In collaboration with the China Academy of Information and Communications Technology (CAICT)

WORLD ECONOMIC FORUM

Digital Twin Cities: Key Insights and Recommendations

INSIGHT REPORT

AUGUST 2023

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Contents

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Foreword

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According to United Nations estimates, nearly 70% of the world's population will reside in cities by 2050. This represents an increase of roughly 2.5 billion urban residents.[1] Cities also generate more than 80% of worldwide GDP, according to the World Bank,[2] and this influence is only expected to grow in the years ahead. Effectively managing the growth of cities is critical to delivering on the United Nations Sustainable Development Goals.[3]

Since the first cities were formed thousands of years ago, innovations and technological developments have been essential to enabling their growth. Today, advances in data collection, cloud computing, the internet of things (IoT), geographic information systems (GIS), 3D modelling and artificial intelligence (AI) have unleashed new opportunities to reimagine and reshape cities through the use of "digital twins".

To better understand the potential of digital twin technology in cities, the World Economic Forum and China Academy of Information and Communication Technology (CAICT), together with key global stakeholders, launched a three-year initiative at the beginning of 2021 to identify and share global best practices and insights. A global advisory committee was created to evaluate promising applications of digital twin technology in cities and glean insights from these efforts. This publication builds on the 2022 *Digital Twin Cities: Framework and Global Practices* report,[4] highlighting early insights to help optimize the planning, design, development and use of digital twin platforms in cities.

Because the integration of digital twin technology into city planning and processes is still at an early stage, many questions remain regarding the financial sustainability and social and economic value associated with these complex, capital-intensive projects. The pioneering efforts showcased in this report offer a glimpse of the potential benefits of digital twin technologies while highlighting the need for further research, monitoring and evaluation. To help shape the development of these technologies and guide cities on how best to leverage these solutions, global collaboration is essential. This report aims to contribute to this multistakeholder dialogue and the shared quest for a more inclusive, safe, resilient and sustainable future.

Executive summary

Digital twin cities bring together the physical and digital worlds, enabling data-driven city management, intelligent services and interactive systems. They have the potential to transform cities into more intelligent entities, leading to high-quality urban development and sustainable growth.

This report provides a guide for city leaders considering the development of digital twin cities and insights for entrepreneurs and investors looking to shape the next generation of applications. It presents preliminary insights and recommendations for building high-quality digital twin cities that can help address pressing urban challenges.

The report emphasizes the need for multistakeholder collaboration, a sustainable operational framework, and a transformative socio-technical programme to deliver on the potential of digital twin city technology.

Through a framework referred to as the SODPA model, the report proposes a methodology, shares key insights and offers a set of recommendations for governments and businesses to drive the high-quality development of digital twin cities, centred on: (1) **S**trategy and talent development, (2) **O**peration and business, (3) **D**ata and infrastructure, (4) **P**latform and technology, and (5) **A**pplication and scenario.

Insights based on the SODPA model

Interviews and dialogues with experts, companies and researchers have led to the following insights into developing and using digital twin technologies.

Strategy and talent – Comprehensively review relevant policies, technologies and resources; develop a clear strategy yet a flexible developmental path; adopt a multistakeholder approach to public-private cooperation; set up key executive roles for digital transformation in the government; develop a talent cultivation system for digital twin technologies.

Operation and business – Clarify the roles of stakeholders to ensure public-private partnerships are sustainable; explore sustainable and innovative business models based on public-private partnerships; extract the value from data and capitalize on its value for sustainable business models.

Data and infrastructure – Strengthen the sensory control system and internet and computing infrastructure; ensure data integration and data quality.

Platform and technology – Build a sensory and video platform, twin city model visualization platform, data integration and service platform and open-source application platform.

Application and scenario – Ensure effective digital twin city and city governance; leverage digital twin city technology to enhance service delivery and advance sustainable development; promote strong public-private collaboration.

Recommendations for governments

- Jointly organize talent cultivation programmes with the private sector; establish chief technology officer and chief digital officer positions to support the city strategy; enact policies to incentivize talented individuals to move to the targeted areas; cultivate an environment that enables government-industry-academia cooperation and synergies for technologies.
- Create a value system with the private sector while clarifying each other's role.
- Ensure the extensive coverage of infrastructure; ensure individual privacy and data quality.
- Open up data access to application development; aggregate different businesses and skills into one platform.
- Explore gaps in demand; create incubation programmes.

Recommendations for businesses

- Establish a digital twin city industry fund; establish an industry coalition for policy formulation and technical support; nurture a localized industrial value chain; promote the integration of digital twin industry and traditional industry.
- Explore business models beyond the government tender system.
- Collaborate with the government on infrastructure building; comply with the local data and privacy regulations and laws.
- Deepen inter-industry skill and technology sharing; encourage the development and the opening up of the platform as a service.
- Develop tailored applications to help the government solve problems; develop tailored applications to help citizens.

This approach aims to facilitate a connected digital twin city environment capable of delivering improved outcomes for individuals, society and the environment as a whole. The report also identifies data integration and open-source application platforms as fundamental tools for strengthening urban governance and public service delivery.

1 Why shared learning is crucial

China's digital twin city market size will reach **$17.3** billion by 2025

The digital twin city market is booming. According to Marketsandmarkets, the global digital twin market will reach $48.2 billion by 2026.[5] According to iResearch Consulting Group, China's digital twin city market size was $5.1 billion in 2022 and will reach $17.3 billion by 2025.[6] Despite growing interest, the digital twin city concept is still in the early stages of development, with many ongoing digital twin city projects still in the concept and planning phases. There is a lack of understanding of the digital twin city concept and a lack of consensus on the exact path to develop related technologies, platforms, data governance structures, and talent and business models.

Those constructing a digital twin city regularly face four main challenges: increasingly complex urban development needs; rapid technological development; investment uncertainty and risk; and protracted construction processes. This report highlights possible solutions to each of the challenges.

1.1 Increasingly complex urban development needs

As cities grow and evolve, they face increasingly complex challenges that span various fields. Urban planning, management, investment and services will become inseparable from a confluence of factors such as transportation, the physical environment, natural resources, public security, public services, and social security. Issues such as traffic congestion, environmental pollution, resource depletion, and social and public security hinder urban development. Therefore, promoting the development of urban infrastructure, public services, urban beautification, culture and education is crucial to sustainable urban growth.

1.2 Rapid technological development

Digital twin technology comprises various sub-branches, such as the internet of things (IoT), artificial intelligence, big data, 3D modelling, and blockchain. With new related technologies emerging frequently, there is potential for them to be integrated into digital twin development. However, implementing technology into city development can be time-consuming and rely on establishing legal frameworks and technical standards. Unfortunately, the development of such frameworks and standards is not consistent worldwide.

1.3 Investment uncertainty and risk

Developing digital twin cities demands significant investment, primarily to foster the creation of digital infrastructure, such as data centres, big data collection equipment, intelligent sensors, and IoT devices. Further, improving 3D modelling technology requires substantial financial input.

Additionally, there is a continuous need for financial investment to maintain the technological application of digital twin technology, including in scenarios like urban planning, traffic management and smart city management. Both public and private sector investments are crucial to fostering innovation.

1.4 Protracted construction processes

Like the saying, “Rome was not built in a day,” the construction of digital twin cities is a protracted process. Achieving seamless integration between the physical and virtual worlds requires a long construction cycle. The primary challenges of this process include ensuring the security of collected data, protecting privacy, establishing a fair and transparent digital governance system, and effectively responding to contingencies. Additionally, digital city construction must balance economic efficiency and social responsibility, with a goal of human-centred and sustainable development.

To address the challenges mentioned earlier, this guide provides direction and guidance for governments and businesses in the process of constructing digital twin cities. This is achieved by dividing the process into five distinct elements and spelling out the implication for each element in the SODPA model: **S**trategy and talent, **O**peration and business, **D**ata and infrastructure, **P**latform and technology, and **A**pplication and scenario.

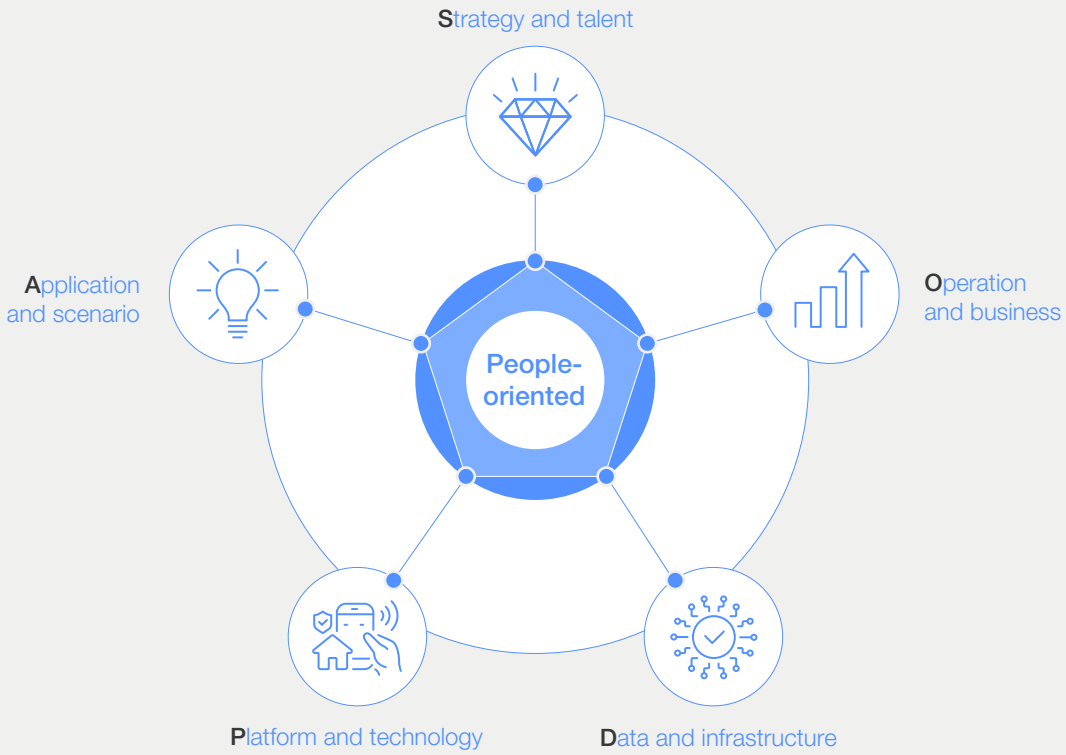
2 Key insights

This report is designed to help promote the development of digital twin cities. To accommodate regions with different social and economic development levels, the guide distils the construction process into common goals and models that can be applied to various areas, including large cities, small and medium-sized cities, parks and urban functional areas.

2.1 The SODPA model

The SODPA model results from multiple rounds of expert dialogues, extensive fieldwork, and detailed inquiries into the vision and future potential paths of both the demand and supply sides of digital twin technologies. It is a methodology for guiding the conception of a high-quality digital twin city. It is based on the "4+5" framework (see details in the *Digital Twin Cities: Framework and Global Practices* report – available in English and Chinese[7]). The model offers a comprehensive answer to the question: What are the foundational building blocks of a high-quality digital twin city?

FIGURE 1 **The SODPA model**



People are at the core of the SODPA model. The underlying rationale of a digital twin city should be addressing human-centred needs, while its goal should be the improvement of people's welfare.[8]

The SODPA model comprises **five building blocks** of a digital twin city:

1. Strategy and talent are the bedrock of digital twin projects. Strategy sets the vision and direction for a digital twin project and talent is the foundational driver of the construction, management and operation of the digital twin city.

2. Operation and business underpin the long-term sustainability of a digital twin city. Only through innovative and practical business models and operational models can the digital twin city deliver both social and economic returns.

