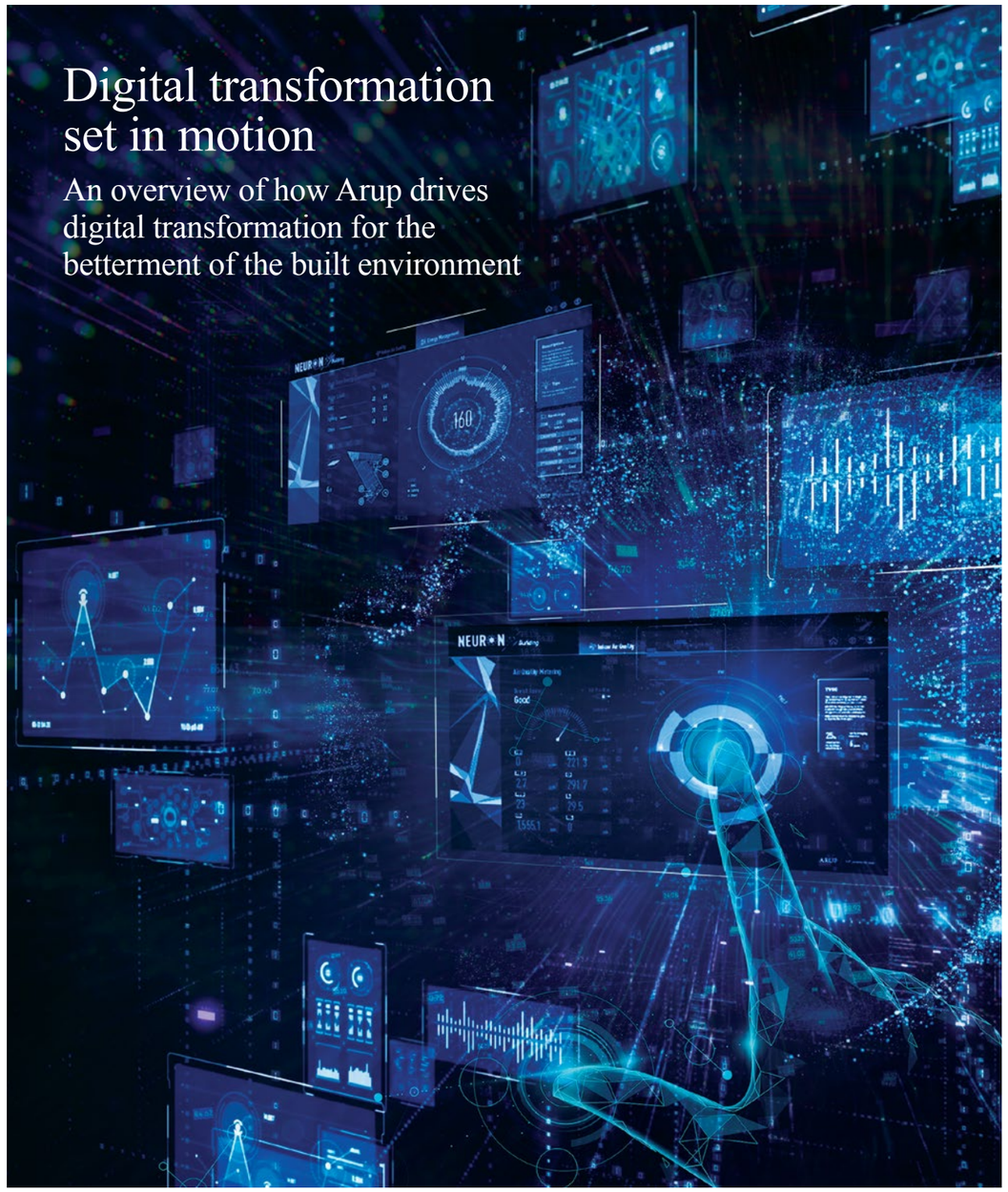
ARUP

FIRST

Issue 11 2022

Foresight
Innovation
Research
Sharing
Training



Digital transformation set in motion

An overview of how Arup drives digital transformation for the betterment of the built environment

arup.com

Foreword

The digital transformation in the architecture, engineering and construction (AEC) sector has created opportunities for improvement in performance, efficiency and cost-effectiveness. This has prompted Arup to drive digital transformation across all disciplines.

In 2018, Arup created a roadmap to support digital transformation initiatives at every level of its organisation. A digital executive board, comprising six executives, was also formed for the East Asia region to formulate and execute a regional digital transformation strategy.

This top-down strategy is helping move us from strategy to action — ensuring everyone across Arup recognises the digital opportunities available and makes them part of their daily activity through various task forces, programmes, training and workshops, research funding support and collaborations with external ventures and universities.

Our efforts have come to bear fruit. We are recognised as leaders in formulating innovative digital solutions that make the built environment more sustainable and resilient. In Hong Kong, for example, we have become a trusted partner of the city's government to support its smart cities initiatives.

Another case in point is Neuron, the smart building management platform initially developed by Arup. Earlier this year, it was spun off as Neuron Digital Group, a joint venture formed between Arup and Venturous Group.

Integrated with remote sensing, our AI-enabled digital twin technology has also been deployed to monitor critical infrastructures, such as offshore wind farms and rivers. This is increasingly important because it can help protect assets, make predictions and provide stakeholders with actionable intelligence.

While we have set a global digital transformation in motion, Arup's business fundamentally remains the same. It is always about providing deep technical expertise and innovative solutions to the toughest challenges our clients can throw at us.

FIRST is a publication produced by East Asia Arup University (AU) for our clients and partners, exploring design, innovation and technical solutions for the built environment. It takes its name from the unique model of AU: Foresight, Innovation, Research, Sharing, and Training.

If you have any thoughts, questions or comments, we would love to hear back from you at ea.arupuniversity@arup.com.

Contents

Technical solutions

Digital transformation set in motion 4

Supporting Hong Kong's smart city blueprint 8

Digital technologies lead to infrastructure of enhanced resilience 14

How smart buildings improve energy efficiency, occupier wellbeing and safety 20

Accelerating shift to smart mobility 26

Profile

Work smart to excel: Peng Liu 30

Cracking the code: Young Wong 34

Foresight and innovation

Navigating the complexity of China's market amid renewed uncertainty 38

Research

Sharing is caring: pilot data sharing framework for smarter planning 40

Using AI and digital technology to survey rock mass discontinuity 44

Sharing and training

Light up the way home 46

Building the global workforce of tomorrow 48

Digital transformation set in motion

An overview of how Arup drives digital transformation for the betterment of the built environment

Arup's digital transformation strategy is underpinned by four pillars: data governance, automation, products and services, and branding.

A more robust data governance structure allows us to create more accurate models in the future. Automation also helps us in terms of work quality, time management and cost efficiency.

Products and services are important because they give us an opportunity to provide data-driven solutions for clients. A stronger digital brand helps us build a stronger relationship with clients and present ourselves as thought leaders in the industry.

Data

The strengthening of data governance is vital to Arup's digital transformation journey. Data governance is the process of managing, controlling, and protecting the value and usage of our data assets. With a consistent approach to data governance, we can generate insights from data to inform our design and business strategy. Providing value and new services for clients is a natural result.

To reduce data silos and prevent us from re-inventing the wheel, we have set up taskforces to link data from our different businesses and disciplines on a global scale. With greater, easier access to the data infrastructure, members across the firm working with corporate data can bring greater focus on exciting and creative ways of working with digital offerings for our clients.

Automation

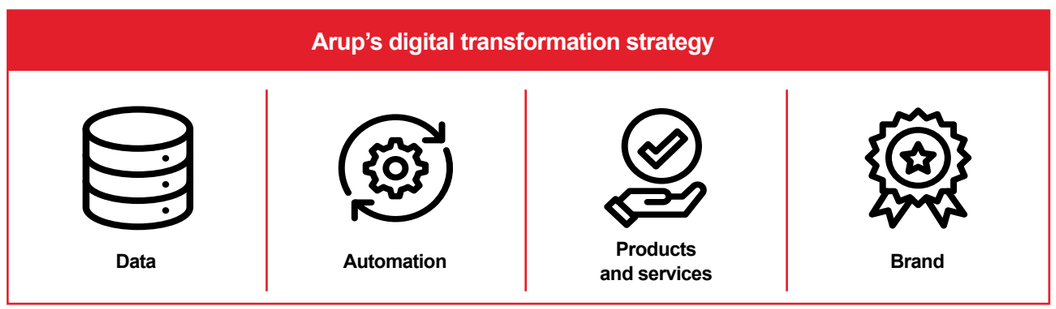
Automation helps us increase our quality of deliverables by improving consistency, reducing errors, providing automatic checking and improving our technical mastery. This gives us a superior understanding of our clients' issues and the factors that affect our plans, designs, and solutions.

New automation tools and platforms allow our teams to automate repetitive tasks and focus on more strategic areas of their work. In East Asia, the Digital Design Team has built a cloud-based Total Design Automation platform to centralise existing automation solutions, making automated workflows available to all project teams in one place.

Products and services

To support this pillar, we have established a set of Digital Services Accelerator Programmes to foster the development of new digital services across all our major businesses. These exemplary projects combine Arup's existing core domain expertise with the new world of modelling and insight based on real-time and big data to provide new value for clients across the whole life cycle of assets.

Over the past few years, the Digital Services Accelerator Programmes have facilitated the digital transformation of our work in the following sectors and domains:



Arup's overall digital transformation strategy is underpinned by four pillars: unlocking insights from data, automating work, innovating services and products, and digital branding.

- Smart building: digital and machine learning-powered services that optimise everything about a building's use, such as energy, air quality, and user health.
- Aviation: digital tools have been built to facilitate a 'real-time airport', enhancing both client operations and our airport planning and design.
- Infrastructure: cloud-based models that analyse real-time infrastructure data, leading to design/build/operate/maintain platforms that optimise value over the whole asset lifetime.
- Smart places: area-based risk assessment—cloud-based web platform to allow building portfolio owners and investors to dynamically assess risks to their building stock quickly.
- We are developing further accelerator programmes for Rail, Highways, Energy and Water, to broaden and deepen our digital offers.

To continue to grow our digital services capabilities and market reach, we have set up Advanced Digital Engineering (ADE) groups in each of our regions, including East Asia. The ADE groups lead Arup's digital service development to meet market needs and address clients' pain points. We have developed many tools for ourselves and deployed some of them in client projects.

Stakeholder engagement was another challenge in a socially distanced world. But Virtual Engage 2 provides a solution, allowing audiences, through a convenient web-based experience, to access information, watch flythroughs, navigate 3D models, and share feedback from any location, at any time.

Other advances involve expanding the scope of existing technologies. Building information modelling (BIM) 3 is the bedrock of a smarter built environment. Using our BIM Maturity Model, we assess the maturity of BIM implementation across all our projects globally to ensure year-on-year improvement. Also, to help collaborate better with our project partners and clients, we have created a single Revit data naming standard to allow consistency in our models.

Neuron spun off from Arup as proptech JV

Neuron is our smart building management platform. It was originally developed by Arup, and was spun off as a separate joint venture, Neuron Digital Group, between Arup and Venturous Group in 2022.

Neuron harnesses data-driven technology to serve modern-day buildings, including energy

© Neuron Digital Group

Arup was named the Winner of ASHRAE Hong Kong Chapter Technology Award 2021.

management, tenant wellness and satisfaction, automation and indoor air quality. It will also help reduce maintenance costs and equipment downtime and optimise asset management.

With Venturous Group's capital, strategy, and technology capabilities, Neuron solutions have been implemented in different projects in Asia, resulting in a significant improvement in building energy and operation efficiency. Neuron will further develop into a cloud-based integrated technology platform with digital twin, AI, and big data capabilities that will meet the needs of building owners, operators, and users.

Headquartered in Hong Kong, Neuron is already serving several prominent clients in the local market. With a global reach, Neuron has won numerous domestic as well as international innovation and environmental awards to date. The company also has plans to expand from its research and development base in Hong Kong and establish operating hubs in mainland China and other key leading smart cities in the region.

Digital brand

Arup is committed to providing career opportunities for talented people from all backgrounds, including IT talents wanting to pursue a rewarding career in the AEC sector. Therefore, we strive to offer a clear career path for digital professionals and with Arup recognised as a tech-driven total design firm. Our people feel they are part of a dynamic and exciting work environment.

Externally, we increasingly engage with start-ups to drive innovation, and mature clients look at us as the go-to partner for designing and deploying disruptive technologies to create new value. Internally, we focus on our clients' digital experiences, evolving the culture through digital education, and strategically exploring new technologies. These

Classification of digital skills			
Design	**Coding**	**Technology**	**Business**
Software solution	.Net / .Net Core	AR / VR	Ecosystem
Architectural	Python	BIM application	Neuron Platform
2D/3D	JavaScript	GIS platform	Knowledge Management
User interface	VueJS / ReactJS	Machine learning	
User experience	ESRIJS	Data analytics	
	SQL / NoSQL	Data visualisation	
	iOS / Android		

endeavours establish Arup as an innovative, tech-driven consultant in the AEC industry.

Promoting a learning culture

Arup University and digital experts organise structured learning programmes, including mandatory, optional and recommended courses, seminars, workshops and case studies in a blended model. Our digital training strategy aims to enable aspiring Arupians to acquire essential digital skills that they can apply to their domain expertise, thereby creating new solutions and revenue streams.

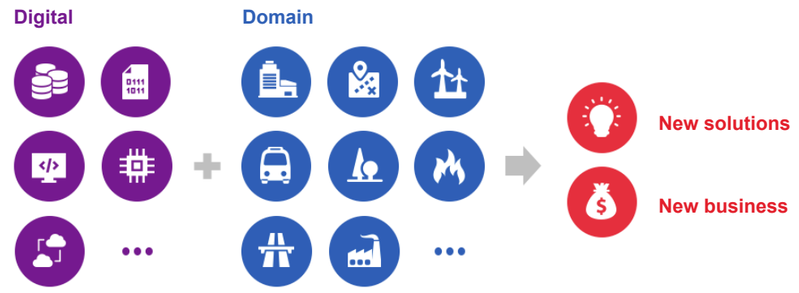
Digital Den is a physical space in the Arup Hong Kong office where digital technology enthusiasts from across Arup and external organisations meet to showcase their latest digital solutions, demonstrate their latest tech and share ideas. This allows our people, clients and partners to experience emerging technologies and explore new possibilities.

We are keen to explore how we can implement innovative digital solutions to address real-world challenges and provide better services. The exploration process requires stimulation and discussion of ideas. Therefore, lunch talks are often organised to allow project teams to share their digital implementation experiences and what they have learned to stimulate open discussions and inspire new thinking.

Arup has also invested in a secondment programme to provide staff with a time-out from the day-to-day pressures of project delivery and allow them to contribute their skills, knowledge, and expertise to the development of new digital services and innovation.

Our applied research programme supports the creation of new knowledge, insights, methodologies, skills, and tools. Our research funding scheme is created to nurture our brilliant minds and encourage our people to develop an intrapreneurial mindset and accelerate innovative change.

As important as driving organisational change from top to bottom, promoting a continuous learning culture is essential for Arup's digital transformation. The best way to allow our people to learn constantly is through structured training and research programmes.



The integration of digital skills with domain expertise helps Arup come up with new solutions and capture opportunities to grow.

