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Engineers as **Urban Systems Innovators**

How Innovative Engineers Helped Build a Liveable and Sustainable City

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foreword

Lawrence Wong
Minister for National Development and Second Minister for Finance

Looking across the picturesque skyline of downtown Singapore, few would be able to imagine the starkly different conditions that our forefathers lived through. Yet the reality was that many dwelled in overcrowded slums with no reliable access to clean water or electricity; roads were often congested, public transportation was chaotic, and widespread floods occurred during the monsoon seasons. As a new nation with resource constraints on many fronts, the odds were stacked against us. Hence, our transformation from mudflats to metropolis certainly did not happen by chance.

The foresight of our founding leaders, and the tenacity with which they rose to these challenges, played a key role. Their legacies are now widely celebrated and studied, both within Singapore and beyond. Credit should also go to the urban systems innovators who turned plans into action, and laid the first bricks for our modern city. These are professionals—including planners, architects, and engineers—who came together to address our urban challenges through innovative and integrated ways. In fact, much of what we are proud of as a city—such as the high quality public housing, the world-class water and power infrastructure, the first-rate airport and sea ports, and the iconic skyscrapers in our bustling central business district—would not have been possible without them.

This book aims to do two things. First, to distil the key elements of what makes present day Singapore liveable and sustainable, and second, to celebrate the trailblazing engineers who enabled the city's transformation through their innovation and grit. Some of them were directly responsible for the development of major public infrastructure or landmark projects; others devoted their time and energy to grooming future generations of urban systems engineers. All of them have stories worth telling.

I hope that this compilation also inspires today's engineers and engineers-to-be in the meaningful work they do. The challenges of our time may be different, and possibly even greater. Climate change, for instance, is not something we can simply plan or prepare for in a matter of years. Land constraints will become more acute as we become increasingly built up.

Nevertheless, I believe we will find ways to overcome them, just as our predecessors did. Together, we can dream of and build a more liveable and sustainable Singapore.

preface

Ho Siong Hin
President, Professional Engineers Board

Engineers are, more often than not, the unsung heroes of the built environment. They work with planners, architects and other professionals to do many things—construct buildings, design foundations for key infrastructure from water and electricity to digital networks and office and retail layouts. They even help formulate national plans for the future. All these contributions, usually behind the scenes, contain many stories. They tell of vision, foresight, multidisciplinary teamwork and dedication to innovative problem-solving, and the dedicated application of skill and adaptive improvisation. Some of these stories need to be told.

This is why the Professional Engineers Board (PEB) is especially glad to partner with the Centre for Liveable Cities (CLC) at the Ministry of National Development to produce this book, Engineers as Urban Systems Innovators, for this bicentennial year. This publication collaboration was engineered with the twin organisational goals of PEB and CLC coming together in one shared purpose—to make Singapore one of the world's leading liveable cities. CLC's perspective shines the spotlight on how some of our best engineers have adopted a holistic, systemic and integrated approach to meet the country's engineering challenges. This book recognises the contributions of these engineers within a national context, spanning from the Republic's earliest days in the 1960s through to an outstanding future that all of us are working towards.

The chapters that follow capture highlights and insights of how engineers can make significant contributions to the development of Singapore in different, but inter-related, ways. The focus is especially on the careers of our pioneer engineers Tan Gee Paw, Cham Tao Soon, Liew Mun Leong, Shahzad Nasim, Chang Meng Teng and Tan Ee Ping. They are all recipients of the PEB's Distinguished Professional Engineer Award, presented in recognition of outstanding achievements in engineering, management, research and development, entrepreneurship and services to the engineering profession.

Most engineers will be familiar with the current, important need to continue to sustain a strong inflow of talent into the engineering profession in Singapore. All engineers, young or old, from every specialisation, need to gain a stronger mastery of new challenges, mostly brought by digitalisation and technology in the present day. At PEB, we hope this book will inspire all aspiring engineers and those already practising, to continue dreaming big and to always think across disciplines and boundaries, as we plan and work together in engineering Singapore.

overview

OVERVIEW

The Value-Add of Singapore's Urban Systems Innovators

In the history of cities, how Singapore metamorphosed from an under-developed colonial trading post into one of the world's leading global cities is a standout story. The Republic's successes in urban development continues to draw a steady flow today of visiting city planners, keen to take a peek behind the scenes of how Singapore tackles the primary challenge of rapid global urbanisation—that of how to make an environment of high-density living highly liveable.

To achieve this, Singapore has always been on the move. What is being added is not just something specific—like a new, fourth tower to what has become a national icon, the Marina Bay Sands hotel—but many geographically extensive developments that are game-changing as they are multidisciplinary and require engineering solutions on a scale beyond what most cities would even contemplate.

For example, under the Urban Redevelopment Authority's Draft Master Plan 2019, a whole new dimension of infrastructural possibilities is opening up. Explorations to use the island's underground space span everything from the Jurong Rock Caverns for storing liquid hydrocarbons such as crude oil, to building an electricity substation in the Labrador/ Pasir Panjang area to power more than two public housing towns and free up surface land for other uses.

Separately, despite the island's limited land area and high-density urban living set-up, Singapore is creating more green cover. Over the next 15 years, about 10 km² of green space—nature reserves and areas, parks and park connectors—will be added to the 78 km² of greenery. The aim is to have over 90% of Singaporean households within walking distance of a park.

Such plans will be the outcomes of outstanding urban systems innovation in greening the city since the 1960s, transforming Singapore from "a garden city" to "a city in a garden". It is not just about planting trees everywhere, but infusing greenery into the urban matrix through creative policies. It is about evolving planning, urban design and building standards—such as in roadside tree planting, regulations on green buffers and vertical greenery, and a planned hierarchy of parks and gardens.

These developments provide an illustration of how dynamic Singapore's urban landscape has always been, and looks set to be—for which planners and architects are usually rightly recognised. But what grabs the spotlight less often is the role engineers have played in shaping the city. Indeed, engineers are urban development's unsung heroes.

An urban systems approach is what mainly differentiates Singapore's development success from other cities' experiences. The main principles have been distilled by the CLC into a Liveability Framework, which says that this systems approach—underpinned by good governance and integrated planning and development—accounts for liveability outcomes of a competitive economy, a high quality of life and a sustainable environment. This requires professionals with imagination and deep knowledge that cuts across the traditional disciplines of planning, architecture and engineering. Among these professionals are a breed of engineers who have a holistic, collaborative commitment to urban systems innovations.

RIGHT
Credit: Ministry of Environment and Water Resources, Singapore

Engineers are the ones who give form—quite literally—to the dreams of many a planner and architect. In Singapore, perhaps more than elsewhere, these professionals adopt an engineering approach that integrates all other main facets of urbanisation to produce many urban innovations and applications, all at the systems level.

Innovative outcomes of urban systems engineering can be seen everywhere in Singapore. A prime example is applying a systems approach towards greater self-sufficiency in water resources—a system called "closing the water loop". Singapore is perhaps the world's only city in which two-thirds of the land area can harvest rainwater, even in heavily populated areas. It has also expanded seawater desalination intensively, and enabled the recycling of water on a greater scale than any other city. Such projects illustrate the leadership of engineers in key areas like closing the water loop, with significant roles in many major initiatives including the cleanup of the Singapore River and the creation of Marina Barrage and a city reservoir, while solving the problem of flooding in low-lying city areas.

Another key area is aviation, which connects Singapore with the rest of the world—urban systems engineering has been a vital factor in major aviation projects such as building a world-class Changi Airport from out of the sea.

Singapore's engineers have also taken their expertise into the private sector, in landmark projects including those at the Marina Bay Financial Centre. They work more closely, and better, with the public sector and other stakeholders than in many other cities, and are aligned to the same goals for the built environment. Others saw industry expertise gaps in the private sector, such as in mechanical and electrical engineering consultancy—and so, helped realise projects ranging from intelligent skyscrapers like Republic Plaza to the energy-efficient Toa Payoh Hub complex.

Engineers who apply an urban systems philosophy have paid it forward in moulding generations of younger engineers, playing instrumental roles in taking university education in all branches of engineering to world-class standards. This broad-based engineering expertise has also been applied to steer complementary, multidisciplinary approaches in other fields, including the humanities and management.

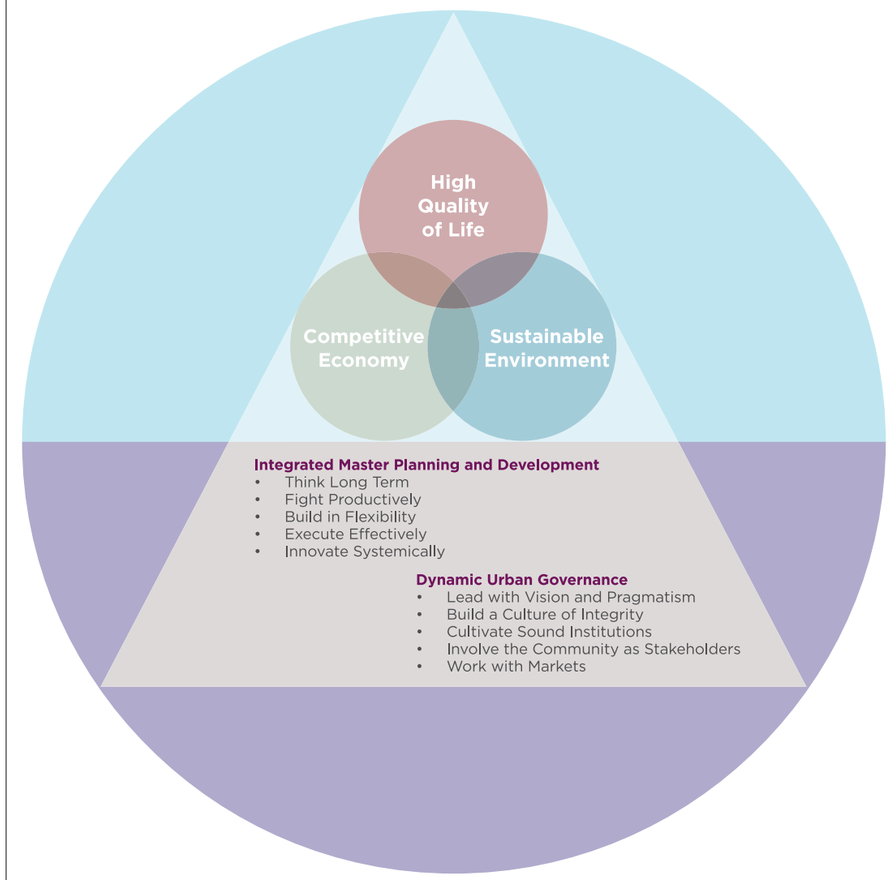
Meanwhile, urban systems innovators have also made a difference in boosting collaborative knowledge-building between the public and private sectors, such as in enhancing expertise in prefabricated construction technology. In these and other ways, these engineers have given back to industry and society in research and lifelong learning, to help Singapore continue to engineer the most liveable and sustainable future possible.

For Singapore to continue to lead in urban systems innovation will require more investment in innovators and research. The greatest aspect of urban systems engineering is anticipating and adapting well to new challenges—this will be tested in a world of rapid technological innovation, rapid climate change and ageing societies. Singapore's overarching future challenge is to make the city liveable despite its density—by being clean, green and blue, all within the confines and constraints of a small island. Its next urban development dream is to become "a city in nature": where a city already nestled in one large garden dissolves interstitial boundaries between living spaces and nature. For this to bear fruit, it will be vital for urban systems innovators to continue playing their vital role.

framework

The Singapore Liveability Framework

RIGHT
The Singapore Liveability Framework
Credit: Centre for Liveable Cities



The holistic, integrated approach practised by Singapore's urban systems innovators is one of the key factors for Singapore's success in balancing density and liveability. This is reflected in the Singapore Liveability Framework, developed by the CLC to distil the tacit knowledge that steered the governance and planning that took the country from the squatters of the 1960s to today's skyscrapers.