3. Data and infrastructure are two instrumental inputs of a high-quality digital twin city. They are the content of a digital twin city and enable people and nature to flourish.

4. Platform and technology are the engines of a digital twin city. They provide a technical framework and digital environment for modelling, simulation and the applications of related technologies.

5. Application and scenario are where the value of a digital twin city is released and made tangible on the ground. Through specific use cases, governments, businesses and citizens benefit from the digital twin city.

2.2 The concept of a digital twin object

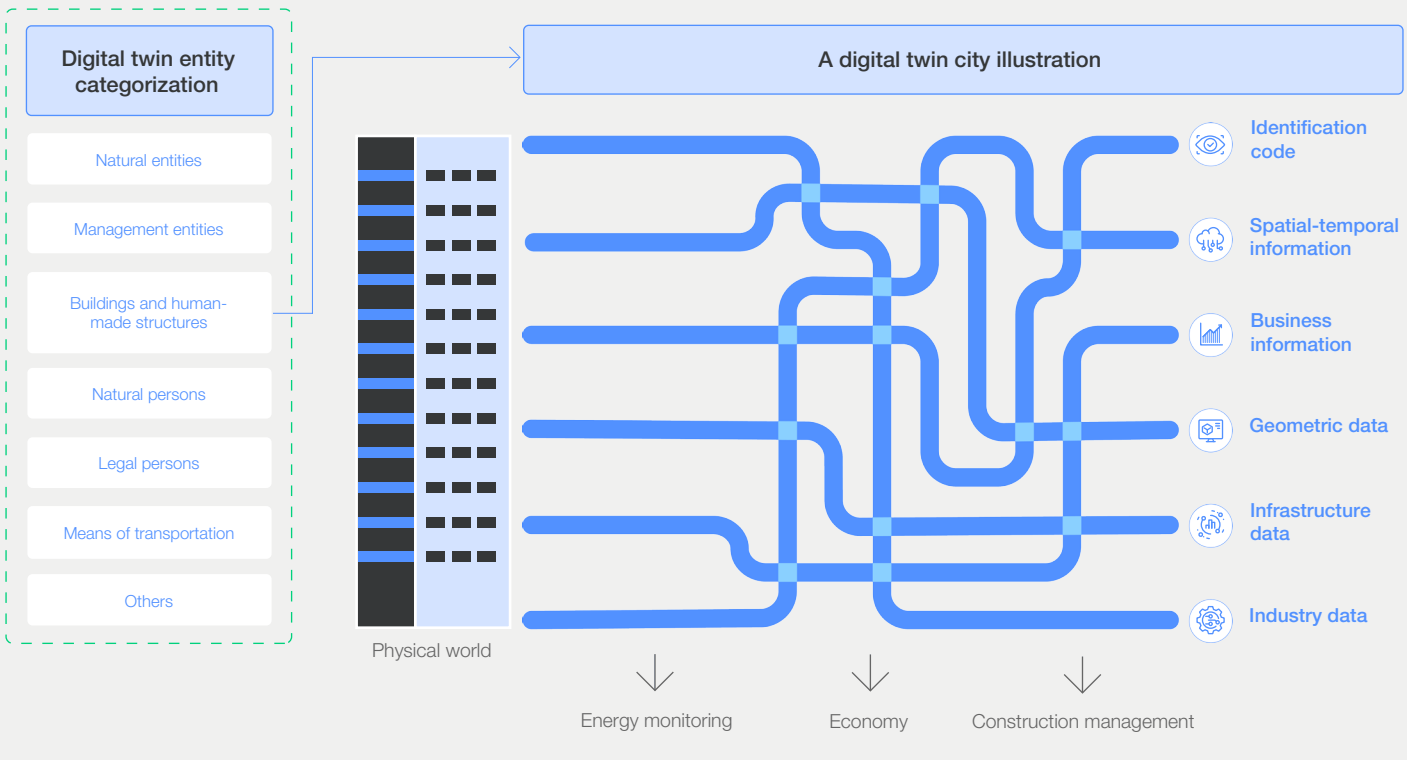
The China Academy of Information and Communication Technology (CAICT) originally conceived the concept of a digital twin object after conducting extensive interviews and dialogues with experts, companies and researchers. A Digital Twin City is a virtual digital model that corresponds to physical objects in the real world. This innovative concept represents a significant advancement in data creation, management and organization. It has two distinct characteristics:

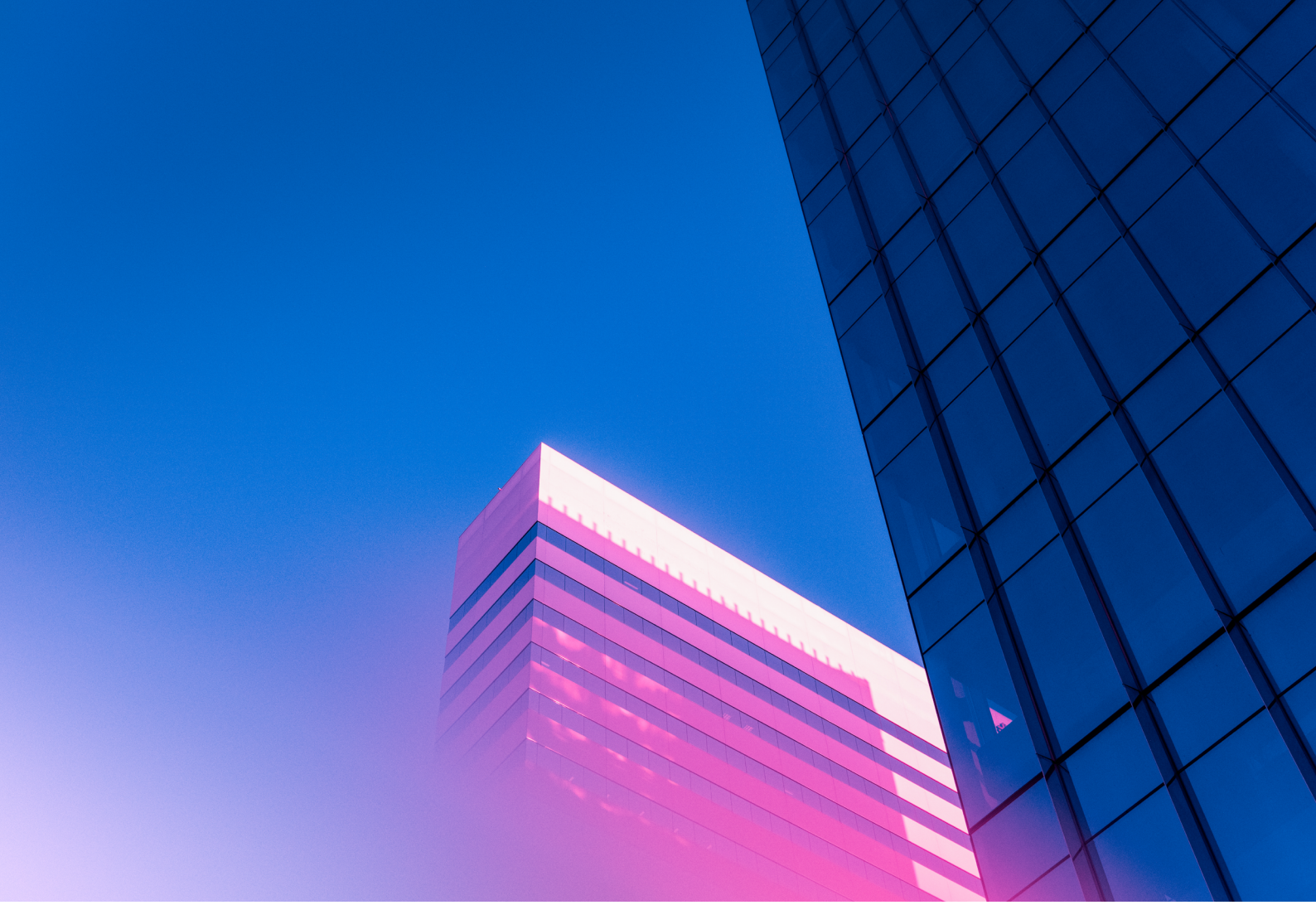
1. A digital twin treats distinct entity objects in the physical world as fundamental data units, combining both static information (such as geometric data and object appearance) and dynamic data (such as live commercial and sensory data).

2. The digital twin can integrate data from diverse industries and sectors, providing more comprehensive and effective data support for urban operations and public services.

CAICT has also created a classification system that divides all digital entities of a digital twin into eight categories: natural persons, legal persons (e.g. government departments, businesses, social organizations, etc.), natural entities (e.g. mountains, rivers, oceans, etc.), management entities (e.g. cities, towns, development zones, etc.), buildings and human-made structures (such as office buildings, residential buildings, pylons, sculptures, etc.), means of transportation, goods and equipment, and others. Each type of digital entity is represented by several layers of data points, including identification codes, spatial-temporal locations, geometric appearance, and status. These entities can be visualized as 3D models. The digital twin also serves as a platform for the development of various types of applications that can empower the government and businesses to provide personalized services and products.

FIGURE 2 **Illustration of a digital twin city**





2.3 Strategy and talent

Strategy refers to the macroeconomic guidance, vision, implementation blueprint and developmental directions of digital twin cities. Talent represents people who undertake the digital twin project and their skills. Simultaneously, strategy formulation and talent cultivation must complement each other to elevate the quality and standard of the digital twin city.

Insight #1: Comprehensively review the relevant policies, technologies and resources

Thorough research plays a critical role in the development of digital twin cities. The success of such cities hinges on the policy environment, including urban planning, data policies, fiscal policies, and industry standards. Conducting in-depth research on the policy environment can reveal the direction, focus and limitations of existing policies, which in turn guides the planning and implementation of digital twin cities. Additionally, the construction of digital twin cities requires advanced technology. In-depth research into the technological landscape can help identify the direction of development, state of technological application, and technical bottlenecks, facilitating optimal technology selection. Finally, constructing digital twin cities requires substantial capital in the form of talent, financial resources and physical assets. A comprehensive review of existing resources can aid in resource allocation and risk management.

Insight #2: Develop a clear strategy yet a flexible developmental path

To ensure the success of digital twin city construction, it is advised that the project establish clear goals and plans upfront. These goals and plans must be informed by extensive and intensive research. Given the significant initial investment and long construction cycle, it is beneficial to prioritize industries and scenarios that can be developed within a short-term timeframe of 3-5 years, thereby enhancing project financial feasibility and investment appeals. However, due to the large-scale complexity of cities and the rapid pace of technological change, it is important to maintain a flexible and inclusive construction framework and implementation path for the medium to long term (5-10 years) to respond to unforeseeable future challenges effectively.

CASE STUDY 1

Strategy setting for the digital twin park in Suzhou industrial zone

Considering the strong demand for digital twin technologies in urban planning, urban management, public safety and ecological conservation, Suzhou Industrial Park decided to learn from domestic and foreign best practices to build a first-class digital twin park.