Arup Ventures

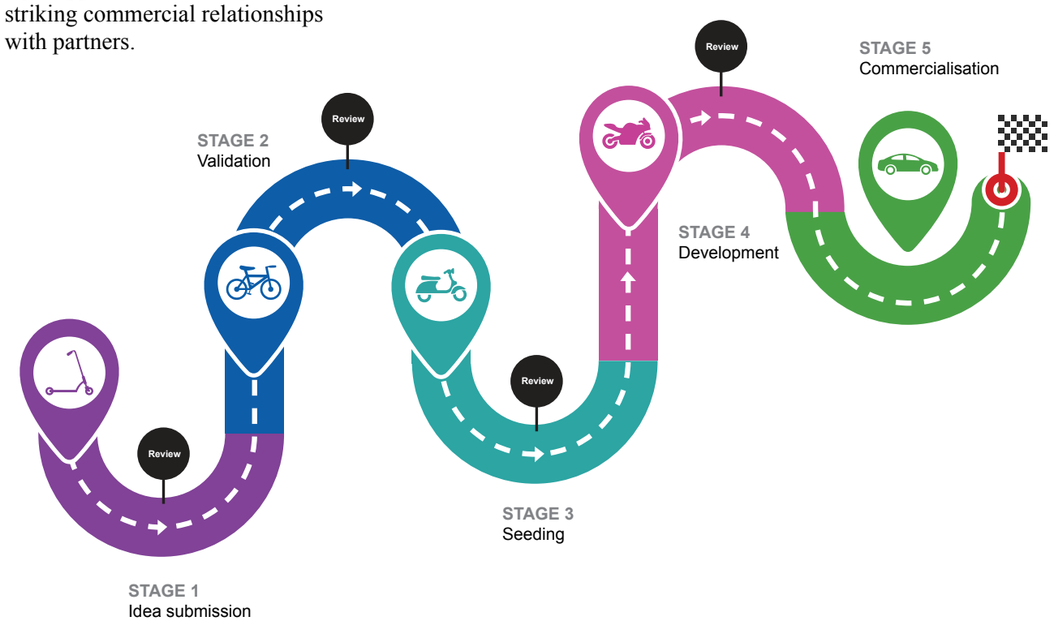
Arup Ventures helps turn our innovative ideas and research results into commercial products or services. The Arup Ventures team leverages Arup's commercial know-how to help Arup innovators and external entrepreneurs realise the full potential of disruptive ideas.

Arup Ventures now has at least 15 ventures to its name and a dedicated team working on deployment and investment. To date, investments made by Arup Ventures include electric charging company in the US, a geothermal joint venture company named Geon, low-energy air conditioning unit Artus, and Neuron, a proptech joint venture company.

Through Arup Ventures, we have developed expertise in commercialising innovation – from spotting and nurturing the right opportunities through to striking commercial relationships with partners.

Digital Den is where digital technology enthusiasts from across Arup and external organisations meet to showcase their latest digital solutions.

With digital transformation, there is an increased focus on developing new commercial propositions. From fully blown digital products, through to software tools that we use to enhance our consultancy and automate our workflows, the Arup Ventures team has been supporting this transformation.



Arup employs an open innovation strategy that cultivates and supports Arup innovators, researchers and external entrepreneurs so that their innovations can advance from ideation to commercialisation.

Supporting Hong Kong's smart city blueprint

Digital technologies that make smart cities more liveable, sustainable and prosperous

Clients:
Development Bureau, Planning Department, Lands Department, and Civil Engineering and Development Department of Hong Kong Government, and MTR Corporation

At Arup, we see smart cities as one of the tools for urban development, with people at the heart of the process. We advise policymakers, government departments, developers and the broader industry on defining how much to invest and how much value they can get from being 'smart'. Our range of services covers strategy and organisation, urban informatics, business systems and architecture, and infrastructure advice that, taken together or individually, will help deliver smart services.

With the rapid development of technology and urbanisation, policymakers in East Asia are looking for ways to improve the lives of their citizens by creating smart cities that are sustainable, inclusive and resilient. In Hong Kong, for example, the city's government released their Smart Cities Blueprint in 2017 and updated it in 2020. So far, it has put forth over 130 smart-city initiatives. Arup has been working with the Hong Kong government on some of these initiatives and formulating digital-enabled planning solutions to support the implementation of Hong Kong's smart cities blueprint.

Built Environment Application Platform (BEAP)

One of the key smart city initiatives is the development of a Common Spatial Data Infrastructure (CSDI) and establishing a geospatial lab to provide a hub for geospatial data exchange to support the development of smart-city solutions.

As one of the government's trusted advisors, Arup was commissioned by the Planning Department (PlanD) to conduct a feasibility study, completed in 2020, on building a Building Environment Application Platform that draws on the CSDI.

The BEAP platform we proposed would become a 'Centre of Excellence' for built environment applications driving collaboration and sharing of best practices and knowledge. The idea is to make it like an 'App Store' providing apps developed for specific needs of the built environment, geared towards city planning, infrastructure, engineering, and environmental works.

Tapping spatial data from CSDI, the study presents ten spatially and digitally enabled built environment applications and services that allow users to search for, interact with, download built environment applications and discover relevant resources via a web portal. It provides a vital tool to enable city stakeholders to use a digital twin approach to make decisions on city planning, management, and operation. It supports the development of Hong Kong as a smart city.

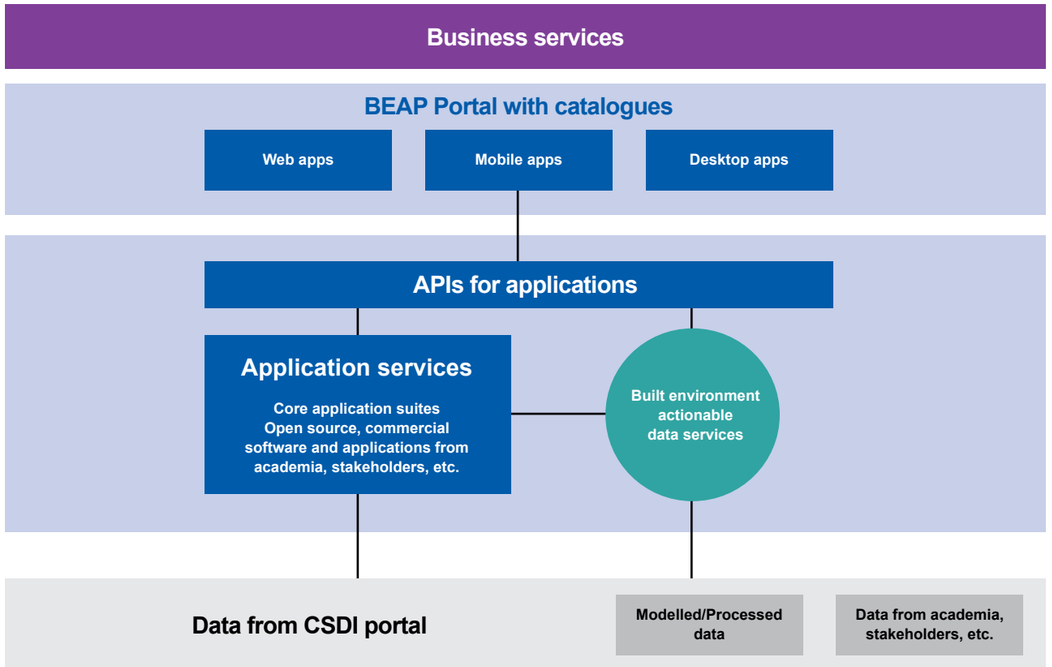
In our study, we suggested a development framework and timeline for the development of BEAP.

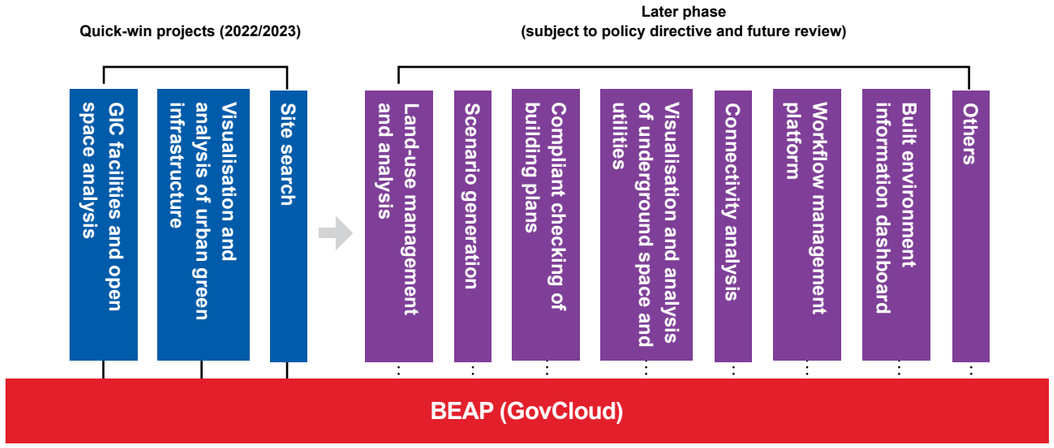
The BEAP portal is the client-facing interface that serves as the access point for intended users, such as Hong Kong government departments, academia and the public, to the BEAP applications, which are broken down into web, mobile and desktop apps in our example.

Through the BEAP portal, the applications are tasked to address specific built environment requirements. The applications include online web apps, mobile apps, or downloadable desktop apps from the application APIs. Applications, data and collaboration tools are listed and searchable through the catalogues provided on the portal.

The application programming interfaces (APIs) are connectors to other data sources from the CSDI platform. Datasets from the CSDI platform would be processed or 'enriched' to support the apps. Network and application-level security protection is also considered in our system architecture.

Conceptual model of the Built Environment Application Platform





Arup has identified the most relevant types of applications and suggested that they be developed in priority order.

To implement the BEAP conceptual model, four plans were proposed: Application Development Plan, Technology Development Plan, Business Development Plan, and Implementation Plan.

Development timeline

Below are the types of applications we identified as the most relevant:

In the near term:

– Site search for housing, land and government facilities

– Visualisation and analysis of urban green infrastructure

– Government, institution and community facilities and open space analysis

In the medium and long term:

– Land-use monitoring and analysis

– Scenario generation for planning and development

– Compliance checking of building plans

– Visualisation and analysis of urban green infrastructure

– Connectivity analysis

– Workflow management platform

– Built environment information dashboard

Take ‘visualisation and analysis of urban green infrastructure’ as an example. For a densely populated city like Hong Kong, green and blue assets (i.e., urban infrastructure relating to water and vegetation) are central to maintaining sustainability and liveability for the population. This prototype can display different types of green and blue information and therefore provide more reference materials for built environment planning.

CSDI-BEAP study recognised at international awards

The CSDI-BEAP study won the 2020 International Data Corporation (IDC) Smart City Asia Pacific Awards under the Urban Planning and Land Use category. Organised by the IDC, the regional award recognises outstanding smart city projects that make the best application of technology in real strategic operations and help accelerate smart city development in the region.

The study also won a merit award at the Smart Cities Awards at the 2021 World Information Technology and Services Alliance (WITSA) Global ICT Excellence Awards, out of 100 entries worldwide.

Consultancy on 3D digital map platform

Further to our involvement in the BEAP as platform as a service (PaaS), allowing app developers to make the most of the geospatial data of the CSDI, we were later engaged by another Hong Kong government department, the Lands Department, to conduct a consultancy study on the generation of a 3D digital map for Kowloon East as a pilot before the territorial map is extended to cover the entire territory by 2023.

The 3D map for Kowloon East covers 27km^2 of urban area, including 284km of roads and around 6,000 existing buildings. The consultancy work involves developing technical specifications and tender documents for producing a realistic and highly detailed 3D digital map of Kowloon East. We are also assisting the government in exploring various mapping solutions and technology and checking the contractor’s quality of 3D map generation, ensuring a state-of-the-art quality of works can be delivered.

The 3D digital map is set to act as the base map and container for the CSDI, not only covering external features but extending to building interior layouts with data provided from beyond government sources. Therefore, this work is of strategic importance as it will enable us to set out the upcoming works and follow closely the forthcoming opportunities on both application and data side of CSDI.

An immersive approach to community engagement in town planning

Tung Chung is Hong Kong’s ninth new town and the first to be built on an outlying island. After 25 years of development, it is now being extended to meet housing, social, environmental and local needs. The detailed design of the Tung Chung New Town extension project commenced in June 2016 to achieve the first population intake in the newly extended areas by 2023/2024 at the earliest.

As early as 2012, Arup was commissioned by the Planning Department and Civil Engineering and Development Department to conduct a study on the Tung Chung New Town extension project. The study included an assessment of land requirements, environmental impact, urban design, landscape, and sustainability. Public engagement exercises were carried out to gather public views and build consensus.

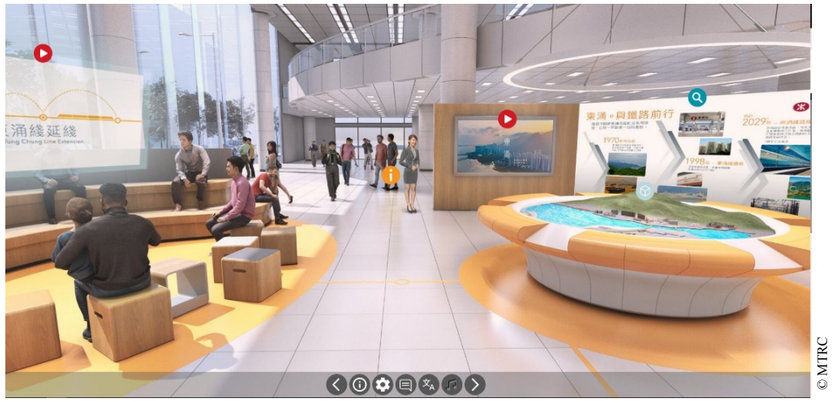
As part of the public engagement exercises, we launched a virtual information centre to facilitate the public consultation for the MTR Tung Chung Line extension project, which forms part of the Tung Chung New Town extension project. This is the first project in the East Asia region using our firm’s proprietary Virtual Engage tool, which interacts with stakeholders in a user-friendly, dynamic and exciting way.

The virtual centre allows the public to take a virtual walk to access the 3D interactive model, project information and video from any web-connected device, when and wherever is convenient. This digital feature provides more engaging information to users.

3D mapping of natural habitat

Ecological surveys and mapping are always the key components for every Environmental Impact Assessment (EIA) and often attract the attention of green groups and the public. During the preparation of large-scale EIAs in Hong Kong and other cities in the East Asia region, there has been a genuine challenge in covering assessment areas which may stretch many kilometres and sometimes through terrains with limited accessibility. The recent COVID-19 pandemic also posts new constraints for surveys during these new normal circumstances.

Therefore, we have developed a 3D ecological habitat mapping solution to visualise habitat

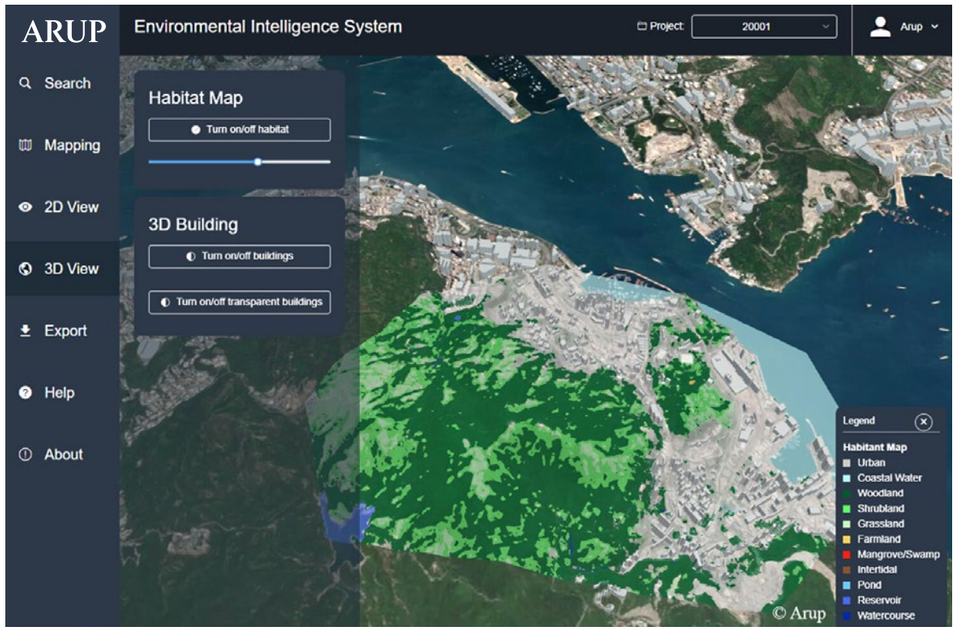


Arup launched a virtual information centre to facilitate the public consultation for the MTR Tung Chung Line extension project.

complexity and applied it during the EIA for Tung Chung Line Extension. We are also implementing a deep learning module developed through LiDAR mapping to recognise habitats that are not easily accessible by ground-truthing, using remote sensing data captured by satellites, helicopters or drones. This technique can save manpower, reduce human error, and bridge the potential knowledge gap due to accessibility issues.

