
Future of
Stations
ARUP

This report is a product of collaboration between Arup Foresight and Arup teams across the world. We would like to thank all contributors for their input and advice.

Foresight is Arup's internal think-tank and consultancy which focuses on the future of the built environment and society at large. We help organisations understand trends, explore new ideas, and radically rethink the future of their businesses. We developed the concept of 'foresight by design', which uses innovative design tools and techniques in order to bring new ideas to life, and to engage all stakeholders in meaningful conversations about change.

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CORE77 DESIGN AWARDS 2020 RUNNER UP

Contents

‘HONG KONG STATION’

Chad McCail, 1998

Detail, Pencil on paper,

Collection Ove Arup and Partners, No COAP0117

INTRODUCTION

Foreword

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Stations are critical pieces of national and urban infrastructure. They are central nodes for inter- and inner-city mobility, provide easy access to facilities and services, and are enablers of economic growth, regeneration and the development of new communities. Their potential for societal and environmental benefit extends far beyond current epidemiological concerns: stations can play a critical role in the recovery from the Covid-19 pandemic towards a more equitable and sustainable future.

As mixed-use hubs for people to move, work, shop and meet, stations are a fascinating and fast-changing typology. Today, new transport modes and business models, digital lifestyles, changing retail patterns, economic, environmental and health concerns are inviting the question of what a station can and should look like in the future.

For owners of station assets, for city planners, and for designers and developers of stations the challenge is to create and maximise the value of investment. This applies to new stations as well as the redesign of existing ones. What will determine our understanding of ‘value’ and ‘return on investment’ in the future? Advertising, ticketing and rental revenue? The sustainable movement of people and goods? Efficient and low-cost operations? Or stations as an enabler for economic growth and social advancement?

This report explores the trends shaping new and existing station assets. It focuses on large inner-city transport interchanges that combine long-distance travel, last mile mobility, and mixed-use commercial offerings, but there are lessons for stations at any scale. It explores what it may mean to deliver ‘value’ and a good ‘return on investment’ in the future. And it proposes principles we should consider for the user experience, operation and design of a station.

The future is never singular. As such, this is not a prediction of what all stations can and should look like. Instead, we offer a summary of the trends, themes and concepts that will redefine transport hubs in the long-term, and recommendations to consider in the design, operation and experience of stations. I hope these stand as a point of departure from where we can redefine what a station is, and where it can take us.

Six principles

Station boundaries should be porous to support greater access and use	Supported by digital technology and the removal of gate lines and ticketing infrastructure, station buildings should dissolve, becoming part of the city to ease interchange, reduce operating costs and improve sustainability.
Stations should diversify beyond transport to embrace convenience	As thresholds blur, the station offer must reflect a wider community of users, with 24/7 operation and new retail and lifestyle trends supporting a variety of amenities, from childcare to public services.
Modes should be integrated, not just accommodated	Diverse transport options – whether cycles, e-scooters or shared autonomous vehicles – should be incorporated into, under and through buildings, prioritising active, shared and low-carbon transport. Charging points and the flexible allocation of kerbs will be key.
Excellent user experiences should be universal	Natural and intuitive wayfinding should make stations legible and efficient. A digital layer should combine with analogue, human-centred infrastructure to work for all users, regardless of their needs.
Adaptable buildings and dynamic systems will maximise efficiency and resilience	Station design should enable adaptation as needs change. Data-driven systems equipped with AI will inform real-time space and mode utilisation, as well as efficient energy use and predictive maintenance.
Station benefits will be environmental and social, not just economic	Station value must be captured to promote long-term financial sustainability. By delivering them in partnership, their ability to catalyse local sustainability and bring inclusive growth can be recognised and emphasised.

Executive summary

Why and how we use transport is changing. This is the result of global urbanisation, digital lifestyles, and new modes. Global passenger use of public transport is expected to increase by up to 300% by 2050, while the transport sector as a whole is already the fastest-growing contributor to climate emissions. Stations, as the gateway to mass transit, have a vital role to play in enabling the former and combating the latter.

This report considers exactly this role, exploring a future in which station boundaries blur – between public and private, physical and digital, the building and the city – and where stations are an enabler for sustainability, well-being and opportunity.

Our research builds on Arup's recent *Transformative Rail* report to consider the impact of multiple trends on the future design, role and experience of multi-modal stations. It looks first at the importance of creating an underlying basis of analogue, human-centred infrastructure that works hand-in hand with digital technologies to provide a positive experience for all. The report then considers the evolution of digital ticketing and its impact on station space, including barrier-free travel, and how real-time data will improve the legibility and efficiency of station spaces for both users and operators.

Ideas for re-imagining and diversifying station space are addressed in the next section, accounting for future shifts in how we shop, work and live. This is followed by a focus on mode and service integration, looking at how stations can act as a single simplified system while also offering new mobility and logistics possibilities. The last two sections see future stations as key actors within their wider contexts, looking at energy and resilience, and economic vitality and social mobility respectively.

The key design features and implications of each section are brought together in an illustration, visualising how these factors might appear in an imagined future landscape. A concluding vision of a future station then draws together the key findings and themes, and lessons from global case studies. It highlights that future stations have the potential to go beyond their traditional transport function to provide us with multiple new destinations – in terms of urban economies, social inclusion and environmental sustainability.

INTRODUCTION

Drivers shaping the future of multi-modal stations

This report is concerned with the future of multi-modal stations, i.e. mobility hubs and interchanges that combine multiple forms of transport. These are referred to as 'stations' throughout, with the research and insights relevant for various modal configurations.

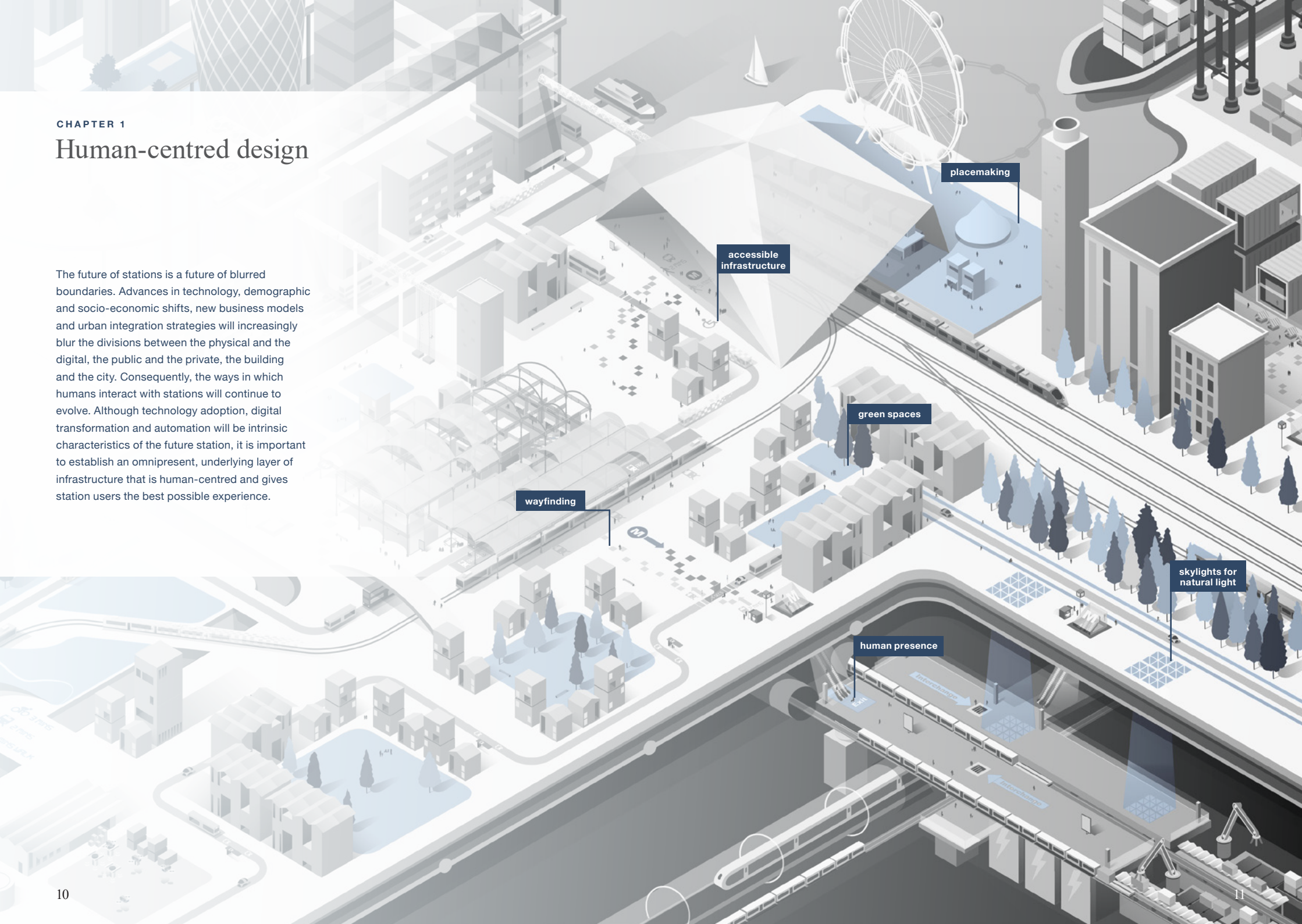
The modes considered by this report include those available now (walking, cycling, rail, light-rail, metro, ferry, bus), new and emerging modes (scooters, and various electric, autonomous or shared modes), as well as future and unproven modes (Hyperloop, passenger drones). Consideration has also been given to freight, including rail and other integrated freight, delivery drones and cargo bots.

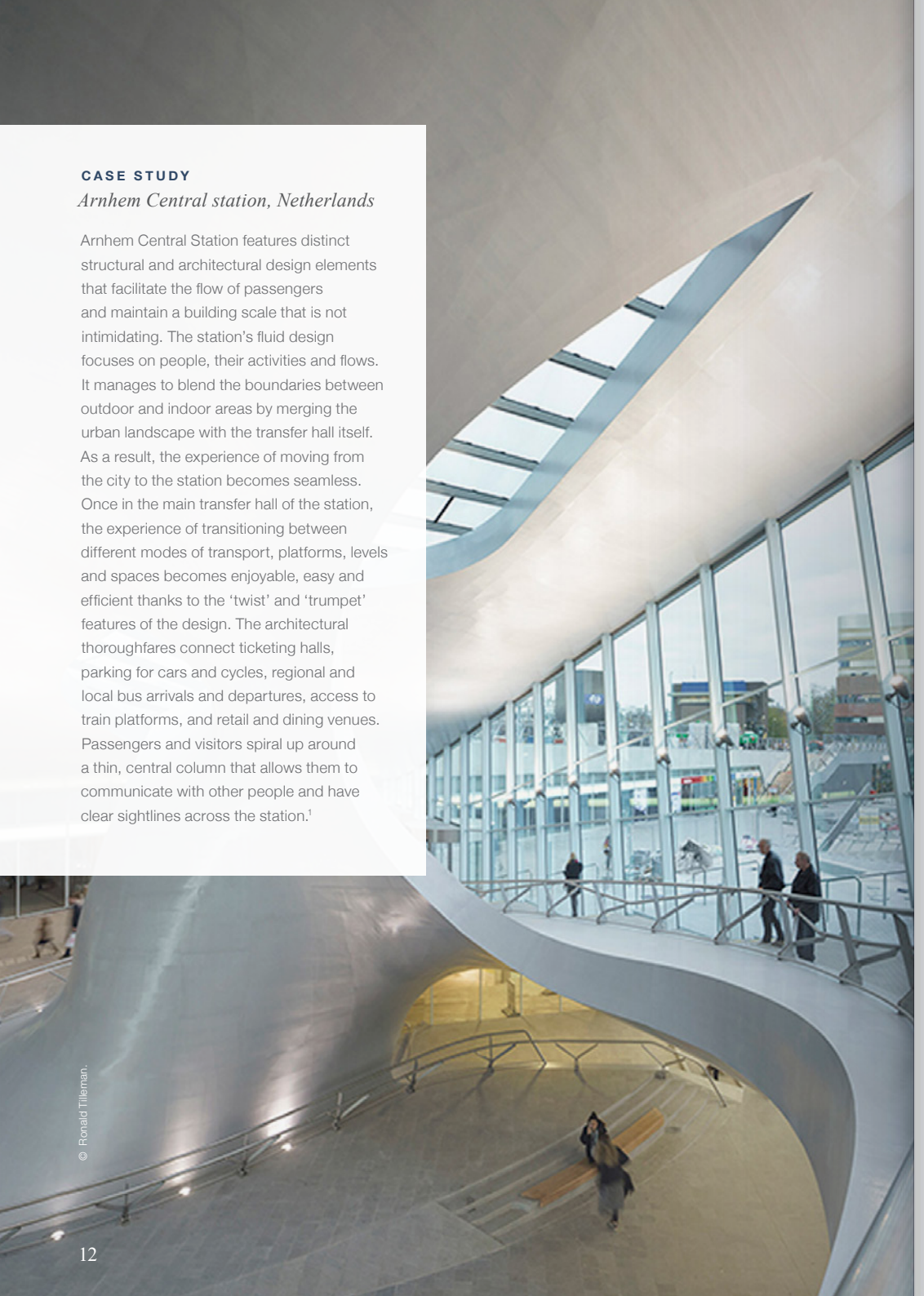
The trends illustrated on the next page also point to an increase in non-transport station functions. As such, the research looks beyond just passengers to include a broad spectrum of future station users and utilisations.

CHAPTER 1

Human-centred design

The future of stations is a future of blurred boundaries. Advances in technology, demographic and socio-economic shifts, new business models and urban integration strategies will increasingly blur the divisions between the physical and the digital, the public and the private, the building and the city. Consequently, the ways in which humans interact with stations will continue to evolve. Although technology adoption, digital transformation and automation will be intrinsic characteristics of the future station, it is important to establish an omnipresent, underlying layer of infrastructure that is human-centred and gives station users the best possible experience.