CAICT, in collaboration with Suzhou industrial park, developed a strategy for constructing the digital twin park. The strategy is called DESIP:

D – digital asset – the management the operation of digital assets

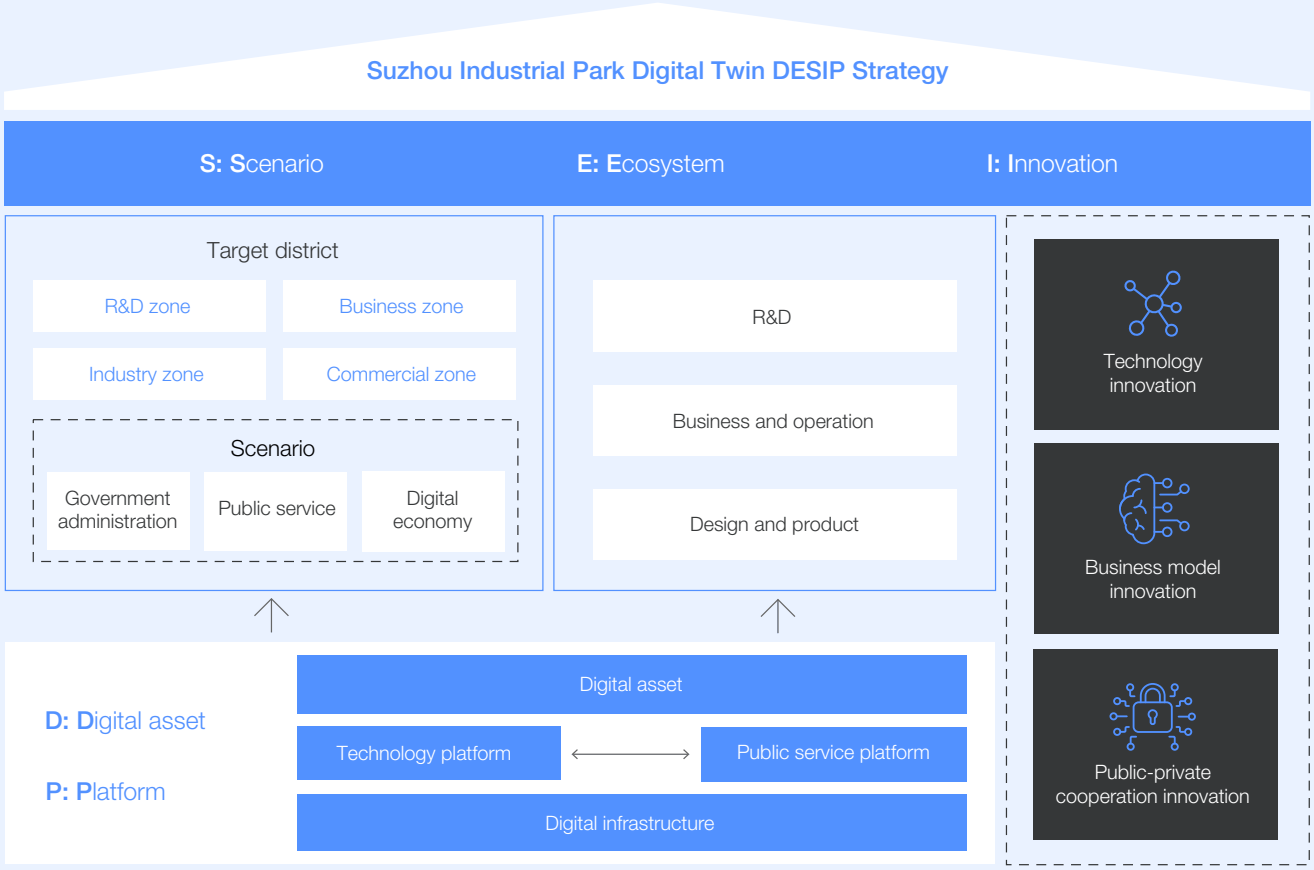
E – ecosystem – the goal of creating a value chain within the digital twin city

S – Scenario – empowers the application of digital twin technology for the benefit of citizens

I – Innovation – the technological basis of a digital twin city

P – Platform – providing ecological enterprises with enabling technologies, patent navigation, resource docking and other services

FIGURE 3 | **Suzhou Industrial Park Digital Twin Strategy overview**



Source: Suzhou Industrial Park Digital Twin Innovation Workshop display.

Insight #3: Adopt a multistakeholder approach to public-private cooperation

To construct a digital twin city, it is imperative to foster collaboration among multiple stakeholders, including government, businesses, society and inhabitants. This collaborative effort is necessary to balance public interests and business needs, thereby promoting sustainable urban development. A people-centric approach that prioritizes social values and business interests is crucial to achieving this goal. In areas where the government has greater management authority (such as urban public services), city managers can demonstrate the value of digital government by pioneering or piloting strategic projects. For scenarios involving greater participation from businesses, the government must formulate clear market policies that create a favourable business environment and enhance long-term industrial competitiveness. In adopting these strategies, constructing a digital twin city can serve all stakeholders' interests and promote sustainable urban development.

CASE STUDY 2

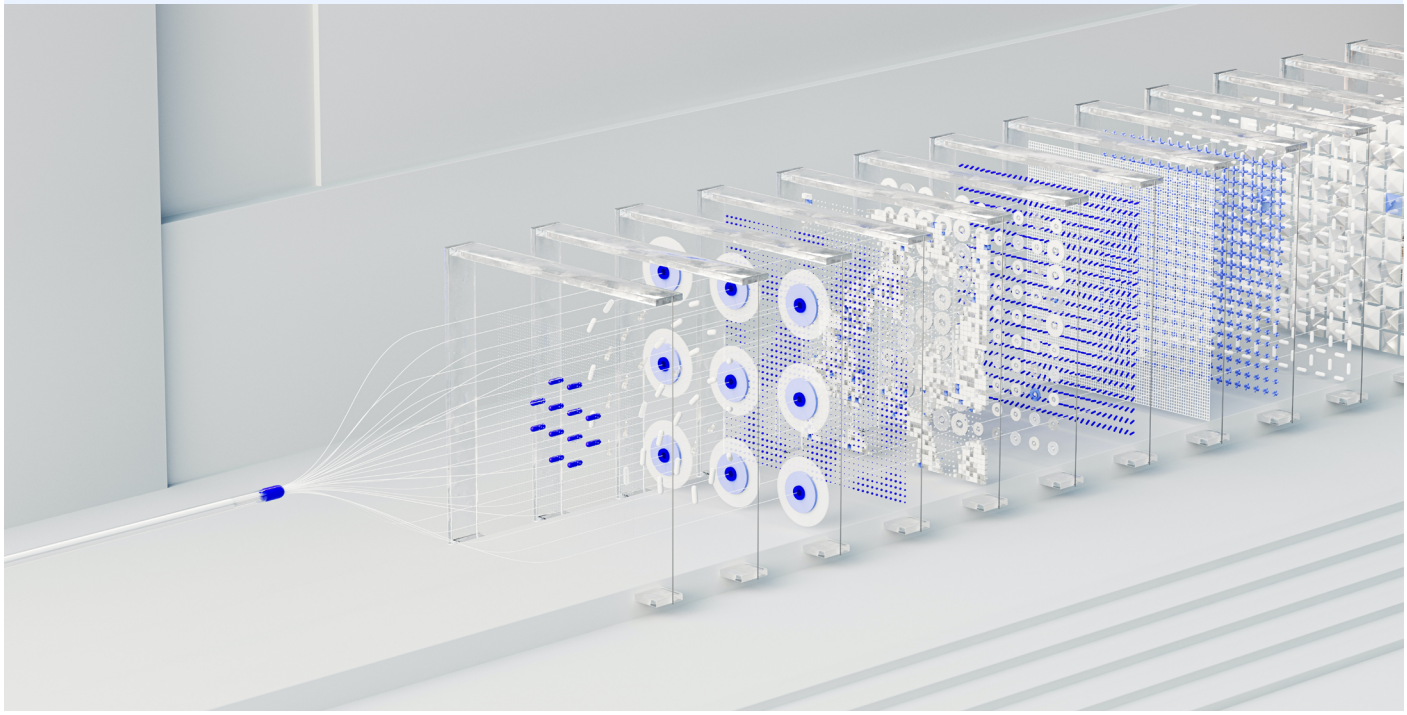
United Kingdom's National Digital Twin Strategy

The United Kingdom's National Digital Twin Principles, released by the Centre for Digital Built Britain, proposes a roadmap for building national-level digital twins based on an information management framework and summarizes nine principles to guide the development and application of national-level digital twins.[9] It focuses on the quality and accuracy of the digital twin model, the protection of sensitive information, the interoperability of the digital twin with other systems, and the sustainable development of the information society. This strategic deployment has integrated relatively independent information technology standards from various industries within the United Kingdom, unlocked the value of data resources, enlivened the participation of various stakeholders from government, academia and industry, and promoted the development and application of digital twin technology in the United Kingdom.

FIGURE 4 | **The United Kingdom's National Digital Twin Strategy**

Purpose Must have a clear purpose	Public good Must be used to deliver genuine public benefit in perpetuity	Value creation Must enable value creation and performance improvement	Insight Must provide determinable insight into the built environment
Trust Must be trustworthy	Security Must enable security and be secure itself	Openness Must be as open as possible	Quality Must be built on data of an appropriate quality
Function Must function effectively	Federation Must be based on a standard connected environment	Curation Must have clear ownership, governance and regulation	Evolution Must be able to adapt as technology and society evolve

Source: Schooling, J., n.d.[10]



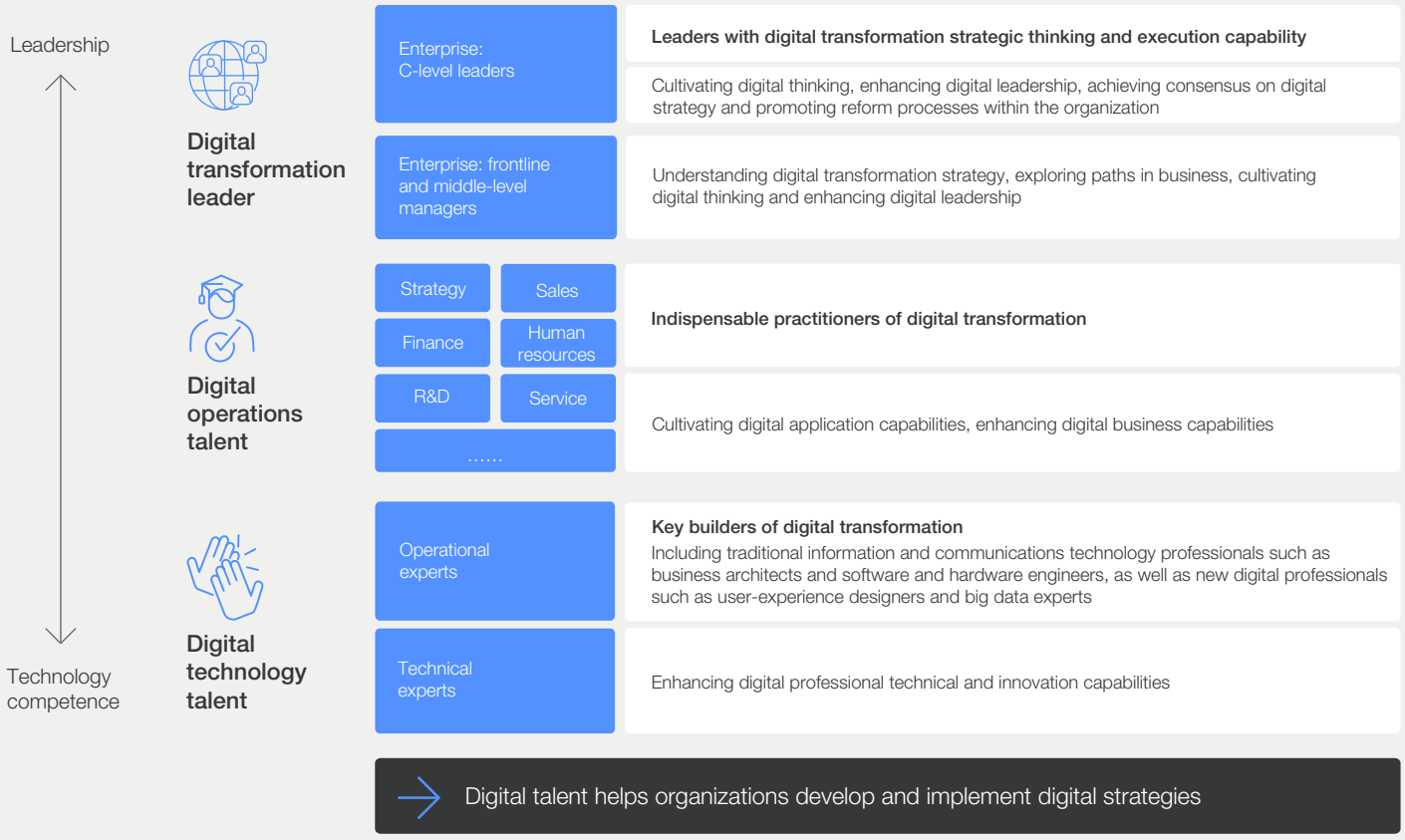
Insight #4: Set up key executive roles for digital transformation in the government