This solution significantly improves the cost-effectiveness and efficiency of ecological surveying by reducing the habitat mapping work on large assessment areas, districts, or cities and conducting habitat classification works consistently from time to time. The environmental survey results were also visualised to help community members to understand the ecological balance.

By identifying habitats through the digitalised map at earlier stages, subsequent surveys can focus on potentially higher ecological value areas. As the platform collects ecological survey data such as habitat types and extents over time, we can produce more accurate habitat maps when survey data are fed back to the system to train the deep learning model.



Arup developed a 3D ecological habitat mapping solution to visualise habitat complexity and applied it during the EIA for Tung Chung Line Extension.

Digitalisation of Hong Kong public works

In 2021, the Hong Kong government allocated HK$100 million (US$12.8 million) for the development of an integrated digital platform for driving digitalisation of public works through data integration and analysis to monitor project performance continuously and enhance the management of capital works projects.

To enhance the governance of public works projects, the Development Bureau of Hong Kong has been actively promoting the digitisation of the works supervision system to supervise effectively the performance of the work projects under construction as well as to alert the project personnel at the earliest possible time about problems encountered so as to reduce the possibility of cost overrun or delay.

Arup was commissioned by the Development Bureau to review the implementation of a digital works supervision system to enable real-time monitoring on progress and performance of major public projects and enhance their productivity.

The annual capital works expenditure in Hong Kong is expected to exceed HK$100 billion (US$12.8 billion) in the next few years. This integrated capital works platform (iCWP) is an inter-departmental management system for collecting and analysing information from different existing systems, such as digital works supervision systems (DWSS), and centrally displaying key information to enable strategic project management. The platform will also facilitate further improvement in compliance, safety, efficiency and quality of capital works projects.

Before the pandemic, Arup carried out feasibility studies with an aim to develope Lantau into a smart and low-carbon community.

The project is being implemented in two phases. In the first phase, Arup will manage and work with the contractor to consolidate critical data from various systems to facilitate project monitoring.

During the second phase, we will study the feasibility of further enhancing the iCWP by integrating advanced technologies, such as BIM, GIS, big data, AI, machine learning and VR/AR, to provide predictive and analytic capabilities for identifying potential challenges.

Developing Lantau into a smart and low carbon community

Before the pandemic, Arup was commissioned by the Development Bureau to provide consultancy services in respect of recreation and tourism development strategy for Lantau – feasibility study. Arup carried out the market, planning and preliminary feasibility studies with a view to formulate a recreation and tourism development strategy for Lantau, while identifying a list of proposals/views on recreation and/or tourism development in Lantau.

The proposed strategy was formulated on the basis of Lantau Development Advisory Committee's planning vision to develop Lantau into a smart and low-carbon community for living, work, business, leisure and study while balancing and enhancing development and conservation. Particularly it is visioned to develop diversified multi-modal recreation and tourism facilities with a view to shaping Lantau into a kaleidoscopic recreation and tourism destination.

Overall, the main direction is locating the larger-scaled recreation and tourism developments in North Lantau (except for the environmental and ecologically sensitive areas) to tie in with the future infrastructure and development direction of North Lantau, while small-scale and sustainable recreation activities as well as improvement works would be proposed in South Lantau.

Relevant United Nations Sustainable Development Goals

Digital technologies lead to infrastructure of enhanced resilience

Infrastructure design has undergone a rapid transformation over recent years with the help of digital technologies, enabling better planning, monitoring, control and reporting.

London Array is a 175-turbine 630 MW Round 2 offshore wind farm off the Kent coast in the outer Thames Estuary in the UK. Arup created a cloud-based system that helps offshore wind farms, including London Array, more reliably monitor irreplaceable foundations.

Clients:
Aboitiz Power (Philippines), London Array Ltd (UK), Northumbrian Water Ltd (UK), Land Transport Authority (Singapore), and Water Services Department (Hong Kong)

From designing solar farms that can adapt to hilly terrains and aseismic offshore wind turbine foundations to forecasts of flooding being made more accurate by digital twins, we are at the forefront of innovative solutions that make our infrastructure more resilient against climate events. Our global teams of multidisciplinary experts can provide solutions to address local challenges and formulate local solutions.

As can be seen from the following use cases, when the power of cloud computing and geospatial data is harnessed to its fullest potential, progression is made at great speed with the added benefits of reduced cost and risk. With Arup's people, process and technology, infrastructure could be more resilient and cost-effective.

Digital workflow for designing hillside solar farms in the Philippines

In the Philippines, flat terrain is not abundantly available, and thus, investors in renewable energy are turning to terrains with significant topographical variances. Designing wind farms that can be adapted to hilly terrains has many challenges, such as different levels of sunlight exposure, landslide and erosion risks, severe wind loading, especially during typhoons, and risk of shadow from nearby trees.

Mapping out terrains for solar farms is no easy feat. A series of preparatory and surveying work has to be done, such as collecting and analysing existing base map data, topographic field surveys, photogrammetry, LiDAR and mapping ground deformation using IfSAR techniques. It is an intensive process that requires many different types of equipment and relies on various software programmes.

Many different options must be evaluated to design the most optimal panel layout that will produce the highest electricity yield for the lowest cost. A single site may be populated with thousands of panels, so a manual approach would take a disproportionate amount of time or not lead to an optimal layout. Arup's Geotechnical Engineering and Geotechnics team has formulated an integrated digital workflow that combines Arup's applied geology/ geomorphological, GIS, remote sensing, solar energy, and digital skills to address these challenges.

An automated workflow has already been successfully deployed on a solar farm project in the hilly regions of the Philippines, including the Cayanga Solar Farm Project 90MW OE and Laoag 1 and Laoag 2 Solar Farms OE 129MW.

The placement of solar panels is critical to their performance and efficiency. For this project, we have developed a working prototype, which includes optimisation algorithms that helps determine the orientation, slope and shading factors of each panel. The core parts of the workflow are neatly aligned with the GIS-related tasks and integrated smoothly with the PVSyst software for the study, sizing, and data analysis of complete PV systems.

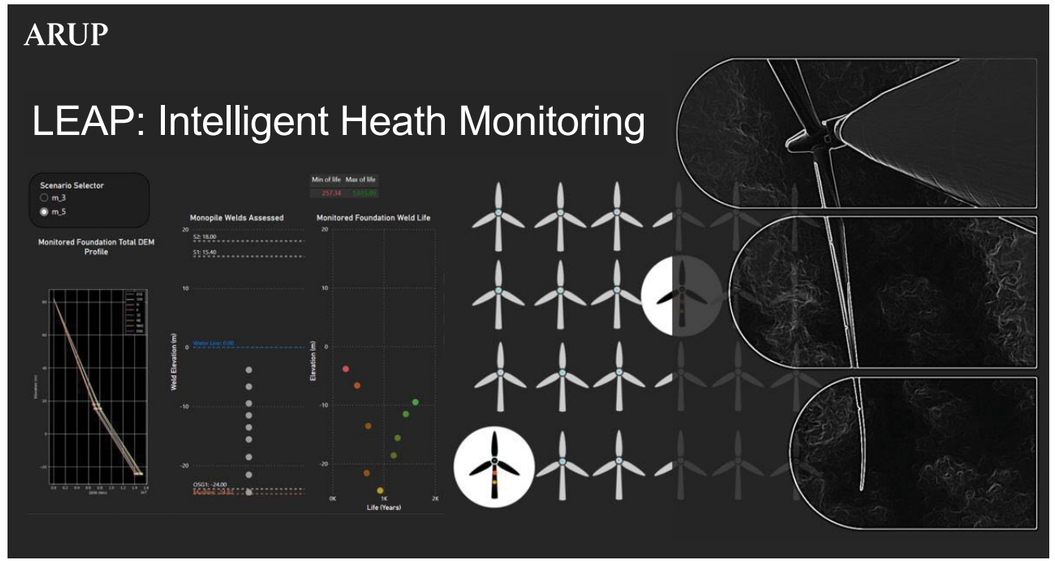
Some other Southeast Asian countries within the equatorial zone are actively considering solar farms, and some are combining them with storage schemes such as battery and pump storage. This digital workflow allows us to scale up our design capabilities to meet future demands.

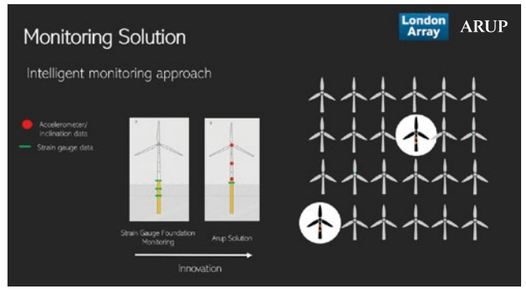
Life Extension and Asset Management Platform

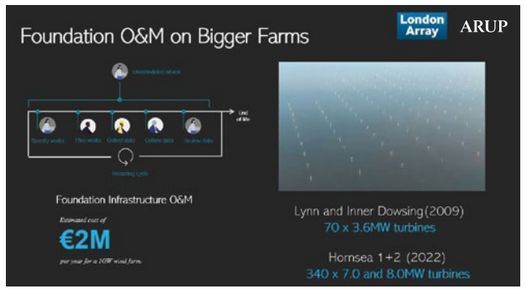
Arup created a cloud-based system that helps offshore wind farms more reliably monitor irreplaceable foundations. Due to conservative assumptions at the design stage, this enables wind farm operating life to be extended – worth US$22.5 – 30m/year for a 500MW farm. By combining monitoring data with the wind farm's asset management system, operators also have greater insights into in-service asset performance, enabling risk-based inspection and maintenance.

Leveraging our proprietary Life Extension and Asset Management Platform (LEAP), a cloud-based modular platform that enables automated processing of monitoring and survey data and fatigue life prediction, we are providing ongoing support for foundation fatigue life reassessment on London Array in light of in-service scour and potential corrosion and have deployed the LEAP system for ongoing integrity assessment and scenario modelling by London Array in-house. The work

An automated workflow created by Arup has been successfully deployed on a solar farm project in the hilly regions of the Philippines.







Arup's Life Extension and Asset Management Platform is a cloud-based modular software that enables automated processing of monitoring and survey data and fatigue life prediction.

was built on expert witness support for the site over several years.

We conducted fatigue reassessment based on existing strain gauge monitoring data to demonstrate the safety case and potential for life extension. This included explicit modelling of scouring levels at all 175 locations to enable accurate prediction of sub-mudline fatigue life, including scour, following the PISA method with validation of location-specific soil springs with 3D FEA and natural frequency data. Sensitivity to potential corrosion of inner welds was also conducted to enable targeted risk-based inspection and maintenance.

We also specified and commissioned an inclinometer/accelerometer-based monitoring system. The system enables insight at all foundation elevations from instruments above the waterline only – reducing cost and improving reliability compared to strain gauge only methods. This novel approach has been validated against strain gauge measurements to form a long-term solution.

London Array will use the LEAP system in-house to gain ongoing insight into foundation integrity as scour conditions evolve. Average industry data indicated that ~US$2m/year is spent on the balance of plant maintenance for the last year of life (500MW). Moving to a risk-based, targeted inspection approach using LEAP will enable these costs to be significantly reduced.

We conducted a Discovery Phase and tailored LEAP's input interface and functionality to meet London Array requirements to inform their usage. This included direct integration of the outputs with London Array's existing asset data management system and automated ingestion of monitoring data via the cloud.

Predicting river levels with Arup's first-time series 'digital twin'

The collective financial and environment cost of flooding events can be huge, not to mention the lasting consequences for local communities. Arup have successfully built and are trialing a digital twin of two river catchments in the UK, helping to mitigate the impact of flooding events by making short-term predictions of river levels ahead of time.

We harnessed the power of advanced digital technology in the form of a rainfall-driven machine learning model which uses near 'real-time' data from a network of environment sensors to provide fast, localised flood warnings. Northumberland, an area in the north of the UK, was identified as a suitable test ground as 97% of its geography is rural and communities are therefore disproportionately challenged in managing flood risk.

Environment data such as river levels, tidal levels and rainfall are extracted 'live' from the relevant source and inserted into a database. These datasets are then fed to a machine learning model to calculate a prediction of the river level at 15-minute intervals up to five days in the future. Predictions are calculated simultaneously for multiple sensors in the network. An example prediction, alongside true values for comparison, is given in Figure 1.

Key benefits

The social, environmental, and economic benefits associated with being able to predict flooding events are clear. However, there are also more subtle benefits to this work.

Traditional hydraulic models are a valuable tool for predicting river levels, but they are not appropriate for short-term applications because they are complex and take a long time to run. Machine learning is much less computationally expensive and can therefore make use of near real-time data to provide more timely predictions. These datasets, along with the machine learning models, are hosted in the cloud which allows predictions to be run in a matter of minutes.

When running, machine learning models can consume a substantial amount of computing power and data, so a cloud resource provides the necessary scalability and efficiency that is not possible on a single machine. It also makes automation of the processes easier, such as training models on a regular schedule, in addition to facilitating links with live data pipelines that feed into the models.

The architecture of the entire system, from data ingestion to model training and predictions, has been deliberately built in a modular way. This means that each component, or 'building block', can be interchanged as required to service any time series-based twin.

The modular system architecture provides flexibility for additional use cases where, for example, different data sources or machine learning models can be switched in and out as required. It also allows the twin to be scaled and deployed in different regions beyond the UK test case. Examples of other use cases for which this system has been successfully tested include:

– Sewer level prediction

– Water quality prediction

– Water treatment works optimisation

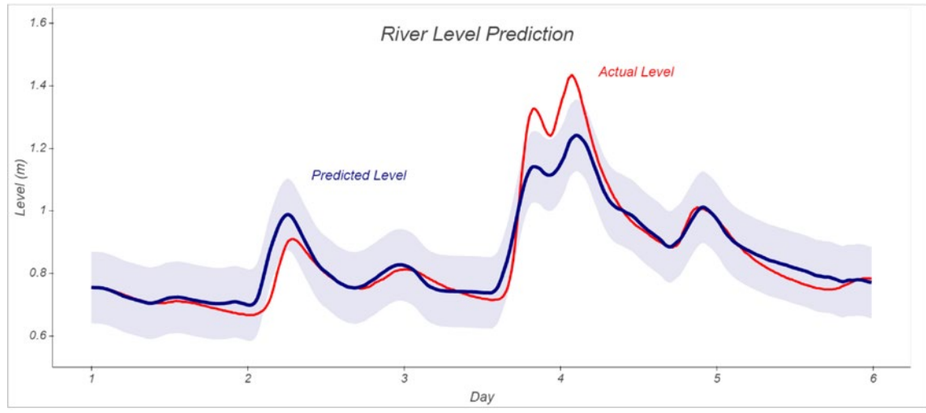


Figure 1 – Example river-level prediction 5 days ahead

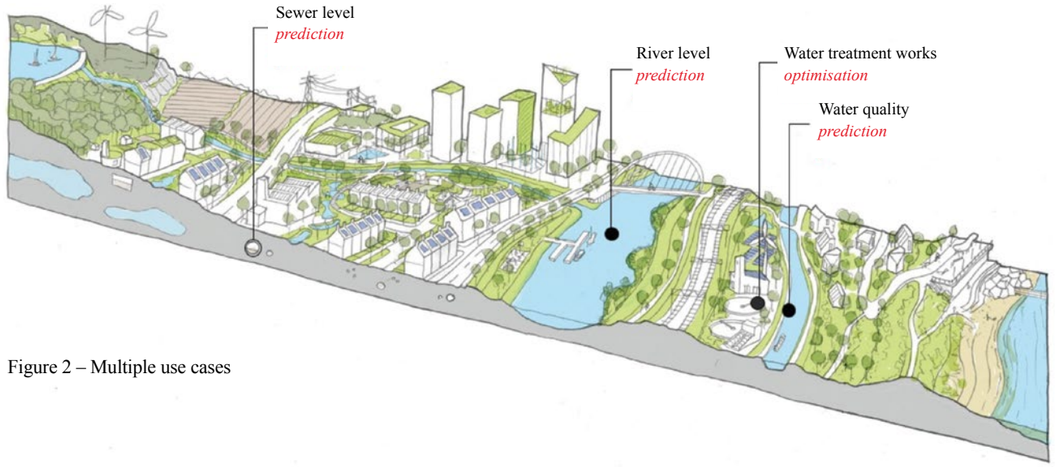


Figure 2 – Multiple use cases

A digital twin project is never 'complete': it must be continually monitored as it is a live system. In order to retain its value, it must also keep pace with changing technology and business requirements. To this end, and to make the outputs of the system accessible, we have created a user interface where it is possible to interact with both historic and forecast data.