Meeting the key challenges of high-density cities, Singapore applied a systems approach to balance social concerns, environmental regulation and economic goals, to achieve three main outcomes:

1. **A competitive economy** to attract investments and create jobs, supporting development with calculated allocation of land and facilities for industry, transport, water, sewerage and connectivity.

2. **A sustainable environment**, surviving with limited land and water by paying attention to how systems foster a clean and green environment; and embedding environmental values into a larger social and economic narrative.

3. **A high quality of life**, addressing environmental and hygiene problems holistically; the provision of affordable education and healthcare, home ownership and social integration; and initiatives for promoting culture, managing the natural landscape and preserving heritage.

Achieving these outcomes requires two key elements, each with their own five key aspects.

A. Integrated Master Planning & Development

Singapore's 50-year Concept Plans, formulated by more than 20 government agencies together, optimise decisions to balance long- and short-term outcomes holistically for the environment, economy and quality of life. Detailed master plans then follow through with execution, integrating individual urban sub-systems such as transport and water.

i. Think long-term
A 50-year planning timeframe moulds a shared, integrated mission and direction, enhanced with rigorous evaluation of projects at every point. This is to pre-empt future needs such as those arising from population growth, and to prioritise investing for later impact—for example, the development of the MRT system for $5 billion in the late 1970s, a huge sum in those days.

ii. Fight productively
The implementation of the flagship Active, Beautiful, Clean (ABC) Waters project at the Bishan-Ang Mo Kio Park is a result of inter-agency coordination and effort. It would not have happened without "productive fights" among agencies.

iii. Build in some flexibility
Stay open to re-evaluating strategies and plans. Having regular reviews of land use and development policies to take into account new technologies, changing needs and public feedback is necessary, like building a new airport at Changi instead of expanding the old Paya Lebar Airport.

iv. Execute effectively
Focus on implementing the master plan with professional inter-agency expertise, as was the case with Marina Bay. An action-oriented public sector, able to mobilise the private sector in the urban development of the area through a transparent planning system, made the execution of the master plan more effective.

v. Innovate systemically
To look beyond conventional solutions through technological and policy innovations such as Singapore's effort to close the water loop.

B. Dynamic Urban Governance

Singapore's geographical scale and government structure allow for efficiency and optimal choices in how agencies interact with citizens and other stakeholders to make decisions on, and have oversight of, how a city plans, develops, uses and manages its physical and environmental resources in dynamic, responsive ways.

i. Lead with vision and pragmatism
Have the political will to push through unpopular policies or projects for long-term national benefit—one example is the state's acquisition of land in the 1960s to solve the critical housing problem.

ii. Build a culture of integrity
Ensure public accountability, with sound financing mechanisms in place to maintain fiscal solvency and sustainability of projects. Sustain zero-tolerance anti-corruption systems that are transparent and have high disclosure requirements, and severe, public punishments.

iii. Cultivate sound institutions
Maintain clear and transparent policies and incentive structures in formal institutions, to adapt systemically to changing policy contexts. Also build informal working partnerships through norms of governance such as rational approaches to policy, respect for professional competence, meritocracy and the separation of politics and professional services in government agencies, which enabled the Singapore River clean-up from 1977–87.

iv. Involve the community as stakeholders
Engage community participation in forming policy and to build legitimacy for policy outcomes, such as working with the Nature Society on preserving the Chek Jawa wetlands.

v. Work with markets
Draw on private sector knowhow and participation—but ensure it is attuned to the government's duty to preserve and enhance public interest—to improve efficiency for fiscal prudence in key public utilities and amenities.

01

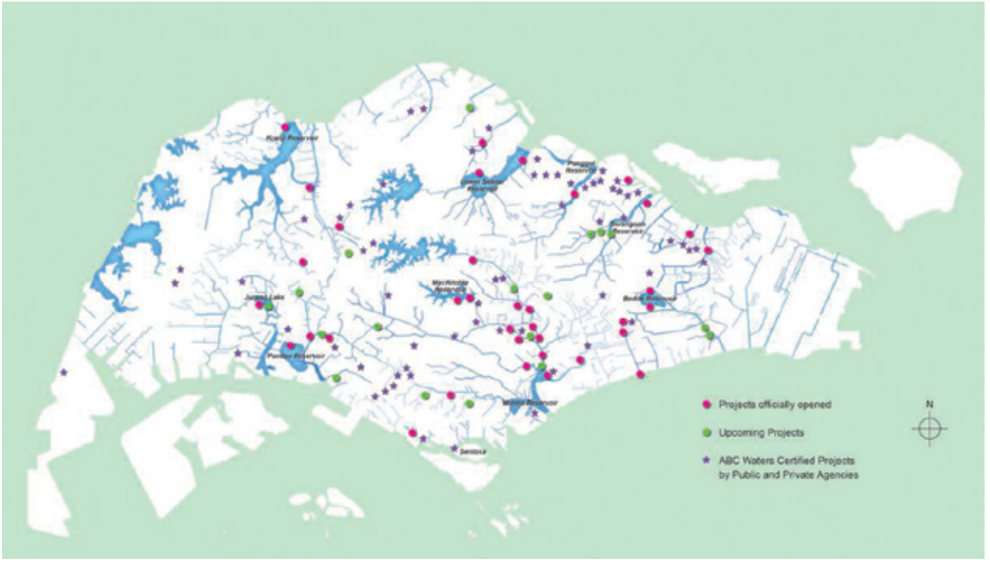
Engineering Water

Chapter One

Chapter One

01

Engineering Water



RIGHT
Singapore's Blue Map: With over 8,000 km of waterways and 17 reservoirs, Singapore has much potential to integrate blue spaces with urban development. Credit: PUB, Singapore's National Water Agency

"Actually, systems thinking is just common sense," says Tan Gee Paw, the engineer who played the most significant role in realising Singapore's water loop system, which is internationally unique in many ways. His modest statement belies the fact that good stewardship of water is actually not that "common" in cities around the globe. His comment also underplays the remarkable "sense" underlying the conception and development of Singapore's system of harvesting, channelling, recycling and using every drop of water from the sky with care.

Although Singapore receives 2,400 millimetres of rainfall on average each year, it has limited land on one main island to collect and store rainwater. With no big rivers or lakes, Singapore was ranked 170th out of 193 countries for availability of natural water resources in the 2006 United Nations World Water Development Report. In 2015, Singapore was ranked joint seventh out of 167 nations as being most likely to face extremely high water stress in 2040 in a report by the World Resources Institute, a think-tank in Washington, DC in the United States. The six ranked above Singapore comprised the five desert nations of Bahrain, Kuwait, Qatar, United Arab Emirates and the Palestinian Territories, and San Marino, a tiny landlocked state surrounded by Italy.

Despite its geographical constraints, Singapore's water challenges have been addressed in a remarkably comprehensive way, and Tan was involved with most of it. He started work as an engineer in the Public Works Department and went on to become Permanent Secretary of the Ministry of the Environment (ENV) from 1995 to 2001, before serving as Chairman of the Public Utilities Board (PUB) from 2001 to 2017.

Simply Understanding How Nature Works

He holds a University of Singapore master's degree in systems engineering, which he says encouraged out-of-the-box thinking. But his application of strategic systems thinking, he reveals, comes essentially from simply understanding how nature works. Systems engineering, he explains, is a tool used in the broader application of what he calls "strategic systems thinking".

> Strategic systems thinking is about the long-term future. You need to think through the entire system not just for today, but project what the future will be like, integrate it into all the planning that you have today so that as time goes by, you find that you are roughly on the right track.

Engineers, in his view, have the capacity to add value to the whole process of building a city by ensuring that all the component parts of the built environment are treated in terms of systems and integrated with everything else.

> Engineers inject systems thinking into urbanisation. This prevents the formation of silos, whether for hard infrastructure, like transport and utilities and telecommunications, or soft infrastructure, like education and social services. Integrating them with systems thinking allows us to reap the benefits of synergy.

To him, water is an area in which strategic systems thinking is especially applicable: "Water is critical; you either have it or you don't." Recognising and reflecting the paramount importance of water resources, Singapore's first significant step towards building a sound water management system for the long term began in 1971 with a Water Planning Unit under the

"Strategic systems thinking is about the long-term future. You need to think through the entire system not just for today, but project what the future will be like, integrate it into all the planning that you have today so that as time goes by, you find that you are roughly on the right track."

ABOVE
Tan Gee Paw.
Credit: PUB, Singapore's National Water Agency

Prime Minister's Office. Tan assisted the then PUB Chief Engineer, Lee Ek Tieng, to formulate the first Water Master Plan in 1972. The plan envisioned a diversified water supply over the next half-century, drawing on what would become known as the "Four National Taps": catchment water from rainfall, imported water from Malaysia, reclaimed water from used water and desalinated water from the sea.

In Tan's eyes, this was "a very simple system" in which the key is where, how and when to bypass the natural hydrological cycle from rainfall to reservoirs to the population and industry, and back. What the PUB did was to create two artificial cycles to short-circuit the process in two places, by reclaiming used water and by desalinating seawater.

The closed water loop works with the limitations and opportunities of Singapore's situation—limited land, little ground water, a fortunate colonial legacy of separate systems of sewerage and drainage, abundant rainfall and even more abundant seawater. Envisioning the water loop required much imaginative thinking to complement engineering expertise. "To try to have such a system in a city that had not conceptualised such a water loop from the beginning is just impossible."

