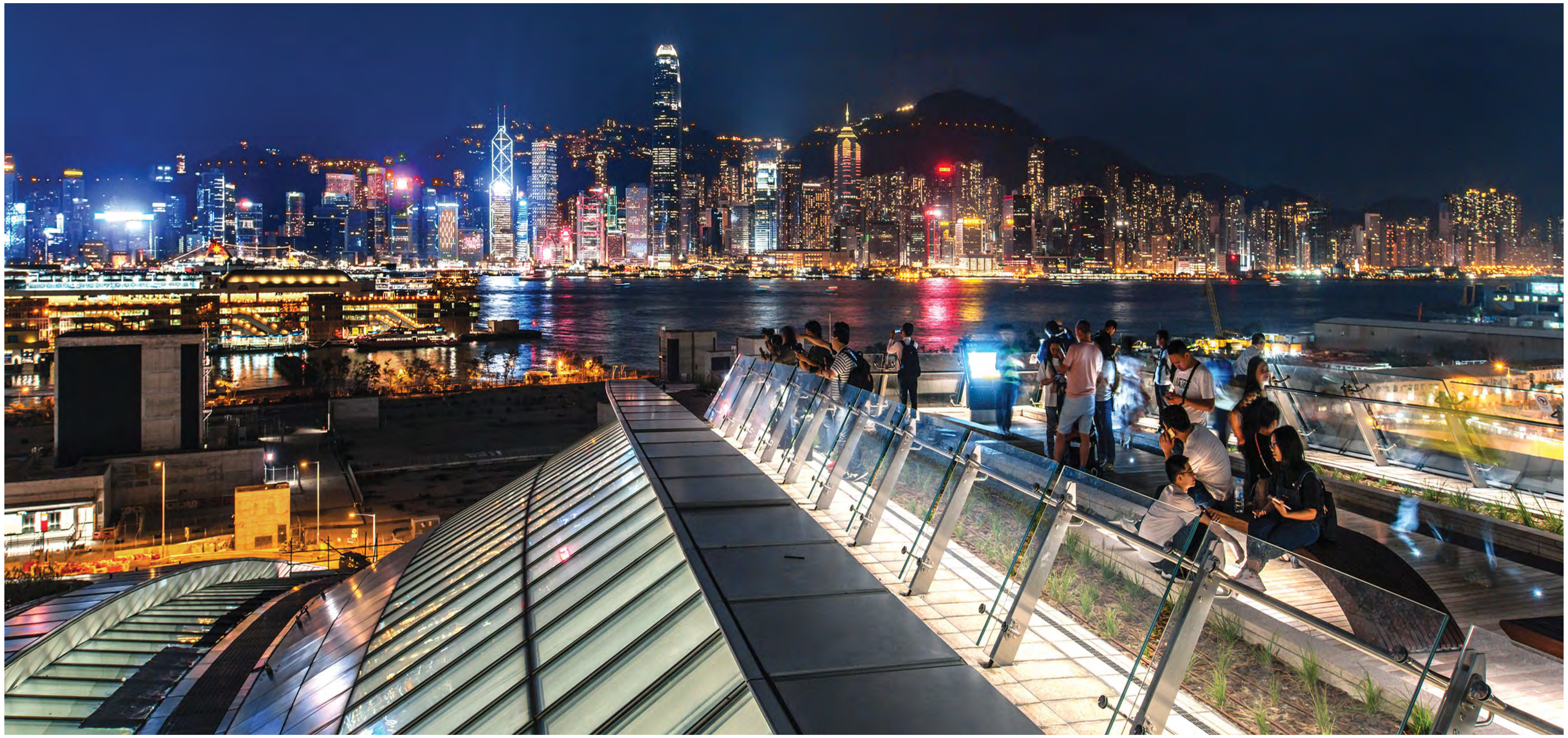
BIM render of the station roof and surrounding Lin Ceung Road underpass and Wu Man Road.

HKWKS also benefited from Gambot™, a Gammon-developed artificial intelligence system that improves a range of construction tasks that were previously more complicated and time-consuming to carry out, such as labour allocation, concrete delivery scheduling and cost management. These and project-specific innovations contributed to the success of the new programme, too.