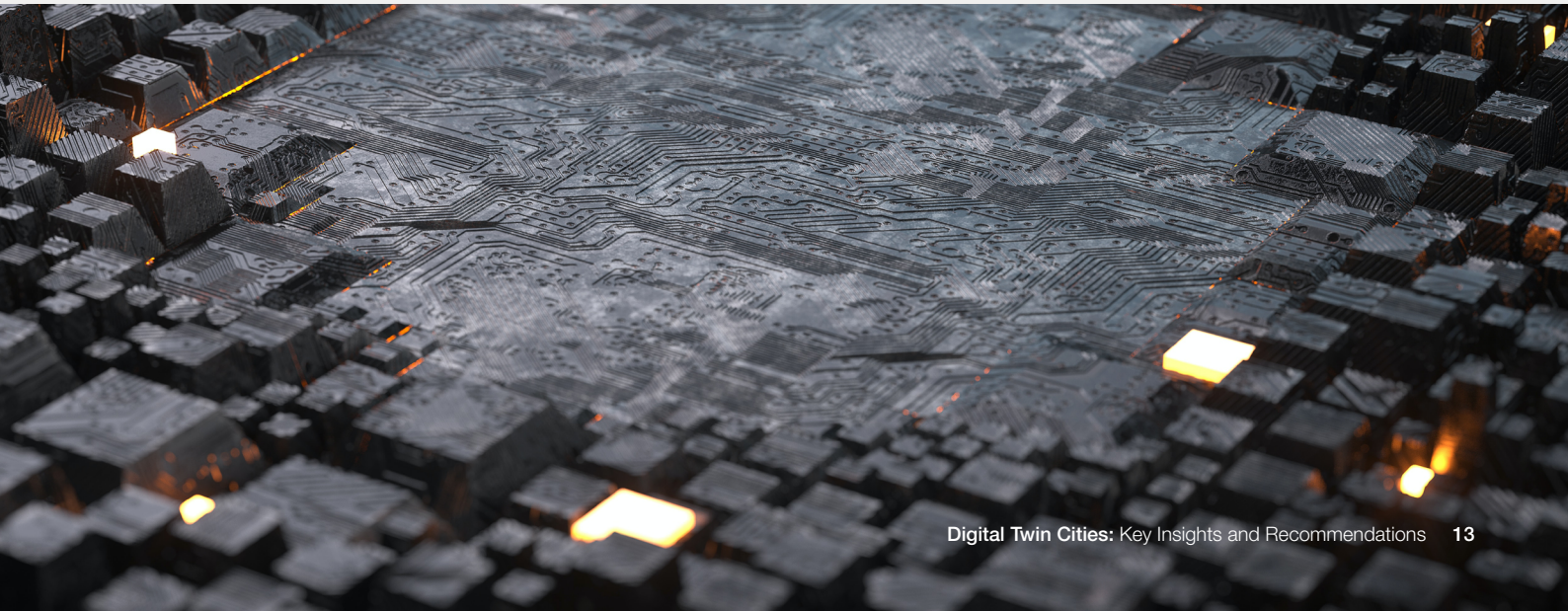
To promote the digital transformation of cities, the government should restructure its organizations and establish key positions responsible for digitalization, such as a chief information officer (CIO) and a chief digital officer (CDO). These city-level positions should be responsible for formulating the city's digital development strategies and plans, promoting innovative applications of city data, fostering the city's data security systems, leading collaboration between city departments and subsidiary units, and improving the data literacy of city residents.

In addition, city CIOs/CDOs must actively explore and test new technologies in different scenarios, such as city management and services. They should also coordinate information sharing and platform interoperability among various departments and units, promoting the integration and efficient utilization of collected data.

Therefore, city-level CIOs/CDOs need to have deep technical knowledge and strong managerial capabilities. They must also pay attention to the city's socio-economic development and public service needs to create a better living environment and service experience for city residents. Figure 5 illustrates the typical role of a CIO/CDO.

FIGURE 5 **Definitions of digital transformation roles within an organization**

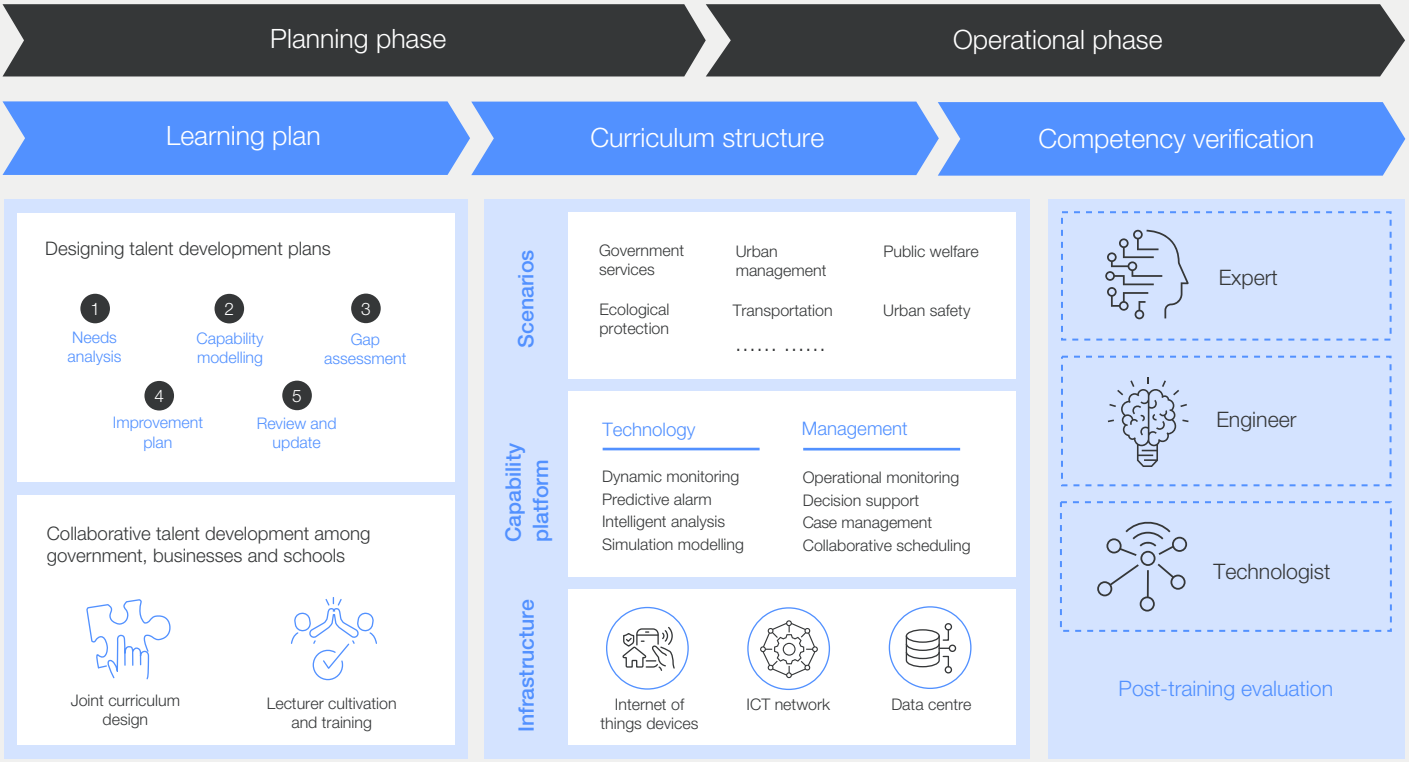




Insight #5: Develop a talent cultivation system for digital twin technologies

Building digital twin cities requires a diverse range of interdisciplinary professionals with expertise in computer science, data analysis, architectural design, urban planning, environmental science, sociology and demography. Cultivating these professionals and these sorts of talent will require sustained investment over a prolonged period. Policy-makers must focus on talent training and certification and career advancement. This may entail collaborating with colleges, universities, professional training institutions, and businesses to establish a Digital Twin Talent Service System that provides top-notch, sustainable training services and work opportunities. Such an approach ensures a continuous supply of high-quality professionals throughout the construction, operation and maintenance phases of digital twin cities. Figure 6 provides a typical case of the talent system model in the Chinese context.

FIGURE 6 **Digital twin city talent cultivation model**



Resources and toolkit

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2.4 Operation and business

The sustainable development of digital twin cities requires the active involvement of businesses. Therefore, public-private partnerships must be actively promoted and a suitable business model must be designed. This business operation model can be based on providing digital urban infrastructure, digital public services, and digital residence services to governments, businesses, and inhabitants. Additionally, an effective risk assessment method is required to identify potential risks in a timely manner, thereby reducing investment risks and the possibility of financial loss.

Thus, constructing a digital twin city is a complex process involving high initial capital input and carries risks and uncertainty regarding long-term returns. Both city managers and business leaders need to collaborate in a manner that respects economic principles and market rules to achieve a win-win situation.

Most business models generate externalities (such as environmental pollution and urban noise) that the market cannot manage alone. In this scenario, the government should take measures to address them, such as enacting environmental protection laws and regulations, implementing environmental taxes, and establishing public service facilities.

Insight #1: Clarify the roles of stakeholders to ensure public-private partnerships are sustainable

The successful construction and operation of digital twin cities requires a high level of collaboration among various stakeholders, including governments, investors, construction and operation companies, and users. The functions and responsibilities of each participant must be clearly defined to ensure a smooth construction process.

The **government** plays a critical role in providing strategic guidance and enacting appropriate regulations and policies. By working closely with other stakeholders, the government must encourage their active participation in ensuring that the construction of the digital twin city proceeds in an orderly fashion.

Building and operating companies are responsible for providing the necessary services and products required to develop the digital twin city. Their primary motivation may be to generate profits, but their profit-seeking behaviours must be compatible with the broad construction strategy for the digital twin city and they must comply with relevant regulations and legislation.

The financing of digital twin city construction can take several forms, ranging from direct government investment and commercial credit to venture capital and personal investments. The specific configuration of financing will directly affect the efficiency of resource allocation for the project. Since different **investors** have varying investment expectations and goals, it is essential to ensure that investments work together to generate synergy and provide benefits to all those involved.

Users, including government entities, businesses and residents, are the heart of a digital twin city. Therefore, they must be a key consideration in designing the business and operational models for such cities. For instance, a business model must prioritize user satisfaction, respect human privacy, and ensure data security to deliver intrinsic value to its users.