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CASE STUDY

Arnhem Central station, Netherlands

Arnhem Central Station features distinct structural and architectural design elements that facilitate the flow of passengers and maintain a building scale that is not intimidating. The station's fluid design focuses on people, their activities and flows. It manages to blend the boundaries between outdoor and indoor areas by merging the urban landscape with the transfer hall itself. As a result, the experience of moving from the city to the station becomes seamless. Once in the main transfer hall of the station, the experience of transitioning between different modes of transport, platforms, levels and spaces becomes enjoyable, easy and efficient thanks to the 'twist' and 'trumpet' features of the design. The architectural thoroughfares connect ticketing halls, parking for cars and cycles, regional and local bus arrivals and departures, access to train platforms, and retail and dining venues. Passengers and visitors spiral up around a thin, central column that allows them to communicate with other people and have clear sightlines across the station.[1]

DESIGN FOR USERS NOT FUNCTIONS

Rapid global urbanisation and other factors have led to a huge increase in the number of people using public transport. Demand for passenger transport is projected to grow in all world regions, increasing three-fold between 2015 and 2050, from 44 trillion to 122 trillion passenger-kilometres.[2] To respond to this demand, it will not be enough to just build more or bigger stations; intelligent design approaches will be required to manage people flows, guide human behaviour and increase operational capacity. This will improve the station experience not only for passengers, but for a far wider set of users.

Through broad consideration of users' particular needs and use patterns, future stations will be welcoming places for people of all ages, abilities and backgrounds. This includes disabled people, multi-generational populations, different gender identities, different social and cultural backgrounds, and people travelling with loads (e.g. with pushchairs, luggage, etc.).

Singapore is already addressing inclusivity issues. More than 80% of the city's Mass Rapid Transit stations have been made accessible with at least two barrier-free access routes, while 40% are fitted with extra lifts to improve accessibility for passengers with reduced mobility.[3] In addition, lift doors stay open longer, communication is clearer for those using hearing aids, and Braille directions, tactile guidance and easy-to-read pictographs help to make spaces more legible and facilitate efficient navigation. In New York, the Metropolitan Transportation Authority is increasing the number of women in its leadership to tackle gender imbalance in the field of public transit design and to better consider the needs of parents and children navigating a station environment.[4]

Beyond this, insight generated through advances in data capture of mobility patterns and spatial use will also inform design decisions, shifting the focus from functionality to user experience-driven design. In addition to an improved user experience this will also maximise operational and spatial performance.[5]

Enhancing users' physical and mental well-being will be central in future station design. To prevent disruptive shocks to passengers' and employees' circadian rhythms, many airports implement circadian lighting approaches that adjust light colour temperature and intensity to match global time zones. Oslo Airport offers passengers nine differently-lit areas to provide ranging levels of stimulation or relaxation.[6] Dynamically tuning (underground) station lighting to stimulate the ideal circadian rhythm could improve alertness, help sleeping patterns and put station users, especially employees, at less risk of chronic disorders associated with reversed sleep-wake cycles.[7]

3x

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80%

of Singapore's Mass Rapid Transit stations have been made accessible

INTUITIVE AND INCLUSIVE WAYFINDING

For existing stations, space optimisation through visual design, signage and wayfinding interventions and the integration of an inclusive digital overlay will be a priority; for new stations, user-centricity, human-scale design, rightsizing and flexibility will be key design principles.

New digital services and multi-sensory and personalised solutions, such as indoor positioning technology for blind and partially-sighted users or navigation and information apps targeted at international travellers, will continue to improve inclusion and accessibility. Yet technology should complement rather than replace the inclusive design of the physical station space.

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As stations diversify in their offerings to meet the demands of users, access to and navigation through stations safely and quickly will become increasingly important for user satisfaction and to maintain the operational effectiveness of the transport system (see section 4).[8] The redeveloped Stratford station in London uses 'super graphics' for its new pedestrian underpass; the graphics on a backdrop of bright colours make entry and exit more intuitive and assist passenger flow and movement, especially within a subterranean space. Other approaches to aid wayfinding include the use of cladding or brightly painted infrastructure and spatial elements (i.e. lifts and escalators), and creating clear sight lines to exits.

For Qatar Integrated Railway Project, UNStudio and wayfinding consultants Mijksenaar designed a wayfinding toolkit based on three core tools that give direct guidance but also trigger human reflex and emotion: material and colour, spatial organisation and signage, and scale. Each space has its own colour and material theme, which varies in scale and texture, and extends from the exterior into the interior, even to urban furniture. 'Tools' such as vegetation, pavement, and urban interventions, i.e. outdoor seating islands, large bollards, light poles and shading pavilions, are used at focal points to further assist wayfinding. In addition, all elements of signage aim to have a literal meaning. This ensures a high degree of recognisability and ease of use.

DESIGN TO NUDGE USER BEHAVIOUR

Some stations use natural light in highly trafficked areas to aid navigation and avoid bottlenecks and crowds. Similarly, artificial light can also be used to guide behaviours. Operating on the theory that exposure to blue light has a calming effect on one's mood, rail stations in Japan began installing blue LED panels as a suicide-prevention measure in 2009. Japanese stations have also been pioneering the use of calming music during rush hour; the harsh buzzer used to signal a train's departure has been replaced with short, pleasant departure melodies, aiming to reduce anxiety and rushing incidents.[9]

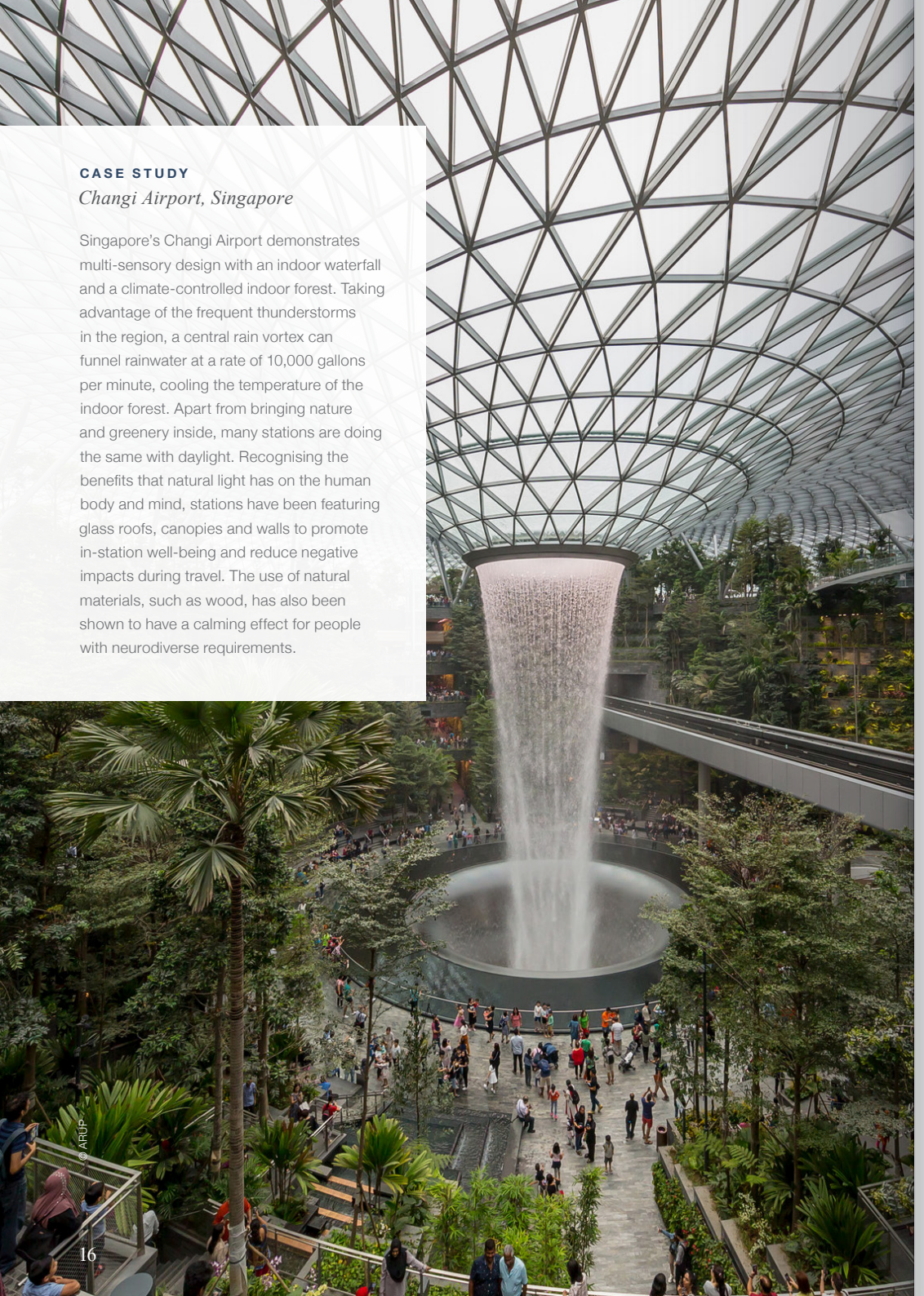
In contrast in Berlin, Deutsche Bahn is experimenting with anxiety-inducing music to deter criminal activity. By trialling atonal music at different volumes in Hermannstrasse station, Deutsche Bahn aims to drive away loiterers, reduce antisocial behaviour and prevent potential travel disruptions.[10] Other operators have trialled classical music to achieve the same results.

Increasing the safety of stations and the public transport network is critical in achieving truly inclusive and accessible mobility for a diverse population, including those who are under-represented or marginalised in current design and provisions. Yet multi-sensory design nudges might not be effective enough in addressing criminal behaviours, harassment or violence in all contexts: to ensure safety, women in Brasilia, Brazil, for example, can request non-designated bus stops anywhere along a route after 10pm. Natural surveillance within stations is also important: design that maximises visibility and social interaction helps not only to reduce anti-social behaviour, but also to increase the perception of safety by all users.

CASE STUDY

Lighting strategy, Bogota

Lighting can play a key role in the delivery of effective and safe public transport. In 2000, the TransMilenio Bus Rapid Transit system (BRT) in Bogota, Colombia, was launched. The aim was to increase the safety of the system in a city where public transport would have not been considered the safest transport option at the time. Today, the TransMilenio is the world's largest BRT system with 12 lines covering a distance of 112km. The lighting strategy played a key role in increasing the attractiveness and accessibility of the scheme by ensuring that large parts of the network were lit at night, increasing safety for passengers and staff.



CASE STUDY

Changi Airport, Singapore

Singapore's Changi Airport demonstrates multi-sensory design with an indoor waterfall and a climate-controlled indoor forest. Taking advantage of the frequent thunderstorms in the region, a central rain vortex can funnel rainwater at a rate of 10,000 gallons per minute, cooling the temperature of the indoor forest. Apart from bringing nature and greenery inside, many stations are doing the same with daylight. Recognising the benefits that natural light has on the human body and mind, stations have been featuring glass roofs, canopies and walls to promote in-station well-being and reduce negative impacts during travel. The use of natural materials, such as wood, has also been shown to have a calming effect for people with neurodiverse requirements.

AUTOMATION WITH A HUMAN TOUCH

Future stations will increasingly embrace digital transformation and adopt automation to cater for people's needs with greater speed and efficiency (see section 2); but human involvement is still required, and the best results are predicted when both are considered together. In customer service, for example, pairing the ability of intelligent systems and devices to predict incidents, with the ability of humans to provide emotionally-driven responses to them, will play an increasingly important role in the way future stations deal with 'moments of truth', i.e. moments where customers invest a high amount of emotional energy in the outcome, such as a cancelled train, lost credit card or missing luggage.[11]

Realtime feedback is already a reality, for example through the use of touch-enabled displays that allow passengers to alert mobile cleaning staff that toilet facilities need attention. In the future this could develop into sensor-based alerts and predictive maintenance by automated cleaning robots. Human staff could then focus on the provision of exceptional customer experience, including assisting passengers with reduced mobility. Optiguide in Lyon, for example, pairs older or disabled passengers with an assistant on their public transit journeys.[12] It is essential, however, to ensure the continued autonomy of those with reduced mobility to enable spontaneous, independent travel.

Automation has given rise to concern of mass redundancies. While fully-automated staff-less stations will likely have a role in our mobility future, the opposite trend can also be observed. Some smaller, traditionally un-staffed stations now use a human presence to introduce a sense of informal supervision, complement automated systems (ticket machines, CCTV, etc.) and create a friendlier, safer environment. These stations and the surrounding community also benefit from the existence of multifunctional shops, where a florist will also be serving coffee and may even be cleaning the toilets.[13]

In December 2018, Greater Anglia became the first train operator in England to roll out 'virtual ticket agents' across all its ticket machines, to enable passengers to connect to a real person – via an audio or video link – for help with ticket purchase and advice on fares. The upgrade aims to provide customers with higher quality, personal and immediate service, to increase the use of ticket machines and reduce queuing times. For passengers, this approach offers human contact with the immediacy and speed of a ticket machine, while operators can enable a pool of staff to be deployed across the network to meet demand in real time.[14] Advances in intelligent digital assistant technology and ubiquitous and multichannel connectivity could lead to message or chatbot-enabled booking or assistance mechanisms anywhere, anytime, and service provision integrated with other apps.

1st

train operator (Greater East Anglia) in England to roll out 'virtual ticket agents' across all its ticket machines in 2018

STATIONS ON A HUMAN SCALE

The principles of human-centred design according to Jan Gehl in his book Cities for People also apply to stations. As an integral part of future city systems, stations will move away from designs that ignore the human dimension towards a more human-scale environment. This will include considerations of walking speeds, ranges, scales, dimensions and reach of different users, including older people, children and teenagers, and disabled people. Predicted increases in passenger numbers will require the expansion of transport hubs, but new developments should reflect the physical limitations of the human body. Instead of single massive structures, a series of scalable and self-contained nodes – similar to those proposed for the expansion of the existing passenger airport terminal at Dubai World Central – that can be replicated to respond to increasing demand would be more manageable and user friendly.