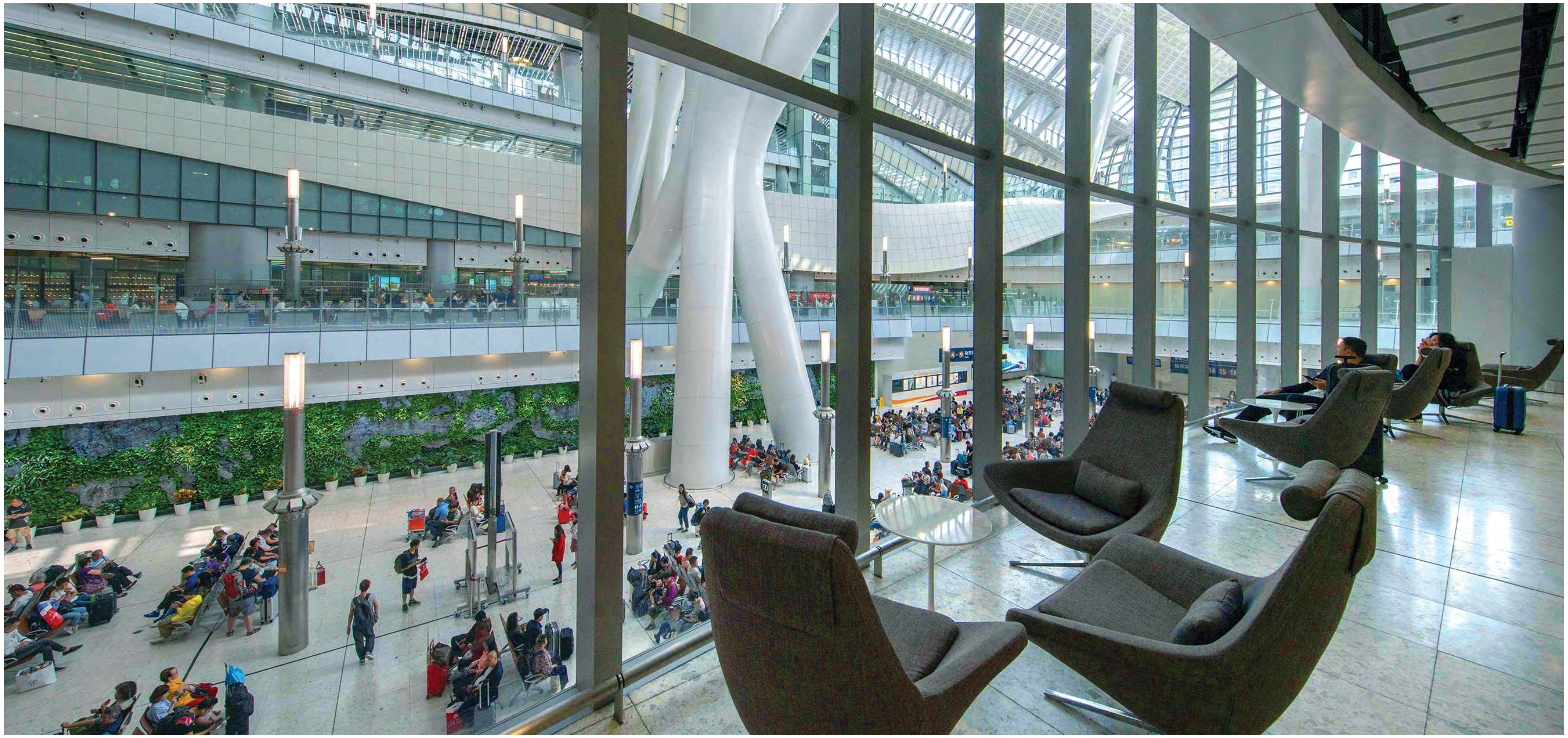
The team is keen to emphasise that the lessons learnt were just as important as the delivery of the project.

"At the start of the project we probably lacked understanding of the full complexity of the job and the actual resources and skills required. We will learn from that; we need to get the right people to the right place for successful delivery," Webster said.

Hau agreed. "We've got to be humble," he said simply. "What we've learnt will stand us in good stead for other big projects that we're doing and will take on in the future."