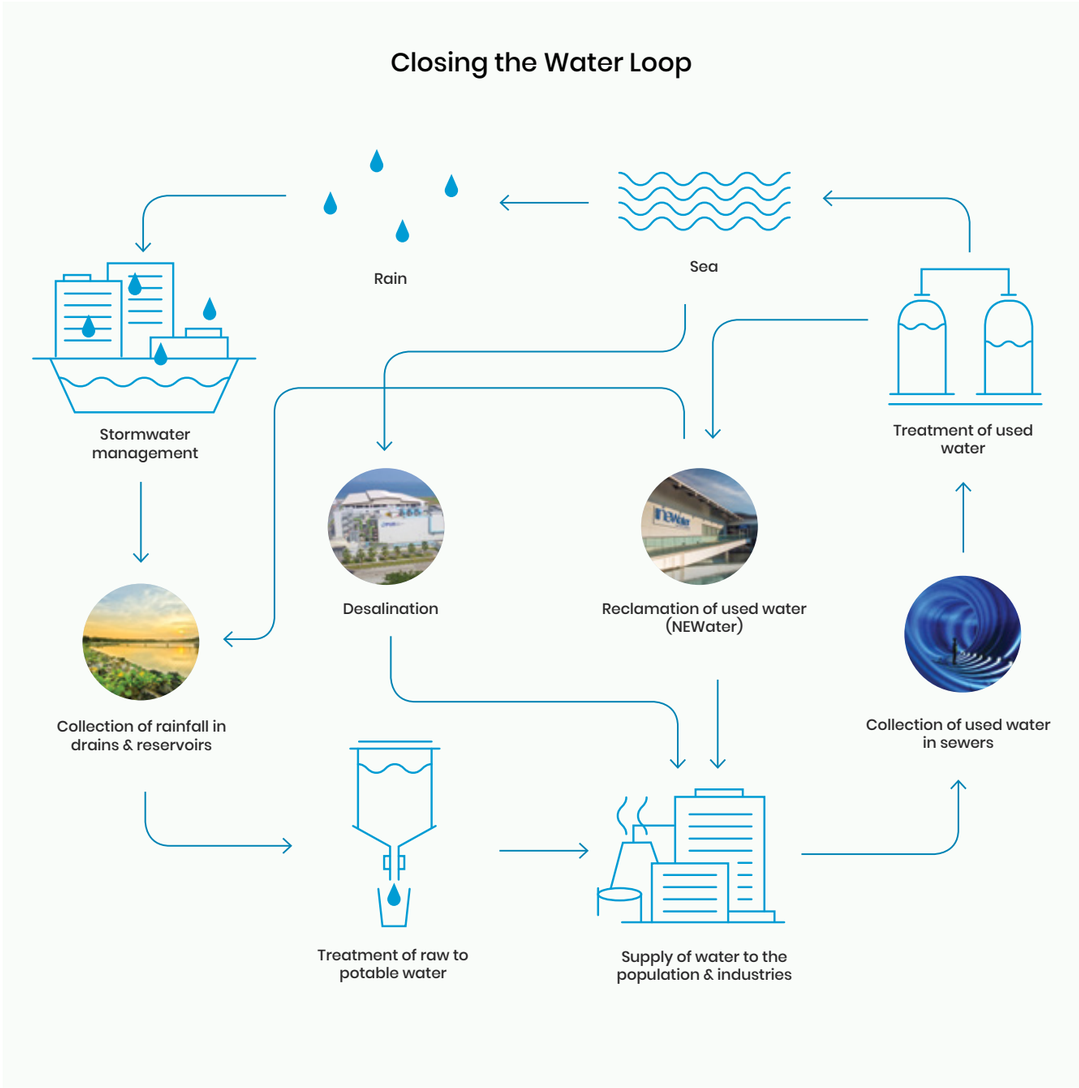
With a starting philosophy of more than 60% of land area as water catchments, Singapore's target is to increase its water catchment area to 90% of its land area by 2060. All such possibilities had to be conceptualised in the first Water Master Plan. Based on the certainties of geography, broad physical parameters were outlined from the beginning, starting with only the three reservoirs left by the British colonial administration—MacRitchie, Peirce and Seletar. The next step was to map out all the other waterways, from Kranji to Sarimbun, culminating in the 17 reservoirs today. New dams expanded the collection capacity of estuarine reservoirs significantly—for example, dams across Sungei Punggol and Sungei Serangoon created 50 km² of new catchment.

With all these works completed, there was a need to plan for the long-term possibility of creating even more reservoirs, such as one that could be created by damming the new water strip that would emerge between the shore off East Coast Parkway and a new reclaimed offshore island directly to the south if this was to be built.

The Water Master Plan was distinct from the 1971 Concept Plan drawn up by the Urban Redevelopment Authority, and therefore, the two had to be integrated. Integrating the two plans required systems thinking as well, especially to forecast more initiatives in later years to soften, and even remove, the boundaries between Singapore's waterways and the rest of the environment.

Other national component plans also had to be integrated, such as the Drainage Master Plan of the 1970s, drawn up by the Drainage Department of the Ministry of the Environment, working with the Urban Redevelopment Authority and the Housing Board. This move ensured more synergy in managing water resources, as the functional responsibilities for drainage, along with sewerage and public health, were all transferred to ENV. Rapid development of new housing and industrial estates had resulted in increased stormwater flows that required an extensive and expanded

RIGHT
Closing the Water Loop.
Credit: PUB, Singapore's water agency



RIGHT
The insides of the Deep Tunnel Sewerage System. Credit: PUB, Singapore's National Water Agency

drainage system, as these land-use changes had impacted rainfall collection and the rate of runoff.

Pre-Emptive Measures Active from Day One

Most cities around the world have their water catchment areas located some distance away from built-up areas, usually on primary land in the suburbs or countryside. In contrast, as a result of its small size and high-density housing, Singapore had to think of how to harvest rainwater. This meant that a water loop system such as Singapore's could only work well if the country's urban planning was well thought-out and incorporated systems engineering at various levels. Therefore, Singapore developed pre-emptive measures like having all the anti-water pollution measures active from the beginning.

Meanwhile, for the system to work, the urban catchment areas had to be cleaned up first, so that the used water would be of treatable quality. Systems thinking was applied to related areas, including solid waste management. The Sewerage Master Plan was put together by the Public Works Department in the late 1960s, but was to take another two decades to be fully implemented.

Until the late 1980s, toilets in Singapore were not much more than wooden shacks with metal buckets. Every night, workers braved the stench to collect the waste and take it to treatment plants. In 1987, a team led by Tan linked every house to a network of sewers and collected the last night soil bucket, and eventually retrenched the workers and closed down the service.

A systems approach to managing sewage has reached a whole new scale and technological level with the development of the ongoing Deep Tunnel Sewerage System, scheduled to be fully completed in 2027. The project, dubbed a "used water superhighway for the future", will have two large deep tunnels, and eventually, three massive water reclamation plants at Changi, Kranji and Tuas to produce NEWater to meet more than half of Singapore's water needs. By centralising water reclamation plants with this tunnel system, some existing plants may be shut down, thus freeing up land for other uses and giving a new lease of life to the country's urban systems approach to land use.

To protect the quality of water collection, industries were relocated to the west at Jurong and Tuas, well away from catchment areas so that any industrial waste and contamination would be contained. PUB would rather not recycle industrial waste water—it is not that the membranes cannot handle it, but to avoid any risk. "We are already dreaming of the day when only domestic waste water will go into the sewers and we can then take it back and recycle it," Tan says, referring to a long-term plan to create two water loops, one for domestic waste water and another only for industries. When this happens, the diagram for Singapore's water loop system will become even more remarkable, to show this double-loop enhancement.

> "You cannot make a mistake because you've only got one city.... That's why we are so kiasu."

Attending to Detail

A systems approach means going down to the small details. Even the incineration of domestic refuse was linked to the Water Master Plan. The household use of plastic bags was necessary for rubbish thrown down the chutes of Housing Board blocks, and to keep the trash dry so that it would not contaminate the waterways on the journey to the incineration plants before going to the landfill on Semakau Island as ash.

The main driving force behind Singapore's urban systems approach towards water is sufficiency. As Tan says:

> You've got to plan Singapore so that you can survive. You cannot make a mistake because you've only got one city. For other countries, if they make a mistake, they can build another one....That's why we are so kiasu. Every water sample must pass the test.

LEFT
The advancement of membrane and ultraviolet technologies has helped make NEWater a viable source of water to supplement Singapore's water supply.
Credit: PUB, Singapore's National Water Agency

RIGHT
From vulnerability to a strength: The Four National Taps
Credit: PUB, Singapore's National Water Agency

The need to survive is at the crux of the systems approach, which defined the mindset of 1960s Singapore as it sought to establish a new nation: "No safety net under you, nobody owes you a living, we give you this responsibility; you've got to see that we survive. When your backs are against the wall, you've got to think 100 years ahead."

With the government committed to long-term survival, engineers like Tan were tasked and empowered to tackle the challenges at hand. He recalled how he and his PUB colleagues had to debate their civil service counterparts in the Primary Production Department, who had wanted to retain pig farms as a fallback food source if needed. However, from a water perspective, the large amounts of waste from pigs would have entered the reservoirs and scuppered the plans for the water loop system. The debate went to the Cabinet, and the PUB's case prevailed.

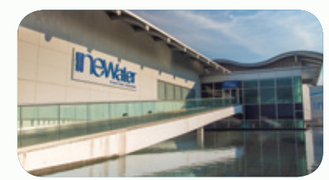
Systems thinking requires patience, as some treatment processes cannot be done until the technology becomes available and/or the cost is economically viable. For example, advancements in membrane technology finally made the Marina Barrage feasible as a freshwater reservoir with a catchment area one-sixth the size of Singapore, meeting more than 10% of the city-state's water demand. The Barrage also solved the problem of flooding in low-lying areas of the city.

Patience was also required for the third and fourth national taps to be turned on. The third national tap—reclaimed water—was more than two decades in the making. It was first experimented with in 1974, but doubts remained

From Vulnerability to a Strength: The Four National Taps

DOMESTIC SOURCES

IMPORTED WATER



NEWATER

DESALINATED WATER

Now

DEMAND		SUPPLY	
Domestic sector	45%	Water from local catchment	
Non-domestic sector	55%	Imported water	
		NEWater	30%
		Desalinated water	10%

2030

SUPPLY		DEMAND	
Water from local catchment		Domestic sector	40%
Imported water		Non-domestic sector	60%
NEWater	50%		
Desalinated water	20%		

2060

SUPPLY		DEMAND	
Water from local catchment		Domestic sector	30%
Imported water		Non-domestic sector	70%
NEWater	up to 55%		
Desalinated water	up to 25%		

over the quality and safety of the water. NEWater is distilled water, too clean to drink on its own, as it can bleach human stomachs. To make it drinkable, some of the pollutants first had to be put back. It was not until the 1990s that the technology had progressed enough and the cost of membranes had fallen by half, that the processes of reverse osmosis, micro-filtration and ultraviolet disinfection became more economical. In 1998, Tan, then Permanent Secretary of ENV, and PUB Chairman Lee Ek Tieng, revisited the idea of reclaiming water. Two years later, Tan chaired a steering committee for a water reclamation plant demonstration at Bedok to determine the feasibility of water reclamation.

It took another two years before the public acceptance of NEWater was sought, with public events such as the audience at the 2002 National Day Parade drinking a toast to Singapore's birthday with NEWater. What helped in the public acceptance of NEWater is the cultivation over decades of a social culture of appreciating water scarcity. In keeping with this, Singapore has lowered its daily per capita domestic water consumption from 165 litres in 2003 to 150.4 litres in 2014, and aims to reduce it further to 140 litres by 2030.

Today, Singapore has four NEWater plants that produce 30% of its daily water needs. The recycled water is of such high quality that it is also diverted for use in industry, notably in wafer fabrication, besides other manufacturing processes and cooling towers. As rainfall-independent sources, NEWater and desalinated water are key to building Singapore's drought resilience. By 2060, these two sources will be able to meet up to 80% of Singapore's total water demand.

RIGHT
A meandering waterway at Bishan-Ang Mo Kio Park, now a recreational space for all ages.
Credit: PUB, Singapore's National Water Agency

Source: PUB, Singapore's water agency

The fourth national tap comprises desalinated water. After being processed, the desalted water has to be mixed with natural water to pick up the nutrients taken out in the desalting process, including micronutrients such as manganese and iron. On the way out, however, one environmental limitation was that the residual seawater would become too salty and disrupt marine life if the salt was simply put back into the sea after the desalination process. In this respect too, systems engineering provided Singapore with a solution. The desalinated water that is sent through to users is all collected back, whereupon the salt is replaced before the water is sent back into the sea.

As part of this whole process, a water distribution system—including treated water reservoirs—is in place to balance demand between peak and off-peak hours in a day.

Just as one key aspect of systems thinking is to prepare for long-term maintenance, it is essential for Singapore to ensure that the urban systems engineering approach is passed on to succeeding generations of practising engineers. At PUB, "urban systems solutions" is the jargon term used to refer to systems thinking, which is reinforced all the time, including at internal talks by invited speakers like Tan.