Sensor locations are presented spatially on a map and clicking on one displays a graph of the data for that sensor. This user interface is known as the Demonstrator and was designed to showcase Arup's capability in time series digital twins both internally and externally. Screen shots of this interface are provided in Figure 4 and Figure 5.

This project is part of Arup's Smart Water Asset Management and Digital Twin Development Programmes. Developing it was a complex process and came with many challenges associated with it being a 'first' for Arup. It was made possible by the collaboration of a multi-skilled team of domain, technical and business development specialists. We believe it adds value to our business and for our clients as we move towards a more digital future.

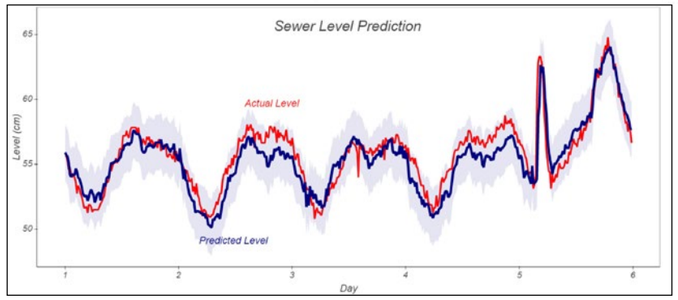


Figure 3 – Example sewer level prediction 5 days ahead

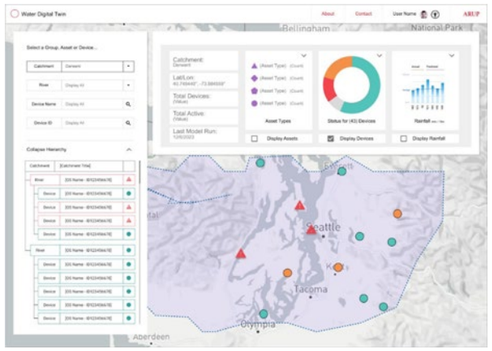


Figure 4 – Demonstrator overview

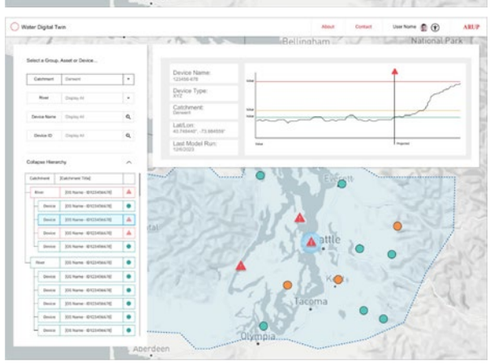


Figure 5 – Exploring data in the demonstrator

Digital twin for remote reservoir monitoring

In Hong Kong, impounding reservoirs, large service reservoirs that have a capacity of more than 25,000m^3 and small services reservoirs that are constructed on hillside next to densely populated areas are required to be inspected by 'qualified reservoir panel engineers' from time to time.

Since COVID-19-related travel restrictions remained in place in 2020-2021, inspections were suspended and this poses a serious threat to reservoir safety. Therefore, we resorted to using digital tools from November 2020 to meet regulatory and compliance requirements. Using Matterport, we designed a user-friendly interface for engineers to navigate through reservoirs, take measurements, and generate layout drawings in case historical records are missing or lacking.

Owing to travel restrictions, the Water Services Department (WSD) and Arup worked together to solve a crucial issue of reservoir safety by adopting remote sensing and digital twin technologies. We used Matterport models to carry out inspections remotely and check measurements, which was previously not possible. These tools were used during pre-inspection reviews by the advisor to highlight any specific issues or areas of concern that require more detailed assessments during a live stream inspection with the WSD. Arup's local team, the advisor and the WSD were able to save a copy of the reservoir model onto a tablet and cross-reference any 'Mattertag' information as they inspected it during the visit.

This digital twin platform made it possible for our team members in the UK to communicate effectively with site staff on the ground in Hong Kong and the WSD. Remote inspection has proven to be a successful solution for the client that resulted in both the client and Arup getting the works done more efficiently despite COVID-19 challenges.

InSIGHT for Singapore's Land Transport Authority

Singapore's Land Transport Authority (LTA) has launched a new Information Management System and digital collaboration platform that aims to digitise their design, engineering and commercial activities to transform the entire lifecycle of infrastructure projects. The Integrated System for Information and Graphical Techno-Environment (InSIGHT) focuses on improving the speed and quality of information management, fostering collaboration among ecosystem partners, driving standardisation and transparency, and promotes lean operations and sustainability by introducing more efficient design, construction, operation and maintenance processes.

In addition to physical Virtual Design and Construction equipment and Virtual Desktop Infrastructure, InSIGHT is primarily enabled by a cloud-based system built on LeapThought's Fulcrum + technology. InSIGHT enables the LTA to collaborate and exchange data with construction industry partners (the supply chain, interfacing parties, operators, etc) and functions as the clients Common Data Environment for new projects. InSIGHT has replaced several incumbent platforms, legacy systems and processes.

Arup is supporting our client and the project lead Accenture to deliver InSIGHT to the end client, the LTA. Arup investigated international industry standards, mega project practices and led stakeholder engagement to propose and document the requirements necessary to customise and configure the platform and redefine parts of the LTA's existing Exchange Information Requirements, in compliance with ISO 19650 where required.

Ultimately, Arup achieved our objective to rationalise and refine existing processes, reduce wasteful activities, improve productivity, enhance collaboration between stakeholders and maximise the usefulness of captured data, traditional and BIM deliverables.

Relevant United Nations Sustainable Development Goals

How smart buildings improve energy efficiency, occupier wellbeing and safety

At Arup, we are committed to developing and deploying innovative digital solutions to smarten up the built environment where we work, live and relax. For example, Neuron, owned and operated by a proptech joint venture between Arup and Venturous Group, has been deployed in many landmark buildings in Hong Kong.

Clients:
Electrical and Mechanical Services Department (Hong Kong Government), Henderson Land (Hong Kong), Nan Fung Development (Hong Kong), Sunstar Group (Japan), and Hong Kong Housing Society

Designed for the Electrical and Mechanical Services Department, this intelligent energy saving control system is an integrated platform powered by AI, big data, machine learning and IoTs to visualise building performance and optimise operations.

Integrating different building systems, Neuron can manage heating, cooling, ventilation, lighting and more while promoting better indoor air quality. The platform can easily be scaled up to support different other building systems. It is also accessible from anywhere with a web browser or smartphone app and reduces on-site manpower needs.

The AI-powered system can make the most of the building's operation data to identify areas where energy efficiency can be improved and create an environment that promotes occupant wellness and ensures safety, an increasingly important feature as East Asia's population continues to age.

Intelligent energy saving control

For the Electrical and Mechanical Services Department, an integrated platform powered by AI, big data, machine learning and IoTs has been developed to visualise building performance and optimise operations. AI-based air side optimisation is one of the features enabled by this system.

System settings are based on dynamic environment parameters, such as occupancy, event schedule and outdoor environment. The system considers all these various parameters for a comprehensive machine learning model to uncover hidden patterns and provide operation suggestions. This centralised data repository is connected to external business intelligence portals like Tableau, Power BI or Grafana to conduct data visualisation. AI analysis results are processed in Tableau/Power BI/Grafana to show setting suggestions through the display portal.

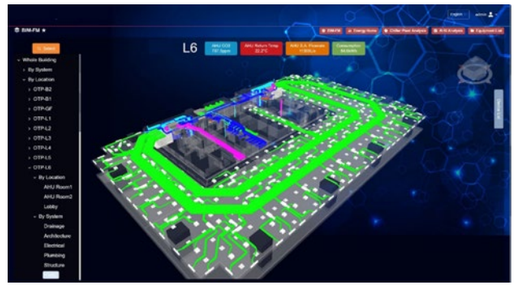
The real-time detected people-counting information, including daily footfall data and peak time, is pushed into the built-in machine learning models for insights derivation. Meanwhile, real-time data from air handling units and ventilation fans are collected by using open protocols like BACnet and Modbus. The platform then consolidates captured statistics and people counting data in a data lake for storage and various analytics.

Neural Network is used to find the optimal solution to minimise the energy consumption of fresh air equipment while satisfying cooling load requirements to maintain the comfort level. The collected data are then filtered and clustered before dropping into big data analytics models. The correlation between parameters and hidden patterns is uncovered to identify potential energy-saving opportunities and suggest optimised operation strategies to reduce consumption.

Through business intelligence software like Tableau, Power BI and Grafana, air side data analytics can be visualised and connected in minutes to support fast and informed decisions, transforming unstructured data into actionable insights. After implementing energy-saving operations, the post-implementation data collected back will be visualised on the dashboard for comparisons and evaluations.

Redefining tenant wellness

Located in Tsim Sha Tsui, one of the busiest commercial areas in the city, the H Zentre project comprises retail, restaurant, car parking facility and medical facilities. Acting as the sustainability consultant, we helped the development to be a community-friendly and sustainable building.



Neural Network is used to find the optimal solution to minimise the energy consumption of fresh air equipment while satisfying cooling load requirements to maintain the comfort level.

The H Zentre is the first project in Hong Kong with a Platinum rating in both provisional assessment (pilot) and final assessment under the BEAM Plus New Building v2.0 scheme. The project also aims to obtain a Platinum rating in LEED and WELL certifications.

We designed a ventilation system that controls fresh air provision precisely while UV lamps are installed to kill airborne pathogens. Natural ventilation was adopted in the upper-ground carpark to remove excessive air pollutants from mobile pollution sources. A solar desiccant system was installed to control the humidity of the supply air and ensure the comfort level throughout the year. The project has been certified with Hong Kong Indoor Air Quality Scheme Excellent Class with these measures.

The electrical and mechanical systems provide a high-performance HVAC system with optimised control. The project was integrated with precise relative humidity control with desiccant wheels integrated into the primary air handling system, demand-driven fresh air control, heat recovery system, and low power density lighting with

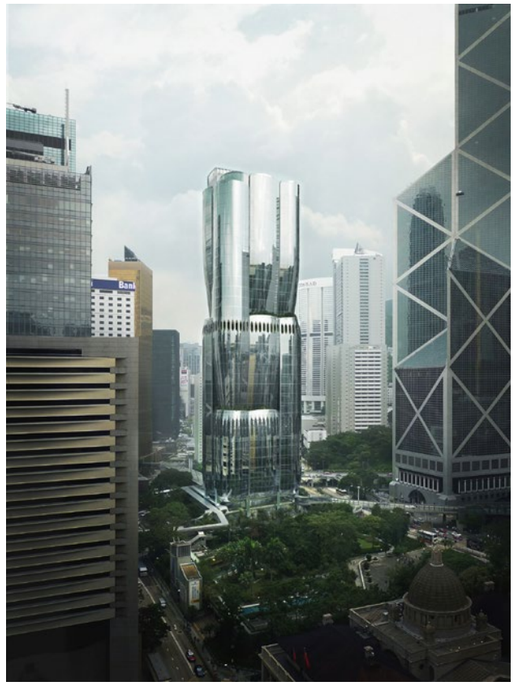
Acting as the sustainability consultant, Arup helped H Zentre to be a community-friendly green building.

daylight sensor control. With these strategies, we helped the building reduce carbon emissions by 23.5% compared to the Hong Kong building energy code baseline.

The fresh air intake louvres were embedded with outdoor air quality and environmental sensors. At the same time, the solar desiccant and UV purification systems within the HVAC system were controlled precisely based on a data-driven approach to provide a pleasant indoor environment. The smart parking system can identify parking spaces and guide drivers to the nearest space. This smart feature will greatly reduce vehicle idling time and pollutant emission.

Tenant centric experience

The Henderson is a 39-storey iconic Grade A office tower located in the heart of Hong Kong and is scheduled for completion in 2023. Arup was appointed to provide consultancy services to design an Integrated Tenant Experience Analytic Platform. The objective is to cultivate an exclusive tenant centric experience while helping the development reshape the city's office landscape as a top-notch green, smart and healthy building.



© Zaha Hadid Architects (ZHA)

Arup was appointed to provide consultancy services to design an Integrated Tenant Experience Analytic Platform for The Henderson which is earmarked for completion in 2023.

Arup has been organising stakeholder workshops to collect user requirements, conducting system designs for the tenant experience analytic platform and tenant mobile app and managing the procurement and implementation process. We use building-wide data assets to improve efficiency by defining appropriate data schemata and implementing bespoke optimisation models.

An insights dashboard for top management, focusing on three main themes: environment, social and governance (ESG), real-time property management and tenant satisfaction, will be deployed. A range of cutting-edge applications will also be implemented, including Metaverse, an AI companion enabled with emotional and intellectual quotient, and a reliable token ecosystem for exchange of 'reward for good'.

Smart analytics deliver business success

Scheduled for opening in 2022, AIRSIDE is a prime office complex in Kai Tak, Kowloon East of Hong Kong. We provided total design service for this project, including architecture, planning, structure, façade, traffic, sustainability, fire engineering, digital, building services, geotechnics, and civil engineering.

Cutting-edge technologies were deployed in a human-centric design approach to distinguish AIRSIDE from other traditional developments. We noted how connectivity statistics could be used to drive business growth through dwell time analysis and increasing customer satisfaction with seamless Wi-Fi. In other words, Wi-Fi-connected devices can help determine hot areas in the mall and provide better business insights to the mall operator and retailers.

We deployed an AI-assisted customer analytics solution with people counting and video analytics along with Wi-Fi analytics. The system also allows queue management and crowd detection to facilitate property management in AIRSIDE. This specific solution can help retail tenants understand customer trends and habits by understanding the demographics and flows of customers across the mall and in each retail store.

With a centralised building information and asset management system, facility managers can streamline operations and obtain valuable insights through real-time monitoring of assets, predictive maintenance and task scheduling. For example, with the help of sensors and data collection, facility managers can better predict when a breakdown is

© Nan Fung Development

To distinguish AIRSIDE from other traditional developments, cutting-edge technologies were deployed in a human-centric design approach.

most likely to occur. Such predictions are based on historical reports and preceding service requests.