CASE STUDY 3

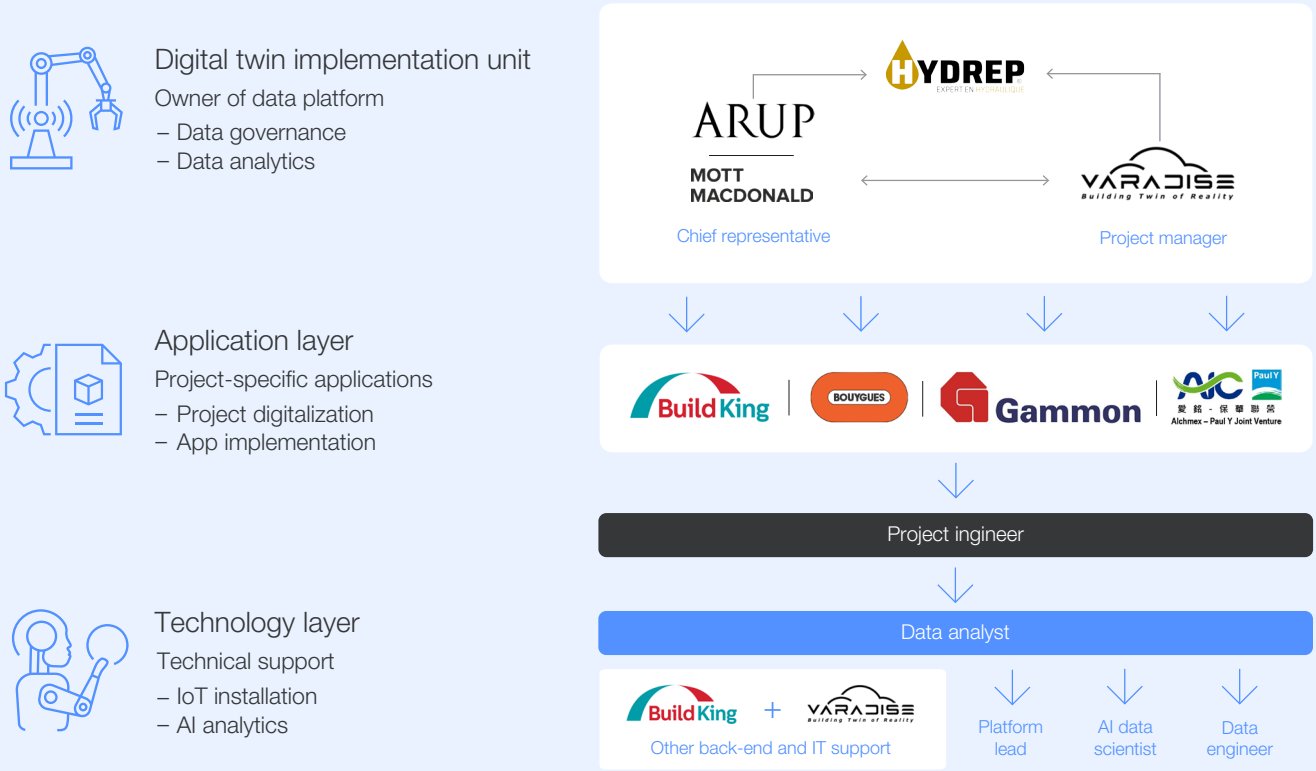
Tung Chung New Town Expansion Digital Twin Project (Hong Kong SAR)

The Tung Chung New Town Extension represents the first pilot project for a smart, low-carbon community on Lantau Island. In terms of organizational structure, this project is divided into three tiers. The first tier is the digital twin operation team, which consists of the Hong Kong Highways Department, Varadise, ARUP, and Mott MacDonald in a public-private (government-business) collaboration style. Their primary responsibility is data governance and data analysis.

The second tier is the application development tier, which includes four organizations: Build King, Gammon, Bouygues, Alchmex and Paul Y Joint Venture, which collaborate on digitization projects and application development.

The third tier is the technical support layer, where Varadise provides technologies such as internet of things (IoT) installation and artificial intelligence (AI) analysis. The clear commercial framework and relationship of authority and responsibility for the new city of Tung Chung have greatly motivated businesses to participate in the city's construction. This approach avoids internal conflicts and ensures healthy and sustainable construction progress.

FIGURE 7 | **Organizational structure of the Tung Chung New Town Expansion Project, Hong Kong**



Source: Digital Twins in Tung Chung New Town Extension, Hong Kong

Insight #2: Explore sustainable and innovative business models based on public-private partnerships

Constructing digital twin cities is a prolonged process that entails high investment, risks and uncertainties. The sustainable construction of digital twin cities relies on the strong coordination capabilities of city managers and the advanced technical expertise of participating companies. In countries such as China, the government plays a primary role in urban public governance. Thus, most of these regions have adopted a digital twin city construction model where the government leads the initiative while encouraging the private sector to participate. All parties share the revenue generated on a pro-rata basis. The facilities and platforms built through digital twin technology provide the government and businesses with a centralized monitoring system, assistance in decision-making, investment services, and other operation and maintenance capabilities.

CASE STUDY 4

Shenzhen Bay Technological Ecology Park – Energy Cloud

For the initial investment, the Shenzhen Bay Technological Ecology Park was entirely built by the Shenzhen Municipal Government. However, through an equity model, other investors can become shareholders of the industrial park by purchasing shares. The park has attracted numerous high-profile businesses, such as Huawei, Tencent, and ZTE, to settle in the area. These businesses generated a total business income of CNY214.9 billion in 2022 and a total profit of CNY27.9 billion.

To reduce costs and improve efficiency, Shenzhen Bay Technological Ecology Park has developed a digital "energy cloud" system that enables the visualization and tracking of the park's energy consumption. By optimizing and adjusting energy consumption, the park's operators can ensure its environmental sustainability. Thanks to the energy cloud platform, electricity consumption has been reduced by approximately CNY3.25 million per year.

FIGURE 8 | **Illustration of the operation of Shenzhen Bay Technological Ecology Park**

Source: Shenzhen Bay Technological Ecology Park Project

Insight #3: Extract the value from data and capitalize on its value for sustainable business models

The digital twin city is a platform where data has a large potential value and many opportunities exist for data-driven innovations. The government can accumulate a large amount of valuable data through the use of sensory infrastructure and other data collection platforms and can open up the data to attract more investment.

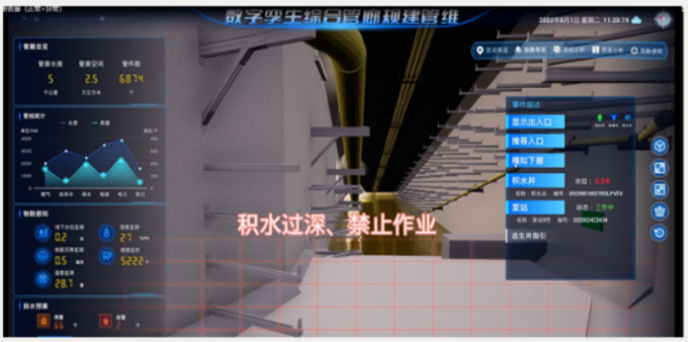
The government can actively promote innovative policies and regulations to encourage and regulate the use of public data resources by businesses and society. Businesses and the government can then jointly explore innovative scenarios in public services to design sustainable business models.

The Lingang District in Shanghai, China is a prime example of this approach. During the construction of its digital twin city, the region amassed a vast amount of data, including a region-wide 2D base map, a hierarchical 3D model of the area, and a digital layout of the underground pipeline system. The Urban Public Affairs Department partnered with businesses to construct a comprehensive underground pipe digital twin, which included numerous infrastructure elements such as electric power cables, water supply systems, sewage pipes and communication lines. Many IoT devices were installed underground to enable the real-time monitoring of the system and robots were dispatched to resolve issues as they arose.

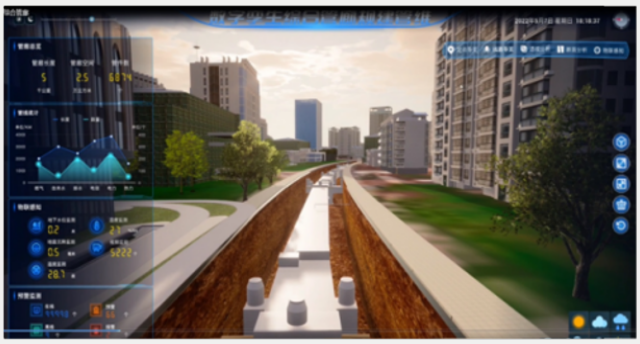
This business model improved the efficiency and safety of public services for the government while generating profits for businesses and refining their technology.

The value of data can also be material to the field of financial innovation. Blockchain can map financial assets to digital assets in the digital twin city. As such, financial institutions can work with digital assets instead of interacting with tangible assets in the real world. For instance, the financial institution will have instantaneous access to detailed real-time information on the status of insured assets through the digital twin platform, allowing for seamless risk monitoring. Applications such as these can be found in other financial services and they reduce the information asymmetry and transaction costs typically encountered in traditional financial service provisions.

FIGURE 9 | **Illustration of the Lingang District in Shanghai, China**



管廊积水处置预案模拟



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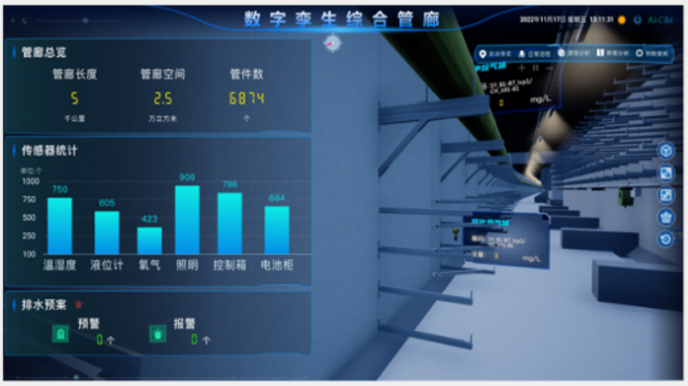

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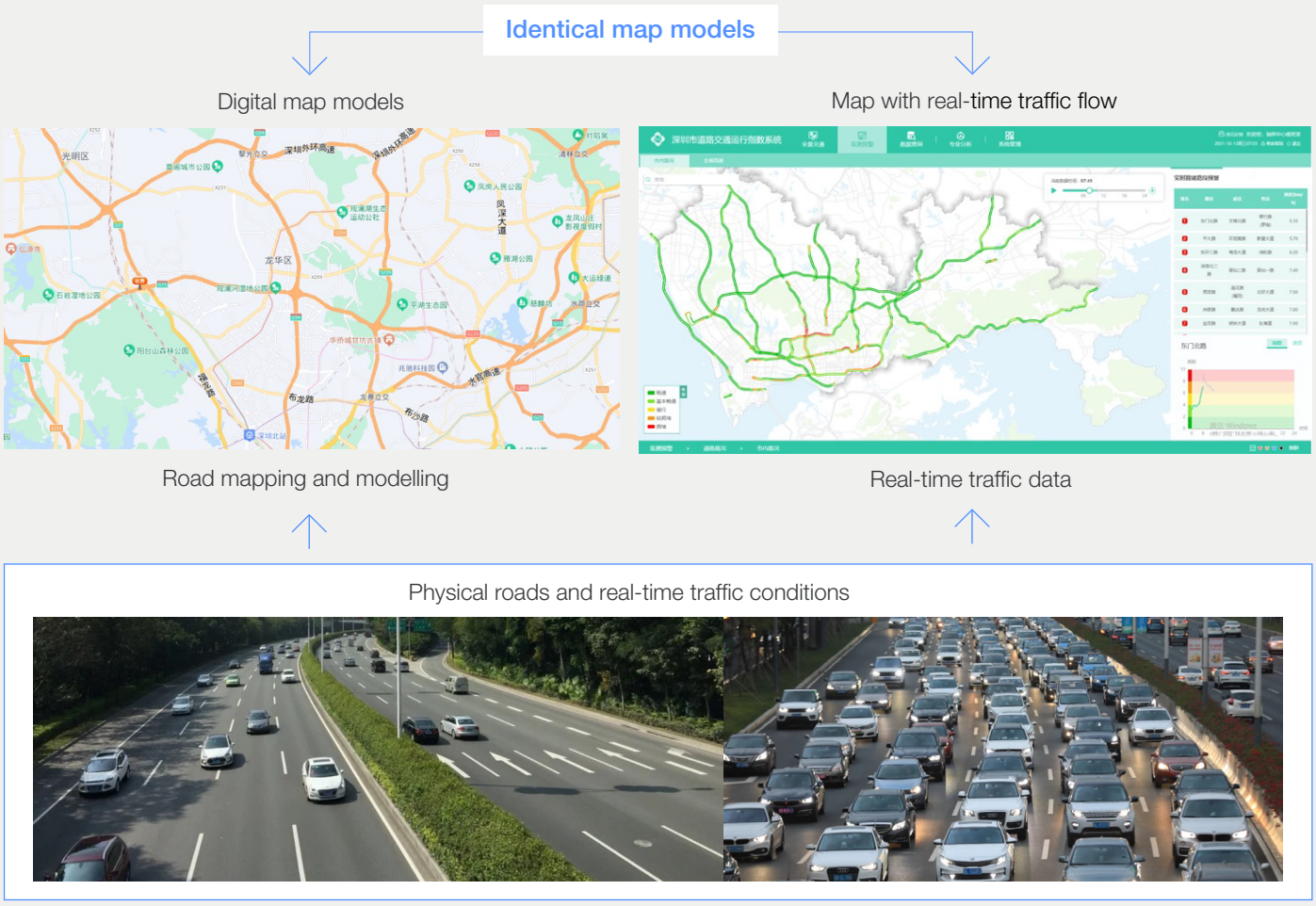
2.5 Data and infrastructure

Data and infrastructure lie at the foundation of a functional digital twin city. Infrastructure – such as sensory devices, network facilities, and computing infrastructure – can be likened to the neural network of a digital twin city. Its coverage and reach are the precondition upon which a digital twin city operates. On the other hand, data makes up the "neurons" of the digital twin city, transmitting information that can be ultimately aggregated and analysed to bring about various value-added services and products.