To advance systems thinking in professional education, he championed the Ministry of the Environment and Water Resources' Centre for Environmental Training, which ran 400 training programmes annually on average for ministry staff and others. At the centre, research is conducted in areas including waste recycling, public health and pollution control. Research is, of course, also important for all the industry sectors

"Once you have a concept plan, you can see where the bottlenecks are... (and) where the R&D money should go to."

related to the environment. As he says: "Once you have a concept plan, you can see where the bottlenecks are. You can also identify where the research and development (R&D) money should go to."

Given his contributions to Singapore's water sector, it was no surprise that Tan's systems engineering approach was also tapped in 2015 when he was asked to advise the Ministry of Transport on increasing rail reliability and achieving its reliability targets by 2020.

The "Soft Systems" of Social Values and Norms

An urban systems approach also incorporates a social aspect, with the need to integrate the "soft systems" of societal values, lifestyle norms and human behaviour. As Tan observes:

> To implement an environmental and water policy successfully, we've got to take into consideration the level of social and economic development—that is fundamental. If you run too far ahead of it, implementation will not be successful. If you lag too far behind, you will create inefficiencies in the system. You can't look at water policy in isolation. You must look at social policies, economic policies—where they are going, when the time will be right to introduce the kind of water policies you want, and so on.

Having addressed some of the more urgent water requirements, in 2007, the ABC Waters programme was unveiled by PUB. The aim of this programme is to take water structures beyond utilitarian water collection, storage and drainage, and to bring an aesthetic dimension to these spaces for recreation and community interaction. For example, canals have their previously bare concrete sides "retro-fitted" to become more "natural", with added greenery, landscaping and sloping sides.

Tan views this as a "social experiment" to bring people back to the water to see if they can appreciate it enough to keep it clean, and whether they have developed a sense of personal involvement in the stewardship of their water.

> Actually, it's about social engineering. We know that the day will come when the larger part of Singapore will be a water catchment. You can't go around enforcing against water pollution. You can't be everywhere all the time, [and thus] public education is extremely important.

Going forward, systems thinking must come into play for the PUB's ABC Waters programme to integrate with the National Parks Board's Park Connector Network to enhance waterways together with gardens, parks and green corridors across the island. More broadly, the waterways under PUB's care will become part of the "City in a Garden" vision, making Singapore even more liveable as a city of gardens, water and nature.

02

Building a Sustainable City

Chapter Two

Chapter Two

02

Building a Sustainable City

Singapore's built environment is admired for many reasons—chiefly, its remarkable consistency in offering all foundational aspects of a liveable city, and how it continues to enhance its infrastructure to support the city's growth.

The three engineers featured in this chapter have helped Singapore become a more sustainable city in major areas, as it happened, in the air, on land and at sea:

1

Liew Mun Leong was instrumental from the outset in not only making Changi Airport the world's best, but also in enabling it to stay at the top with constant, daring reinvention.

2

Chang Meng Teng's role in the development of Singapore's power grid was essential in realising the national economic and industrialisation strategy.

3

Tan Ee Ping contributed towards establishing Singapore's shipbuilding industry, which has also gone on to become a world leader.

1

Connecting Singapore to the World

One key aspect of Singapore's urban infrastructure is the extent to which this small island is linked to the rest of the globe, and how well this connectivity is conceptualised, built and sustained. Singapore has been a centre for global trade and commerce throughout its history. This was the case even centuries before the arrival of the British, mainly because of its strategic location. The best economic dividend of this geographical blessing is connectivity to the world.

One asset of connectivity is Singapore's Changi Airport, which serves more than 65 million passengers annually, travelling on an estimated 120 airlines to about 380 cities in about 100 territories worldwide. This was possible due to an integrated, holistic approach that allowed it to build ahead of demand.

Getting the airport right in the first place, and then fuelling its expansion and enhancement to become the world's best, has required studious and sustained management of what Changi Airport Group Chairman Liew Mun Leong calls "a complex system of systems". This is a task he has managed at all levels starting from when he was a Public Works Department (PWD) engineer after graduating in civil engineering from the University of Singapore. He worked on building the first runway from the beginning in 1975, and later, on the construction of Terminals 1 and 2. "Engineering has taught me to be...systematic in thinking about solutions to problems; to be a very pragmatic person, and at the same time, never forgetting to be cautious and building in margins of safety in any plan."

"You can compete on only one thing—systems. We are very good at systems in Singapore—not only in developing systems but also in maintaining discipline for systems."

ABOVE
Liew Mun Leong
Credit: Changi Airport Group

BELOW
View of the sunken car park at Changi Airport Terminal 1.
Credit: National Archives of Singapore

What worked in Singapore's favour, he says, was the practice of conducting urban planning together with transport planning, which not many countries consider. If the original plan in the 1970s for the proposed site for an international airport at Paya Lebar had gone ahead, it would never have become the world's best airport, as there would have been very little space to expand. As it turned out, then Prime Minister Lee Kuan Yew wanted the international airport to be by the coast at Changi, thus not limiting development in the vicinity with height restrictions, and also having the scope and liberty to expand further out into the sea through land reclamation.

Putting all the pieces together for the airport required adopting a holistic, systematic and scientific approach. In fact, even where to construct an airport is itself a doctoral research subject, Liew notes. "An airport is one of the most complex public infrastructures to build and operate," he says, because of the need to integrate and harmonise many elements that are independent and yet interdependent. These

aspects range from basic efficiency and safety related to the handling of aircraft, passengers and baggage, to a spectrum of unpredictable demands, including managing major disruptions from the external environment such as floods and volcanic ash. Hence, close attention to detail is non-negotiable: "Being paranoid forces me to plan ahead to deal with even the most remotely possible adversity...the consequence of not doing so may be regretful and unforgiving," he wrote, in a note to staff, published in his book *Building People: Sunday Emails from A Chairman*, Volume 4.

Across complex interdependencies including ground transport, air traffic control, terminal operations and cargo, a bottleneck at any touchpoint can cause a domino effect across airport operations. Technology plays a crucial role too, given the multiple complex engineering and IT sub-systems that work hand-in-hand at the airport. These include the baggage handling system, as well as newer innovations such as the integrated fast and seamless travel (FAST) self-service platforms that leverage biometrics and are fully automated. Additionally, there is the aspect of providing the best passenger experience while seeking financial sustainability at the same time

—a successful airport is one that can earn enough from satisfying passenger demand for shopping, dining and entertainment. This is why Changi Airport seeks to excel in catering to more than 60 million passenger-shoppers a year—this is crucial, as non-aeronautical revenues make up almost half of the airport's total revenue.

Jewel Changi Airport, the new mixed-use complex adjacent to Terminal 1 that opened in April 2019, is the latest—and best—example, Liew says, of the systems approach applied to build and sustain the airport. Constructed on the site of a sunken car park for Terminal 1 that was built in the 1970s, the idea for the commercial development was conceived by systemically thinking about optimising land use at Changi Airport.

LEFT
Jewel, the most complex "system of systems" so far in the development of Changi Airport.
Credit: Changi Airport Group

All aspects of the airport's environment were studied carefully for structural and environmental sustainability, because they are so closely inter-related. For example, Jewel's dome has more than 9,000 pieces of specially manufactured glass, which allow maximum sunlight in, but also have the ability to cut thermal heat. This means less energy needs to be used, and it also allows more than 2,000 trees and 100,000 shrubs to survive indoors. To provide comfort and to conserve energy, ground cooling slabs are used, and air-conditioning is provided not for the whole dome but only up to a height of about two metres from the ground.

The official go-ahead for Jewel—now hailed as an industry game-changer—depended on persuading all key stakeholders on various facets of sustainability. It took three years to secure all the approvals needed for this project. There were concerns about traffic congestion at the airport, whether the large number of retail outlets would adversely affect the surrounding malls, and whether the complex would aggravate the problem of a shortage in retail workers. Liew and his team made sure these concerns were addressed, and then convinced the Singapore Government that the project was crucial for Singapore's long-term strategy as a leading global aviation hub.

As it turned out, the successful opening of Jewel now makes it a model for other major projects of the built environment for the next few decades. In his National Day message 2019, Prime Minister Lee Hsien Loong named Jewel among the six

major infrastructure projects in the next phase of remaking Singapore. The other five are: Changi Airport Terminal 5, Tuas Megaport, the Jurong Lake District, the redevelopment of Paya Lebar Airbase and the Greater Southern Waterfront.

Global competition in the airline industry is so intense that planning for the next phase of Changi Airport's development is already underway. Again, building ahead of demand will require sound judgment and systematic attention to all key facets of construction. Terminal 5, which is scheduled to open in the 2030s to cater to 50 million passengers, will need systems planning and engineering at a whole new scale. The new terminal will have a floor area multiple times that of VivoCity, one of the largest retail malls in Singapore, and large tunnels will connect it to the other terminals. The rooftop of such a large building will pose an architectural and engineering challenge, requiring deep expertise and innovative solutions.

The scale of the building and the challenge will be unprecedented and cutting-edge technology must be incorporated to solve engineering problems, Liew reckons. "In the 21st century, everything is going to be scaled up, whether it is finance, engineering methods, people...and the only way to resolve scale is with systems thinking." A glimpse of the future can already be seen in the FAST system at Terminal 4, where technology such as facial recognition enables new levels of efficiency and security.

Owing to these developments in technology, he observes, the "traditional" disciplines of civil, mechanical and electrical engineering are no longer going to be the only ones occupying the core of engineering. Technologists who can

ABOVE
More than 9,000 pieces of glass were specially manufactured for the façade of Jewel.
Credit: Credit: Matteo Morando – own work, CC BY-SA 4.0 https://commons.wikimedia.org/w/index.php?curid=78179622

straddle all engineering disciplines and adopt a systems approach will be at the forefront of engineering and project leadership.

The impetus for a collaborative approach, while maintaining a "helicopter view" in overall management of a project, was a key learning in 1985 while building Terminal 2. With 11,000 critical path activities of one-month duration, the "traditional model" of one design architect leading a team of engineers, quantity surveyors, contractors and other professionals, was ruled out. Instead, the new project management model comprised a team of project managers with distinct yet interwoven areas of responsibility managing the three main critical components of time, cost and quality. This framework has since become an industry norm for project management.

To encapsulate all the complexity of building and maintaining an airport, Liew drew an analogy between the integrated ecosystem of an airport and the "mixed development" concept that has become a signature feature of Singapore's urban development—blending accommodation, commercial and retail facets into an integrated system. Once again, the engineer in him applied

this model literally, in concrete terms. During his time at CapitaLand Group, as founding President and CEO between 2000 and 2012, he spearheaded the building of eight Raffles City developments across China, from Shanghai to Chongqing.

The kind of mixed development seen in a typical Raffles City requires many aspects to work well. There has to be a critical mass of retail tenants, the hotel entrance has to be systemically planned to segregate footfall, and malls, offices and car parks must have easy access and exit. "Those [malls] are really systems. You might think it is very simple, but I think we have really championed the mixed development concept in China, ahead of many countries."

There is also a cultural dimension. Raffles City malls in China sell Singaporean food and beverage favourites like roti prata and teh tarik. These lifestyle and cultural aspects were "incorporated naturally", he says, as part of the food court sub-system that he believes was largely introduced in China by Raffles City malls. Indeed, Raffles City malls have done so well in the country that their staff who secure and manage tenants are highly sought after, and even their security guards command higher salaries.

In Liew's view, the key attribute of organisational culture is discipline, as seen in operational efficiency and integrity of character. This is also why, in connecting a sustainable city to the world, Changi Airport does so well. For example, at some other airports, baggage handlers do not pick up bags that have "priority" tags first, hence undermining the priority system. As he says:

> In a market like China, you cannot compete on capital, technology and manpower. You can compete on only one thing—systems. We are very good at systems in Singapore—not only in developing systems but also in maintaining discipline for systems.