To guarantee customer satisfaction, sensor systems are installed throughout the complex to monitor indoor air quality and regulate air conditioning. These different modules are integrated into and can be accessed via the single Neuron platform customised for the building. Powered with machine learning and AI, the Neuron platform in turn recommends the best operational settings to control power consumption and cooling according to the needs of the building.

BIM-based AR for building maintenance

Apart from deploying a centralised building management system, we have also developed a building maintenance platform that leverages AR

The building maintenance platform designed for the AIRSIDE project can be accessed via a mobile app in which site engineers and technicians and in future, facility managers, can review MEP details in a virtual environment.

and 5G for AIRSIDE. The platform features a web portal and mobile app that enable site engineers, technicians and facility managers to locate the building's components in a virtual environment via the app installed on their smartphone or tablet when they work on site.

BIM files are large and require a long time to download in 4G networks. However, with the launch of 5G networks in Hong Kong, BIM files can now be downloaded quickly and viewed in real-time. By using AR based on 5G for building construction and maintenance monitoring after completion, optimal life cycle cost can be achieved at a lower cost than before, and it can be used as an effective solution in terms of building maintenance as well. When deployed in a production environment, the user only has to define two reference points on the model randomly and overlap them with the physical environment.

Apart from AIRSIDE, the building maintenance platform has also been tested at One Taikoo Place, an office complex in Quarry Bay, Hong Kong. Project owners, contractors and facility managers found the platform and app helpful in managing inspections and saving time. They also help reduce the risk of errors, thus improving the quality of work and minimising costs in a project. We are planning to extend the platform's features to include a 360-degree camera for a more holistic site inspection.

Putting employee wellness on corporate agenda

Japanese conglomerate Sunstar's new headquarters in Osaka is a smart, cutting-edge office complex designed to promote employee health and wellness while supporting business growth. The building is spread over three storeys with 7,000m^2 of floor space. Arup provided multidisciplinary services spanning structure, MEP, lighting, acoustics, digital and project and programme management.

The building boasts a skylight and atrium in the centre that interconnects the public areas on the ground and upper office floors. The structural design and building services were carefully tailored to create open, high-ceilinged office spaces and an acoustically controlled, well-ventilated, and well-lit environment. The landscape garden extends outwards to the public space, creating a restaurant on the ground floor serving healthy diets for employees and visitors.

The IoT system allows employees to declare their preferred thermal comfort via smartphone, automatically setting the temperature in each HVAC zone to increase the thermal satisfaction of the employees while optimising energy efficiency. We also developed an algorithm to control the HVAC, including self-adjustable thermal control that interacts with the weather and temperature outside.

In addition, employees can search the real-time locations of their colleagues with the Wi-Fi indoor positioning system. This system allows tracking and tracing people who may have been infected with COVID-19 and, therefore, can pinpoint the areas where sanitation/sterilisation is needed.

Since the successful implementation of this project, more other office new-build and refurbishment projects in Japan have followed suit. This new office exemplifies a smart office that answers tomorrow's challenges with intelligence and flexibility and showcases corporate Japan's renewed commitment to providing wellness-based offices where employee health is prioritised.

For Sunstar's headquarters building in Osaka, Japan, Arup developed an algorithm to control the HVAC, including self-adjustable thermal control that interacts with the weather and temperature outside.

How smart tech can help elderly age in place

The Hong Kong Housing Society operates multiple senior housing projects in the city providing different levels of care, including independent living, assisted living and nursing homes, to the elderly. These residences are licensed under the Senior Citizen Residences (SEN) and Residential Care Homes for the Elderly (RCHE) schemes.

Arup was commissioned to design and integrate different 'gerontech' solutions into a centralised smart elderly home system that ensures the safety and wellness of elderly residents of two of its complexes under the SEN and RCHE schemes. The system customised for the RCHE complex features an anti-wandering system and activity tracking system with facial recognition cameras and motion sensors to ensure the safety of senior residents with dementia or Alzheimer's. The system customised for the SEN complex is geared towards assisted living, equipped with door contact sensors, daily-use water monitoring sensors, and morning call services.

The common features for both complexes include: a central control monitoring system, wireless panic button, bluetooth-based indoor positioning, a nurse call system, and a WLAN system. The central monitoring system is also connected to the HKHS' other internal care-related systems.

The central platform receives alarms and alerts from the nurse call, activity tracking, emergency call button, and anti-wandering systems to give caregivers real-time information on residents' safety, help them identify safety risks, and take follow-up actions if necessary. The platform is designed with web-based and mobile apps to enhance caretakers' mobility and facilitate their work under heavy routine operations.

The central platform receives alerts from the nurse call, activity tracking, emergency call button, and anti-wandering systems to give caregivers real-time info on residents' safety.

By deploying our smart solutions in homes designed for the elderly, older adults can remain in their homes rather than moving to nursing homes, which can help them maintain a sense of dignity, independence and autonomy.

Relevant United Nations Sustainable Development Goals

Arup has designed a green mobility strategy for Siem Reap, Cambodia and Luang Prabang, Laos. Siem Reap is close to Angkor Wat, a UNESCO World Heritage Site, while Luang Prabang itself is also a UNESCO World Heritage Site.

Accelerating shift to smart mobility

Smart transportation can broadly be defined as a variety of technologies to monitor, evaluate and transportation systems to enhance efficiency, safety, accessibility and sustainability. Smart transportation strategy is now being implemented around the world, from emerging cities building new infrastructure to developed cities upgrading or expanding their transit networks.

Harnessing the power of big data and machine learning, our digital capabilities are increasingly crucial for traffic and transport planning, ridership forecasting, crowd management and wayfinding, mission-critical facility management, and promoting smart tourism, as exemplified by these works.

Clients:
World Bank, Transport Department (Hong Kong), Ministry of Transport (New Zealand), and Network Rail (UK)

Using mobile phone data to forecast e-bus ridership in Cambodia

Arup has had various commissions from the World Bank to conduct studies on Southeast Asia's transport infrastructure and identify opportunities to implement low-emission mobility strategies. One recent work is designing a green mobility strategy for Siem Reap, Cambodia and Luang Prabang, Laos. Siem Reap is a mere ten minutes away from Angkor Wat, a UNESCO World Heritage Site, and Luang Prabang itself is also a UNESCO World Heritage Site. The objective is to improve both cities' public transport, walkability, and bikeability while preserving the countries' world-renowned heritage and cultural tourism sites.

To enable sustainable accessibility in both cities, we are developing a blueprint to facilitate a modal shift to walking, cycling, non-motorised transport and public transport to safeguard the unique heritage from being overrun with cars, motorcycles and tuk-tuks. As part of this work, we are undertaking a concept development study for the introduction of an electric bus (e-bus) system in Siem Reap. The study will elaborate on the e-bus options, including opportunity charging and energy sources to power the infrastructure and the charging.

The e-bus study is broken down into three phases: a review of bus ridership and the operating plan, an assessment of existing energy supply and energy sourcing strategies, and lastly, an assessment of the private sector and identifying feasible commercial models for use in the e-bus plan.

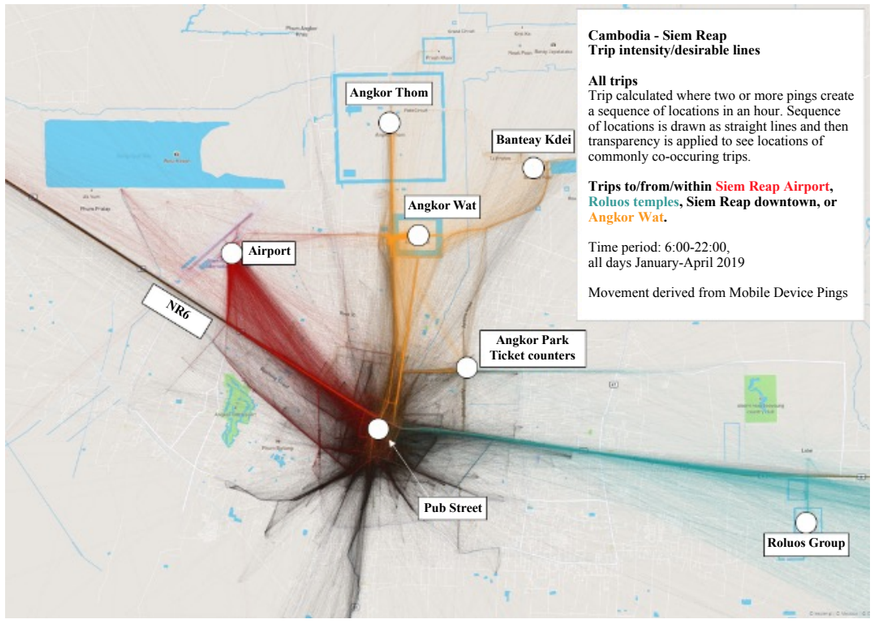
To determine the key routes to be served and understand how people move in the city to develop the operating plan, we employed a data-driven methodology, relying on a large sample of user location data from app-based anonymised data. Such data provides opportunistic sensing and the means for transit operators to match supply with mobility demand inferred from mobile phone locations and trajectories.

This method works by deriving frequent patterns of movements from anonymised mobile phone location data, merging them to identify predominant trips (and origins-destinations), and then formulating a route network to match. This information can then be matched to existing data sets (i.e., the volume of annual airport arrivals and departures and the scope of visitors to/from Angkor) to inform service headways during different times of the day.

Activity-based modelling for citywide transport strategy study

In early 2022, Arup was commissioned by the Transport Department of Hong Kong to carry out a Traffic and Transport Strategy Study (TTSS) to map out a comprehensive and visionary set of transport strategies covering a broad spectrum of issues. The study is scheduled for completion in 2024. We will help the Transport Department seek breakthroughs in mapping out forward-looking traffic and transport policies and initiatives to bring new opportunities and impetus to Hong Kong's transport development.

Before this commission, Arup had been carrying out the decennial Comprehensive Transport Study (CTS) Model. This extensive assignment considers every aspect of transport within the city, with work ranging from survey design and supervision to data analysis and model enhancement of the city's transport network. However, this time, the study is more challenging than ever since it will have



Arup employed a data-driven methodology based on a large sample of anonymised user location data obtained from smartphones to determine the key routes to be served and understand how people move in Siem Reap (Cambodia) and Luang Prabang (Laos).

to factor in the impact of COVID-19 on travel behaviours by incorporating big data application into the model.

The first stage of the survey involves data collection through an extension of the Travel Characteristics Survey and the Goods Vehicle Trip Characteristics Survey. Data collected from these two surveys are processed, analysed and aggregated into a database. The second stage will enhance and calibrate the CTS Model to the TCS and GVTCS database for 2022 and validate it against 2023 traffic conditions. The enhanced CTS Model will produce robust travel demand forecasts on the territorial road and public transport networks for the design years up to 2046.

Notably, as we embrace a 'new normal' after the pandemic, the enhanced CTS Model will provide insight into the travel demand changes due to increased work-from-home arrangements and online interactions. Furthermore, the improved CTS Model will quantify the impact of new demographic and behavioural trends, including an ageing population, the rise of e-commerce and the need for encouraging non-motorised travel.

We will also take the lead in innovating transport modelling methods by using big data to supplement and validate survey data. Activity-based modelling, a more complex and individualistic approach than traditional trip-based modelling, will also be explored to determine the best model that will give an accurate snapshot of the many possibilities in Hong Kong's future mobility.

Building an agent-based modelling capability for New Zealand

At the end of 2019, Arup was selected as a strategic partner for the New Zealand Ministry of Transport (MoT). Leveraging our expertise in New Zealand, Australia, and London, we are working with the MoT to co-develop a national-scale agent-based model. This is being used to assess different policy options against the MoT's Transport Outcomes Framework.

Whether it is new transport infrastructure, emissions reduction, assessing the impacts of COVID-19 on the transport system or other community infrastructure projects, the model can analyse the potential impact of proposed changes, factoring in a wide range of issues, such as what planners should consider given the impact on the environment and society-at-large.

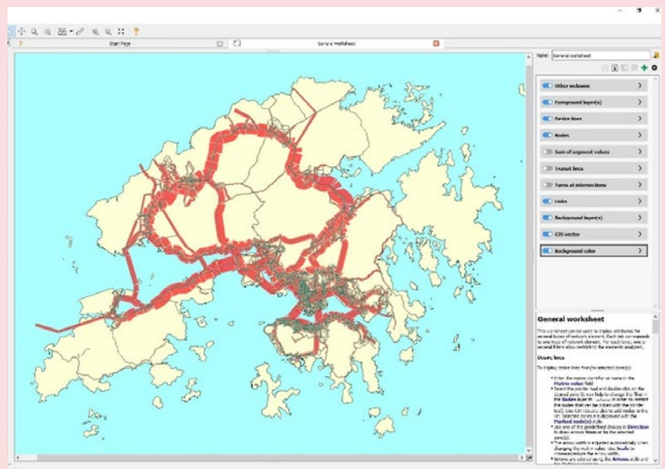
The ability to predict, forecast or simulate changes to a national transport system is limited. The MoT is responsible for shaping the country's transport system, but understanding the impacts of regulation, policy or investment on this interconnected system is challenging.

Arup teams from New Zealand and London, together with the MoT, have co-designed the plan for developing the simulation model for New Zealand to help the ministry improve its ability to plan and evaluate potential changes to the transport system and ensure a more sustainable future. The new model will support decision-making through better use of data, technology, and innovation to help navigate transport challenges and multiple policy options over the next 5-50 years.

We built the baseline model with the ministry, with a sample of 10% of the country's population, totalling almost 500,000 unique agents. The model replicates residents' daily activities, i.e., New Zealanders with plans to travel for work, leisure, or other purposes, in collaboration with a transport network model to define how and where the agents travel.

The simulation shows how the agents interact with the network and each other. As they learn and evolve, new behaviours emerge, enabling greater analysis of the impact of policy changes on transport. The model is now being built, aiming to be able to be used as business as usual in the decision-making process in two years.

Moving forward, we will expand the model to encompass New Zealand's broad mix of transport services, including ferries, aviation, rail and active modes, to provide a holistic representation of travel activities. We will also be simulating the consequences of transport policy scenarios. The MoT is an integral part of the development team, and together we will build the capability to use, develop and maintain the model within the MoT to help ensure the long-term sustainability of New Zealand's transport system.



Agent-based model

The conventional trip-based model is adopted in many cities to assess the transport network capacity issue regarding land-use development and the intake of new infrastructure. However, the trip-based model produces static forecasts only and is less responsive to traffic measures (e.g., differential tolls, early-bird public transport discounts, etc.) that could be better simulated by a dynamic forecast platform.

To address the shortcomings of the trip-based model, multiple Arup offices, including Hong Kong, London, Birmingham, Melbourne, and New Zealand, are collaborating on a research project to develop an agent-based model for application in a dense, compact city with a complicated public transport system. Such a model could apply to cities with many different types of public transport, such as early-bird discounts, monthly passes, and rebates for mode-to-mode interchange.

Arup's agent-based model indicates transport movements by activity for New Zealand, including work, home and recreation.

Intelligent Infrastructure Programme for Network Rail, UK

Intelligent Infrastructure is Network Rail's five-year transformation programme (2019-2024) focused on turning data into intelligent information to improve services for freight and passengers. The main objective is to use existing and emerging digital technologies to move the business from a 'find-and-fix' approach to 'predict-and-prevent'.

Arup was appointed together with Amey and Cognizant as a consortium by Network Rail as a Delivery Partner for the Civils discipline workstream and we are currently supporting the client in developing a vast array of digital solutions that will drastically improve the intelligence asset engineers will have for decision-making.

These tools range from live KPI dashboards, reporting systems to improve assurance, workflow management and decision support systems to digitise key cyclical asset process such as inspections, maintenance, renewals and enhancements, and risk assessments.

To achieve this, we are providing a mix of expertise: business analysts, asset management SMEs, rail engineering SMEs and project managers. The introduction of these tools is expected to result in more than £50m total annual benefits to the business.