Through thoughtful design and architecture, future stations can transform the human experience. Good station design – on a human scale – will affect people physically and emotionally at every moment of their journey. Plants, natural light, sounds and the lack thereof, scents and textures will stimulate station users and positively affect their brain and physiology.[15]

> "If cities and buildings are going to invite people to come and stay, the human scale will require new and consistent treatment."
>
> Jan Gehl
> Cities for People

CHAPTER 1

Key takeaways

INCLUSION

Spaces and facilities should be designed to accommodate or adapt to an increasingly diverse set of users that will vary in terms of their language, physical and mental ability, digital knowledge, and cultural expectations.

USER-CENTRICITY

Stations should be designed around the user through diverse services, offerings and intuitive design. Simple, multi-sensory design solutions including colour, sound and lighting can inform user behaviour to improve flow, efficiency and comfort.

HUMAN PRESENCE

The role of station staff should be reimagined to complement automated and digital operations, with human presence and a focus on assistance helping to deliver exceptional customer experience.

ANALOGUE INFRASTRUCTURE

Accessible and resilient physical infrastructure, including circulation spaces, entry and exit points and wayfinding, should provide a self-sufficient baseline for any digital overlay. Then aim for a complementary mix of analogue and digital.

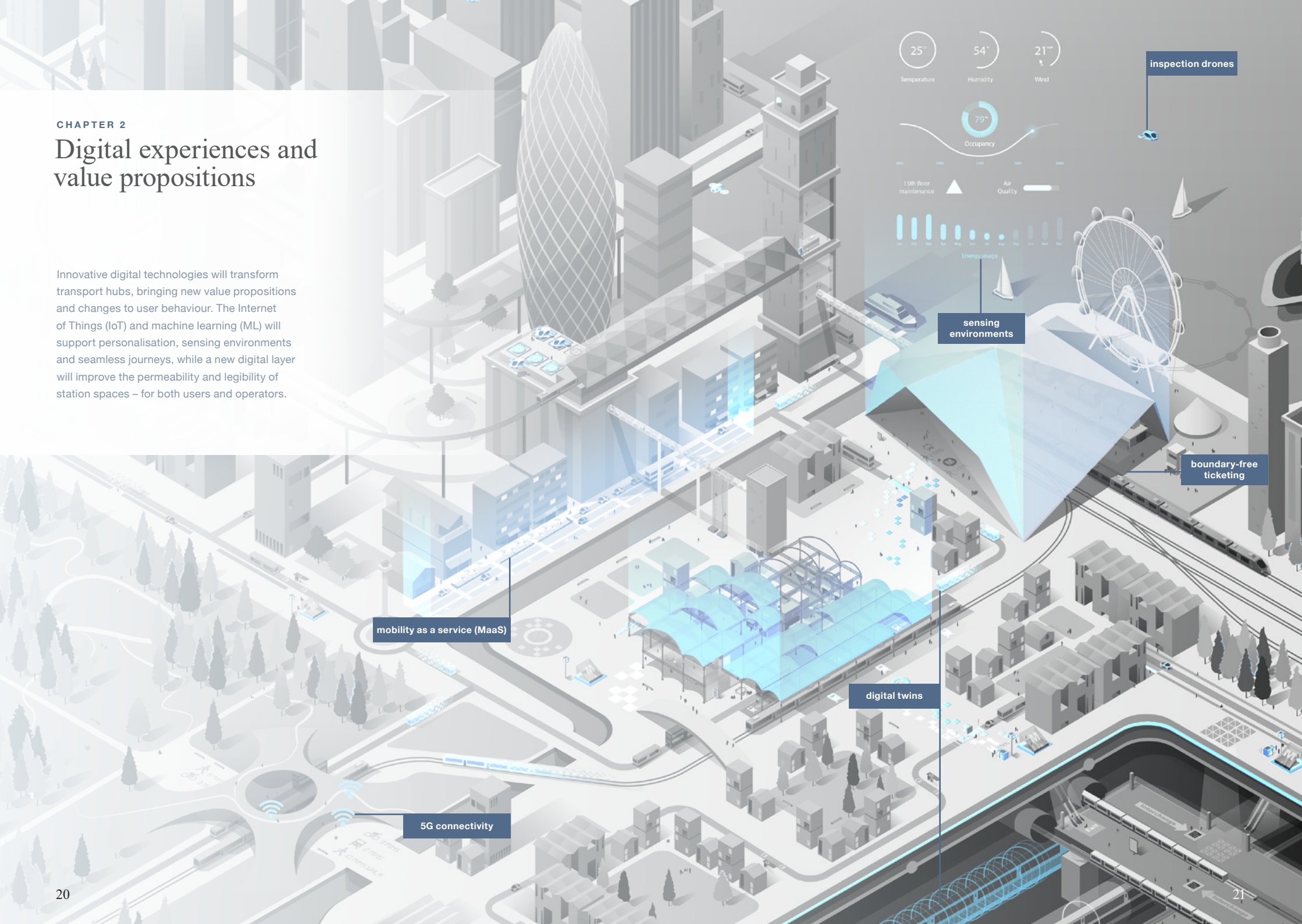
HUMAN SCALE

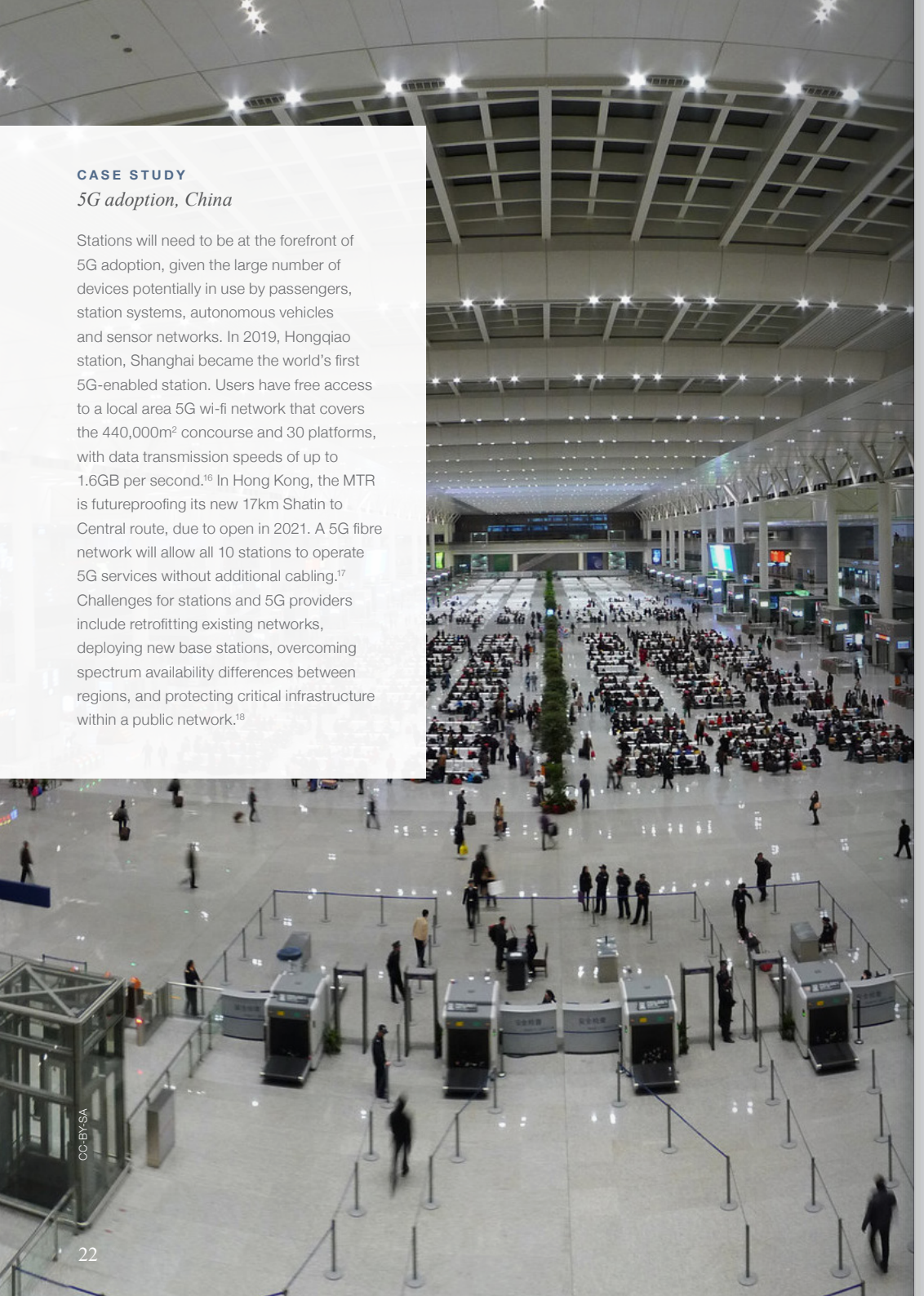
Station design should consider the movement, variety and limitations of the human body, with spaces that are scalable, flexible or self-contained to support improved user experience and greater efficiency.

CHAPTER 2

Digital experiences and value propositions

Innovative digital technologies will transform transport hubs, bringing new value propositions and changes to user behaviour. The Internet of Things (IoT) and machine learning (ML) will support personalisation, sensing environments and seamless journeys, while a new digital layer will improve the permeability and legibility of station spaces – for both users and operators.





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CASE STUDY

5G adoption, China

Stations will need to be at the forefront of 5G adoption, given the large number of devices potentially in use by passengers, station systems, autonomous vehicles and sensor networks. In 2019, Hongqiao station, Shanghai became the world's first 5G-enabled station. Users have free access to a local area 5G wi-fi network that covers the 440,000m² concourse and 30 platforms, with data transmission speeds of up to 1.6GB per second.[16] In Hong Kong, the MTR is futureproofing its new 17km Shatin to Central route, due to open in 2021. A 5G fibre network will allow all 10 stations to operate 5G services without additional cabling.[17] Challenges for stations and 5G providers include retrofitting existing networks, deploying new base stations, overcoming spectrum availability differences between regions, and protecting critical infrastructure within a public network.[18]

DISSOLVING BARRIERS

As recently as 2016, 70% of UK rail tickets were purchased at the station,[19] but advances in digital ticketing, for example QR codes sent to a passenger's smart device, are reducing the time and space needed to buy a ticket onsite, and associated staff support spaces. Self-service and automation have had a similar effect and will continue to do so.

Self-service, however, still has an impact on station space and can lead to queues, delays and illegal ticketless travel where there is no gate line or on-board ticket inspectors. India's National Railways is tackling this problem by encouraging passengers to buy unreserved tickets via a proprietary smartphone app. Between 2015 and 2018, the average number of tickets sold via the UTS app in Chennai grew from 1,900 to 83,000 per day, reducing station congestion and ticketless travel.[20]

Biometric technology, blockchain and faster data processing speeds promise to simplify ticketing and payment even further, supporting gateless transport hubs. London-based ObjectTech is working with Dubai Airport to develop a digital 'passport' that securely combines an individual's biometric, identity and payment data on blockchain. This could enable barrier-free movement in stations that require identity checks and on-demand or pre-approved ticketing,[21] for example through facial recognition ticketing. Additional features of digital ticketing such as geo-fencing and enhanced payment security will also reduce ticket fraud, although new vulnerabilities and digital counterfeiting may emerge.[22] Likewise, concerns over the accuracy, ethics and inclusive application of facial recognition technology will need to be resolved.

By reducing conventional pinch-points from multiple (ticket purchase, collection, validation or gate line) to zero, the boundary between the functional station space and retail, amenity and public spaces beyond becomes all but invisible. This would open access to underused areas of the station behind the gate line and improve the experience for passengers switching between different modes (see section 4).

This blurring of previously defined hard boundaries, however, calls for improved design of circulation, access and platform spaces to define user behaviour, including walking pace, direction and wayfinding, and to differentiate station functions spatially. Likewise, as gate lines are sometimes used as a crowd control measure, their removal suggests a wholesale rethink of station operations to improve safety performance. Any increased use of technology will also need to remain universally accessible, e.g. to older people or low-income users and – as discussed in section 1 – complemented by human assistance.

> "…once a passenger starts to use self-service technology, such as kiosks, websites or mobile devices, they have a high propensity to continue using self-service rather than returning to human contact for that step of the journey." [23]
>
> Francesco Violante
> Former CEO of SITA, IT service provider to the air transport industry

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CASE STUDY

Informing spatial configuration with AI

Companies including Steelcase and Willow are using sensing networks to inform the design and utilisation of commercial office space. Combined with artificially intelligent applications, the data can be used to determine user satisfaction and optimal spatial configuration, as well as inform the real-time adaptation of workplaces. Approaches like these can be used to determine station layout, helping to maximise space for commercial opportunities as well as planning for major events or station evacuations.

DYNAMIC AND ON-DEMAND SERVICES

The increasing shift from provision of 'mobility as a means' to 'mobility as a service' (MaaS)[24] will further reduce barriers between modes. MaaS providers combine different mobility options – public and private – into a single digital platform that integrates payment, booking and routing. MaaS apps put the user in control of their journey, agnostic to their choice of mode and focusing instead on their travel preferences, such as route, duration, access needs or cost. As part of digitally-enabled integrated transport networks more broadly, MaaS can also encourage a shift away from private car ownership, reducing congestion, pollution and resource use.

The benefit of MaaS for transport systems is the potential to better match supply and demand and deliver services that are led by the customer; its success relies on real-time data sharing and the interoperability of different systems. Stations will have to ensure their data is not only open, but usable and comprehensive; managing the transition from current systems will be a significant financial hurdle, along with improved approaches to data governance and data security.

An increase in MaaS – and real-time data generally – offers stations further advantages in terms of new data-informed revenue opportunities and in managing people flows, the latter particularly significant in the absence of gate lines.