LEFT
Raffles City Chongqing in China, one of nine Raffles City developments, each of which is a system in itself.
Credit: Junyi Lou – Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=81872457

2

Providing the Spark for Singapore's Industrialisation

Singapore sparkles in many ways. It is electricity that provides and sustains the spark, making the place come to life. Engineers like Chang Meng Teng, an electrical engineer in the electricity department of the Public Utilities Board (PUB) from 1967 to the mid-1970s, have played a crucial role in lighting up the city. Chang was instrumental in the development of Singapore's power grid and worked on vital facilities including the Pasir Panjang power station and Paya Lebar Airport. The timely and reliable supply of electricity was essential to realising the national economic and industrialisation strategy.

ABOVE
Chang Meng Teng

In the 1960s and 1970s, British engineers from colonial times were still working at PUB, Chang recalls in a 2011 book titled *Brighter: Electricity In Singapore: From Beginning To Beyond*, which marks 100 years of electricity in Singapore. More homegrown engineers like Chang were being sent for overseas training with major electrical industry manufacturers, but it was not until the 1980s that Asian engineers were fully recognised.

In those early years, an integrated approach to solving engineering problems came about from learning on the job and pooling ground experience. What the young engineers did was to pick up knowledge from the old hands, who passed on what they knew, willingly. He says:

> In those days, there was a lot of team spirit among the engineers. At Armenian Street, we had a chill-out area in the coffee shop opposite the substation. After work, young engineers like me drank coffee there with the older engineers. They told us stories about the electrical faults they had attended to and how they resolved them. We could sit there till 7 or 8 o'clock listening to these stories.

"The engineer may not be the glamorous public face of a project, but he or she plays an essential part in all we take for granted around us."

He found this informal sharing so useful that when he was President of the Senior Officers' Association at PUB, he initiated luncheon sharing sessions, where everyone would spend 45 minutes during lunch on a discussion about someone's latest overseas course or attachment with a manufacturer.

Those were days when electricity maintenance required a lot more manpower. Electricity supply is provided through a complicated network of cables, transformers and circuit breakers that comprise the transmission and distribution network, which is vital to a reliable electrical supply. This network of equipment is mostly remote and unattended, which could mean that problematic equipment could go undetected till a serious fault occurs. "In the early days, we needed a lot of manpower because it was all manual. They had to run down to all the substations if anything happened. And our substations are all over Singapore." By the late 1970s, a centralised data and control system was introduced by PUB, using computerised control and a new energy management system at the Ayer Rajah substation that enabled remote control and monitoring of networks, which improved efficiency tremendously. Today, even more powerful, state-of-the-art systems are used. These systems are continually being improved to further enhance response time and effectiveness.

In 1979, Chang moved to the private sector and co-founded the engineering consultancy firm Squire Mech with fellow engineers and architects from the firm RSP. It was his belief that strategic collaboration between engineers and allied professionals, including surveyors, would produce a highly positive multiplier effect, especially for larger infrastructure projects.

His major projects included the Green Mark Gold award-winning intelligent building, Republic Plaza, where he and his design team developed a software system for Asia-Pacific's largest double-decker lift system. It maximised the efficiency of transporting 6,000 people in the 66-storey building. This saved energy, reduced floor space

RIGHT
Republic Plaza has intelligent building features that came out of integrated collaboration between engineers and many allied professionals, including architects and surveyors.
Credit: Nicolas Lannuzel, CC BY-SA 2.0

RIGHT
An example of an integrated approach to engineering: HDB Hub complex in Toa Payoh, which won the BCA Energy-efficient BuildingAward.
Credit: User Sengkang – Own work, copyright-free use.

for the lift and, in doing so, maximised rentable floor space. Another significant project was the HDB Hub complex in Toa Payoh, which won the BCA Energy-efficient Building Award.

Chang believes knowledge is meaningless if it is not passed on to future generations. He has contributed much to the promotion of engineering as a profession of choice here in Singapore. As President of the Institution of Engineers Singapore (1990–1992), he championed a Continuing Education Centre, which evolved into today's IES Academy for engineers' lifelong learning. His belief is reflected in his speech made at the Professional Engineers Board Day of Dedication 2014: "Learning is a continuous process. The field of engineering is fast paced and ever changing. We should seek to learn not solely for knowledge itself, but with the aim of application of our knowledge to make lives better for people and contribute to society."

"...strategic collaboration between engineers and allied professionals, including surveyors, would produce a highly positive multiplier effect, especially for larger infrastructure projects."

BELOW
Jurong Industrial Estate in the early 1970s, the cradle of Singapore's industrialisation, was the outcome of engineers' integrated approach to planning, design and project management.
Credit: JTC Corporation

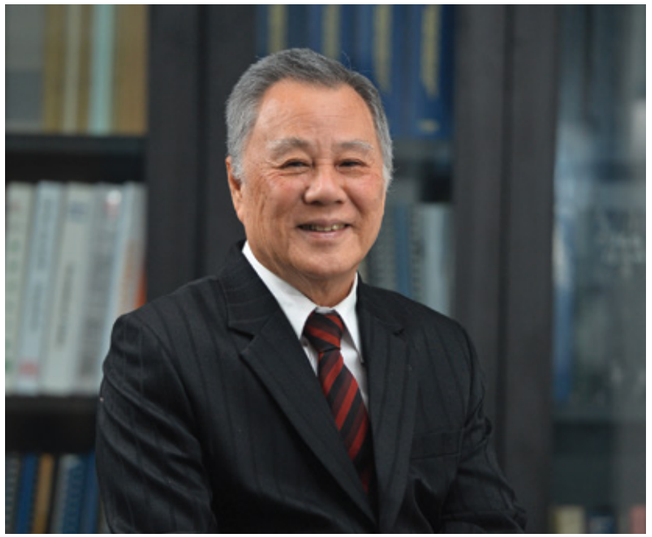
3

Integrated Infrastructure Development for Economic Growth

A key success factor for Singapore has been its openness—it has always been a welcoming home with a conducive environment for companies from overseas. This is evident from the sustained inflow of multinational companies—since the 1960s—looking to set up base in the city-state to command their regional and international expansion efforts from. The development of Singapore's built environment in the past five decades has required close coordination between agencies such as the Economic Development Board and JTC Corporation (earlier known as the Jurong Town Corporation). The key is to maintain a stakeholder-sensitive strategy to enhance economic growth in an integrated manner. This is done by providing all major facilities and support infrastructure that foreign multinationals require for their initial business relocation to Singapore and subsequent expansion from here.

Jurong Industrial Estate was central to this strategy, both as staging post as well as launch pad. Jurong became a magnet for brick-and-mortar companies, including manufacturers requiring land for factories with enough space for assembly lines, and even chemical and other companies requiring more facilities such as for the safe disposal of waste materials.

Since then, the requirements of companies have evolved with the onset of the Fourth Industrial Revolution. Today, companies are less dependent on a physical setting and more on abstract factors like mindset, skills and communications connectivity. Through all of this, Jurong Industrial Estate has continued to grow, accommodating multinationals moving up the value chain into higher-tech sectors.



ABOVE
Tan Eee Ping
Credit: The Straits Times © Singapore Press Holdings Limited. Reprinted with permission.

"There are a lot of other things that engineers also have to acquire in terms of knowledge and experience to be all-rounded, well-balanced and experienced."

Building Jurong and keeping it going was possible only with the integrated approach adopted by pioneer engineers involved in the industrial estate's planning, design and project management. Tan Ee Ping is one of those veteran engineers.

He advises young engineers to always draw ideas from a larger context to offer the best solutions. This is his perspective on the need for holistic approaches towards solving engineering challenges. Speaking at the 2016 Day of Dedication of the Professional Engineers Board, he emphasised the professional responsibility and duty of care of engineers, which is inseparable from the concept of legal liability:

> It is imperative that engineers should not just be conversant with design, but there are a lot of other things that engineers also have to acquire in terms of knowledge and experience to be all-rounded, well-balanced and experienced.

The focus of engineers' work, he believes, is to weigh constraints and conflicting interests, and to make professional judgments based on experience, to seek optimum solutions in terms of function, quality, cost and time. However, meeting more complex and demanding project requirements and to offer value-added work and services requires taking into account new and additional types of knowhow.

These other areas of expertise include project management, communication and legal knowledge, he told his audience of newly-accredited engineers:

> When commissioned to do work, it is important, while rendering service, to bear in mind that there are things beyond our knowledge and experience; and when you get into that sort of situation, you should consult somebody else or appoint a consultant.

Tan, who graduated in 1964 as a civil engineer from the University of Malaya, worked for the Economic Development Board and Jurong Town Corporation (now JTC Corporation) after graduation until 1969. In addition to Jurong Industrial Estate, he also worked on crucial amenities that were part of the original foundations of the built environment for Singapore's economic development, including Jurong Port with its deep-water wharves and facilities for fishery and warehousing, the Metal Industries Development Centre and Jurong Marine Base.

Tan moved to the private sector in 1970, setting up an engineering consulting firm in his own name. There, he continued to contribute to the development of Jurong Industrial Estate through building up the shipbuilding industry, in projects including Hitachi Robin Dockyard and Robin Shipyard. These efforts helped Singapore become one of the world's premier and largest ship repair centres, as well as a leading builder of rigs, offshore structures and smaller ships.

In the 1980s, his contributions moved to the aviation sector, mainly for the development of Changi Airport, providing engineering consultancy services for projects. This included features such as the flyover bridge over the East Coast Parkway and the innovative design, prefabrication, installation and delivery of mobile tail docks for maintenance of Singapore Airlines aircraft. His private sector work has also included projects overseas, from China to the Maldives.

Tan is an innovator himself, holding a patent granted in 1990 for his invention of a space frame system by the Comptroller-General of Patent, Design and Trade Work, London. In promoting a similar spirit of innovation, his service to the profession includes chairing the research collaboration between the Building and Construction Authority and NTU on flat plate building structures. He has persistently promoted the adoption of precast, prefabricated reinforced concrete elements in enhancing the industry's construction quality and productivity to alleviate Singapore's over-reliance on foreign labour.

He played a part to create another milestone in Singapore's building construction history when he was commissioned to provide independent professional structural review and design analysis for the world's tallest residential project using the prefabricated and pre-finished volumetric construction system. As Singapore continues to focus on developing its built environment in a sustainable manner, such grit to innovate and to foster innovation will be increasingly crucial for the future.

ABOVE
Jurong Port's deep-water wharves and facilities for fishery and warehousing, part of the original foundations of the built environment for Singapore's economic development.
Credit: Jurong Port

03

Reaching New Heights

Chapter Three

Chapter Three

03

Reaching New Heights

Cities are usually planned by the public sector, but built by a combination of public and private sector entities and actors. Close collaboration between government and business is a key success factor in Singapore's national systems approach to urban development. One private sector player who has featured prominently in this journey is Dr Shahzad Nasim, who played a leading role in managing the engineering works for most major buildings in and around Marina Bay and the city centre, including OUB Centre (later renamed One Raffles Place), which was the world's tallest skyscraper outside North America when it was completed in 1986.

"Urban systems engineering is a technological, integrated approach to planning the cityscape and infrastructure so that it works for the benefit of citizens," says Dr Nasim, Group Executive Chairman of Meinhardt International Group, a firm he joined as a structural engineer in 1978. Within seven years, he was managing director of the company's Singapore operations, and he subsequently went on to buy the company in 2010, moving its headquarters from Melbourne to Singapore. The firm is known internationally for its innovative, cost-effective and buildable engineering solutions for very tall buildings and complex infrastructure projects.