Relevant United Nations Sustainable Development Goals

Work smart to excel

Peng Liu

Dr Peng Liu is a Director and Arup Fellow, and he heads up the Arup Beijing office. As a structural engineer, he has actively contributed to the digital transformation of Arup's structural engineering practice since he joined the company in 2001.

"My academic research and software development work was enlightening... the decision to join Arup has proven to be one of the best choices in my life."

The parametric modelling tool he led a team to develop has improved the efficiency and quality of Arup's structural solutions, facilitating Arup to design some of China's most iconic landmarks.

Walking out of ivory tower

After graduating with a PhD degree in structural engineering from Tongji University, he worked as a research associate in structural engineering at the Hong Kong University of Science and Technology (HKUST). This led to his joining Arup in Hong Kong a year later.

During his time at the HKUST, Peng continued with his PhD research on tall building design optimisation, focusing on software development.

"In a research environment, the work can be challenging, but it doesn't provide the same level of satisfaction that real-world projects do. It's true that it takes a lot more communications and collaboration with many project stakeholders, but it's incredibly rewarding to see the final deliverable when all is said and done."

China World Tower

In 2005, Peng was engaged as the project engineer of the China World Tower project. At 330m tall, this 74-storey tower has approx 200,000m^2 of gross floor area. The mega tower comprises a composite central core, a composite perimeter frame and the interconnecting outriggers.

Arup's rigorous analysis showed that the structural designs are safe in high seismicity zones, such as Beijing. This was verified by a shaking table test. Peng's team overcame the challenge of engineering China World Tower in a high seismic region by proposing a composite structure of concrete and steel, a combination that tolerates movement without being too flexible.

"To meet the requirements of local authorities and experts, we also conducted a shaking table test on a 1:30 scale physical model to prove that our proposed design would withstand earthquakes of up to Intensity VIII."

Since the building sits on a high seismic zone, the team had to factor in seismic loading. Therefore, the team created a composite steel plate shear wall system, which was new and innovative at that time. The system embedded a steel plate with boundary elements into the normal reinforced concrete wall and the RC walls are connected to the steel plate by means of sheer studs.

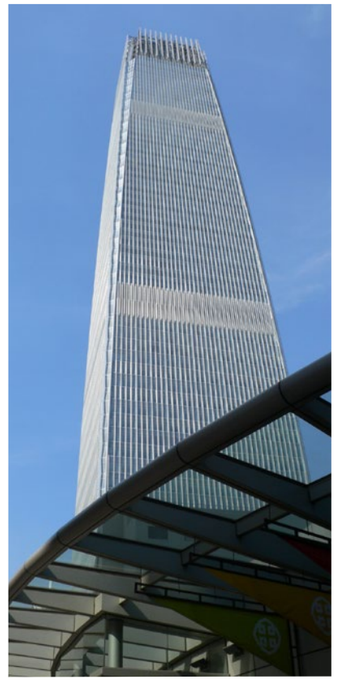
This system constitutes the structural core of the tower from the basement to the 16th floor — the first of its kind in China.

On the one hand, the system has better seismic behaviour than the RC wall, and on the other hand it is also more cost-effective than seismic steel structures. This technology was implemented in many other tall buildings in China after this pioneering case.

CITIC Tower ('China Zun' tower)

The 'China Zun' tower rises to a height of 528m and is the tallest building in the capital city of China. The tower is narrow in the middle and slightly conically widened outwardly towards the top and the base, forming an elegantly streamlined geometry.

To meet structural requirements for seismic and wind resistance, the structure is a dual system composed of a perimeter mega structure made of composite mega columns, mega braces, and belt trusses, and a reinforced-concrete core with steel plate-embedded walls.



Arup overcame the challenge of building the China World Tower in a high seismic region by proposing a composite structure of concrete and steel.

The architecturally distinctive 'China Zun' tower stands majestically in the commercial heart of Beijing.

© Institution of Structural Engineers

The Institute of Structural Engineers 2019 Award for Tall or Slender Structures to Arup and Beijing Institute of Architectural Design (Group) Co., Ltd – CITIC Tower in Beijing.

"For this project, we used our proprietary parametric design technology to work out the most efficient outer-perimeter structure system. I would say the China Zun project represents the culmination of our experiences in technology over the past 20 years."

This building stands majestically in the commercial heart of Beijing, and together with other Arup-designed landmarks such as the Bird's Nest and the Water Cube, it makes up the capital city's skyline.

Chapel of Sound

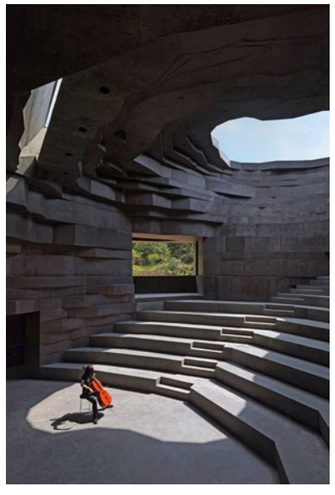
Chapel of Sound sits in a rocky valley at the foot of the Jinshanling Great Wall, near the northern boundary of Beijing municipality. It was a pilot project that aimed to revitalise this remote mountainous region.

The structure resembles a natural rock formation, as if a boulder. It is a semi-open concert hall that features a 1,229m^2 semi-outdoor amphitheatre, an outdoor stage, viewing platforms, and supporting spaces.

Though it is small in scale, the design process for its complex structure is challenging. Peng's team received the 3D-scanned file of the architect's handcrafted model and then performed detailed structural optimisation analyses in the early stages of the design phase, says Peng.

"Our structural engineers conducted detailed parametric modelling as part of the geometry fine-tuning process to achieve continuous structural optimisation in parallel with the design process." This was followed by topology optimisation to calculate the most efficient basic shape (topology) of concrete shells in order to provide the best loading paths for resisting loads.

"The architectural work is a fine example of the merge of art and science in its design."



© 2021 Jonathan Leijonhufvud

Chapel of Sound is a fine example of the merge of art and science in its design.

Evolutionary aesthetics

In the past 30 years, China has added many buildings exceeding 100 storeys. The trend has recently changed. "In China, though there're still some who look for building heights and distinctive features, now more clients care more about the functional and sustainability benefits of their design."

China is a big country and there is a wide spectrum of interpretations of beauty, which vary from city to city, province to province. The trend is now towards a better balance of aesthetics, functionality, comfort and sustainability.

"As structural engineers, our role is to help property owners realise their visions while maximising the positive impact on the building occupants, community, and environment. Designing tall building structures is challenging, but we do not confine ourselves to this area of work."

A dedicated leader of digital transformation

Since joining Arup, Peng has led a team to develop Arup's parametric and optimisation design tools which become our proprietary tool, Ovabacus. It is a turnkey plug-in that can be adapted to and interact with multiple modules in Rhino Grasshopper. This improves the design workflow so they can generate and evaluate a large variety of design options within a short time.

After years of development, Ovabacus has become a fully-fledged application with a clear user interface, user manual and documentation back-up, which is widely used across Arup.

"The digital tool is the outcome of the market dynamics of China over the past 20 years. China's rapid urbanisation required us to deliver bigger and better projects faster while ensuring structural integrity and increasingly sustainability. This unique environment with our mix of programming and engineering talents enabled us to create this powerful software."

"We've reached a point where we not only want to automate repetitive, tedious tasks but look to develop and use more powerful algorithms to perform higher design intelligence."

Allow employees room to grow

As a leader, he knows attracting and retaining talent is key to success. The workplace must allow room for people with different skill sets and personal traits to grow. "Arup is open to new ideas and ways of thinking, no matter the seniority of employees. We keep talent as long as they find Arup a place where they can do their best."

Peng is a keen marathon runner. Pictured is his participation in a Beijing marathon in 2013.

To stay ahead of the game, Arup invests in driving digital transformation and fosters a culture of innovation. "Some colleagues on my team enjoy software development as a career. And Arup takes it seriously and is willing to accommodate their aspirations by providing a career path."

As an example, the Digital Inception Plan is a company-wide platform where digital talents from across the region come together and explore the potentials of digitalising processes, help develop new digital services, or improve client relationships.

Over the years, he has won an accolade of awards and worn different hats in the professional field, including being a regional representative and city leader of the Council on Tall Buildings and Urban Habitat, an executive director at Architectural Society of China Structural Branch, and an executive director at the China Engineering and Consulting Association Structural Design Branch.

"Despite having a hectic work schedule, Arup's work-life balance culture allows me to spend time with family, pursue my hobbies, and do my research work. This culture can keep our people motivated, engaged, and productive."

Cracking the code

Young Wong

Dr Young Wong leads a team of fire engineering experts to navigate and interpret complicated fire safety codes and formulate performance-based fire strategies tailored to each project.

"Innovation is a key component of our corporate culture. We have a diverse team, and our people are encouraged to think outside the box."

Dr Young Wong is a Director with Arup, a Member of Arup's East Asia Board, and the region's Technical Services Portfolio Leader. He is also currently Chair of Neuron Operation Limited, part of Neuron Digital Group, a proptech joint venture Arup formed with Venturous Group in 2022. He is a specialist in formulating performance-based fire engineering solutions for projects of a wide range of complexities.

Young has been in Hong Kong for 17 years after a stint at an engineering consulting firm in the UK. He thinks relocating to Hong Kong and joining Arup is the best career decision he has ever made, describing the career in East Asia as 'life-changing' and 'eye-opening'.

An eye-opening career

Young graduated from the University of Sheffield in the UK with a degree in civil and structural engineering and pursued a PhD in structural fire engineering afterwards. After graduating in 2002, he joined an engineering consulting firm based in Bath, the UK, where he worked for six years.

In 2005, he relocated to Hong Kong and joined the Arup East Asia fire engineering team, where he reported to Dr Ming-chun Luo, Arup's fire discipline leader at that time.

As a Malaysian Chinese with multiple language skills, he moved to Hong Kong with his Hong Kong-born girlfriend, now his wife, to embark on a career that has rewarded him with great opportunities thanks to China and Southeast Asia's rapid urbanisation.

"It took me months to really understand the culture and industry norms in Hong Kong, like the working relationships between architects and engineers and communications with the authorities. It requires a lot of time and effort to build trust and establish credibility," he recalls, "but that trust would lead to a long-term relationship when doing it right."

Pioneers of performance-based approach

The fire engineering field constantly evolves in response to changing city planning and safety requirements. Each new project has to have its own customised solution, and Arup fire engineers play a critical role in addressing this complexity.

A fire engineer is responsible for the strategic level of the fire safety design. Arup fire engineers have been pioneers of the performance-based approach, he says. As opposed to the traditional code-based system, the performance-based approach is primarily based on fire engineering principles, calculations, and modelling instruments (such as structural and thermal models) to meet building regulations.

This approach allows for increased design flexibility and enables engineers to assess the level of safety in each design and derive potentially the most cost-effective fire safety solution. Young says Hong Kong is one of the few places in East Asia to adopt the performance-based approach in designing fire-safe complexes. Early success cases include the Hong Kong International Airport in Lantau and the Festival Walk shopping centre in Kowloon Tong.

This picture was taken just moments after Young came out of a real compartment fire. The smoke clogged up left him with black marks on his face. Pictured with him is Eva Ho, an Arup fire engineer.

In these projects and many others designed in later years, such as the Langham Place shopping mall in Mong Kok, large atriums are built into the structure to increase architectural aesthetics. But large empty spaces pose more fire safety risks if they are not properly compartmentalised. Remedial measures such as sprinklers, fire separations, and evacuation routes have to be adopted to mitigate increased risks.

"In addition to a holistic solution, our early involvement in designing a complex project could also help reduce costs. The lower the construction cost would be if fire safety measures were included at an early design stage. For example, sprinklers and mechanical ventilation systems can help push the design boundaries, allowing large atriums and other interesting spaces to be designed."

"Our experience in the Hong Kong International Airport, tall buildings, MTR stations, and large-scale developments have significantly impacted our later projects in mainland China."

A case in point is Arup's performance-based approach to the fire safety design of Hong Kong's transit-oriented developments (TODs) and complex MTR stations. This approach has been extended to the mainland's multi-modal. One recent example is the Beijing Daxing International Airport Terminal connecting to the high-speed rail and metro network.

Witnessing Macau's transformation

Cotai Strip is a reclaimed strip of hotel-casinos in Cotai. "While aesthetically impressive, the form and structure of these buildings pose immense challenges. As a multi-disciplinary engineering consultant for these projects, we provided practical fire engineering solutions that strike a delicate balance among aesthetics, sustainability, functionality and fire safety."

"When I first visited the construction sites of Cotai Strip, it was just covered in dirt and dust. I was told that that piece of reclaimed land would be transformed into Asia's Las Vegas. It was fascinating to watch Cotai's transformation since the mid-2000s."

Introduction of evacuation lifts to tall buildings and deep stations

"In China, some of the tallest buildings today are in excess of 500m and 600m, although the high-rise fire safety code caters for buildings in the region of 250m," he says.

Since the late 2000s, Arup has formulated fire safety strategies and conducted fire engineering assessments on many super high-rise buildings across China, including the International Commerce Centre in Hong Kong (484m, 108 storeys), Shanghai World Financial Centre (492m, 101 storeys), Shenzhen Ping An International Finance Centre (600m+, 115 storeys) and the China Zun (528m, 108 storeys).

When it comes to fire safety, there are many complications with building skyscrapers, such as long evacuation times, difficulties for firefighters to arrive at the fire scene, structural robustness in fire, vertical fire spread on the facade, and requirements of water supply and stack effects.

The 911 attack on the World Trade Center twin towers was a wake-up call on designing safe, resilient tall buildings. Nowadays, high-rise building codes in many countries require the provision of refuge floors.

"Each super tall building project requires unique solutions because of their complexity. We were the first to introduce evacuation lift/elevators to China's skyscrapers through the Shanghai World Finance Centre project."

Apart from super-tall buildings, Arup is the first fire engineering consultant to introduce lift-assisted evacuation for deep underground train stations in Hong Kong. The HKU and Sai Ying Pun Stations, both part of the Hong Kong MTR Island line, are built deep underground. In an emergency where a fire breaks out, passengers can leave the station via lifts, escalators and staircases.

This evacuation strategy for deep stations was developed over six years with statutory authorities and emergency services personnel. This method was also included in the second edition of the 'Guidelines on Formulation of New Railway Infrastructures' issued by the Fire Services Department of Hong Kong.

Young spoke at the Arup InnoVision Lecture series in Macau in 2016 on the city's transformation.

Michelin star chef

Located in Kowloon East of Hong Kong, the Kai Tak Sports Park is set to be completed in 2023. The main feature of the main stadium is the retractable roof driving system, which can be opened or closed depending on climate, the time of the year, and weather conditions.

"When it's closed, should the stadium be classified as an indoor venue? How about when it's wide open? We adopted a performance-based approach for the main stadium to ensure it complies with complex, sometimes ambiguous, fire safety codes. Like what we did for the Innovation Tower of The Hong Kong Polytechnic University, the Central Police Station Compound ('Tai Kwun'), as well as M+ and Palace Museum in the the West Kowloon Cultural District.

"Project owners come to Arup because of our ability to help them solve some very complex problems and give them a complete solution," he says, likening Arup's consultants to Michelin star chefs who know how to play with ingredients for creating a delicacy.

"We work with clients and architects to identify the full range of risks and opportunities and develop a customised approach to each project. We create value for our clients by providing an optimised solution which often helps them save valuable spaces and resources."

An evolving regulatory landscape

Hong Kong's building fire safety codes were inherited from the UK system and have been updated multiple times after the occurrences of fire tragedies claiming people's lives. The city's most tragic blazes include a karaoke bar fire in 1997 that killed 15 people, the Garley Building fire in 1996, another fire in the Mei Foo Sun Chuen housing estate in 1997, and a mini-storage fire in an industrial building in 2016, to name a few.