Insight #1: Strengthen the sensory control system

The installation of smart sensors is necessary for monitoring the status of various city elements, such as water quality, traffic conditions, energy, pedestrian safety and road maintenance. For example, digital mapping technologies such as geographic information systems (GIS) can create a virtual map of the city's transport network. Traffic sensors and cameras on roads and intersections help collect real-time traffic and pedestrian information. Once the information is overlapped with the GIS data, a digital twin of the transport system is created. This digital twin system empowers value-added functions such as route planning, traffic prediction and evacuations. Figure 9 illustrates a typical case where sensory infrastructure can be set up to capture real-time traffic information and how this information is rendered digitally on a 2D map.

FIGURE 10 **Illustration of a transportation digital twin body**



Insight #2: Strengthen internet and computing infrastructure

Strengthening the reach and stability of internet connections in all corners of the urban area – such as by installing supporting infrastructure like fibre optic cables and 5G network stations and building cloud and computing infrastructure to improve the city's computing capacity and data analysis efficiency – supports large-scale data processing and real-time simulation, analysis and intervention.

CASE STUDY 5

Shanghai Lingang Digital Twin Project

The Shanghai Pudong Lingang area leveraged existing building information modelling (BIM)/GIS and other big data technologies and platforms to construct a digital twin port. In terms of infrastructure, the whole region covers 12 types of sensors across different functional regions, including smart parks, public facilities, municipalities, roads and communities. These sensors upload approximately 140,000 data points daily. For the city centre, which spreads over a 70-square-kilometre area, drones were used to map the area and supplemented by AI and other digital tools to help monitor and manage of garbage dumping and traffic flows.

FIGURE 11 | **Control centre of the Shanghai Lingang Digital Twin Project**

Source: Shanghai Lingang Digital Twin Project Demonstration

Insight #3: Ensure data integration and data quality

Data collected from the digital twin city must be integrated with data from other sources, including socioeconomic and spatial data. This ensures that the digital twin city is not an amalgamation of data but a dynamic and digital replication of the city. There may also be opportunities to connect together different digital twin cities to enable more holistic views and collaboration across regions.

CASE STUDY 6

Chicago Smart City Digital Twin project

The City of Chicago partnered with IBM to establish the Smart City Digital Twin project. It was aimed at improving the efficiency of city management and raising the living standards of its residents. Since then, a large amount of high-quality data has been collected, which is useful in areas including public transportation, buildings, the physical environment, and social security.

AT&T has undertaken a massive data-driven infrastructure overhaul and installation programme, after which the IoT sensors throughout the city will be intertwined to form an ecosystem. This system will provide the city with a wealth of data that will enable smarter solutions to improve the quality of life.

In addition, the city of Chicago has also opened up access to its database. This enables residents to find any available information they might need about their neighbourhoods and localities.

FIGURE 12 | **Chicago's IoT-based Smart City Digital Twin Project**

Source: Array of Things, *Array of Things Ten-Year Symposium Report*, 2022, https://arrayofthings.github.io/AoT-10yr-Symposium-Handout.pdf.

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2.6 Platform and technology

The platform and the technology are analogous to the brain and nervous system of a digital twin city, collecting all kinds of data about the city and transforming the data into valuable information. These technologies and platforms can support the multifaceted needs of cities, such as the remote management of urban smart facilities and equipment, visual representation and simulations of buildings, roads and traffic flow, and real-time analysis of the status of a city's various elements. Four platforms are essential to a digital twin city: a sensory and video platform, a twin city model visualization platform, a data integration and service platform, and an open-source application platform.

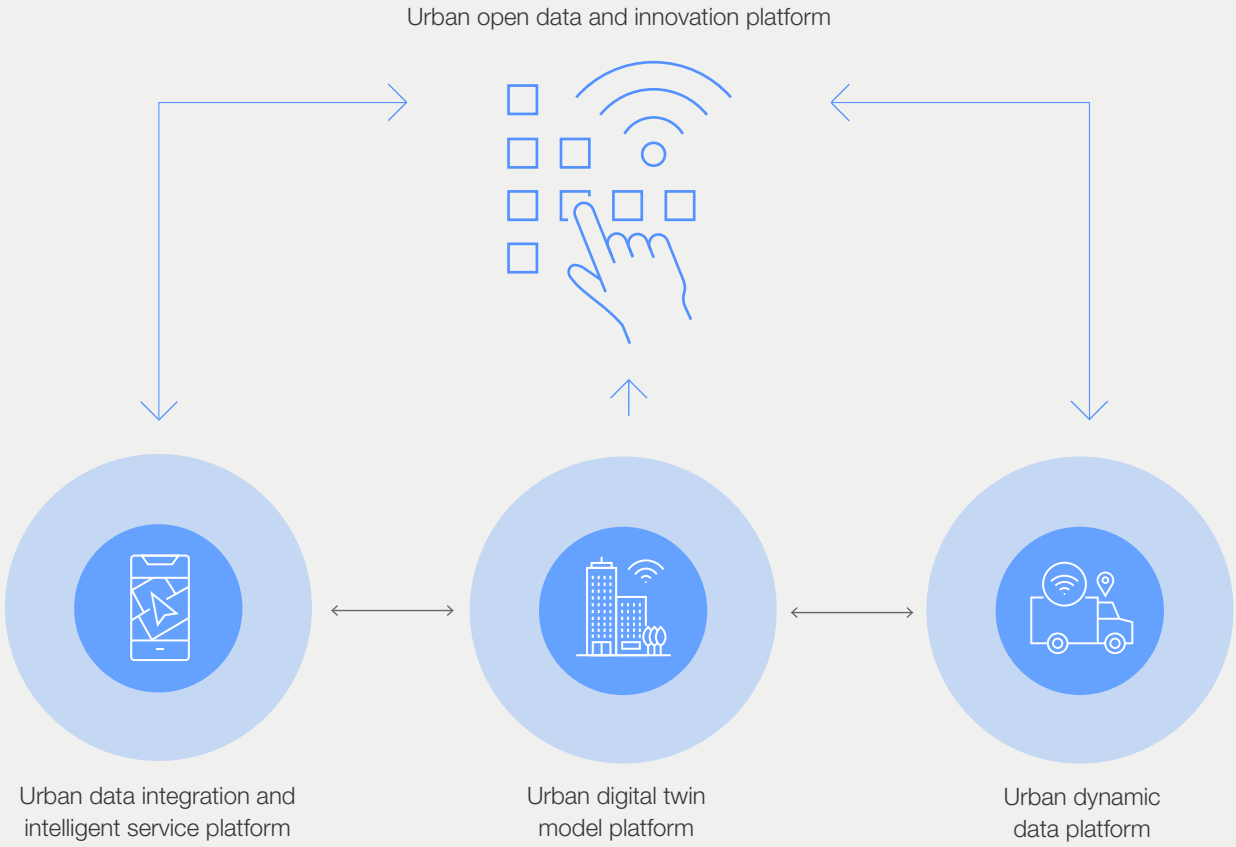
Insight #1: Build a sensory and video platform

By establishing a sensory and video platform, cities can obtain dynamic data from various types of IoT sensory terminals, including information on water, electricity, gas, transportation, environmental protection, public security and meteorology. Such data can provide rich indicators that help administrators with decisions. The video monitoring platform enables administrators to seamlessly integrate data with videos.

Insight #2: Build a twin city model visualization platform

Using modelling techniques such as tilt photography and manual drawing to build a 3D model basis for all types of physical elements within a city, including buildings, natural landscapes, roads, bridges, underground pipeline networks, vehicles, facilities and infrastructure, constitutes the basis of the twin city model visualization platform. In addition, this platform should allow users to edit, operate on and interact with different layers of information of the twin city model.

FIGURE 13 **Four essential platforms of a digital twin city**

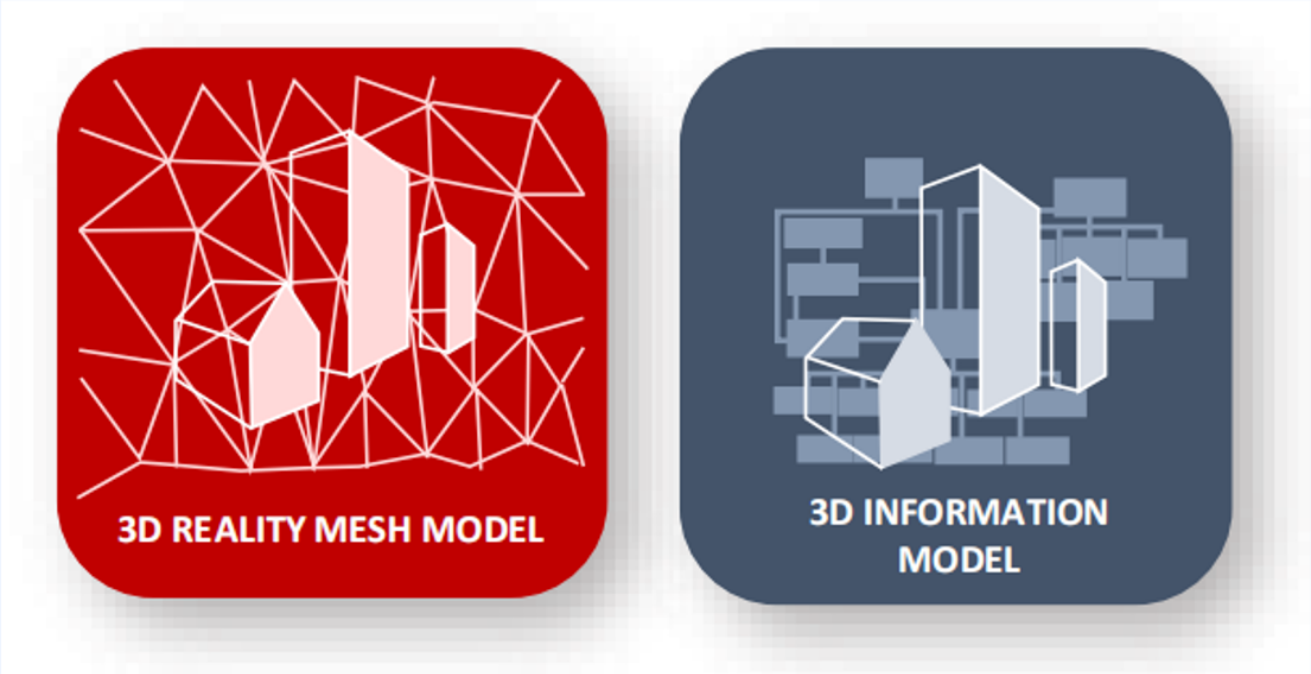


CASE STUDY 7

Helsinki 3D City 2050 plan

At a cost of €1 billion, the City of Helsinki has used innovative modelling techniques to build two state-of-the-art 3D city models, a live-view Mesh model based on 50,000 tilted photographs and 11 terabytes of data, and a CityGML model with rich semantic information based on the live-view Mesh model.[12]