According to him, in Singapore's cityscape, Marina Bay is the best example of "complete integration"—a systems approach to forecasting future needs, providing now for adjustments later, and overcoming things that stand in the way, such as the default human behaviour of working in silos. "Everything has been pre-planned and a lot of the hurdles have been taken away. You have to future-proof these things for the long term."

LEFT
A number of prominent developments that shaped the skyline of Singapore's Central Business District were led by Dr Nasim and his team.
Credit: Mokkie - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=54663355

RIGHT
One Raffles Place, formerly OUB Centre, was the world's tallest skyscraper outside North America when it was completed in 1986.
Credit: Choo Yut Shing/Flickr/CC BY-NC-SA 2.0

The ideal mechanism for such systems integration is the combined services tunnel, an extensive network of underground tunnels that connects buildings in an extended area, and houses electrical and telecommunication cables, district cooling and water pipes, and a pneumatic refuse conveyance system. This subterranean facility allows for new connections to be added or changed underground in the future, and for maintenance and engineering services to be upgraded as and when technology changes, without causing any disruption above the surface.

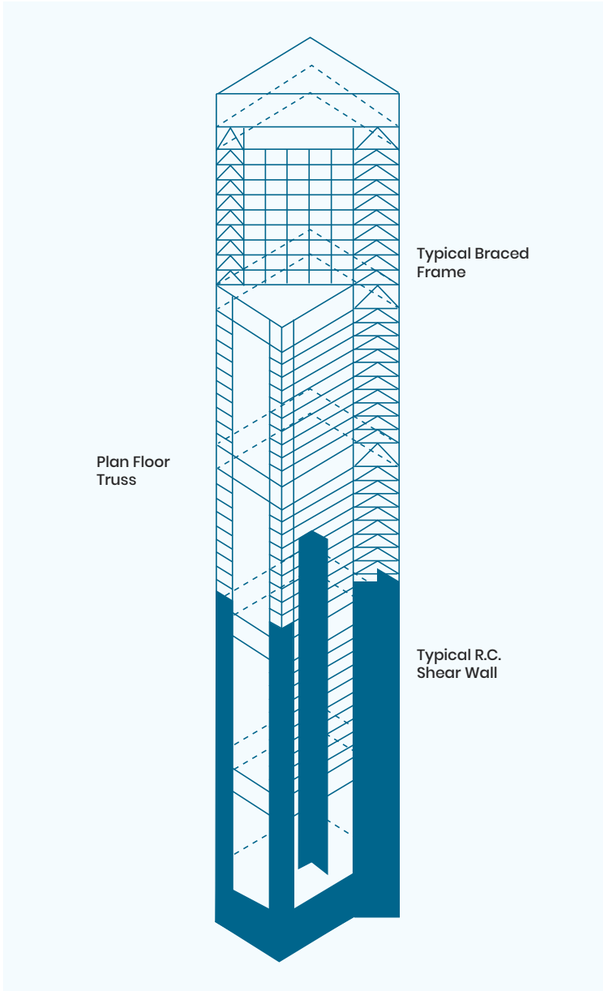
The combined services tunnel at Marina Bay is a prime example of forward-thinking provision in Singapore's national systems approach to urban

planning, which has a story going further back in time. The land adjacent to the Central Business District had been reclaimed in phases between 1969 and 1992, but the long-term vision for Marina Bay was first crystallised in the Urban Redevelopment Authority's (URA's) 1983 conceptual Master Plan.

The long history of such a long-term, integrated approach to planning in Singapore shows that the integration of systems, stakeholders and needs is not something that happens naturally, Dr Nasim observes. "Everyone is used to doing just their part of the work; very few people take an integrated approach." What differentiates an urban systems engineer is taking an active, rather than passive, approach to realising a building plan, he says.

Good Relations with the Private Sector, and Maintaining Integrity

Ever since the 1960s, urban renewal in Singapore has not only been a means to improve living conditions but also a way to generate economic growth and jobs. To facilitate the implementation of the Concept Plan and Master Plan, state land is released for development through the Government Land Sales (GLS) programme. The identification of GLS sites, which is planned for and announced every six months, is a means to harness resources of both the public and private sectors, with a proactive government seeking partnership with developers to understand market needs. Public officials have to balance between establishing a good relationship with the private sector, and maintaining the integrity of the system—a principle upheld to this day.



ABOVE
The steel mega-frame design adopted for Tower 1 of One Raffles Place, formerly OUB Centre, allows for column-free office space.
Credit: Meinhardt Group

To a large extent, Marina Bay is a perfect platform for urban systems engineering. The reclaimed land there offered almost a blank slate for all building aspects to be conceptualised and weaved together from the very beginning. Away from Marina Bay, in most other locations, the systems approach can also be realised by applying the same holistically technological approach, but precinct by precinct. A good example of this active systems approach is Dr Nasim's work on OUB Centre, with Tower 1 completed in 1986. There was no precedent then for constructing this 280-metre building with four basements, which was highly non-symmetrical, with lift shafts at the rear and only two columns in front. The solution that Dr Nasim and his team settled on was to build a composite steel building, the first with a mega-frame, with a foundation that was the deepest in the world, with very large caissons (watertight retaining structures) using special equipment from Japan.

The 63-storey skyscraper was the first in Asia with no internal columns and had to have the highest-speed lifts available. With the Raffles Place MRT station set to be built right next door, safeguards for stability had to be put in place so that the excavation for the subway later on would not affect the building. A retention system was placed in the basement foundation to keep the soil in position to accommodate the excavation.

Devising such a solution required systems thinking. Dr Nasim says:

> An urban systems approach means that engineers, working with other stakeholders, need to question the status quo, think out of the box and come up with unconventional solutions. That includes rejigging the design.

ABOVE
Dr Shahzad Nasim.
Credit: Meinhardt Group

> "Engineers...need to question the status quo, think out of the box and come up with unconventional solutions. That includes rejigging the design...the best outcome is about improving safety, environmental sustainability, cost and time."

LEFT
One Raffles Link, a six-storey column-free high-tech office building, was tailor-made to cater to financial institutions. Credit: Meinhardt Group

> You have to get the best outcome, and the best outcome is about improving safety, environmental sustainability, cost and time.

The megastructure approach first used at OUB Centre came to be recognised by the industry as safe and smart, and a similar approach is now used in many projects, such as for the Merdeka PNB 118, a 118-storey skyscraper currently under construction in Kuala Lumpur, which will be the tallest in the country once completed.

Working Together on Singapore's Biggest Future Development Challenge

Looking to the future, Dr Nasim thinks that Singapore's biggest development challenge is not knowing the foundation layouts and related details of old buildings and infrastructure without any records dating back beyond 40 years. To remedy this, the Singapore government has been investing in R&D. For example, Virtual Singapore, a dynamic three-dimensional (3D) city model and collaborative data platform, including 3D maps of Singapore for use by people and the public, private and research sectors, is a project championed by the National Research Foundation (NRF) and supported by Singapore Land Authority (SLA) and Government Technology Agency of Singapore (GovTech).

This model will enable the development of sophisticated tools and applications for test-bedding concepts and services, planning and decision-making, and research on technologies to solve emerging and complex building challenges. In addition, there are also R&D efforts in the area to enhance underground mapping accuracy. A better understanding of what lies below the ground will facilitate better planning and

decision-making, thus reducing the cost of underground development. Such efforts to create a digital map of the whole island will allow Singapore to apply a systems approach to the overall development of the country.

Beyond hardware, putting a whole system together also means integrating the "software" of meeting human needs, which entails understanding the culture and habits of human stakeholders and working around them. Such an approach is encapsulated in the One Raffles Link and CityLink Mall project, which Dr Nasim and his team were involved in. Developed together with One Raffles Link, a six-storey column-free office building, CityLink Mall is Singapore's first purpose-built underground shopping centre. To provide direct and convenient connections to public transport and to encourage pedestrian activities, especially in Singapore's hot and humid weather, the fully air-conditioned tunnel incorporated shops as well as food and beverage outlets. High ceilings, skylights with coloured lightings, and sophisticated exhaust and air-filtration systems are some of the features installed to give the mall a pleasant and clean environment.

A Team-Oriented Approach to Finding Holistic Solutions

To help foster an even more holistic engineering approach in Singapore, Dr Nasim contributes in a few ways, including serving on the industry advisory committees for the schools of civil and environmental engineering at institutions such as NTU and the Singapore Institute of Technology (SIT), where he interacts with the engineering faculty to help them understand the current and future practical needs of the profession. He thinks

> "Government agencies are always very forward-looking and seek good ideas. There is a lot of study, research and consultation before devising rules."

LEFT
CityLink Mall, completed in 2000, provided bright and pleasant connections for users linking the developments in the vicinity of the Marina Centre area and City Hall MRT Station.
Credit: Chun Hong Lim - Own work.

this is unique to Singapore—the way universities work so closely with industry to stay abreast of the industry's needs, shortcomings and new trends in areas such as information technology and post-tensioned and precast concrete.

As for nurturing the next generation of engineers, industrial work-study programmes include attachments with firms like Meinhardt during the 4-year degree course, which enables them to learn how design and other aspects of engineering can adopt and apply a systems approach. In this way, when these students graduate and start work, "they are useful on day one".

Dr Nasim seeks to nurture such a team-oriented approach to find holistic solutions among his engineers. A culture of innovation and research is cultivated by having group design teams of several staff members from different technical specialisations to brainstorm ideas, put together computer models to predict how the modelled buildings will "behave", and then recommend the best solution to use for project proposals. "Everyone looks for the best solution; it takes out the guesswork and overcomes passive engineering," he explains. "Innovation is not something that you do once-off; it's in an organisation's culture."

This kind of comprehensive application of a systems engineering approach must have prompted the Ministry of National Development to involve Dr Nasim and his team in formulating the national Construction Industry Transformation Map in close partnership and consultation with the industry, trade associations and chambers, unions and institutes of higher learning. Led by the Future Economy Council, which is responsible for driving the growth

“Beyond hardware, putting a whole system together also means integrating the "software" of meeting human needs, which entails understanding the culture and habits of human stakeholders and working around them.”

and transformation of Singapore’s economy for the future, this initiative aims to transform the construction sector and enable its adoption of technologies to make it more advanced and integrated. The vision includes training 80,000 professionals specialising in three key areas—green buildings, integrated digital delivery and design for manufacturing and assembly—by 2025.

This is an excellent example of how the private sector plays a major role in helping shape Singapore’s built environment not only downstream in realising actual building projects, but also in the very upstream stages of conceptualising and planning from a national perspective. This is only possible because in Singapore, Dr Nasim notes, “government agencies are always very forward-looking, and seek good ideas. There is a lot of study, research and consultation before devising rules.”

Partnership between the public and private sectors in Singapore looks set to remain just as deep, going into the next phase of the economy. As Singapore advances its Smart Nation Initiative, launched in 2014, the government will need to maintain a successful economic partnership with the private sector, in areas including the harnessing of technology, greater access to data and technology-enabled participatory policy making approaches. Engineers can help by making the interface of technology infrastructure with the public as seamless as possible.

Along with the planning and installation of new technology for public use, effort has to be made to bring users on board. Building a smart nation, Dr Nasim says, is not just about putting in the technological systems, but also about training and upgrading people’s skills so they can interact well with the new technologies. “You have to change habits; not everyone is ready for technology.”