"Most updates made to Hong Kong's building fire safety code were prompted by major incidents. By comparison, mainland China's approach to preventing fire is more pre-emptive. Their codes have been fast catching up with developed countries," says Young.

"Over the past two decades, China has made significant progress in building safety legislation and regulations and cut red tape by making building plan submission and approval easier."

Apart from China, the East Asian region has a lot of countries with varying levels of development. Japan and South Korea, for example, have relatively mature building safety codes, whilst emerging countries like Vietnam, Cambodia and the Philippines have recognised the importance of building fire safety since four or five years ago.

"Project owners in the Southeast Asia region recognise the value of our multi-disciplinary services, including fire engineering, and are more willing to engage us than ever before."

Bringing the industry's voice to the table

As former vice president of the Hong Kong Institute of Fire Engineers, Young believes that being part of a professional industry association is a strong foundation for engaging with key industry stakeholders, such as local fire and rescue authorities, building authorities, and other professionals.

"No matter who it is — the authorities, project owners, or consultants — we all have our roles to play. We can build professional connections and understand each other better through these professional bodies, which helps a lot when we have to solve problems together."

As well as building professional networks, industry bodies can advocate for policy change when it comes to making the built environment safer. "We've been advocating for sprinklers to become a standard provision in public and subsidised housing, which we hope could encourage private developers to follow suit."

Defining excellence

As Head of Excellence Pillar for Arup in East Asia, he defines excellence as a top priority. For Arup, excellence means a mindset across the firm and is a partner of choice — to be seen as reliable, trustworthy and professionally competent across regions and sectors.

"With this mindset, clients will rely on us and trust Arup's work, and they feel confident and proud by working with us. In the broader context, the firm's vision is to shape the world in a better way through the projects we undertake."

"Innovation is a key component of our corporate culture. We have a diverse team. Our people are encouraged to think outside the box, and we want to build a culture of curiosity. We are also committed to creating an inclusive and collaborative culture that delivers better outcomes for our clients."

"We strongly believe in fostering a work environment where employees can thrive and contribute towards achieving their personal best, whether for the LGBT community, ethnic minorities, or people with disabilities," he says in the role of Arup's Equality, Diversity and Inclusion Champion for East Asia.

Young trusts his team's ability and gives them the flexibility to deliver the best outcome. For young engineers who aspire to pursue a career in fire engineering, he suggests that they start by learning about the field and the role of fire engineer, stay curious, and keep learning throughout their careers.

DIT participants explored and identified the key drivers of change and what opportunities and risks these raise for UK-China trade cooperation in the infrastructure and energy sectors.

Navigating complexities of China's market amid renewed uncertainty

In March 2022, the Arup Foresight Team organised a workshop for the UK's Department for International Trade to help their officials understand China's evolving business environments.

To help the UK's Department for International Trade (DIT) understand the implications of China's COVID-19 restrictions, economic and sustainability policies for foreign trade, Arup conducted an engagement workshop for the DIT officials in China to help them cut through these complexities.

The DIT has been Arup's long-time partner in promoting our services to the China market. The workshop was designed for the DIT's Infrastructure, Energy and Transportation China team members. Over 30 DIT officials from mainland China participated in the half-day hybrid workshop remotely and at Arup's offices in Beijing, Chongqing and Guangzhou.

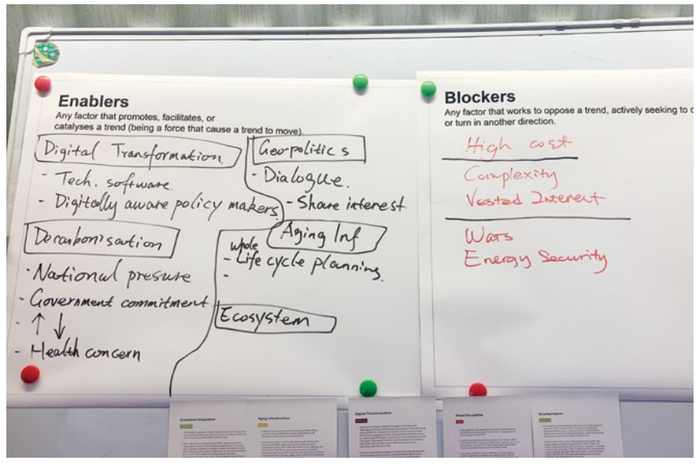
Rather than predicting what might happen to the industry in 2030, the goal was to help policymakers see beyond the horizon and prepare for various possible futures. This was achieved by bringing different perspectives using a social, technological, economic, environmental and political (STEEP) framework. We demonstrated the importance of systems-thinking and multi-sector approaches to uncover needs and opportunities.

Through talks with our experts and group discussions, we helped the DIT participants explore and identify the key drivers of change and what opportunities and risks these raise for Sino-British trade cooperation in the infrastructure and energy sectors.

The key trends identified range from decarbonisation to global geo-politics and from ageing infrastructure to ecosystem integration. These trends present tremendous opportunities for British firms to export knowledge, technology, and planning skills. Governance was identified as the primary enabler of these trends. With the help of government regulations and investment, such as specific policies to address the importance of ecosystems in China, more new development of emerging strategies can occur.

These trends are also interlinked with factors not usually considered when analysing trade. For example, norms and social values influence what services are in demand and thus produced domestically or imported. The workshop received encouraging feedback from all of the DIT participants.

"The insights gained have furthered our knowledge base and broadened our understanding



Digital transformation and decarbonisation, among other factors, were identified as enablers that catalyse a trend.

of what drives trade co-operation beyond economic factors. Having a clear understanding of the country's dynamics and cultural norms will help our department identify opportunities in the future with a holistic approach," said Matt Ashworth, Head of Infrastructure, Energy and Transportation of DIT in China, after attending the workshop.

The importance of strengthening the DIT's partnership with Arup in China to tackle sustainable development challenges was addressed at the workshop. Opportunities are vast in exploring growing domestic markets for renewable energy and decarbonisation solutions.

Through collaborative efforts with cities that leverage each side's network and connect with cities, Arup's leadership as a sustainability advocate is being established across the country.

Sharing is caring: pilot data sharing framework for smarter planning

Intermodal Transport Data Sharing Programme

In this pilot study, Arup analysed the travel data of passengers taking buses and the MTR, including those interchanging at the Exchange Square Public Transport Interchange.

Led by the University of Hong Kong (HKU), the Intermodal Transport Data Sharing Programme aims to develop a proof-of-concept to show that data sharing is possible using a trusted third-party model to replace the siloed approach whereby each transport operator or service provider only shares a limited amount of data with the government or for the purposes of limited scope, mode-specific research.

The proposed data sharing framework allows transport operators and stakeholders to contribute data, encourages collaboration, and addresses data privacy concerns. Though anonymised, the quality of the data aggregated and analysed was kept intact so that they could be merged with other datasets to generate more comprehensive insights.

Arup's Transport Consulting team in Hong Kong provided transport data analysis and visualisation services, supporting the establishment of the proposed data-sharing framework. We combined our transport data analysis expertise and industry knowledge to examine the sample transport data and develop valuable insights.

We analysed the anonymised travel data of passengers taking public buses and the Mass Transit Railway (MTR) through Central/Hong Kong Stations, including those interchanging between the two modes of transport at the Exchange Square Public Transport Interchange (PTI) in Central. The study revealed different commuter patterns between weekdays and weekends, hourly variations within the day, and interchanging demand. The final report was published in the fourth quarter of 2021.

Methodology

When passenger data were sampled in May 2019, the Octopus card was the primary contactless payment method used by passengers to pay for bus and MTR fares. As such, Octopus card records from different transport operators were indicative of Hongkongers' travel patterns statistically.

Therefore, Octopus Cards Ltd, MTR Corp, Kowloon Motor Bus, CityBus, and Hongkong Land, the owner of a major PTI underneath Exchange Square in Central, were engaged in this study to provide passenger data to the research team. Such passenger data allowed the team to connect the dots across different transport modes and depict more insightful findings of commuters' travel patterns.

We conducted a visualisation analysis of the anonymised data made available to the HKU team. Visualisation platforms including ArcGIS and Kepler.gl were used alongside our in-house algorithms to handle around 13 million data records and perform a range of analyses, such as trip and simulation, strategic transport modelling, agent-based modelling, and population synthesis.

Our team explored data availability and the possibility of combining different transport datasets for further insight. We also worked closely with the HKU research team to develop the data-sharing agreement, resolve concerns about data privacy and develop a practical approach to anonymise and store the data.

In this study, 33 popular bus routes that serve areas in the proximity of Exchange Square PTI were sampled. These routes cover the Shatin District of the New Territories, the Kwun Tong District of Kowloon, and various districts of Hong Kong Island. All station-to-station movements from/to MTR Central/Hong Kong Stations were also selected. These two sets of data were interconnected to conduct detailed rail-to-bus and bus-to-rail interchange analysis.

Summary of Octopus Card datasets

Octopus Card Dataset	Citybus	KMB	MTR
Number of distinct card holders	650,900	63,600	2,041,500
Number of raw records	2,671,500	172,500	10,138,700
Number of cleaned records (% of raw data)	2,671,500 (100.0%)	172,500 (100.0%)	10,128,600 (99.9%)
Data captured	30 bus routes serving areas in proximity of Exchange Square PTI	3 bus routes serving areas in proximity of Exchange Square PTI	All station-to-station movements from/to MTR Central/Hong Kong Stations

Note: Regarding Octopus card datasets for Citybus, KMB and MTR, the passenger's complete trip may not be fully captured if the passenger's trip involves other transport modes other than buses and MTR or the passenger did not use Octopus card during the whole trip.

Rail-to-bus interchange analysis

The mapping highlighted a significant change in travel pattern/behavior between weekdays and weekends. There were many more rail-to-bus interchange trips to the leisure areas of Repulse Bay and Stanley on the weekends.

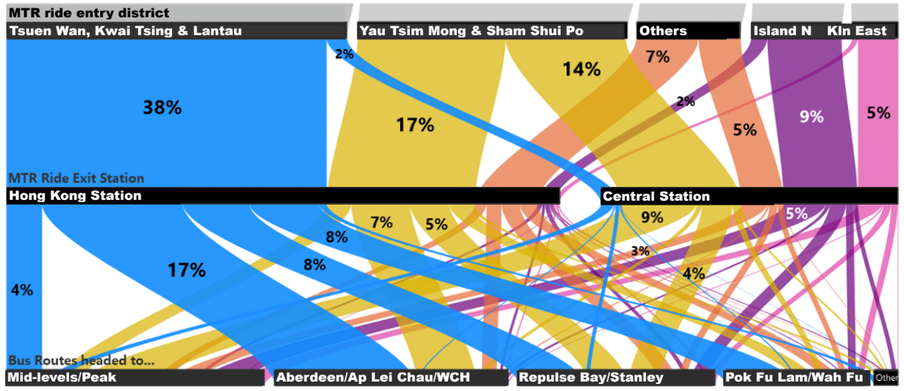
Bus-to-rail interchange analysis

The biggest challenge of this research was to replicate the bus-to-rail interchanges near Exchange Square due to the absence of bus tap-off data. To overcome this limitation, Arup developed an intricate algorithm that not only connected bus and rail trip legs made by the same individual, but also the time that the interchange was made.

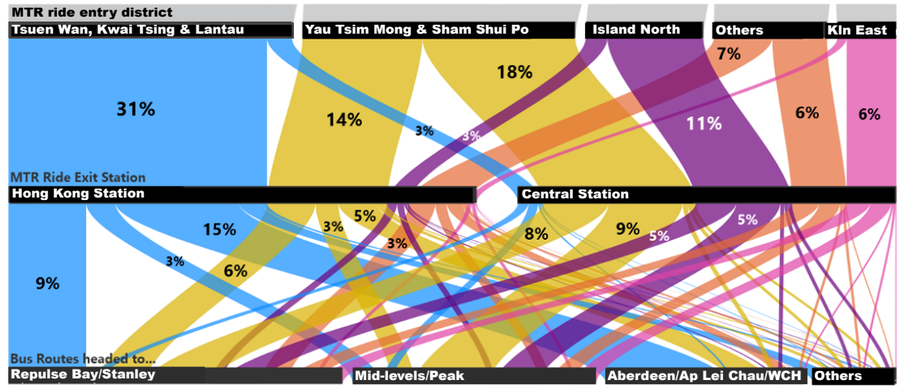
Over half of the studied bus-to-rail interchanges (58% on weekdays and 68% on weekends/holidays) boarded the bus from the Southern District. A substantial proportion of bus-to-rail interchange passengers – 22% of passengers on weekdays and 16% on weekends/holidays – also boarded the bus from Mid-levels and the Peak.

These origins are mostly areas not within walking distance of MTR stations. Also, the origins are consistent with the areas where most of the buses boarded for rail-to-bus interchanges served.

Average weekday rail-to-bus interchange flow diagram



Average weekend/holiday rail-to-bus interchange flow diagram



These two flow diagrams illustrate the chain of rail-to-bus interchanges in the form of a flow diagram for an average weekday and weekend/holiday, respectively. Note: It is currently impossible to figure out exactly where the interchanging passengers get off the bus since there were no tap-off data available.

Approximate daily bus-to-rail interchange

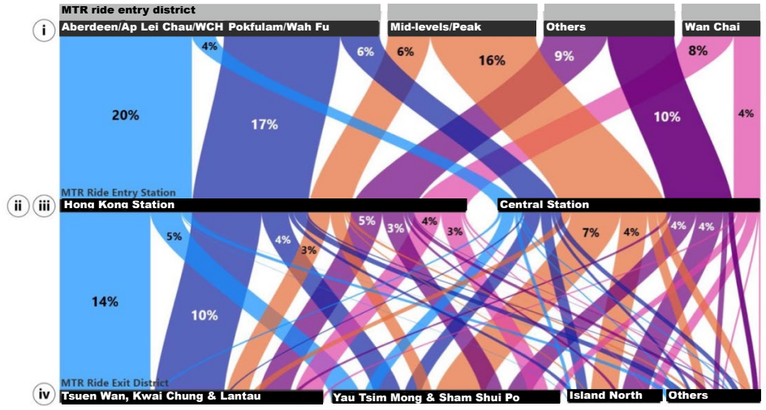
	Average weekday	Average weekend/ holiday
Approximate daily bus-to-rail inter-change	3,200	3,700
Percentage of rail-to-bus inter-changes to total MTR boarding at Central/Hong Kong Stations	1.7%	2.9%
Percentage of rail-to-bus inter-changes to total bus boarding near Exchange Square	3.3%	4.5%

The daily bus-to-rail interchanges near Exchange Square on an average weekday and weekend/holiday in May 2019 are summarised in this table.

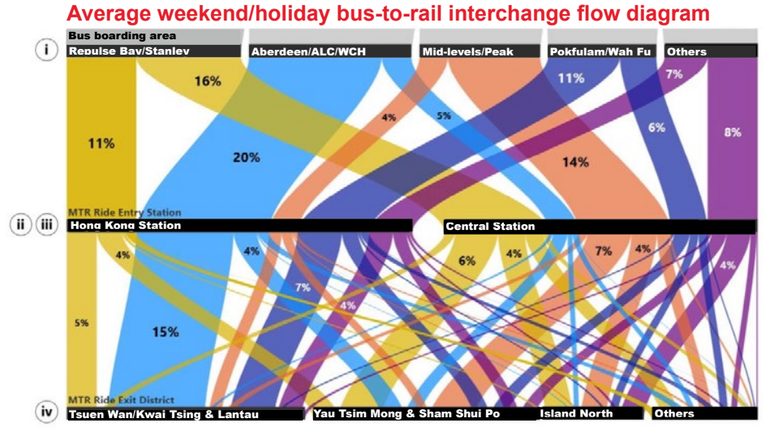
Like rail-to-bus interchanges, the difference in trip purpose between weekdays and weekends/holidays is evident when comparing the bus entry points of bus-to-rail interchanges. Again, the number of interchange trips made from leisure areas, such as Repulse Bay and Stanley, is greater (27%) on weekends/ holidays than on weekends (11%).