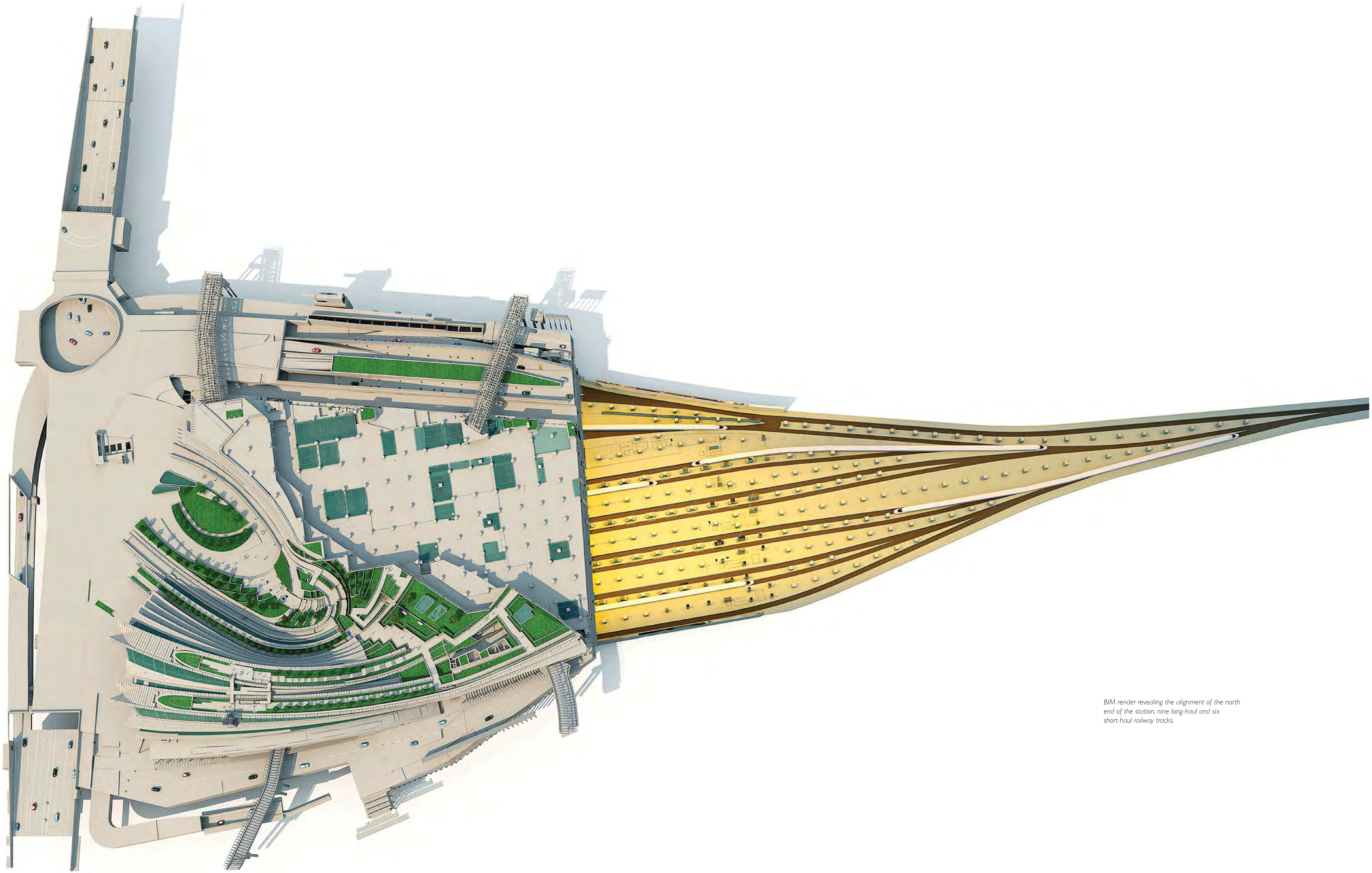


***Above:** The Sky Corridor leads to the rooftop observation deck overlooking Victoria Harbour.*
***Below:** The Business Lounge on level B3.*



THE TEAM TOOK ADVANTAGE OF NEW TECHNOLOGIES THAT BECAME COMMERCIALLY AVAILABLE WHILE THE PROJECT WAS ONGOING

"Under that iconic roof, hundreds of thousands of people will soon be travelling back and forth, disembarking or catching high-speed trains to Mainland China, or using the pedestrian connections to reach places in West Kowloon and wider Hong Kong. I am grateful to all our partners for sharing this opportunity to deliver a truly historic project."
Thomas Ho, Chief Executive, Gammon.



BIM render revealing the alignment of the north end of the station, nine long-haul and six short-haul railway tracks.