Dynamic pricing is a common feature of on-demand taxi apps such as Uber and Lyft, with higher 'surge' prices used to affect customer demand and driver supply.[25] Highways apply the same logic: in Tel Aviv, a high-occupancy toll lane is informed by real-time data on how many drivers are using it, with a lower price attracting more vehicles and vice versa.[26]

The lever of price, if applied to station congestion, could help to even out passenger flows and reduce overcrowding, with dynamic fares based on real-time data 'nudging' passengers to travel at less busy times. Used ethically and transparently, integration with MaaS platforms would amplify this effect, moving beyond simple rush-hour or off-peak distinctions to offer the user precise gradations in cost and routes.

Automation is a vital component of transport systems if they are to respond to real-time demand. The automation of Paris Metro line 1, for example, has enabled schedules to adapt dynamically to increased usage, improving capacity by 20%.[27] (The effect of automation on freight is explored in section 4.)

Demand dynamics could even form part of wider strategies to manage the urban environment, with transport systems responding to live or predicted conditions, such as air pollution or extreme weather events. Stations' operations and transport capacity could respond autonomously to move people away from certain districts, e.g. by increasing the availability of shared modes.

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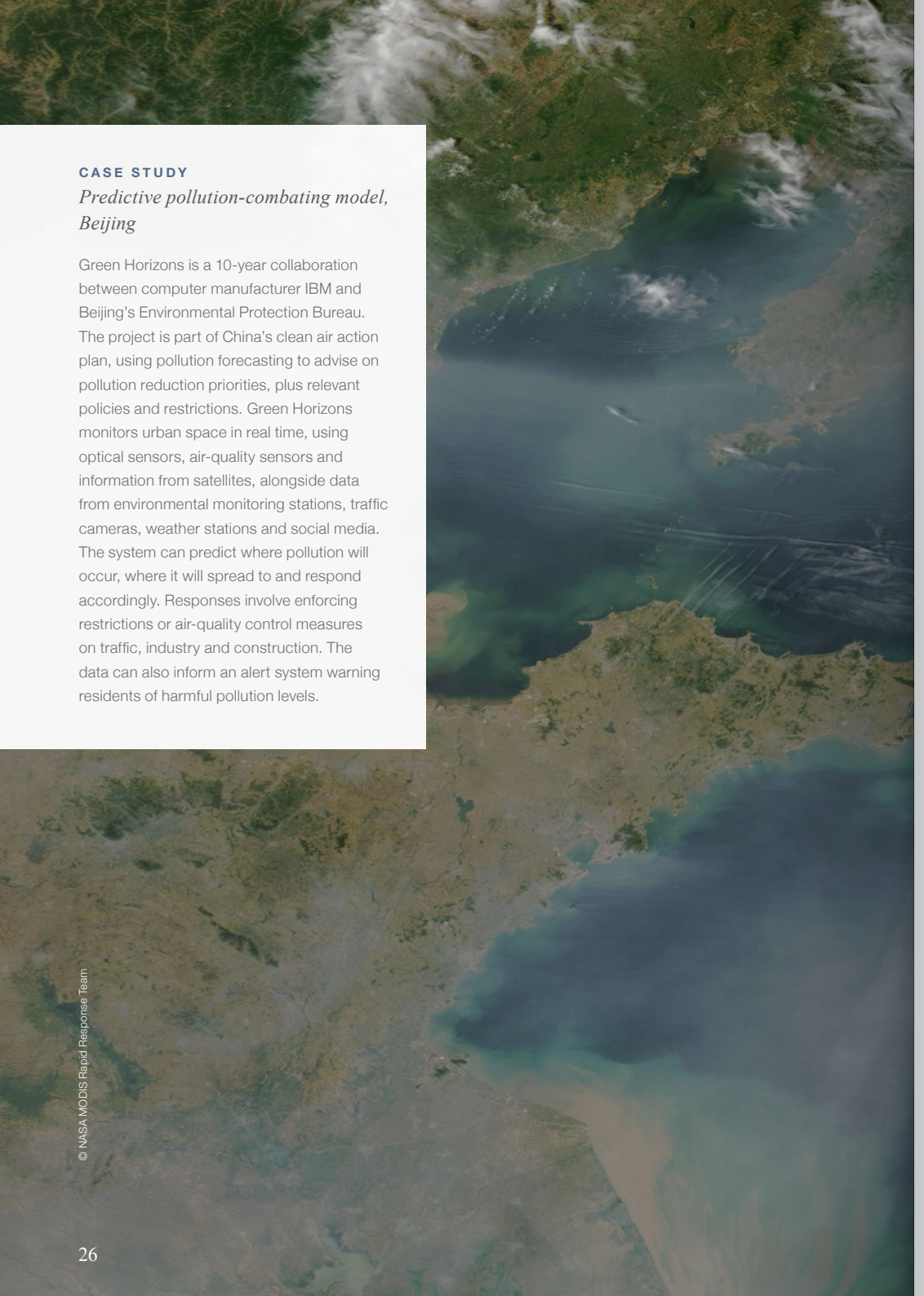
CASE STUDY

MaaS app, Helsinki

Helsinki tech company MaaS Global has partnered with local transport providers to offer a multi-modal transport subscription service that is cheaper, easier and more environmentally-friendly than private car ownership. The Whim app offers unlimited or discounted access to several transport modes for a monthly fee, including bus, taxi, cycle, metro and car hire. Unlike other ride-sharing apps it encourages rather than usurps public transport options. As of 2018, Whim had 70,000 registered users in Helsinki. Data shows that use of the service encourages a shift away from reliance on private vehicles to more sustainable shared or public modes.



CASE STUDY

Predictive pollution-combating model, Beijing

Green Horizons is a 10-year collaboration between computer manufacturer IBM and Beijing's Environmental Protection Bureau. The project is part of China's clean air action plan, using pollution forecasting to advise on pollution reduction priorities, plus relevant policies and restrictions. Green Horizons monitors urban space in real time, using optical sensors, air-quality sensors and information from satellites, alongside data from environmental monitoring stations, traffic cameras, weather stations and social media. The system can predict where pollution will occur, where it will spread to and respond accordingly. Responses involve enforcing restrictions or air-quality control measures on traffic, industry and construction. The data can also inform an alert system warning residents of harmful pollution levels.

Demands for personalisation and seamless journeys are driving changes to customer experiences and people flow, yet station operators are also under pressure to maximise revenue and improve efficiency. This is leading to new approaches to monitoring and automating station operations.

Siemens estimates that, with significant investment, the adoption of best-practice IoT-related opportunities could add nearly US$100bn to the global economy through increased throughput, availability and improved customer experiences.[28]

Advances in sensor technology, processing power and connectivity are making sensors cheaper and easier to install, and capable of providing rich data on all aspects of station performance, such as air quality, structural movement and maintenance requirements. Anonymous data 'crowd-sensed' from people's smart devices adds another dimension to this real-time sensing layer.

Digital twins could help stations to realise the benefits of these various data sources and make sense of how different factors interact. A digital twin is an accessible digital model of a physical asset that can incorporate BIM models as well as real-time data on the performance of physical spaces and systems.[29] The predictive ability of AI with machine learning offers the most radical benefits of such a tool, using the data to determine how spaces should be configured with predictions on passenger flow, retail revenue, modal capacity and maintenance.

US$100bn

added value to the global economy by adopting best practice of IoT-related opportunities

Predicting maintenance needs and preventing failure will reduce accidents and unplanned closures, as well as helping to maintain barrier-free access. Intelligent robots and drones are already being used for the remote inspection of transport infrastructure including tunnels and bridges. As autonomous robotics develop, maintenance drones will be able to both identify and repair damage, mitigating more substantial problems. Station networks can amplify this effect by combining real-time and historic performance data across multiple sites to accurately predict when a component needs to be cleaned, repaired or replaced.

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SEAMLESS USER EXPERIENCES

An integrated digital layer also offers opportunities for improved customer and traveller experiences, supported by uninterrupted wi-fi networks and 5G. In rural areas, stations have a role as digital hotspots, compensating for poor connectivity and providing a significant community asset. A trend towards personalised advertising could also improve retail spend and advertising revenue, enabled by Bluetooth, NFC and GPS.

Between wayfinding, live travel information, station signage and advertising however, the competition for passenger and visitor attention is significant; operators will need to develop strategies that deliver more effective communication and increased commercial value to avoid overwhelming the station visitor. New digital technology is already supporting greater synchronisation of advertising screens, with personalisation a key emerging feature. Virtual and augmented reality will also facilitate new forms of experience-led advertising, crucial for some stations to supplement fare-box recovery.

Data collected on an individual's preferences as they move through a station can help retailers to personalise their offer, and integration with MaaS apps could allow recommendations even before a user arrives at the station. To support this, station operators, public and private transport providers and MaaS platforms will need to cooperate on sharing – and protecting – user data; the security and resilience of digital systems will remain a fundamental concern.[30]

The promise of data sharing for individual passengers is a set of station experiences that fits to a user's unique needs. Such personalisation could mean specific routes through the station depending on your onward journey, autonomous mobility support for older passengers, or recommendations for which carriage or shared autonomous vehicle matches your temperature preferences. The challenges will be around data privacy, building a commercial or funding model that supports such advances and, crucially, developing effective governance models.

CHAPTER 2

Key takeaways

DIGITAL TICKETING

Advances in digital ticketing will free-up space currently used for onsite ticket sales and help reduce station congestion. Stations should continue to push ticket transactions beyond the station itself, including via digital passports or integrated with MaaS providers.

SENSING ENVIRONMENTS

Operators should use sensor networks and real-time data to inform and predict station requirements and wider travel dynamics. This will require significant long-term investment, as well as the right command and control systems.

DIGITAL TWINS

Digital twins that combine BIM, live data and AI can improve operational and spatial efficiency, supporting predictive maintenance, the dynamic re-configuration of station space, and real-time modal capacity.

INTEGRATED WI-FI

Integrated wi-fi and 5G networks should combine multiple digital touchpoints into a single seamless digital experience. This will improve the station experience for all station users, supporting personalised retail and live travel data.

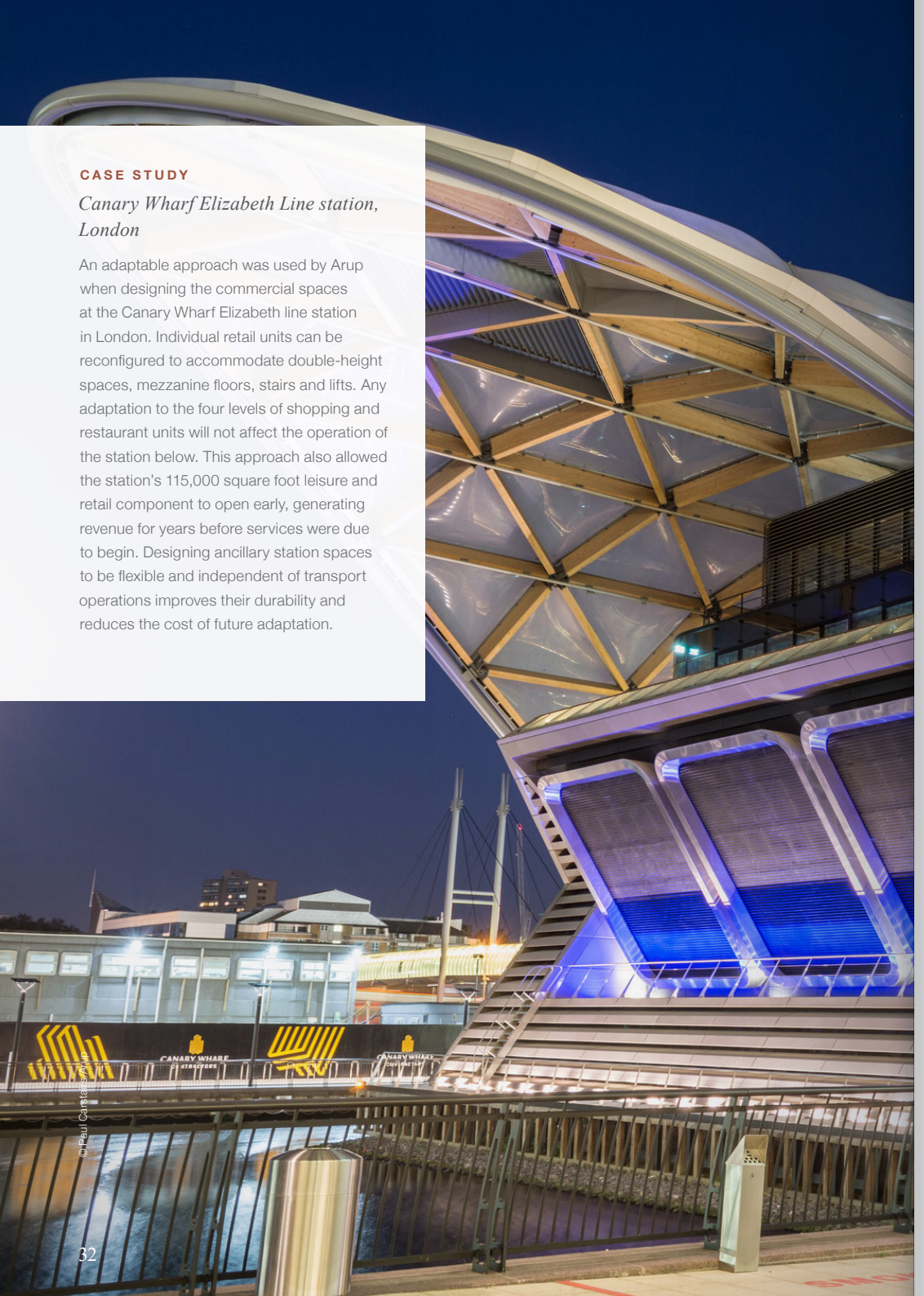
DATA

Owners and operators should explore the data opportunity, partnering with other providers (including apps, services and city authorities) in order to guide people flows in real time and optimise services. Data must remain private and secure.