04

Engineering the Future

Chapter Four

Chapter Four

04

Engineering the Future

RIGHT
Cham welcoming President Wee Kim Wee to the opening of Nanyang Technological Institute in 1981, where Prof Cham applied a systems approach in engineering education for decades. Second from left are then Education Minister Tony Tan and then Chairman of NTI Council Michael Fam. Credit: National Archives of Singapore

For urban systems engineering to have shaped Singapore's built environment to the extent it has, there must have been some decisive quality in the making of Singaporean engineers. Perhaps there was a little extra in their education and training across generations, not only at university but long after, in the lifelong learning that is essential in keeping a practising engineer at the top of his or her game.

Indeed, one of Singapore's success factors was applying a holistic way of thinking and working to its engineering education sector in the formative decades. This is an ongoing effort to engineer the future, as this approach is continually being applied to adapt and integrate new technologies, techniques and methods.

A key player in this process over the decades has been Cham Tao Soon, President Emeritus of Nanyang Technological University (NTU). Cham served there for 21 years from 1981 as a founding President, first at the fledgling Nanyang Technological Institute (NTI), the predecessor to NTU, and later of NTU. He made sure engineering students had a broad-based study of the fundamentals not only at NTU, but at other universities and institutes that he worked at too.

"When you deal with real engineering problems, it's always multi-disciplinary; you don't just solve one engineering problem, there are always other implications."

ABOVE
Cham Tao Soon
Credit: Singapore University of Social Sciences

He went on to champion a similarly broad-based curriculum and pedagogy, and continues to advocate such an approach to this day.

While Cham was serving as the founding President of NTI, he was also double hatting at the National University of Singapore (NUS), as Dean of Engineering from 1978 to 1983. As the Dean, he ensured that all courses across different disciplines of engineering were common in the first two years, so that students could absorb the general fundamentals of engineering before they branched out to the various disciplines of civil, mechanical or electrical engineering. As a result, students were able to draw on a foundation of broad-based understanding as they specialised in

a particular discipline, making their experience richer. "To me, that is the way to produce engineers with a systems approach," he says.

Cham's broad approach to knowledge came from a mindset he developed when pursuing his own first degree in civil engineering at the University of Malaya on a Singapore State Scholarship in 1960. At the time, Singapore did not have an engineering department. His education there was even more broad-based than at NUS—three out of the four years had a common curriculum. He explains that in Malaysia, students had to learn the basic facets of engineering because "when you graduate, you are sent to a district where you may be the only engineer in that whole area, and therefore you must know everything".

The Value of a Wider Perspective

Ironically, it was this traditional, rural district necessity that nurtured his modern, urban mindset about how engineering can help shape a future-oriented environment. Although he himself went on to earn a doctorate in fluid mechanics from Cambridge University, he understood closely that while scientists require in-depth specialisation, developing a wider perspective was more valuable for practising engineers.

When he started his career as a lecturer at NUS, he already held a holistic view towards modernising engineering education, and when he was extended the opportunity to start an engineering school at NTI, he envisioned a school with a difference. Not convinced by what he saw as engineering's excessive emphasis on academia and theory, he recruited lecturers with extensive industry experience.

"In real life, there's very little that is just A to B, it's usually A to Z."

Going broad rather than deep was the rationale behind his coining of the term "practice-oriented curriculum" to differentiate NTI (and later NTU) from the more established NUS. A hands-on stance in staying focused on real-life concerns inevitably demands consideration of other disciplines and dimensions: "When you deal with real engineering problems, it's always multidisciplinary; you don't just solve one engineering problem, there are always other implications."

Cham has certainly made significant contributions in laying the foundations of a holistic way of thinking and working as part of the "DNA" of engineering university education in Singapore. Even after leaving NTU in 2002, he went on to promote the idea of assuming a wider perspective on knowledge when setting up the Singapore Institute of Management (SIM) University in 2005. This was with a mandate from the Ministry of Education to pioneer private university education for working adults. As the founding Chancellor and Chairman of UniSIM, he advocated diverse fields of study, including niche and emerging needs from across the whole spectrum of academic disciplines, from early childhood education to gerontology.

BELOW
Cham who is no stranger to the rail industry in Singapore, was appointed the head of Singapore Rail Academy in 2016. Seen here at the launch of the Singapore Rail Academy with Transport Minister Khaw Boon Wan, LTA Chief Executive Ngien Hoon Ping and LTA Chief Deputy Executive Chua Chong Kheng.
Credit: Land Transport Authority

A "System of Life" in the Classroom

Unlike the usual undergraduate classroom, at UniSIM there was something of a "system of life". As the students at UniSIM were working adults, they could bring their problems from the worlds of business and government to class. Seeing such practical applicability, students realised these issues were not unique to any discipline and that ideas and insights were needed from varied areas of expertise. It would be practically impossible to slip into narrow, theoretical abstraction. By the same token, the lecturers recruited were those with "good working experience", and were drawn from diverse backgrounds. They adopted a practical, hands-on approach to gaining and imparting knowledge. In short, they were always bringing concrete experience from "the real world" to the classroom.

"In real life, there's very little that is just A to B, it's usually A to Z," says Cham, summing up the need to reach for solutions by taking the longer and sometimes circuitous route. This approach includes considering all relevant aspects while seeking to predict and pre-empt potential problems. His grasp of the operational dynamic is straightforward—in setting out to lead a group to achieve an objective, once you ensure the parameters are right, the organisation will then have a culture with a systems approach.

This, after all, should be the nature of an ideal collegiate campus—always guarding against retreating into the human default behaviours of a

silo mentality of selfish hoarding of information. For example, when NTU wanted to set up a technopreneurship centre, one idea was to house this in the business school, but Cham was sure that doing so would have resulted in failure, as some engineers would have hesitated to participate in a programme run by a school that they were not part of. Instead, the best way to draw from a wider talent pool was to have it as a university centre, not at any risk of favouring one school over another, and open equally to all.

Keeping an open mind is another fundamental aspect. Cham cites the example of current discussions around digital transformation, which will be heralded by the development of smart cities, big data analysis and companies encouraging employees to become more conscious of disruptive technologies. However, it takes someone who can step back and look at the big picture—from another discipline, like a historian—to ask the right questions about the unforeseen consequences of the fourth industrial revolution, and whether these changes will adversely affect the environment. What is true is that projections of the future are never exact, and it is therefore suggested that people must be conscious of the various factors at play, and always be ready to adapt and adjust to change.

Cham's extensive public service includes promoting the professional development of engineers in industry. In 2016, he was appointed head of the Singapore Rail Academy, which was set up to build engineering expertise and further research capabilities. In addition, he was entrusted with setting standards for the training of engineers and technicians at institutions of higher learning and at SMRT (Singapore Mass Rapid Transit) and SBS (Singapore Bus Service)

RIGHT
Delivery of the first MRT trains at the Bishan Depot on 8 July 1986.
Credit: National Archives of Singapore

Transit networks. An indication of Cham's belief in the systems approach is the emphasis he places not just on boosting skills but also on fostering teamwork. The Academy's remit includes promoting apprenticeship and through-train programmes for 6,000 workers in rail operations and maintenance, half of whom are engineers and technicians. This is important for Singapore, given that an additional 5,000 workers will be needed to work on the expansion of the rail network to 360 km by 2030.

His observation was that training on its own usually tends to become a bit too specialised, and that can be limiting, given the many different factors at play and the various implications of decisions. For example, managing drainage today is not simply about dealing with water levels or hydraulics, but also about other facets such as complex electrical systems.

Disruptive Technology Demands a Systems Approach

Sometimes, it is crucial to take into account more aspects, such as when the pervasive use of a new disruptive technology changes almost everything else. For example, big data offers fresh information and perspectives that compel a holistic grasp of all relevant factors. This enables analysis of how any one component of a system

LEFT
Other than St Petersburg's metro in Russia, Singapore's Mass Rapid Transit (MRT) was the only other system in the world to be fitted with platform screen doors at all stations when it opened in 1987.
Credit: National Archives of Singapore

> "...projections of the future are never exact, and it is therefore suggested that people must be conscious of the various factors at play, and always be ready to adapt and adjust to change."

can affect other parts: "Everything must include big data, whether you like it or not. You have to monitor many sensors, so you need a systems approach."

Preventive maintenance is a major area where this applies, to anticipate what might increase the risk of breakdowns—whether in elevators or subway lines—by looking out for signs that signal the imminent need for maintenance intervention. Going beyond immediate concerns, a systems approach helps determine where priorities should be placed for research and development. This is crucial towards ensuring the proper monitoring of gaps in knowledge or expertise that may require more funding to fill. One growing research area is the use of robotics, for example—to check railway lines through the night. This would make light work of a task otherwise much harder for human manpower to execute.

A rail network demands detailed planning and management. Developing an MRT system requires the planners and engineers to take into account many considerations and to balance trade-offs. This was the approach Cham took in his many years of service to the rail system in Singapore—from the early 1980s when he was on the technical committee of the then MRT Corporation, to being a founding Director of SMRT. He was then a representative on the board of the Land Transport Authority (LTA) and then Chairman of the LTA Academy until 2014.

When the MRT system was first being developed, it was a huge investment for Singapore to undertake, and costs had to be saved wherever possible. One such cost-saving decision was for trains to have six carriages instead of eight. However, Singapore did not scrimp when it comes to comfort and safety of the passengers. A decision was made to install air-conditioning in the underground stations and screen doors on the station platforms. The screen doors not only helped to manage electricity costs but also doubled as a safety mechanism.

As Singapore's rail network expands, it has to stay flexible to cater to the changing priorities of society and the population. It also has to be open to the application of re-engineering where needed—something that is reflected in the continual upgrading and retro-fitting of MRT stations and facilities over the years. For example, covered walkways, ramps and other features for easier access at the stations were built only later. These features were added with a view to providing a more inclusive service for the whole population, including people with disabilities and the elderly, who have increasingly became a national priority in a rapidly ageing society.

In another 10 years, the MRT network aims to double its mileage and enable 95% of the population to walk to a station within 10 minutes. To reach this goal, Singapore's rail system will require flexibility and nimbleness to adapt to change, which can only be delivered by adopting a systems approach.

"Going beyond immediate concerns, a systems approach helps determine where priorities should be placed for research and development. This is crucial towards ensuring the proper monitoring of gaps in knowledge or expertise that may require more funding to fill."

LEFT
The Green Roof at Marina Barrage.
Credit: IamDoctorEgg / Shutterstock.com

afterword

Khoo Teng Chye
Executive Director,
Centre for Liveable Cities

Once a squalid, slum-ridden and polluted city of less than 2 million people in the 1950s, Singapore has transformed into a liveable and sustainable city of 5.6 million people today. Much of this transformation has come about through urban systems innovations, such as "closing the water loop" to produce NEWater and solving the water issue. Another example is how the provision of transport services and other utilities was integrated into the city's planning. Urban systems innovators have been the linchpins behind these systemic innovations.

Singapore's urban systems innovators are professionals who can work across interfaces of independent, yet interdependent, systems in city infrastructure. Increasingly, this is the only way to deliver good integrated policies, plans and solutions. In the Fourth Industrial Revolution, technology continues to advance at a rapid pace, and the foundation for organising and managing everything is now digital. Therefore, all relevant disciplines need to be integrated. While the engineers of the future may still have an area of specialisation, they must be comfortable operating across various specialist domains and subsystems. Only then will they be able to solve the most difficult urban systems problems, which are only becoming exacerbated.