In contrast, the number of bus-to-rail interchanges that start from residential or employment areas in the Southern District, such as

Average weekday bus-to-rail interchange flow diagram



Average weekend/holiday bus-to-rail interchange flow diagram



These two flow diagrams illustrate the chain of bus-to-rail interchanges in the form of a flow diagram for an average weekday and weekend/ holiday, respectively. Note: Hong Kong Island North includes Central and Western, Wan Chai and Eastern districts.

Scan this QR code to download the full report.

Aberdeen and Pok Fu Lam, is slightly greater on weekdays (47%) than on weekends/holidays (42%). This also validates similar conclusions made for rail-to-bus interchanges.

A little less than 2% of bus-to-rail interchanges started on long-haul KMB bus routes on all days. Most of these long-haul interchanges (76% on weekdays, 90% on weekends/holidays) originated from Sha Tin District. This was attributed to the strong passenger demand attracted by a direct long-haul bus route operating between Sha Tin and Exchange Square and the convenience of the service.

To sum up, both rail-to-bus and bus-to-rail interchanges share similar assumptions. Therefore, data insight generated from preliminary findings can be complementary.

For privacy reasons, the passenger data processed by Arup were anonymised. But even so, these records allow us to understand travel patterns like never before. The insights of this research study provide a deeper understanding of the utilisation of existing transport services.

We also believe that the continuous opening and sharing of passenger and traffic data among transport operators, tunnel and highway operators, and other stakeholders will help policymakers and planners better utilise resources and infrastructure to improve the passenger experience and walkability.

Using AI and digital technology to survey rock mass discontinuity

In this study, Arup's geologist team analysed point cloud models generated from laser scanning datasets acquired in three distinct locations in Hong Kong, including a rock exposure.

The advancement of point cloud, remote sensing and 3D scanning technologies has resulted in notable opportunities for the application of innovative approaches to land and geological surveying. One area in which the industry has pinned its hopes is the automated surveying and mapping of rock discontinuities, with associated rock mass assessments undertaken through automated analysis of the point cloud models generated to increase accuracy and save manpower.

To further explore this potential, Arup was commissioned by the Hong Kong Geotechnical Engineering Office of the Civil Engineering and Development Department to develop an AI algorithm to identify discontinuities in point cloud models obtained by 3D scanners and other remote sensing technologies. The study was completed in early 2022.

Rock masses and discontinuities

To address the complexity of rock masses and evaluate the stability of rock exposures, geotechnical characterisation and modelling is necessary. This is achieved through the assessment of discontinuities in a rock mass, with a discontinuity comprising any interruption in the continuity of a rock mass that possess negligible or no tensile strength.

From an engineering perspective, the presence of discontinuities exerts significant control on the mechanical, structural, deformational, and hydraulic properties, as well as the overall behaviour of the rock mass. It is thus crucial to conduct measurements and characterisation of discontinuities through rock discontinuity surveys that provide a comprehensive picture of the rock mass condition.

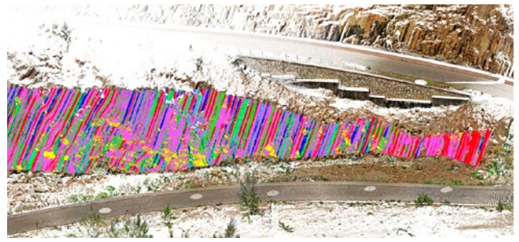
The aim of these surveys is to identify any mechanisms through which movement or deformation of rock blocks or the rock mass may occur. In terms of slope stability, this includes the identification of blocks within the rock mass which could fail by means of planar, wedge or toppling movement.

The study's objective

The objective of this study was to digitise and automate the practice of rock mass discontinuity mapping with the aid of data acquired by remote sensing techniques such as laser scanning and digital photogrammetry.

Traditionally, data for rock slope mapping is collected by engineering geologists taking manual measurements of discontinuity locations and characteristics using compass clinometers and measuring tapes. This is a time and resource demanding approach that is also somewhat nonreproducible thanks to the introduction of personal subjectivity during the data collection.

The subsequent reporting procedures, which involve demarcating discontinuities on photo-overlays of the rock face and digitising the readings taken to



Individual discontinuities were extracted from this trial site, a man-made feature at High Island Reservoir East Dam, as well as two other trial sites, for comparisons.

spreadsheets adds on another layer of manpower requirements. The need to physically access steep rock faces to take the measurements also introduces safety issues. The use of point cloud data, which can be collected remotely, together with computerised algorithms, is intended to provide a gateway to streamline the workflows and generate repeatable results.

Following in extensive literature review to document state-of-the-art practices, Arup's team of engineering geologists developed a computerised system called the enhanced Discontinuity Set Extractor (eDSE), which is used to perform analyses on point cloud models generated from either photogrammetry of images captured by drones or point clouds captured by hand-held and terrestrial laser scanners. Trials were conducted for three distinct locations in Hong Kong.

Extracting discontinuity planes

3D point cloud segmentation is the process of classifying point clouds into multiple homogeneous regions through identification of points in the same region with similar properties (i.e., orientation and planarity in the case of discontinuity planes). To achieve this, eDSE first establishes the spatial relationship (topology) among the point data and then classifies discontinuity planes using a K-Nearest-Neighbours (KNN) Searching Method.

eDSE then uses a Kernel Density Estimation (KDE) to determine the presence of major discontinuity sets (separated sub-parallel planes with similar orientation properties) within the rock mass Orientation information (dip and dip direction), normal set spacing, and discontinuity persistence for these are subsequently deduced. The output generated includes all geometric information for the discontinuity planes, with the point cloud datasets classified visually for the discontinuity sets identified. The orientation data can also be displayed in the form of a stereoplots for kinematic analyses, the tool most commonly adopted to identify instability potential in rock masses.

All of these outputs were integrated into one single file in eDSE to provide high quality visualisations that allow quick interrogation of the data and enable engineering assessment and judgements to be made.

We also took the eDSE tool a step further and integrated functions to compute a number of other key rock mass metrics used in rock slope and rock tunnelling projects from the geometric information extracted from the point clouds, including block dimension (Bv), volumetric joint count (Jv), and Rock Quality Designation (RQD). Through integration with user input data on non-measurable aspects, this allows users to rapidly compute the anticipated Q-value and Rock Mass Rating (RMR) for the exposure, which provide indications of the overall rock mass quality and the need and type of rock support measures potentially required.

Conclusion

Based on our research findings, the use of remote sensing and eDSE can make discontinuity surveys quicker, more robust, and safer. Digital mapping using eDSE yields reproducible results in an objective and systematic manner that mimics, and in many ways enhances the data from manual discontinuity surveys.

Despite some limitations with regard to the extraction of linear trace features (discontinuities with no discernable offset in the rock mass), discontinuity data for a rock mass can now be acquired in a shorter period, with less labour intensity, and without the need for extensive scaffolding to physically access the entire rock face. The output generated also contains all necessary spatial and geostatistical information to facilitate informed engineering judgement.

Whilst there are some limitations and constraints associated with this approach, primarily related to the quality of the point cloud data being used and the parameterisation adopted for the analysis, and we are still a ways from fully unsupervised mapping, the combination of remote sensing point cloud data with eDSE yields a far more comprehensive and less biased mechanism for mapping and assessing rock mass exposures that can only enhance our subsequent engineering designs.

Light up the way home

In a course co-organised with the HKU, Arup's Lighting experts taught HKU students on how night-time lighting design could create a sense of security for pedestrians.

In collaboration with the HKU's Common Core, Arup's Lighting experts from Hong Kong and Melbourne delivered a series of lectures and workshops between January and March this year, teaching participating students about how night-time lighting may cause people to perceive certain areas as safer than others.

Night-time lighting is one of the important elements in urban design. Perception of safety is a hidden mystery which correlates environmental design, crime control and design standard requirements. In Hong Kong, there is a growing need for a considerable human-centric night-time design that can provide convenience and safety to residents across neighbourhoods.

Apart from lectures, the series includes two workshops, in which students learned about night-time lighting principles, human-centred design approach, and global night management trends. Students also learnt hands-on skills of measuring horizontal illuminance (lx), vertical illuminance (lx), colour temperature (K) and colour rendering (Ra) during the evening field trips. After learning from class and fieldworks, students presented their reports to our Hong Kong and Melbourne experts at the end of the programme.

The presence of well-lit streets with clean walkways gives an overall feeling of safety.

Students learned how to measure night-street lighting and its influence on residents' perceptions of street safety by taking field trips to several neighbourhoods in the evening.

Lighting design principles

Lighting in residential areas is a complex decision that includes many factors. For example, designers can consider how to balance between sufficient lighting and light pollution in order not to affect residents' quality of sleep. However, there should also still be moderate lighting to increase safety and for those who come home late to notice quickly when threats emerge.

In a commercial area, it should be generally brighter for better visibility. Designers can also think of the balance between usability and aesthetic, such as festive decorations to attract more visitors and tourists.

When it comes to installing lighting, location matters. Certain urban areas may be designated for environmental or recreational purposes. It is important to consider the intended use of the area when installing lighting fixtures. The use of fixed ground-based light sources should also be considered when designing such facilities to prevent accidents from happening.

There is no one-size-fits-all approach to measuring night safety in Hong Kong, and there are many different aspects of lighting that should be considered. It is time for the existing Hong Kong night-time lighting designs to be reviewed and optimised if necessary to make it a safe, convenient, and inclusive city.

The collaboration with the HKU has also raised students' awareness of the importance of night-time and its strategic nuances in cultivating a safe and engaging environment for residents of neighbourhoods.

Building the global workforce of tomorrow

The transformation of Arup's Global Skills Networks will prepare our people for the new challenges in the built environment and deliver on our primary purpose to create a sustainable future with our clients, partners and the communities in which we work.

Global Skills Networks are central to Arup's mission to develop skills and expertise. We have curated more than 50 Global Skills Networks, covering the full breadth and depth of domain expertise and skills we have as a firm. They span our business groups, aiming to drive technical excellence across geographies, ensuring we remain focused on looking ahead and anticipating future needs.

The first Global Skills Network was formed in the 1990s. Led by Arup University, the structure has recently been renewed to promote more effective collaboration and to increase focus on the highest-quality technical skills. To this day, the Global Skills Networks are led by five regional Skills Leaders. They are dynamic, impactful people with a wealth of expertise and experience. We are excited to celebrate the appointment of Skills Leaders in the Arup East Asia region.

Advisory

1 Business & Investor Advisory
Sanny Kwong

2 Programme & Project Management
Thomas Lee

3 Strategy & Insights
Josephine Wong

Cities & Planning

4 Architecture
Dennis Ho

5 Landscape
Dennis Ho

6 Masterplanning & Urban Design
Atlas Chan

7 Town Planning & Policy
Wai-Lam Lee

8 Transport Planning
Clement Ho

Digital

9 BIM
Ray Ng

10 Computational Design & Digital Geometry
Ramon van der Heijden

11 Cyber Security
Kieron Norris

12 Data & Advanced Analytics
Peter Ty

13 Digital Technology & Advisory
Jimmy Chan

14 Geospatial & Earth Observation
Vicki Lau

15 Product Management & Delivery
Sankar Villupuram Santhanam

16 Software Development
Andrew Mole

Infrastructure

17 Bridges & Civil Structures
Ngai Yeung

18 Civil Engineering & Utilities
Davis Lee

19 Ground Engineering
Alvin Lam

20 Tunnel Design
Andrew Raine

Overarching

21 Commercial
Peter Wong

22 Construction
Raymond Wong

23 Marketing
Ellen Lee

Buildings

24 Building Performance and Systems
Kentaro Suga

25 Building Retrofit
Jack Lo

26 Electrical Engineering
Jimmy Li

27 Environmental & Building Physics
Hirotaka Ogihara

28 Mechanical Services
Clement Chung

29 Public Health, Hydraulic and Plumbing
CF Wong

30 Structural Engineering
Goman Ho

Resource & Energy

31 Chemical Engineering
Simon Tsang

32 Energy
Jin Sasaki

33 Resource & Waste Management
Fiona Sykes

34 Water Engineering
Yuvi Luo

Sustainable Development

35 Circular Economy
Tammy Tse

36 Decarbonisation & Sustainability
Tony Lam Ngan-Tung

37 Environment & Biodiversity
Franki Chiu

38 Human Health & Wellbeing
Teri Tan

39 Resilience
Bruce Chong

40 Social Value
Natalie Leung

Technical Services

41 Acoustics, AV & Theatre Consulting
Henry Chan

42 Building Envelopes
Nina Yiu

43 Fire Safety
Allen Sun

44 Lighting
Junko Inomoto

45 Materials
Nuno Ferreira

46 Security & Risk
Kieron Norris

47 Seismic
Ryota Kidokoro

48 Wind Engineering
Neptune Yu

Transport

49 Aviation
Jack Lam

50 Highway Engineering
Ken Chan

51 Intelligent Mobility
Carmen Chu

52 Maritime Engineering
Terence Leung

53 Rail
James Musgrave

Asia's first climate change alliance

Initiated by the World Green Organisation, with Arup and PricewaterhouseCoopers Hong Kong as technical advisors, the Asian Corporate Coalition for Climate Change Resilience (A4CR) was launched in April 2022 to support businesses in tackling climate change. Arup is serving as the coalition's climate technical advisor, drawing on its in-depth understanding of the built environment to help businesses identify, assess, mitigate and adapt to current and future climate change risks.

Read the full story

Arup projects scoop Structural Excellence Awards

Arup has received six awards at the Hong Kong Institution of Engineers Structural Excellence Award 2022, including two Grand Awards and four Commendation Merits. The award-winning projects, including M+ in Hong Kong, Suzhou Bay Cultural Centre (pictured), Lohas Park Package 7, Lhasa Gonggar Airport and TianAn 1000 Trees, demonstrate how Arup pushes the boundaries to shape next-generation landmarks that redefine the urban fabric of our cities.

© Suzhou Wujiang City Investment And Development Co., Ltd / China Construction Third Engineering Bureau Co., Ltd

Read the full story

Read the full story

Youth empowerment for sustainable development

In early 2022, Arup organised the 'Envisioning a sustainable Hong Kong' video competition to raise environmental awareness among young people, aiming to extend a positive influence on their peers, family and the community. This competition offered youngsters a precious opportunity to draw up their own blueprint for the future Hong Kong and amplify their voices and aspirations through video production. The competition received an overwhelming response, attracting more than 230 entries from teams formed by 480 students across 51 local secondary schools.

Acknowledgements

Arup contributors

Sankar VS
Bruce Chong
Joey Leung
Ariel Mak
Franki Chiu
Lynn Dimayuga
George Walker
Robin Price
Andrew Nelson
Amy Mayer
Amy Jones
Bretton Davis
Felix Chan
Dio Wong
Tracy Yeung
Kenneth Chong
Corey Wong
Lian Duan
Yung Loo
Raman Lee
Tszchun Chow
Clement Ho
Dennis Wong
Stuart Millis
Yuvi Luo
Elizabeth Halsted
George Alexander
Izumi Takayama
Sharon Lee
Kunal Gosrani

Arup University

Ricky Tsui
Anita Siu
Xue-Mei He
Yannick Lenormand
Samuel Tang
Alice Wong
Eva Xie

Editorial

Jimmy Chow
Christina Yang
Noel Lau

Layout design

Celine Yip

Follow us on

Twitter | @ArupGroup
Instagram | @ArupGroup
Facebook | @ArupGroup
LinkedIn | Arup
YouTube | ArupGroup
Weibo | Arup 奥雅纳
WeChat | ArupinChina