CHAPTER 3

Diversification of spatial uses and facilities

Competition for space in cities is making station land more valuable and useful. At the same time, ridership and footfall is increasing. This provides opportunities to rethink how station space is used, and how stations relate to their context – both physically (i.e. above, below and around) and in terms of the breadth of uses and users they are designed for. By following a citizen-focused approach, stations can better share the benefits of their unique combination of location, fabric and function for the benefit of all.



© Paul Carstairs/Arup

CASE STUDY

Canary Wharf Elizabeth Line station, London

An adaptable approach was used by Arup when designing the commercial spaces at the Canary Wharf Elizabeth line station in London. Individual retail units can be reconfigured to accommodate double-height spaces, mezzanine floors, stairs and lifts. Any adaptation to the four levels of shopping and restaurant units will not affect the operation of the station below. This approach also allowed the station's 115,000 square foot leisure and retail component to open early, generating revenue for years before services were due to begin. Designing ancillary station spaces to be flexible and independent of transport operations improves their durability and reduces the cost of future adaptation.

'DESTINATION' STATIONS

Public transport ridership in the US has increased by 21% since 1997,[31] and in the UK, rail passenger numbers have doubled in the past 20 years.[32] This growth is increasing footfall in stations and the potential spend in station retail spaces. Crucially, station retail is not just for passengers: in dense urban contexts, the handy location of station shops is another driver for increased revenue and tenant demand. More than a quarter of the 1 million weekly visitors to London's St Pancras station come to eat, drink and shop rather than take a train, while Leipzig's main station is also the city's largest shopping centre.[33]

Stores generally are starting to respond to broader retail trends, including consumer demand for experience-led retail[34] and the merging of traditionally discrete sectors, e.g. fashion retailers incorporating coffee shops. 'Destination' stations with a large retail footprint will need to create and maintain a welcoming and safe environment with an exciting and dynamic retail mix. Pop-up spaces and temporary uses can play a part in this – an evolution of simple brand activation stands on station concourses.

Porous station design that maximises integration into the surrounding context will help to drive footfall, as stations move from a passenger-oriented approach to a broader philosophy that embraces all potential users. In attracting more and diverse groups into the station, however, designers and operators need to consider the impact on transport users and maintain accessibility; both a visual and spatial distinction is needed to avoid congestion and competing people flows. Tactics include stacking retail spaces on floors above the platforms, as at the World Trade Centre transportation hub in New York, or clustering and colour-coding areas that have different uses.

21%
increase in public transport ridership in the United States of America since 1997

2x
Rail passenger numbers in the past 20 years in the United Kingdom have doubled

250,000+
weekly visitors to London's St Pancras station who come to eat, drink and shop rather than take a train

CAPITALISING ON CONVENIENCE

Clearly, stations should be more than just shopping centres: they can capitalise on the convenience that makes retail an attractive proposition to diversify their offer and income, supporting mixed-use places with amenities that benefit users and local communities.

Growth in flexible and mobile working and the rise of the 'gig' economy have spurred demand for subscription-based co-working spaces. With their convenient locations and 24-hour amenities, transport hubs are well-suited to host these spaces, either partnering with existing providers or creating their own proprietary networks.

In Tokyo, railway operator Tokyu Corporation has opened a network of co-working office spaces in or close to 20 of its metro stations; these NewWork offices operate on a membership basis, with users taking advantage of their convenient locations to reduce commuting stress and improve productivity. On a smaller scale, Tokyo Metro Co. operates a Satellite Office Service, a suite of one-person work booths in subway stations intended for short sessions.

For stations, the opportunity will be in accommodating an ever more diverse 'convenience layer' of work or hospitality spaces far beyond the conventional offer, including 24-hour gyms with virtual classes, childcare and educational facilities, maker spaces and logistics services.

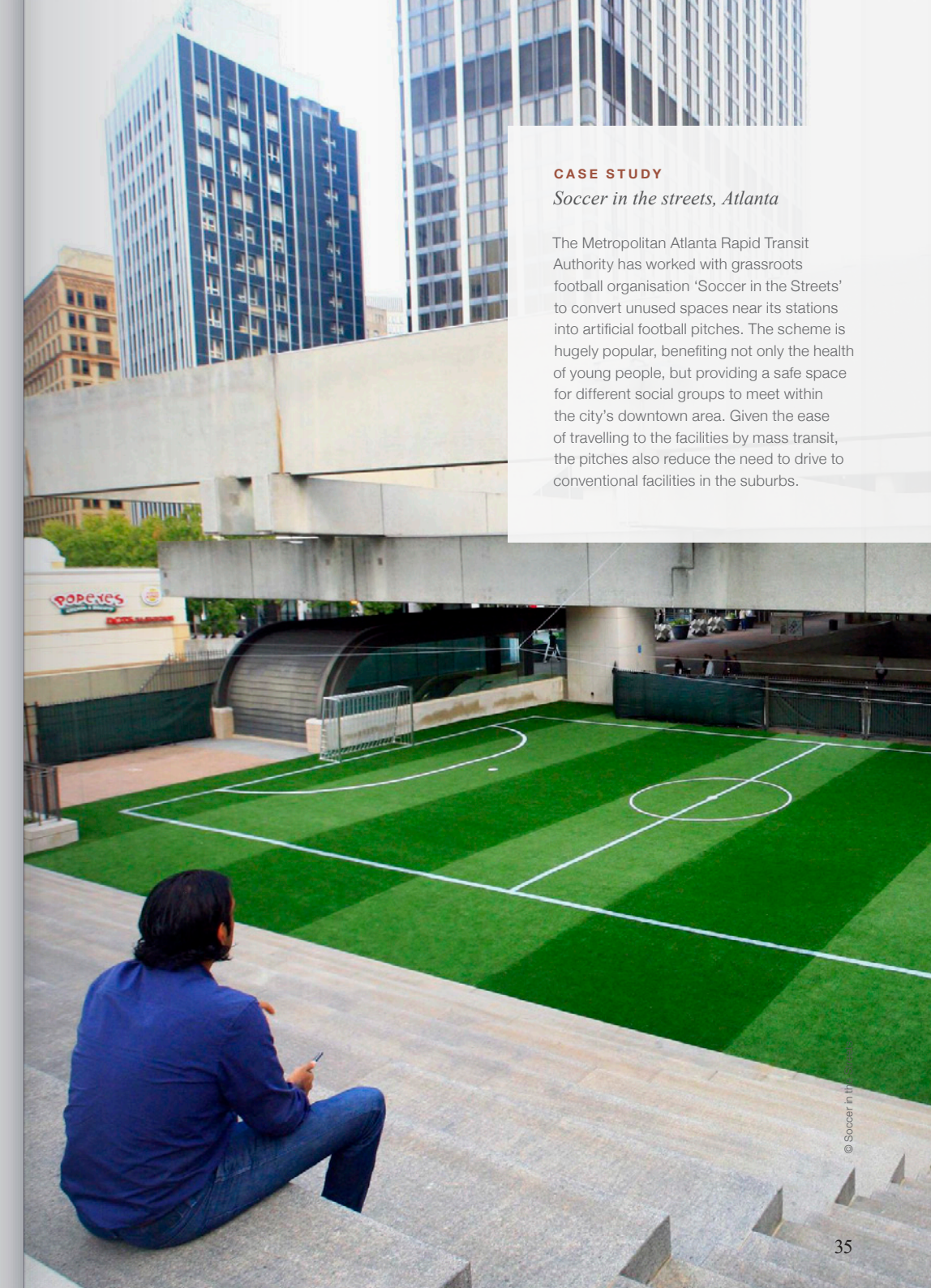
CONNECTING PEOPLE

The need to create value from footfall should be balanced with providing amenities and services that add social value to the local community, regardless of station scale or location. Infrastructure projects are facing increased scrutiny for the level of public good they deliver, with expectations in terms of public benefit and value for money.[35]

Expanding the role of voluntary groups, community activists and arts organisations can help to sustain these non-commercial actions and ensure local needs are met.[36] The Incredible Edible movement in the UK has seen multiple stations incorporate areas for food cultivation – from planters full of herbs on platforms, to raised beds on surrounding station land; in Bristol this is accompanied by a #PickYourOwnOnTheWayHome campaign, encouraging healthy eating.

Redundant station functions also provide creative opportunities. At the world's oldest active passenger railway station (Edge Hill in Liverpool), a local arts organisation has converted a disused engine house and boiler room into a studio and performance space forming a creative hub for the area.

Stations can provide affordable space in desirable and convenient locations; they can also provide new audiences with greater access to organisations that support community cohesion and improved health and well-being.[37] There is a role, too, for local public services – such as libraries or health clinics – benefiting from a station's location to maximise access.



© Soccer in the Streets

CASE STUDY

Soccer in the streets, Atlanta

The Metropolitan Atlanta Rapid Transit Authority has worked with grassroots football organisation 'Soccer in the Streets' to convert unused spaces near its stations into artificial football pitches. The scheme is hugely popular, benefiting not only the health of young people, but providing a safe space for different social groups to meet within the city's downtown area. Given the ease of travelling to the facilities by mass transit, the pitches also reduce the need to drive to conventional facilities in the suburbs.

CASE STUDY

The 'Rail plus Property' model, Hong Kong

The 'Rail plus Property' model adopted by Hong Kong's MTR Corporation demonstrates the potential for mixed-use over-station development on a large scale. New stations and the developments on or around them comprise residential, commercial, retail and local amenity uses. More than half of the network's stations feature above-station developments, totalling more than 13 million m^2 of floor area.[38] MTR also benefits from increases in property values that accompany new stations, using revenue to fund network operations and future developments as well as sharing profits with developers. MTR has also applied this approach in Shenzhen, China, providing 1,700 apartments and 10,000m^2 of retail space above and around a rail depot.

BLURRING THE 'RED LINE'

We have seen how new technologies will break down the thresholds between the neighbourhood, station, and transport modes (section 2). Spatially, this would allow transport interchanges to become smaller, more physically integrated with the existing urban fabric and dissolve the 'red line' of station space, supporting a more symbiotic relationship with the surrounding context. This may increasingly become a necessity as station ownership rights are often very close to existing boundaries.

Copenhagen's Cityringen metro line already embodies aspects of this approach. Each of the 17 new stations reduces requirements to a minimum, with no amenities or shops within the 'red line'. Instead, passengers make use of existing urban assets, whether a shop or café. The stations have also provided the city with 17 new public spaces at ground level further benefiting the local neighbourhoods.[39]

As conventional thresholds blur, porous stations should in effect 'borrow' and incorporate assets and spaces that are external to them, both at street level and below grade. The Umeda underground mall complex in central Osaka connects two metro lines, a commuter station and a mainline hub; its combined 1,200 retail stores and restaurants service an average of 400,000 users every day.[40] On a smaller scale, the inclusion of digital departure boards or ticketing services in nearby shops can extend the functional reach of a station. Redundant transport land will also provide an opportunity for station operators to work with development partners to create a beneficial precinct that integrates with and complements the station.

THE CAPACITY CHALLENGE

Expanding a station's spatial capacity to accommodate diverse uses is a challenge for existing stations. Automation, digital ticketing and payment, and cloud computing will release underutilised areas for adaptive reuse, for example ticket halls, back offices and server rooms, but other approaches may be required to significantly expand station capacity in the context of urban densification and increasing competition for space.

Building above stations is expensive and technically challenging but in certain locations can be a major value generator. Factors restricting upward growth include vibration and noise from vehicle or train movement, as well as ensuring access for maintenance and repair. Weight restrictions can also limit the number of storeys permitted. Subterranean expansion is also possible, with notable examples in Canada, Singapore, South Korea, China and Japan, although again the engineering challenge and costs are a limitation.

Another approach is to future-proof new developments by covering the station and adjacent tracks with a station 'box' or with decking.[41] Estimates show that at Clapham Junction in London, one of Europe's busiest stations, decking over the station and tracks could create 41 acres of land for development.[42]

In future, data on spatial utilisation across the day or week will allow station operators to understand user flow in real time. This could enable a flexible approach to station space if combined with adaptable design. Existing retail tenants, for example, could 'open' their shop

CASE STUDY

Cityringen, Copenhagen

With 17 new stations and 16km of metro lines, Copenhagen's Cityringen is the largest construction project to take place in the city in 400 years, one that redefines how people move around the city. Features include skylights that bring natural light down into the station, while distinctive internal facades reflect the local identity of the areas they connect to. Various design strategies also helped to reduce the overall footprint of the underground stations to roughly 64m x 20m. The new line ensures that a majority of Copenhagen's residents will be within 600 metres of a train or metro station.

> Data on spatial utilisation across the day or week will allow station operators to understand user flow in real time. This could enable a flexible approach to station space if combined with adaptable design.

fronts and claim available space, supporting variety in the station offer and increasing retail density. A flexible design strategy is evident at Elizabeth de Portzamparc's scheme for the new LeBourget metro station in Paris, which embeds a concept of 'total flex', including platforms that can expand in height and length, and partially in width.[43]

The adaptation of existing but underused spaces can provide further areas for stations to expand their offer. Viaduct undercrofts, for example, are often neglected and can attract antisocial behaviour and vandalism. An Arup research project, Under the Viaduct, found alternative uses for these spaces to turn them into places of value, including community or pop-up uses, planting schemes to improve biodiversity, and climbing walls. A project in Moscow by Snøhetta and Strelka Architects has seen the Krymsky Overpass transformed from an abandoned car park into a colourful all-weather skate park.[44] These approaches can also be applied on a short-term 'meanwhile' basis, for example during construction phasing, or as a permanently flexible space for experimentation and adaptation.

CHAPTER 3

Key takeaways

DESTINATION

Spaces and amenities should create a sense of destination with a dynamic offer and strong local relevance attracting more and diverse user groups. Use spatial distinctions including separate floors and circulation routes to avoid competing people flows.