Singapore will keep growing, but as an island city-state, the margin for error remains small. As urban development intensifies, how can Singapore continue to remain liveable? Rather than leaving things to chance, this will require Singapore to continue to apply urban systems innovation.

In earlier decades, Singapore's engineers were motivated by addressing urgent needs such as water, housing and sanitation, which were multi-faceted issues. Tackling these problems required good and thoughtful leadership to bring separate agencies and stakeholders together to manage a few component aspects holistically. The challenges are arguably even more urgent now. For example, taming the greatest threat of climate change may cost around S$100 billion over the next 50 to 100 years, as Prime Minister Lee Hsien Loong noted in his 2019 National Day Rally.

Remaking the built environment is an ongoing marathon, and Singapore's urban systems innovators have run a remarkable race so far. Now, as the baton passes to the next generation, a similar spirit of holistic, integrated planning and urban systems innovation is needed. Only then can momentum be maintained, into the next lap of engineering Singapore.

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glossary

1

1971 Concept Plan
The first Concept Plan was drawn up in 1971, with assistance from the United Nations Development Programme. The focus of the Plan was to meet the basic infrastructure needs of a new nation. It laid the foundation for the future development of Singapore with the development of new towns, transport infrastructure, and parks and recreational spaces across the island.

A

Active, Beautiful, Clean (ABC) Waters Programme
The ABC Waters Programme aims to create beautiful and clean streams, rivers and lakes with community spaces for all to enjoy.

B

Building and Construction Authority (BCA)
The Building and Construction Authority (BCA) is an agency under the Ministry of National Development, championing the development of an excellent built environment for Singapore. “Built environment” refers to buildings, structures and infrastructure in our surroundings that provide the setting for the community’s activities.

C

Cabinet
The Cabinet of Singapore led by the Prime Minister, is responsible for all Government policies and the day-to-day administration of the affairs of the State. It is collectively responsible to the Parliament.

City in a Garden
More than a ‘Garden City’, where the main function of greenery is to be decorative, Singapore is becoming a ‘City in a Garden’, an all-embracing living and working environment. Where space is short, green has spread to walls and rooftops. The revolution is ‘blue’ as well as ‘green’, involving rivers and canals.

D

Deep Tunnel Sewerage System (DTSS)
The Deep Tunnel Sewerage System (DTSS) is a superhighway for Singapore’s used water management. The system uses deep tunnels to convey used water entirely by gravity to three centralised treatment plants located at the coastal areas of Singapore. The treated used water is then reclaimed and further purified into NEWater, with excess affluent discharged to the sea in an environmentally responsible manner.

E

Economic Development Board
The Singapore Economic Development Board (EDB), a government agency under the Ministry of Trade and Industry, is responsible for strategies that enhance Singapore’s position as a global centre for business, innovation and talent.

F

Future Economy Council (FEC)
The Future Economy Council (FEC) comprises members from government, industry, unions, and educational and training institutions. It is chaired by the Deputy Prime Minister & Minister for Finance Heng Swee Keat to drive the growth and transformation of Singapore’s economy for the future.

G

Government Land Sales (GLS) Programme
The Government Land Sales (GLS) Programme releases State Land for development by private developers. The GLS Programme is an important mechanism for achieving key planning objectives in the long-term development of Singapore. Each GLS Programme is planned and announced every six months. The GLS comprises sites on the Confirmed List and Reserve List.

Government Technology Agency of Singapore (GovTech)
The Government Technology Agency is a statutory board under the Prime Minister's Office (PMO). It was restructured from the former Infocomm Development Authority of Singapore (IDA) in 2016 with the aim to strengthen its tech capabilities and increase the interconnectedness between various government networks.

Green Mark Gold Award
The Building and Construction Authority (BCA) Green Mark Award scheme was launched in 2005 and is an internationally recognised green building rating system tailored for the tropical climate. Depending on the level of building performance and Green Mark Score, the development will be eligible for certification under one of the ratings, namely BCA Green Mark Gold, GoldPLUS or Platinum.

H

Housing and Development Board (HDB)
The HDB is a Statutory Board under the Ministry for National Development. It is the primary agency in charge of resettlement and the provision of alternative public housing.

J

JTC Corporation

JTC Corporation (JTC) is the lead agency in Singapore to spearhead the planning, promotion and development of a dynamic industrial landscape. Since its inception in 1968, JTC has played a major role as the specialist agency tasked to spearhead the planning and development of industrial infrastructure for Singapore's economic development.

K

Kiasu

A term originated from Chinese, used to refer to a person "governed by self-interest, typically manifesting as a selfish, grasping attitude arising from a fear of missing out on something."

L

Land Transport Authority (LTA)

Formed in 1995, the LTA seeks to maximise the use of the road network, improve public transport and develop and implement policies to guide commuters to use the most appropriate transportation mode. The LTA designs and supervises the construction and maintenance of roads, operates traffic control systems, designs and constructs the MRT system and administers parking regulations.

M

Marina Barrage

The Marina Barrage is a dam built across the mouth of Marina Channel, creating Singapore's 15th reservoir and the first in the heart of the city. Completed in 2008, the project has since helped increase Singapore's water catchment from half to two-thirds of the country's land area. Besides providing a source of water supply and help with flood control, it is also a lifestyle attractive venue.

Mass Rapid Transit (MRT)

The MRT is a rapid transit system forming the major component of the railway system in Singapore, spanning the entire city-state. The initial section of the MRT, between Yio Chu Kang and Toa Payoh, opened on 7 November 1987, making it the second-oldest metro system in Southeast Asia, after Manila's LRT System. The network has since grown rapidly in accordance with Singapore's aim of developing a comprehensive rail network as the backbone of the public transport system in Singapore.

Ministry of Environment (ENV)

The Ministry of Environment was first formed in 1972 to tackle issues such as pollution control, sewerage, drainage and environmental health. The Ministry was renamed to what is known today as the Ministry of the Environment and Water Resources (MEWR) to better reflect the Ministry's role in managing water resources.

N

Ministry of Transport (MOT)

The Ministry of Transport overseas the air transport, land transport and sea transport sectors. It is responsible for the formulation of policies and facilitation of outcomes in the transport arena.

Nanyang Technological Institute (NTI)

Nanyang Technological Institute (NTI) was set up in 1981 on the grounds of the former Nanyang University to educate practice-oriented engineers for the burgeoning Singapore economy. In 1991, NTI merged with the National Institute of Education to form Nanyang Technological University (NTU).

Nanyang Technological University (NTU)

Nanyang Technological University (NTU) started out as a teaching university on 1 July 1991, which has today transformed into a research-intensive global university. Its predecessor institution was the Nanyang Technological Institute (NTI). NTU became autonomous in 2006 and is today one of the two largest public universities in Singapore.

National Environment Agency (NEA)

The NEA oversees the implementation of environmental policies. It was formed by the Ministry of the Environment in July 2002. The NEA has three divisions: Environmental Protection, Environmental Public Health and Meteorological Services.

National Parks Board (NParks)

NParks is a statutory board within the Ministry of National Development. NParks manages 1,763 hectares of parks, playgrounds, park connectors and open spaces; 3,326 hectares of nature reserves; and 4,200 hectares of roadside greenery and vacant state land. (Singapore: The Encyclopedia)

National Research Foundation (NRF)
The National Research Foundation (NRF) was set up on 1 January 2006, as a department within the Prime Minister's Office. The NRF sets the national direction for research and development (R&D) by developing policies, plans and strategies for research, innovation and enterprise. It also funds strategic initiatives and builds up R&D capabilities by nurturing research talent in Singapore.

NEWater
NEWater is a term coined by the PUB for high-grade reclaimed water that has been purified with advanced membrane and ultraviolet technologies. NEWater is ultra-clean; it has passed more than 30,000 scientific tests and surpasses the World Health Organization's requirements for safe drinking water.

P

Primary Production Department
The Primary Production Department (PPD) was formed in 1959 with the amalgamation of the agriculture, co-operatives, fisheries, rural development and veterinary divisions of the Ministry of National Development. The focus was to improve production by introducing new methods of farming and fishing. When agricultural land was greatly reduced by urbanisation in 1980s, the PPD turned its attention to high-tech farms as well as the management and inspection of imported food products. It was restructured into a statutory board and renamed the Agri-Food and Veterinary Authority (AVA) on 1 April 2000.

Public Utilities Board (PUB)
The PUB is the statutory board of the Ministry of the Environment and Water Resources responsible for ensuring a sustainable and efficient water supply. The PUB regulates and oversees Singapore's entire water supply system, which comprises the water catchment systems, drainage systems, water reclamation plants and sewage systems.

Public Works Department
The PWD had its genesis in 1833 with the appointment of George Coleman as superintendent of public works and convicts. Over the following century the PWD built roads, schools, amenities and many of Singapore's early iconic buildings, such as the Supreme Court. In 1999, the department was corporatised as PWD Corporation and in 2002 was renamed CPG Corporation.

S

Singapore Institute of Technology (SIT)
Established in 2009, the Singapore Institute of Technology (SIT) is a university set up for applied learning. It offers applied degree programmes targeted at growth sectors of the economy that integrates work and study.

Singapore Land Authority (SLA)
The SLA is a Statutory Board under the Ministry of Law. It is the land use and administration agency in charge of processing and assessing land acquisition proposals by public agencies. The SLA is now the primary agency responsible for administering the Land Acquisitions Act.

Singapore University of Social Sciences (SUSS)
The Singapore University of Social Sciences (SUSS) is Singapore's sixth autonomous university under the ambit of the Ministry of Education. It was renamed from SIM University (UniSim) as part of its restructuring in 2017.

Smart Nation Initiative
Prime Minister Lee Hsien Loong launched the Smart Nation Initiative in 2014 with the aim to harness infocomm technologies, networks and big data to create tech-enabled solutions to improve people's lives and create new economic opportunities.

U

University of Malaya
The University of Malaya was founded in 1949 with the merger of the King Edward VII College of Medicine (founded in 1905) and Raffles College (founded in 1928). The university was organised as two autonomous divisions on 15 January 1959, one located in Singapore and the other in Kuala Lumpur. In 1960, these two divisions became autonomous and separate national universities. The branch located in Singapore later became the National University of Singapore (NUS) after the independence of Singapore from Malaysia while the branch in Kuala Lumpur retained the name University of Malaya.

Urban Redevelopment Authority (URA)
The URA is an autonomous body, responsible for land planning and development control. It was created in 1974 to take over the functions of the Urban Renewal Department of the HDB. In 1989, the URA was made Singapore's national conservation and planning authority. It acts as a coordinator for redevelopment plans, integrating the development of transport into these plans, and implements policies arising from laws on land-use.

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Nanyang Technological University
PUB, Singapore's National Water Agency
Singapore Tourism Board
Urban Redevelopment Authority

Engineers as Urban Systems Innovators

How to harvest every drop of rainwater... How to make Changi Airport the world's best... How to make engineering education effectively multi-disciplinary... Singapore has overcome these and other development challenges.

One key reason for Singapore's success is a characteristic that the distinguished engineers featured in this book share—always taking a holistic, integrated approach to problem-solving, based on multi-disciplinary, collaborative teamwork. This made them urban systems innovators.

This book, a collaboration between the Professional Engineers Board and the Centre for Liveable Cities at the Ministry of National Development, captures their experiences and insights. The career highlights of Singapore's pioneer engineers—including Tan Gee Paw, Liew Mun Leong, Cham Tao Soon, Shahzad Nasim, Chang Meng Teng and Tan Ee Ping—illustrate key facets of the Singapore story, in the making of one of the world's most liveable cities.

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Engineers as Urban Systems Innovators