FIGURE 14 | **Helsinki Reality Mesh Model with 3D Information Model**

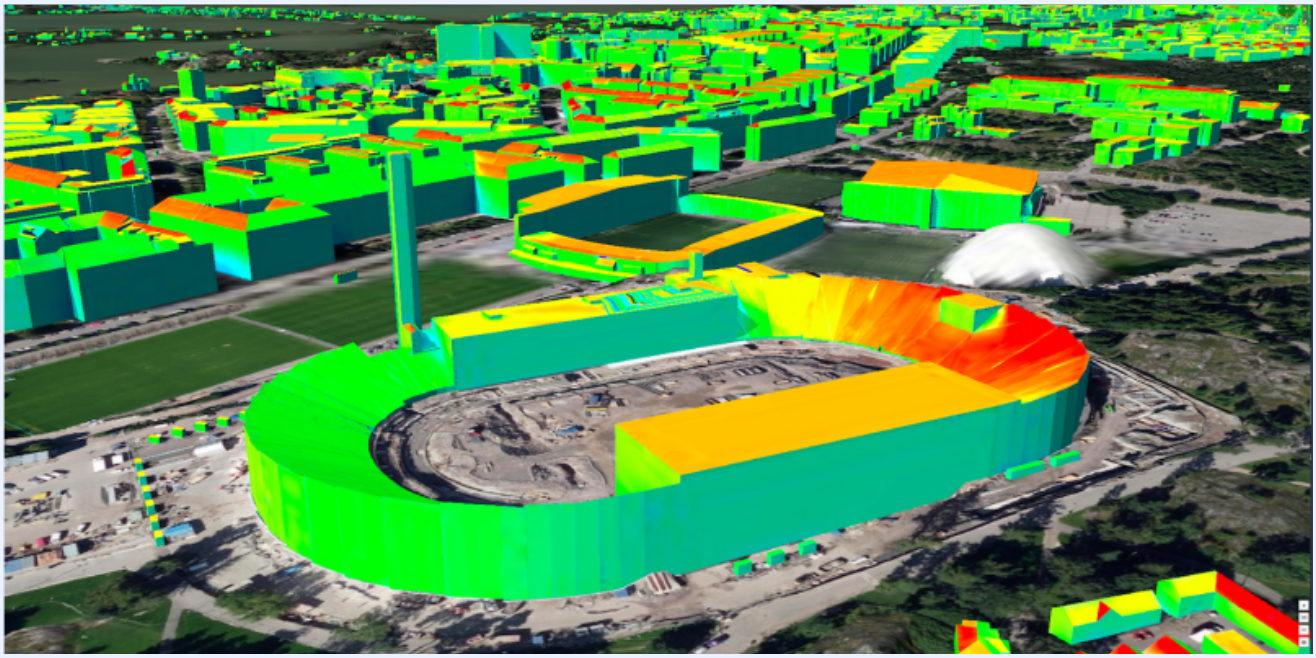


Source: City of Helsinki website

FIGURE 15 | **Helsinki 3D Information Model and Reality Mesh Model in action**

Source: City of Helsinki website

FIGURE 16 | **Helsinki's solar feasibility analysis based on 3D modelling and Language CityGML model**



Source: City of Helsinki website

Insight #3: Build a data integration and service platform

Multidimensional data can be integrated and aggregated into one platform, which can then be used to locate and analyse the status of all city elements in real-time. As data accumulates, its predictive capability can be unleashed to help administrators foresee human flow, traffic and other high-value information.

Insight #4: Build an open-source application platform

The open-source application platform will provide the public, businesses and individual developers with open access to data so they can work innovatively to build personalized and diversified applications. In turn, this benefits urban governance and public service delivery.

CASE STUDY 8

Shenzhen Bay Technology and Ecological Park – a Unified Digital Pedestal

The Unified Digital Pedestal at the Shenzhen Bay Technology and Ecological Park combines two-dimensional data (such as spatial grid data and vector data) and three-dimensional data (BIM, manually made model, industry model, oblique photography, and virtual scenes) to realize a spatial digital twin. Using industrial data and spatial information, it renders a digital visual image of a holistic industrial cluster, the local supply chain, the industrial size, and its stages of development. This amounts to an industrial digital twin.

FIGURE 17 | **Aerial view of the Unified Digital Base at Shenzhen Bay Technology Ecological Park**

Source: Shenzhen Bay Science and Technology Ecological Park project display map

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2.7 Application and scenario

Applications reflect ways to materialize the value of the digital twin city. Applications occur in several scenarios, including city governance, citizen services and industrial development. These applications enable all city stakeholders to benefit from the construction of a digital twin city. It is through applications in different scenarios that a digital twin city exhibits its substantial socioeconomic potential.

Insight #1: Ensure effective digital twin city and city governance

With an increased diversity of city functions, the problem of city governance has also become increasingly complex, undermining city resilience. The digital twin city brings about new approaches to city governance. For instance, digital planning and simulation could vividly present city planners with different ways to configure the city layout to select the optimal layout. For transporting hazardous materials, a digital twin city allows for the tracking, in a three-dimensional space, of the location of the materials in real life. This reduces the uncertainty and risk posed by the transportation operation.

Insight #2: Leverage digital twin city technology to enhance service delivery

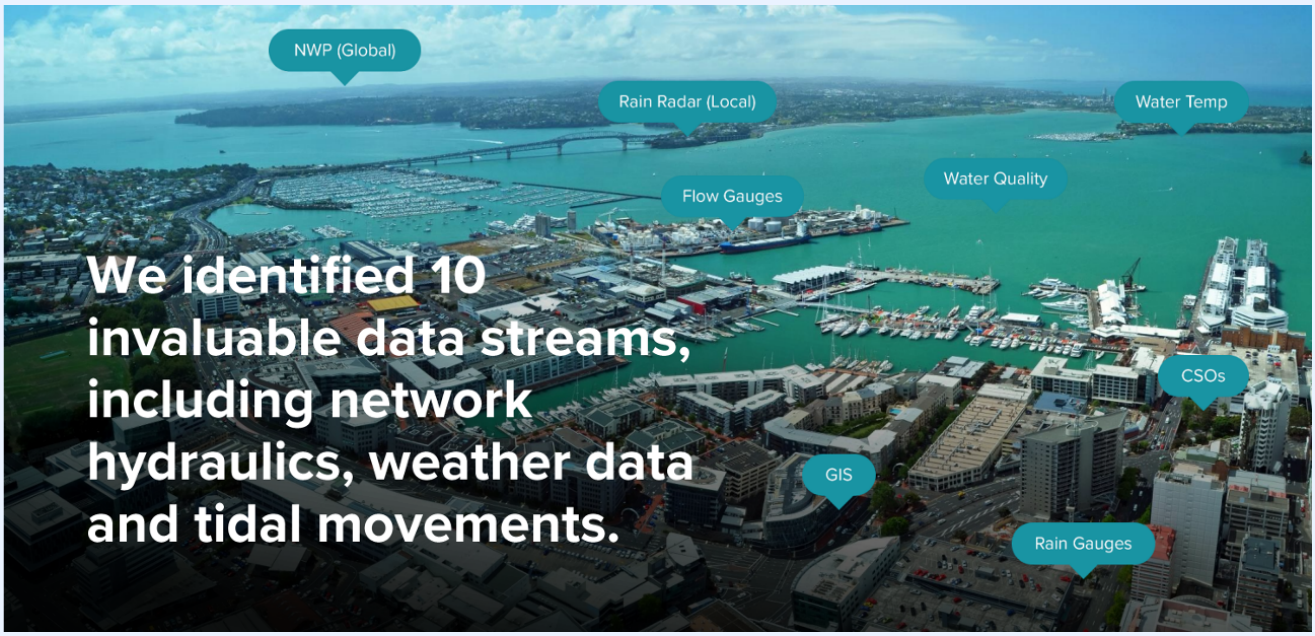
Digital twin cities could enhance service delivery for citizens, thereby improving their living standards. Inhabitants in urban areas face a multitude of challenges, such as traffic congestion, housing shortages and resource constraints. All of these problems may be tackled by applying digital twin technology. For instance, the safety of ageing populations in their homes could be significantly improved by applying smart door locks, infrared sensory devices, and smoke and gas leak detectors. Traffic congestion is alleviated with real-time traffic detection and warning. A smart monitoring system installed at the seaside could help inhabitants obtain timely knowledge of the quality of the beach and the seawater. Remote hospital services and online digital education could become public amenities for everyone.
These applications, among others, make cities more liveable.

CASE STUDY 9

New Zealand (Auckland) Safeswim project

The Safeswim project applies digital twin technology to water quality monitoring in Auckland, New Zealand. The project creates a data integration platform that combines 10 data streams, such as water networks, weather and tides.[13] Complemented by IoT information and laboratory microbiological testing data, the platform can monitor the water quality of many recreational water bodies throughout Auckland. For the public, the Safeswim project has built a consolidated public-facing platform for all users to access information on water quality and health risks of 84 beaches and 8 freshwater bodies around Auckland. This facilitates the public's travel decisions, thereby enhancing public health and safety. At the same time, the Safeswim project has highlighted the water quality problem for the government and the public alike. This has further nudged businesses to combat wastewater spillage.

FIGURE 18 | **The Safeswim project helps with water quality monitoring**



Source: New Zealand Safeswim Project website at https://www.safeswim.org.nz/

Insight #3: Leverage digital twin city technology to advance sustainable development

Digital twin technology offers a whole new set of tools for sustainable city development. It can help city planners optimize resource allocation, refine industry distribution, and improve environmental protection. The digital twin technology could also kick-start the development of a series of green transitions in the trade and logistics industries through automation, remote control and autonomous driving.

Insight #4: Promote strong public-private collaboration

At the early stage of digital twin city construction, the applications and technologies should solve high-reward challenges in low-stake scenarios. In the expansion stage of digital twin city construction, the focus should be on creating standard-setting solutions to challenges that involve multistakeholder participation. During the maturity stage of digital twin city construction, the focus should be on creating value-added applications to empower industries to reduce costs and increase efficiency.

CASE STUDY 10

China's Urumqi uses digital twin technology to create a China-Europe digital train

The Silk Road Smart Port is a digital twin platform created by the Urumqi Dry Port Group to improve port efficiency and safety. For container management, the digital twin technology is used to track the status of containers along the route. It enables the visualization of the entire logistical process, including loading, unloading, transit, packing, unpacking, receiving, dispatching, handing over, storing, stacking and handling. To make the tracking of goods possible, the platform uses IoT technology and spatial computing to collect their location and the number, departure and arrival information of the cargo train. At the same time, all logistical and tracking data can be overlaid on one map to help planners highlight all necessary information.

FIGURE 19 | **Silk Road Smart Port**

Source: Silk Road Smart Port project display map

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3 Recommendations

Coordinated action and a shared commitment by governments and business is critical to facilitate a connected digital twin city environment capable of delivering improved outcomes for individuals, society and the environment as a whole.