NEW USES

Owners and operators should think beyond conventional station uses to incorporate convenient amenities and non-commercial or civic functions. These can benefit from a station's strategic location and add social value.

CONTEXT

Design that explores a more symbiotic and permeable relationship with a station's context will help to maximise value, healthy choices and incorporate or complement existing local assets.

FLEXIBLE SPACE

Flexible spaces can serve multiple programmes over time, and designers should embed adaptability from the start. This will reduce the cost of future station adaptation and accommodate a changing transport offer.

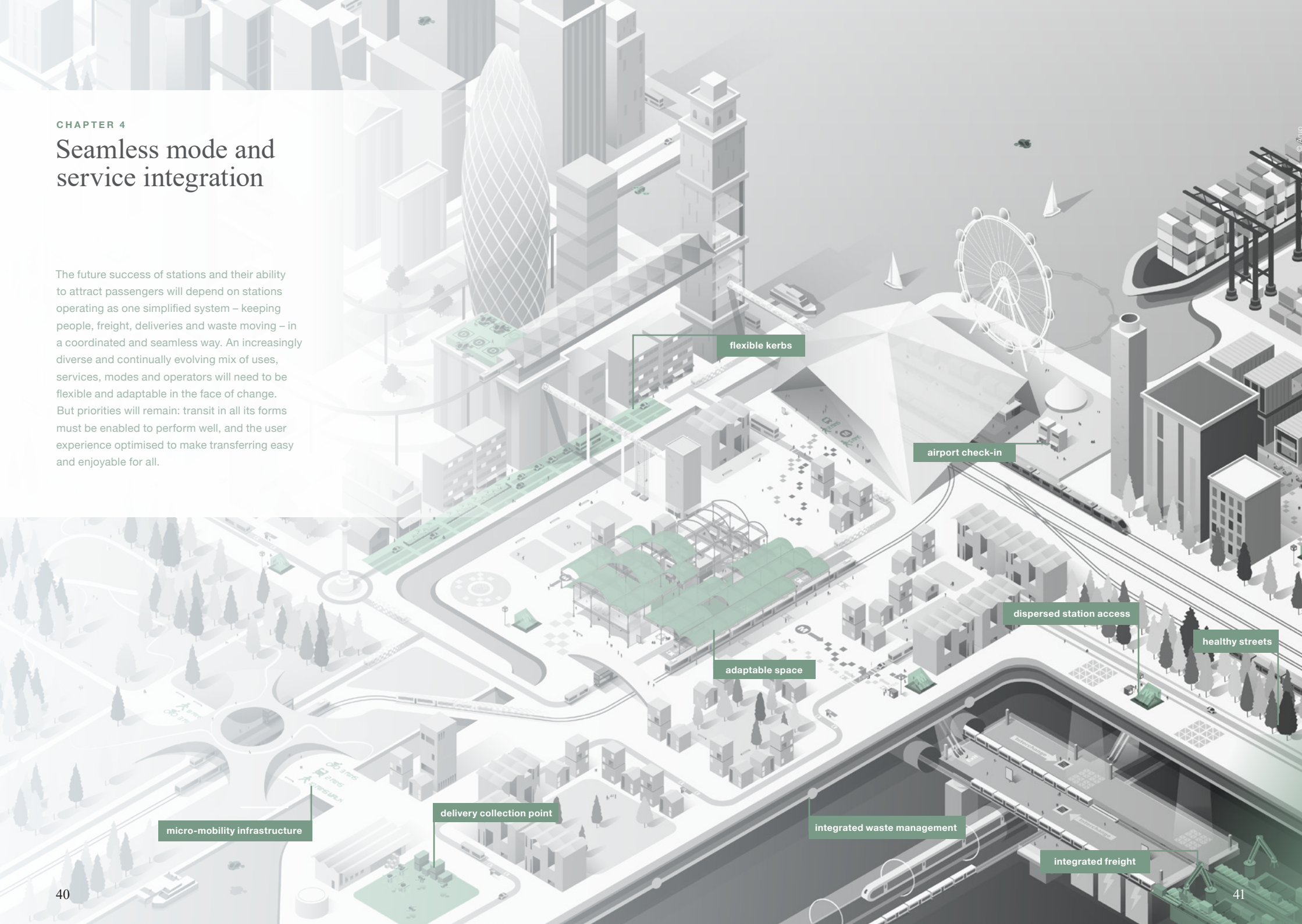
REUSE AND REPURPOSE

Owners should maximise the reuse of redundant station spaces, including viaducts, ticket offices and server rooms, providing capacity for a more diverse, relevant and valuable offer.

CHAPTER 4

Seamless mode and service integration

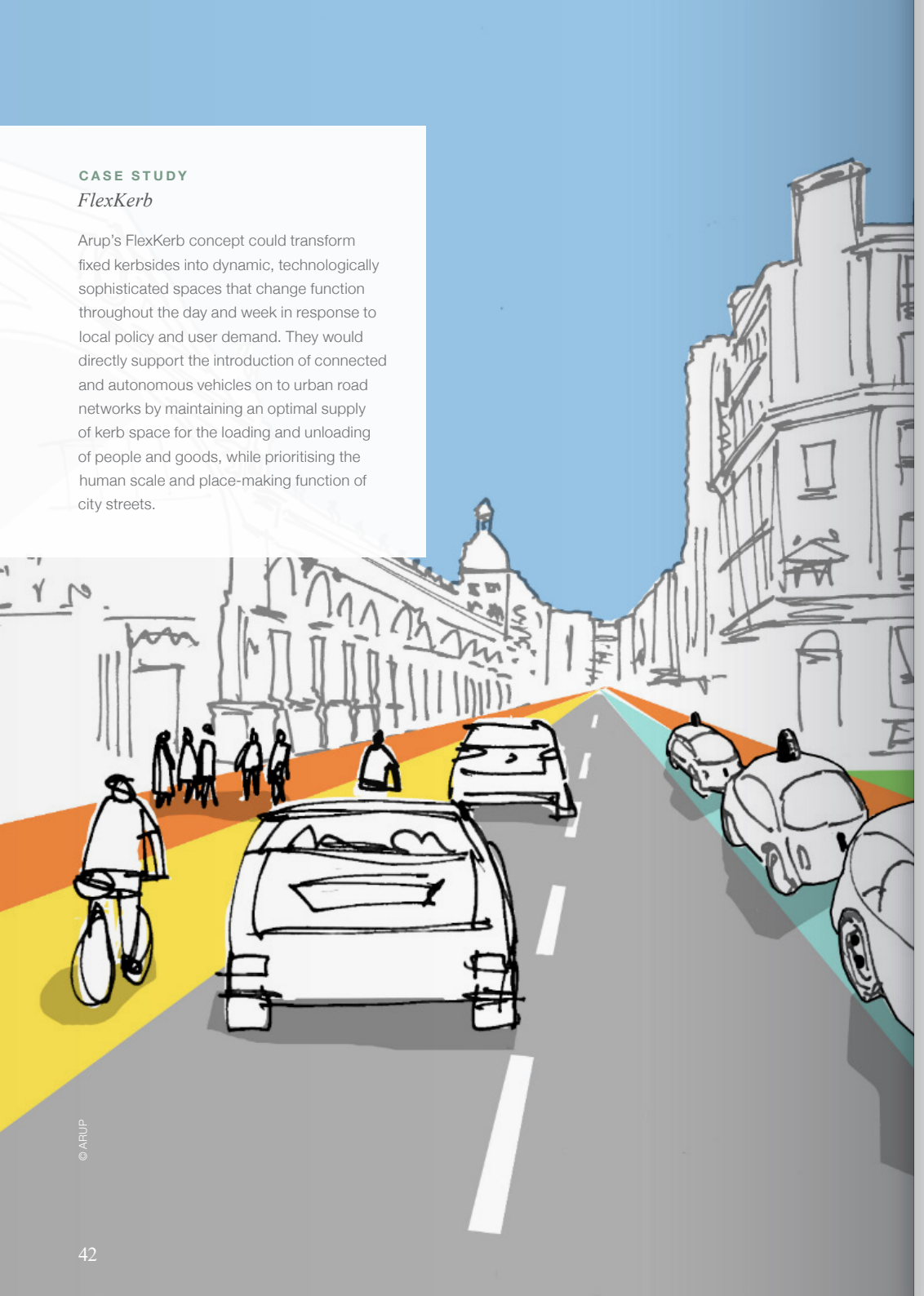
The future success of stations and their ability to attract passengers will depend on stations operating as one simplified system – keeping people, freight, deliveries and waste moving – in a coordinated and seamless way. An increasingly diverse and continually evolving mix of uses, services, modes and operators will need to be flexible and adaptable in the face of change. But priorities will remain: transit in all its forms must be enabled to perform well, and the user experience optimised to make transferring easy and enjoyable for all.



CASE STUDY

FlexKerb

Arup's FlexKerb concept could transform fixed kerbsides into dynamic, technologically sophisticated spaces that change function throughout the day and week in response to local policy and user demand. They would directly support the introduction of connected and autonomous vehicles on to urban road networks by maintaining an optimal supply of kerb space for the loading and unloading of people and goods, while prioritising the human scale and place-making function of city streets.



STATION ACCESS

Facilitating access to stations by locating them within the heart of communities rather than on the periphery will be vital to encourage the uptake of sustainable transport modes. Those accessing city stations will benefit from the redistribution of street space to people, shorter first- and last-leg connections, safe journeys for active modes and a high-quality public realm. Establishing safe connections to the station for walking and cycling – whether underground, via the forecourt, at grade or elevated above and through buildings – is important, particularly as new modes are developed, such as e-scooters and autonomous vehicles. This could be achieved through design interventions that link existing infrastructure, or requirements for private developers to provide high-quality pedestrian links in return for bonus floor area.

As new modes of transport, such as autonomous vehicles, increase in variety and number, the application of emerging technology to streets and places promises an integrated network approach to managing space and prioritising modes. This will enable dynamic and real-time allocation of finite street space and kerbs. In addition, as private car ownership falls, so will the need for vehicle parking provision; therefore, parking facilities can be repurposed as pick-up points.

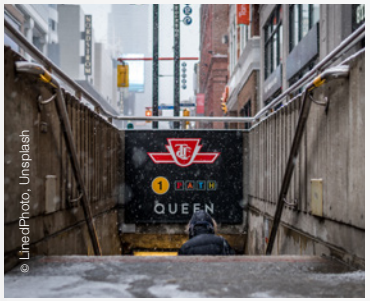
Acceleration in the uptake of shared and low-emission mobility, such as e-bikes and e-scooters, together with the need to de-clutter spaces for pedestrians and maintain security, will require stations to incorporate innovative parking, docking and charging infrastructure. Underground facilities integrated into the station and neighbourhood fabric – such as Utrecht Centraal station's 12,500-space cycle garage[45] and Tokyo's Kasai metro station's 9,400-space automated subterranean parking facility[46] – could be powered via renewable energy and supported by induction- or solar-powered ReCharge Parklets[47] and designated geo-fenced zones. As the number of shared mobility providers expands, stations will need to work with them to manage and monitor their fleets to operate as a unified system.

12,500

cycle spaces integrated into Ultrecht Central Station's underground.

9,400

cycle space automated subterranean parking facility at Tokyo Kasai metro station.



CASE STUDY

PATH, Toronto

PATH is the world's largest underground pedestrian walkway network, comprising 30km of walkways that link 1,200 shops, restaurants and services, and ten subway and LRT stations. Complete with its own wayfinding system, it is used by over 200,000 commuters on an average business day, providing direct access to more than 50 office buildings.

MOVEMENT THROUGH THE STATION

Flexible design and planning of the core area layout of stations – informed by real-time data responding to demand (see section 2) – can facilitate seamless traffic movement. Separation of routes based on speed, convenient spatial links between modes, and synchronisation of service delivery will all enhance ease of use. The removal of gate lines will also support faster and easier interchange, and spatial permeability more broadly. Here, passenger screen doors could work to demarcate platform space, in addition to keeping station users safe. At one extreme, platforms could be integrated directly into the public realm, dissolving the station boundary altogether.

Where appropriate, stations need to work with mobility providers to ensure ease of transfer on to cycle-friendly public transport, designing circulation routes that allow people to cycle or scoot straight on to the onward mode. Cyclists can already do this in Amsterdam when catching the ferry across the IJ river to Amsterdam Noord[48], and in Copenhagen where commuter trains have dedicated cycle carriages equipped with storage racks. Similarly, priority boarding together with step-free access will assist pushchair and wheelchair users. In the case of new electric modes, innovative design approaches will be needed to make sure people are aware of vehicle proximity, given a reduction in conventional acoustic cues.

The launch of 'mobility as a service' (MaaS) platforms, bringing together all mobility providers on to one subscription-based payment and booking platform, will allow users to easily change between multiple modes and operators. Supported by personalised navigation features, and live data, passengers will be able to compare prices, travel times and options for shared mobility. Over time, through the application of artificial intelligence with machine learning linked into real-time data affecting trips, personalised suggestions will be possible for the best option available at the time of travel.

EFFICIENT AND FLEXIBLE SYSTEMS

Future stations will embrace emerging data-driven technologies to make transport systems more efficient and flexible and improve the passenger experience. This includes sensing systems, feedback loops and machine-learning engines that respond to transport demand. Coupling these technologies with autonomous systems promises significant time saving and convenience for customers through reduced waiting and disembarkation times, and more personalised services; a hierarchy of users can also be built in, i.e. prioritising buses at peak times.

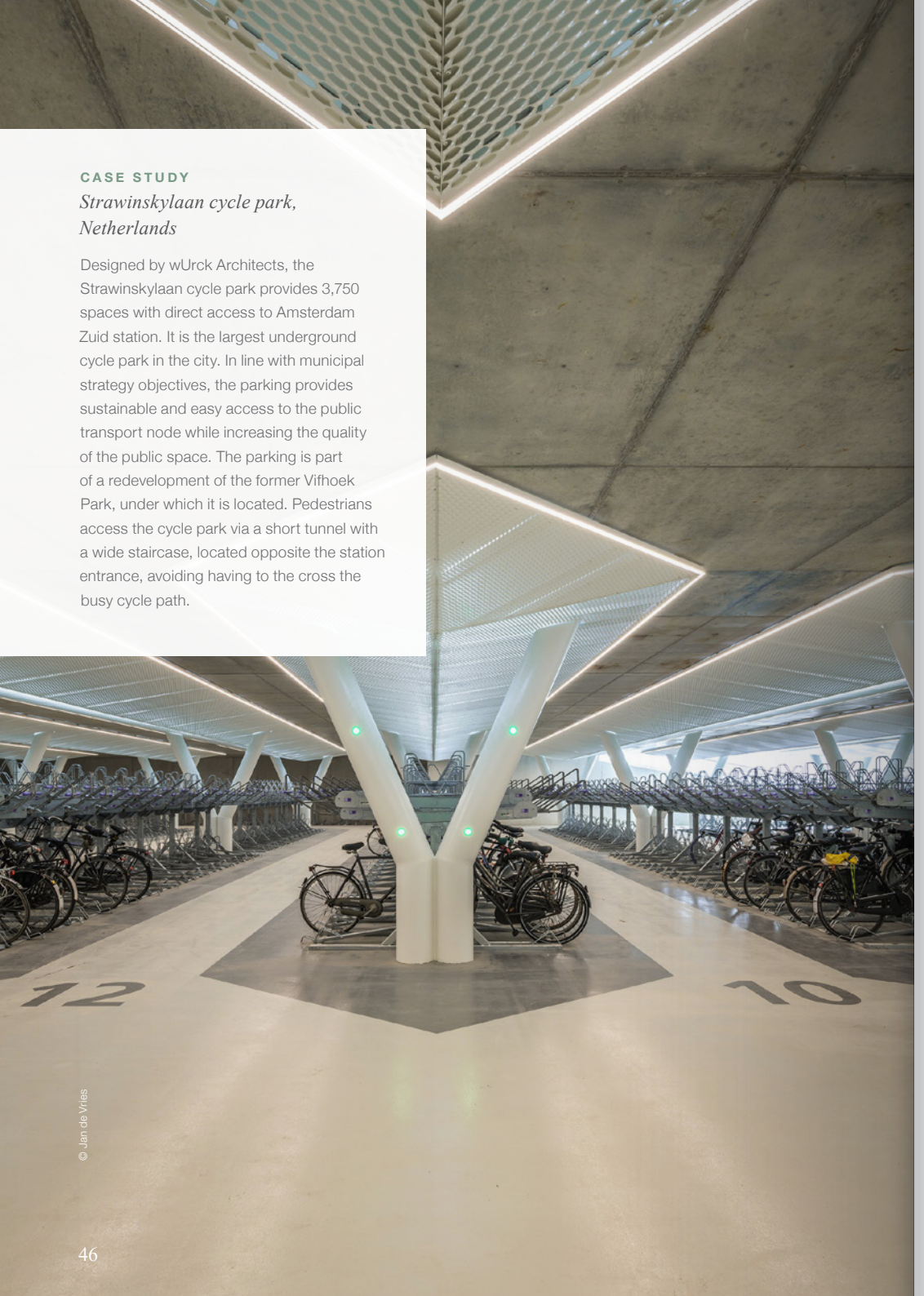
Automated systems and flexible routing can also offer enhanced station capacity and optimisation of assets. Riccarton Bus Terminal in Christchurch, New Zealand for example, allocates platforms in real-time enabling a more compact design and reduced walk times for passengers, while optimising platform utilisation.

Despite increased efficiency, stations will still need to integrate spaces and facilities for people to wait and linger, combining functionality and comfort.

CASE STUDY

In-town check-in, Hong Kong

The service allows passengers to use an Octopus smart card or Airport Express ticket to check-in for their flights at the train station, between 90 minutes and sometimes up to a day in advance. Passengers can check-in bags at either of the centrally located stations for no additional fee. More than 60 airlines offer the service.



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CASE STUDY

Strawinskylaan cycle park, Netherlands

Designed by wUrck Architects, the Strawinskylaan cycle park provides 3,750 spaces with direct access to Amsterdam Zuid station. It is the largest underground cycle park in the city. In line with municipal strategy objectives, the parking provides sustainable and easy access to the public transport node while increasing the quality of the public space. The parking is part of a redevelopment of the former Vifhoek Park, under which it is located. Pedestrians access the cycle park via a short tunnel with a wide staircase, located opposite the station entrance, avoiding having to the cross the busy cycle path.

PERSONAL DELIVERY SERVICES AND AIRPORT CHECK-IN FACILITIES

To meet increasing demand for convenience, stations will need to integrate new services to attract, accommodate and retain users and meet demand from the station neighbourhood. The proliferation of click-and-collect services and lockers in stations indicates that they are already becoming hubs for personal deliveries. The 2018 decision to install Amazon Lockers in nearly 1,000 French train stations is perhaps the largest single roll-out to date.[49] Retailers are also now offering to receive packages on behalf of individuals, substantially reducing failed delivery rates for logistics companies. Developments in additive manufacturing and the availability of 3D printers at stations will enable some components to be produced onsite, removing the need for transportation.

As well as offering more services for the receipt of goods, stations of the future will provide services to free people of goods – and support the uptake of public transport in the process. To relieve customers of carrying luggage on public transport or opting for a taxi to avoid the trouble, more stations will have airport check-in facilities, as already available in Hong Kong,[50] Abu Dhabi,[51] Taipei[52] and Seoul.[53]

Stations might also offer automated or human concierge services, providing delivery of a personal item – such as a pushchair or sports gear – to a designated location at a selected time, enabling passengers to enjoy easier onward journeys.

OPERATIONS AND LOGISTICS SYSTEMS

Previous attempts to integrate freight and other services into existing stations and their networks – through trials of night-time deliveries or freight carriages added to passenger trains – have compromised passenger journeys or been commercially non-viable for reasons of scale. Indeed, cities including Houston and Chicago are actively working to remove the legacy of rail freight from city centres, de-coupling them from passenger networks and roadways to improve safety and reduce congestion.[54]

However, with the development of autonomous, real-time and dynamic systems, combined with the impetus for cities to look for innovative solutions to the exponential growth in e-commerce activity, there is the potential to engage future stations and new modes in reducing land-based congestion. For high-speed rail or commuter services, advanced robotics and tray technology could transfer goods from transit to station during the wait time at platforms. Thereafter, predictive analytics, IoT and smart-tracking technology could be employed to transport the goods through the station and on to the last leg of their journey.

All emerging Hyperloop designs also include provision for light urban freight, whether in separate pods using the same network as passengers, integrated in the belly of trains as in aircraft, or as separate carriages. (There is debate, however, as to whether Hyperloop presents a genuine alternative to mass air travel or merely a new mode of expensive, luxury transport).

In committing to carbon neutral station environments, priority will be given to last-leg deliveries by foot, cargo/e-cargo cycles, and models that leverage existing movements, networks and spaces, i.e. freight-on-transport and informal logistics models enabling peer-to-peer deliveries.[55] Stations will need to actively manage the integration of land-based droids such as the Starship Delivery Bot, as well as protecting air rights for the use of drones.[56]

With logistics centres being squeezed out of many cities because of high rents, some stations could use existing networks and evolve into micro-consolidation centres. For example, the Chapelle International logistics hotels project in Paris offers a combination of railway shuttle and road transport to move goods into the city centre in an efficient and environmentally friendly way.[57] However, any considered approach to passenger-freight integration will need to be made on a city-by-city basis, determined by legacy systems and the extent of the congestion challenge.

WASTE AND RECYCLING SYSTEMS

Pressure from increasingly environmentally aware citizens, combined with potentially greater waste production within stations, means that stations need to embrace circular economy principles and consider waste as a resource. Sophisticated smart waste systems will reduce waste going to landfill by using localised recycling and composting systems, together with smart hold systems that reduce the number of waste pick-up trips where relevant.

Smart monitoring and use of data will enable station managers to understand and manage tenant and customer requirements, and procurement strategies will promote integrated delivery and waste management systems to limit trip activity, including throughout construction periods. In London, the Bond Street Waste Consolidation Project reduced waste service providers operating in the street from 47 to five, cutting vehicle movements from 144 to nine trips a day.[58]

CHAPTER 4

Key takeaways

HEALTHY STREETS
City authorities and station owners should invest in high-quality active travel links and public realm improvements in and around the station precinct, making it part of a porous walkable urban environment.

MICROMOBILITY INFRASTRUCTURE
Station design should aim to integrate parking, charging and docking infrastructure and end of trip facilities, supporting the uptake of low-carbon and active modes.

FLEXIBLE KERBS
Integration of dynamic kerbside systems and flexible charging with local mobility-as-a-service platforms will help operators prioritise, manage and optimise value from pick-up and drop-off zones.

SEAMLESS TRANSFERS
Improvements to the transfer experience through circulation design, service synchronisation and mobility-as-a-service platforms, will encourage (faster) interchange and an optimal journey.

EFFICIENT AND FLEXIBLE SYSTEMS
Investment in automated transit systems, flexible routing and dynamic platform allocation will enhance station and modal capacity.

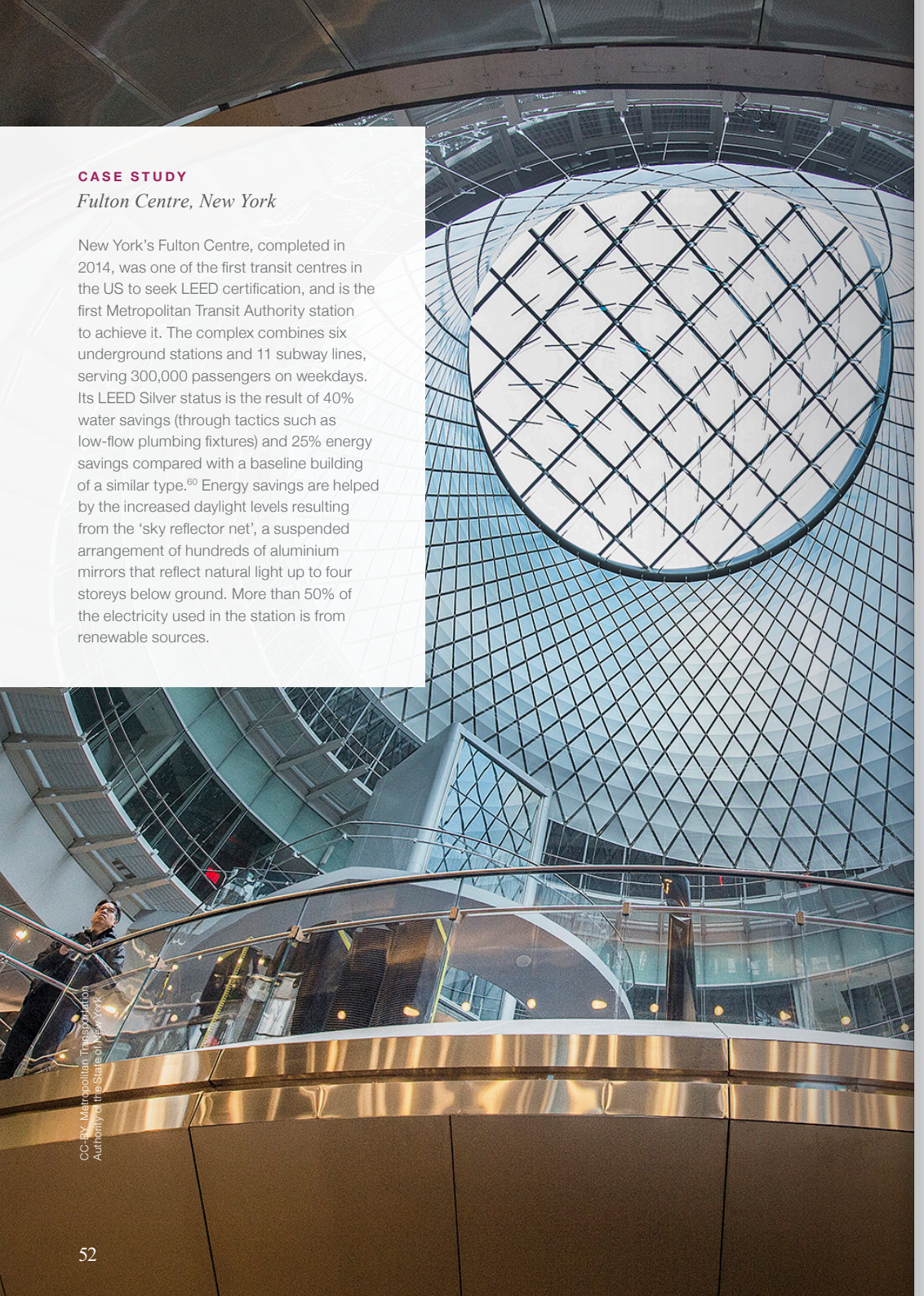
PERSONAL ITEMS AND GOODS
Station design should integrate new personal pick-up and drop-off services including drone and robot delivery and airport check-in facilities to meet demand for convenience and baggage-free travel.

INTEGRATED SOLUTIONS
The coordinated (automated) and relevant movement of freight, waste and people into station environments and via existing transport networks could alleviate land-based congestion.

CHAPTER 5

Catalysts for sustainability and resilience

The transport sector is the fastest-growing contributor to climate emissions,[59] the result of increased energy use by land transport globally, including cars, and by growth in freight transport. Mass and shared transit have a considerable role to play in providing a sustainable mobility future through renewable, electric or hydrogen-powered vehicles, greater energy efficiency and lower resource use. The contribution of stations to achieving the UN Sustainable Development Goals is also significant: their scale, strategic locations and high throughput make them valuable sites to help improve the environmental sustainability of the urban realm and add to its resilience.