3.1 Strategy and talent

Recommendations for governments

- **Establish talent cultivation programmes:** It is recommended that the government and private sector jointly organize talent cultivation programmes. The government could set up training infrastructure and provide educational resources, while businesses could develop targeted training materials based on practical experiences and industry standards.
- **Define clear leadership roles:** To promote the implementation of the digital twin city strategy, it is recommended that the government establish chief technology officer (CTO) and chief digital officer (CDO) or equivalent positions to support the technical and digital aspects of the digital twin city strategy and ensure their alignment and integration with broader city operations.
- **Help attract top talent:** To build local capacity and talent, it is recommended that the government enact policies to incentivize talented individuals to immigrate to the targeted areas. Specific policy instruments can vary, including tax breaks, education incentives, subsidized healthcare and housing.
- **Support collaboration between government, industry and academia:** The government should strive to cultivate an environment that enables cooperation and synergies between government, industry and academia. In this environment, the three actors can jointly carry out research and development on digital twin city-related technologies and test applications to promote the development of digital twin cities.

Recommendations for businesses

- **Establish a digital twin city industry fund:** The construction of digital twin cities requires significant investments and financial support. Establishing a designated fund to help with the construction process of a digital twin city can improve the investment uncertainty of potential investors and diversify the risk of investment in the project.
- **Establish an industry coalition:** Developing digital twin cities requires collaboration among industries and businesses. An industry coalition could have a say in policy formulation. It can also offer technical support to businesses involved in constructing digital twin cities. And it can be a platform for experience and knowledge sharing among businesses in the industry.
- **Nurture a localized industrial value chain:** Businesses, investors and the government should work together to cultivate an industrial ecology with the digital twin cities at its centre. The upstream businesses in this value chain may be technology providers and research institutes, manufacturers of IoT devices and data collection equipment. The downstream businesses in this value chain may be e-commerce platforms, digital retailers and public service platform developers. Such an ecology creates many market opportunities and stimulates the local economy.
- **Promote the integration of digital twin industry and traditional industry:** The development of digital twin cities needs to be integrated with traditional industries. In particular, digital twin technologies should upgrade and optimize services and products provided by traditional industries. For example, they can provide intelligent optimization solutions for traditional industries such as urban transportation, energy and environmental protection and promote the integration and development of traditional industries with digital twin cities.

3.2 Operation and business

Recommendations for governments

- **Create a value system with the private sector while clarifying each other's role:** The government should ideally delegate some responsibilities for digital twin city construction and service provision to social organizations and businesses. Businesses can leverage these opportunities to create profit and social values, which feed back into the investment needs for further construction of the digital twin city. Throughout this process, the government can supervise businesses to ensure the equity, fairness and legality of their business models and operations.
- **Explore business models beyond the government tender system:** Ensure the extensive coverage and coordinated layout of sensory facilities, network infrastructure and computing warehouses. This may imply integration with the city's existing digital infrastructure.

Recommendation for businesses

- **Explore business models beyond the government tender system:** Ensure the extensive coverage and coordinated layout of sensory facilities, network infrastructure and computing warehouses. This may imply integration with the city's existing digital infrastructure.

3.3 Data and infrastructure

Recommendations for governments

- **Ensure the extensive coverage of infrastructure:** The government should pay attention to the coordinated layout of perception facilities, network facilities and computing facilities, make full use of the city's existing digital infrastructure, and gradually build comprehensive coverage, multimedia perception and data collection facilities for scenario needs; moderately over-build the network transmission system; and actively guide the industry to build a three-dimensional urban computing facility system with cloud computing and graphical processing unit (GPUs) computing as the main, and edge computing and terminal computing as the supplement.
- **Ensure individual privacy and data quality:** Safety precautions with regard to user privacy and confidentiality should be an integral part of the digital twin city data system. Therefore, data practices within the digital twin city must be based on anonymized and encrypted data. Appropriate software and hardware systems should be set up to store, prepare and protect such data.

Recommendations for businesses

- **Collaborate with the government on infrastructure building:** Businesses should avoid taking on large projects independently. They should instead take advantage of specialization and the value chain, cooperating with both upstream and downstream partners in the value chain for joint participation in the construction of urban digital infrastructure and technology platforms.
- **Comply with the local data and privacy regulations and laws:** Businesses should strictly comply with the laws of different countries and the regulations of different cities on data security, collection, storage, use and sharing. They must take effective technical and procedural measures to safeguard data security and individual privacy.

3.4 Platform and technology

Recommendations for governments

- **Open up data access to application development:** It is recommended that the government adopt a strategy to facilitate the integration of public data from various sources while ensuring that appropriate measures are taken to protect individual privacy, such as anonymization and safety precautions. The public data should then be shared on interoperable platforms, allowing businesses to access the data and develop practical applications based on it.
- **Aggregate different businesses and skills into one platform:** The government should lead or guide the construction of a central and integrated platform that brings together different technical capabilities and businesses.

Recommendations for businesses

- **Deepen inter-industry skill and technology sharing:** Different upstream and downstream value chain businesses should carry out different tasks tailored to their specialization while ensuring sufficient inter-industry skill and knowledge transfer.
- **Encourage the development and opening up of the platform as a service (PaaS) model:** Build a digital twin lower-order programming language to carry out application development based on a PaaS platform.

3.5 Application and scenario

Recommendations for governments

- **Explore gaps in demand** by adopting a bottom-up approach to developing applications to solve problems in different scenarios, rather than sticking to a top-down approach.
- **Create incubation programmes** to encourage stakeholders to explore innovative digital twin technology and system applications.

Recommendation for businesses

- **Develop tailored applications to help the government solve problems**, focusing on integrating digital twin technology with public services to solve real-life problems and improve the efficiency of urban design decisions and operations.
- **Develop tailored applications to help citizens** and optimize the service experience of citizens by, for instance, exploring customized product design.

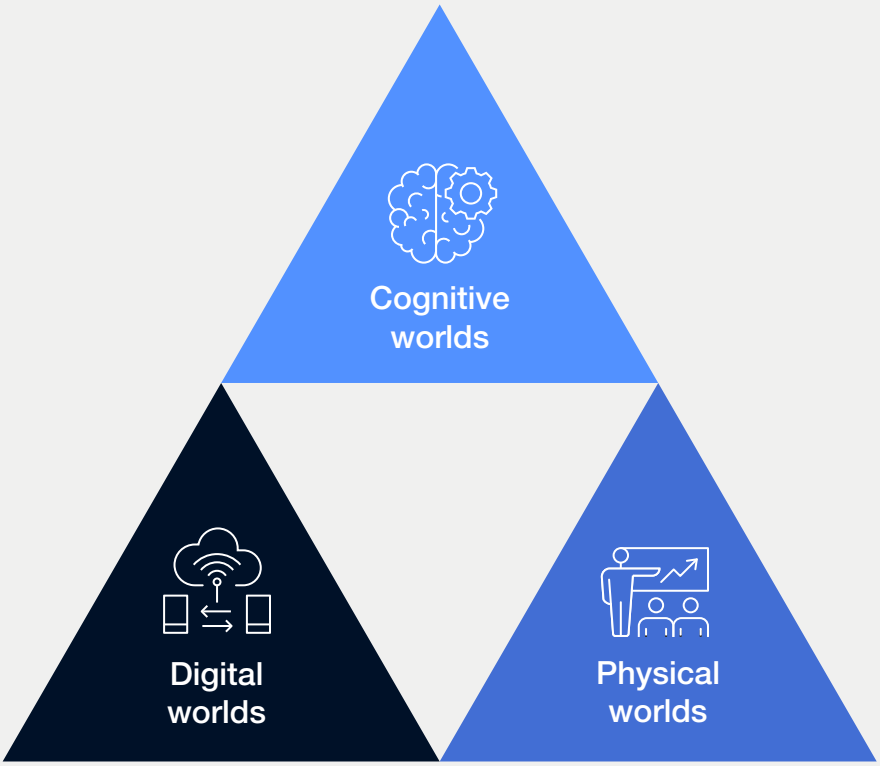
4 Looking ahead: From digital twin city to Metavercity

As digital twin technologies advance, new opportunities also arise to explore connections with the metaverse. The metaverse can be viewed as the amalgamation of all digital worlds and also serves as a fundamental interface between the physical world and the cognitive realm of human thought. Two-way interfaces connect each of these worlds.

The interfaces between the different worlds are as follows:

- Physical to cognitive: humans use their five senses to comprehend the physical world around them.
- Cognitive to physical: humans interact with the physical world, such as kicking a ball or opening a door.
- Physical to digital: sensors collect data about physical assets, which is then translated into digital information.
- Digital to physical: 3D printing technology is used to create physical objects based on digital models.
- Cognitive to digital: humans use game controllers or typing commands to interact with software and digital systems.
- Digital to cognitive: augmented, virtual and mixed reality technologies provide a means to visualize and interact with digital models.

FIGURE 20 **Two-way interfaces connecting the physical world and cognitive realm of human thought**



As smart cities continue to grow and evolve, the potential of digital twins in bridging the gap between the digital and physical worlds is only starting to be realized. The development of interconnected digital twin systems is still in its early stages. Nonetheless, there is a wealth of untapped opportunities in exploring the value of all the interfaces mentioned above within the context of cities. This could pave the way for the emergence of a **Metavercity**.

As a specific use case of the metaverse, the Metavercity is gaining attention alongside the rising popularity of the metaverse concept. Many cities have already implemented strategies to advance the development of metaverse industries and meta-cities, including London, New York, Seoul, Beijing, Shanghai, Singapore, Dubai and NEOM.

A digital twin city could be a foundation upon which a Metavercity is built because it provides the data and infrastructure needed to simulate the working order of a city. At the same time, a Metavercity is a direct and impactful way of applying digital twin technology. Therefore, the digital twin city's and metaverse's future are mutually beneficial and intertwined. In the first step, physical cities will make the important transition into digital twin cities, complementing tangibility with digitalization.

With the advancement of augmented and virtual reality technologies, digital twin cities will gradually transform into a metaverse, deepening the interconnectivity between physical and virtual spaces and instilling mutual dependence between the physical and the virtual.

4.1 A more immersive digital space

Users will have a much more immersive experience with the Metavercity. Elements in the metaverse are more refined in detail and users will also be able to interact with the metaverse through gestures, language and touch. This creates a more natural and direct way of experiencing a virtual space.

NEOM in Saudi Arabia has been devoted to the development of the metaverse. In this newly constructed city, users can experience what it is like to walk around and interact with physical spaces from far away by using holograms and virtual human avatars.

4.2 A more diverse mode of service delivery

The Metavercity will have more virtual buildings, tourist spots, and vehicles. When combined with generative artificial intelligence based on large language models, users can interact with virtual objects in a more realistic and intuitive way. Miami has created a virtual city in the Metaverse, allowing remote tourists to tour the city through augmented reality devices. City managers could also collect public opinions and feedback through the metaverse platform and carry out personalized urban planning and management to better meet the needs and expectations of different users.

4.3 A more vibrant engine of growth

Metavercities have the potential to create new engines of growth by cultivating new industries and employment opportunities. Cities of the future will invest heavily in the infrastructure, platforms and technologies needed to support this new industry, attracting entrepreneurs and businesses to their regions. In Metavercities, people can establish their own businesses through virtual reality technology and use new technologies such as digitalization and cloud computing to provide urban residents with various services and commodities. For example, virtual stores can be created in Metavercities to provide residents with virtual goods and services and virtual billboards can be developed to conduct virtual advertisements for businesses. These digital business models can create momentum for economic growth, promoting the rapid recovery of the global economy.

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We would also like to thank the following people for their support:

Chang Xiangkui
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Senior Expert, Digital Government, Alibaba Cloud

Zhao Wenkong
Chief Technology Officer, Greater China, Dassault Systèmes

Endnotes

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