CC-BY Metropolitan Transportation Authority of the State of New York

CASE STUDY

Fulton Centre, New York

New York's Fulton Centre, completed in 2014, was one of the first transit centres in the US to seek LEED certification, and is the first Metropolitan Transit Authority station to achieve it. The complex combines six underground stations and 11 subway lines, serving 300,000 passengers on weekdays. Its LEED Silver status is the result of 40% water savings (through tactics such as low-flow plumbing fixtures) and 25% energy savings compared with a baseline building of a similar type.[60] Energy savings are helped by the increased daylight levels resulting from the 'sky reflector net', a suspended arrangement of hundreds of aluminium mirrors that reflect natural light up to four storeys below ground. More than 50% of the electricity used in the station is from renewable sources.

IMPROVED ENVIRONMENTAL PERFORMANCE

Stations' spatial qualities make them prone to high energy use.[61] Typically, their large floor space, porous building envelope, high ceilings, high occupancy and 24/7 operation requires considerable energy in terms of climate control, lighting and internal transportation systems (such as lifts and escalators). Increases in station footprint, global climate fluctuations and growing consumer expectations around comfort and accessibility are also likely to add to stations' future energy demands.

The first goal should be to reduce energy demand and resource use. Passive design can support demand reduction, with tactics including building orientation, thermal mass, and the use of daylight and natural ventilation.[62] Inspired by traditional mashrabiya, the permeable west-facing façade of Casablanca's Casa Port station achieves this by providing shade from direct sunlight while allowing cool breezes into the station.[63]

Intelligent building control systems can help to optimise the performance of multiple building systems, including HVAC, power distribution and lighting, and are applicable to both new and retrofitted station projects. Advances in sensor technology and artificial intelligence promise to deliver further efficiency gains, from intelligent AHU and HVAC systems based on real-time occupancy to adaptive lighting. Research suggests that intelligent controls could help reduce energy use in station buildings by as much as 40%.[64]

MATERIAL AND STRUCTURAL CHOICES

Innovations in construction methods and materials will help to improve station sustainability. Current approaches to construction are characterised by high carbon emissions, ecosystem pollution and unsustainable water extraction; in the EU, construction and demolition waste account for about 25-30% of all waste generated.[65]

The circular economy challenges this paradigm, proposing a shift from our current 'linear' take-make-use-dispose pattern, towards a system where assets are designed and built to be more durable, materials reused or recycled, and natural capital preserved and enhanced. This approach is also a key tenet of UN Sustainable Development Goal 12 (sustainable consumption and production).[66]

Station design that reduces total material use should be paramount. Alongside this, 'design for disassembly' supports the recovery and reuse of building materials at the end of the station's life. Designing-in the potential for future material recovery encourages the safe and appropriate use of second-hand materials in construction more broadly.

Recycled concrete, steel and plastic are also viable material options, with innovations such as recycled plastic bricks and CO_2 absorbing concrete additives increasing their effectiveness. More than 20% of the construction materials used on New York's Fulton Centre contained recycled content and were sourced locally.

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CASE STUDY

Nuevo Norte, Madrid

The Madrid Nuevo Norte project is revitalising a 300-hectare district in the Spanish capital. At the heart of the scheme is Chamartín station – an integrated public transport and high-speed rail hub. Local and regional authorities, the ministry of public works, the national railway body, private investors, developers and residents have collaborated on the development, with sustainability a central tenet. The site connects to the rest of the city by a 450,000m² 'green corridor' that includes parkland, playgrounds and green spaces. Here, developers have sought to restore the area's natural hydrological processes as part of a resilience approach, including natural drainage and stormwater management.

Depending on the end-of-life disposal scenario, timber can result in a net-zero carbon impact, while its lighter weight also provides opportunities to build with reduced foundations, for example, on top of station buildings.[67] It can also be reused and remanufactured as part of a circular component-based construction system.[68]

A new generation of experimental biomaterials also promises reduced environmental impact, including textiles from banana fibres, mycelium-bound construction materials, and peanut-based particle board. As with timber, novel materials such as these will need to satisfy stringent durability and fire performance requirements for use in stations, increasing the R&D challenge.

Beyond the materials themselves, modular construction and the use of standardised and prefabricated components across a network of stations could reduce construction waste and support reuse and repurposing. UNStudio's Hardt Hub concept for a proposed Hyperloop route between Amsterdam and Frankfurt uses a modular design to organise and link multiple station spaces and adapt to different contexts.[69] The triangular modules can contain different functions – including baggage check-in, cycle parking or pocket parks – while their configuration adapts to each site, for example a small town airport or a new city-scale development. The interchangeability enabled by modular construction also supports the easier adaptation of station functions over time.

CASE STUDY

Flood prevention, New York

After Hurricane Sandy in 2012, New York's Metropolitan Transit Authority installed flood-prevention systems across its network, supported by Arup. Surface-level subway entrances and stairwells are one of the most vulnerable points, allowing stormwater and debris to flood into the network. Traditional flood-prevention techniques utilise sandbags or aluminium flood logs; however, these require multiple components and are labour intensive to assemble. Engineering manufacturer ILC Dover designed a flexible flood-proof stairwell barrier from layers of coated fabric and Kevlar webbing. The Flex-Gate sits permanently above subway entrances and can be deployed in 5-10 minutes. Unlike other solutions, structural reinforcement is not needed, helping to minimise costs.

© Lerone Pieters

HUBS OF ENERGY GENERATION AND DISTRIBUTION

The unique characteristics of station typologies provide multiple opportunities for clean energy generation. These include solar power (on roofs or platform canopies), waste heat recovery (from electric motors and brakes) and near-surface geothermal geotechnics (in underground tunnels).[70]

Waste energy was the target of Transport for London's 2015 trial of a regenerative braking system on the Victoria Underground line. Within the first seven days of the trial, the inverter technology – which recovers energy from braking trains as they approach a station platform – had recovered enough electricity to power a large underground station for more than two days a week.[71] In addition to reclaiming energy, the technology also reduces the amount of heat produced by braking trains, in turn reducing demands on station climate controls.[72]

Above ground, platform canopies provide an ideal surface for solar power generation. Many station solar roofs are already in operation, including at Nanjing South station in China, where integrated photovoltaics have an estimated 7.17MW capacity.

Station energy demands will also grow and become more complex as diverse forms of e-mobility become commonplace. Clean energy generated at the station could be used to charge shared autonomous vehicles, e-scooters and delivery drones onsite. Microgrids and new forms of energy storage will also help to support these increased loads and distributed sources, supported by accurate demand predictions.[73]

Beyond the building itself, transport interchanges have the capacity to work as central nodes in district-wide energy systems, supporting new sustainable neighbourhoods. Multiple stations have already pioneered district heat systems, for example, where excess heat from various sources (i.e. transport networks, factories and data centres) is combined into a single network and reused to heat local homes and businesses. In London, businesses and 1,450 homes are currently powered by waste heat from the Northern Line, and the scheme could cover up to 63% of the city's heating demand by 2050.[74] Vienna Hauptbahnhof in Austria successfully initiated a district cooling system in 2015, locating a refrigeration centre beneath the station's platforms. When fully operational, the system will have an output of 25MW, with the capacity to cool approximately 500,000m^2 GFA.[75]

Circular systems such as these are part of a broader view of stations as key actors in district- or city-level systems, using their strategic locations to add value beyond their transport function. This is another facet of stations' increased permeability and connection to their context. This role will become more significant given the pressures of population growth on space and energy demands, and the need to radically reduce global carbon emissions. Their related function in terms of transit-oriented development, regeneration and social mobility is discussed in section 6.

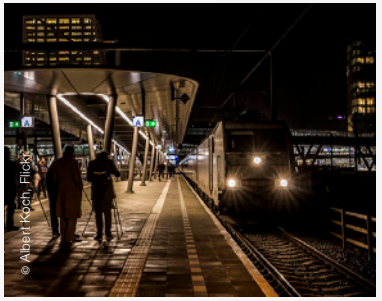
7.17MW
capacity of the integrated photovoltaics at Nanjing South Railway Station in China

RESILIENT INFRASTRUCTURE

Stations should play a central role in combating the effects of urban densification and pollution. Reducing the introduction of pollutants should be the first goal, for example by limiting onsite combustion (vehicle emissions, gas boilers, and a switch to battery electric and hydrogen fuel cell trains), followed by measures to tackle local pollution and climate effects more generally. Green walls and roofs can absorb noise, provide insulation, reduce the urban heat island effect and, in some cases, improve local air quality.

Beyond the station building envelope, forecourts or boundaries that feature large areas of tarmac, concrete or paving provide an opportunity for multi-functional urban spaces that are part of city-wide resilience strategies, such as stormwater management, rainwater collection and adaptable infrastructure. Enghave Park in Copenhagen, Denmark, combines climate resilient city infrastructure with a multi-functional public space: a tiered amphitheatre, football and hockey pitches are all built below grade and can transform into surface water tanks in the event of extreme rainfall.

Spaces such as these provide opportunities to restore natural processes and improve biodiversity. Plans for the public realm around a ferry terminal in Auckland, New Zealand, aim to reconnect people with the harbour as well as supporting coastal and marine habitats. Here, floating pontoons that support kelp growth and mussel ropes will help to filter and improve water quality.[76]



CASE STUDY

Adaptive lighting, Netherlands

Beilen, Hoogeveen and Meppel stations have installed an adaptive lighting solution to reduce energy consumption and address local concerns about light pollution. Lighting on station platforms dims to 40% during off-peak hours; when motion sensors are activated, the relevant lighting returns to full brightness.

> It will be crucial for stations to remain operational in the face of natural disasters or sudden shocks. This includes the integration of hostile vehicle mitigation into landscape design, and evacuation strategies that reflect more permeable station boundaries. In addition, city authorities and transport operators will want to avoid the economic impact of closure and costs to repair any damage from extreme weather.

As people move away from private vehicle ownership and become more reliant on shared and public systems, it will be crucial for stations to remain operational in the face of natural disasters or sudden shocks. This includes the integration of hostile vehicle mitigation into landscape design, and evacuation strategies that reflect more permeable station boundaries. In addition, city authorities and transport operators will want to avoid the economic impact of closure and costs to repair any damage from extreme weather. It is estimated that the effects of Hurricane Sandy on New York City's transportation system in 2012 cost US$4.8bn to repair.[77]

Climate change will lead to an increase in extreme weather events and the associated damage and disruption. Retrofitting existing transport interchanges and designing-in adequate protection and mitigation – both in stations and the surrounding urban landscape – is the shared responsibility of designers, asset owners and city authorities.

CHAPTER 5

Key takeaways

ENVIRONMENTAL PERFORMANCE

Station spaces can improve environmental performance with intelligent building control systems, low-energy lighting and renewable energy sources. Demand reduction for both energy and materials will have the biggest positive impact.

CARBON NEGATIVE

Owners and operators should demonstrate a clear path towards achieving carbon negative stations, including opportunities for onsite renewable energy generation, including regenerative braking systems and solar power.

MODULARITY

Designs that use modular, recycled and reusable components can reduce a station's carbon footprint and limit material waste, with standardised and prefabricated elements applicable across a network of sites and spaces.

DISTRICT ENERGY SCHEMES

Larger stations should consider using excess power as part of district energy schemes, providing heating, cooling or electricity locally as key actors within sustainable neighbourhoods.

GREEN INFRASTRUCTURE

Station perimeters should integrate green infrastructure including stormwater management, green walls and porous pavements to combat the effects of pollution and urban densification and contribute to city-wide resilience.

CHAPTER 6

Urban regeneration and (social) mobility

Stations can act as nodes within the greater urban and mobility ecosystem by facilitating regeneration, economic vitality and social mobility. They can be drivers for inclusive and sustainable growth, and stimulate the development of vibrant, mixed-use communities.

CASE STUDY

King's Cross and St Pancras, London

The redevelopment of King's Cross and St Pancras stations together with the planned redevelopment of Euston station sought to move beyond a pure transit investment towards an integrated transport and land-use approach to catalyse economic development. The benefits quantified included traditional transport-related and economic benefits, as well as wider socio-economic ones. This included the capacity for future growth beyond a 30-year appraisal framework, a gateway for London as an attractive place to live, work and invest, and improved connections to elsewhere in the city to generate future demand. The improvement to the pedestrian environment has been hailed as a major factor in the station becoming a destination in its own right.

© Andy Gardner/Arup

STRATEGIC DENSIFICATION

Worsening congestion worldwide is costing cities in terms of wasted time, increased pollution, challenges with transporting goods, higher incidents of accidents, reduced productivity and increasing social inequality. In 2018, road congestion in London is estimated to have cost the UK economy nearly £8bn.[78]

Stations can help to tackle urban congestion and promote regeneration by providing good access to public transport and by facilitating transit-oriented developments (TODs), which can unlock housing potential alongside other uses. There are worldwide housing shortages – England, for example, is forecast to need 240,000-340,000 new homes a year to meet population growth[79] – so governments are increasingly looking to stations as anchors for the next generation of urban housing developments.

Previously underused areas of land can also be released for development by integrating multiple transport modes at stations. For example, in Greater Mumbai, the many job centres within satellite towns are connected by numerous transport modes – suburban rail, metro, monorail, public buses, auto-rickshaws and pedestrians – which all feed into suburban rail stations.

As stations support the shift towards public transport in cities by investing in mass transit systems, cities need to make an effort to redevelop station areas and neighbourhoods along these mobility spines. To achieve this, land use, transport planning and investment need to be aligned. Delhi and Ahmedabad are currently doing this by introducing policies to support higher-density TODs around stations and their environs, offering good access to the mobility corridors.

© Urban Land Conservancy

CASE STUDY

Urban land conservancy, Denver

The Urban Land Conservancy (ULC) is a not-for-profit community land trust that provides affordable rental homes and ongoing maintenance of community facilities and schools. It ensures an affordable lifestyle as well as an affordable place of residence. More than US$15m from public, private and not-for-profit partners has enabled the ULC to buy land near existing and planned transit stations and sell building rights to partners who commit to using the land for community benefit. The close proximity of these to transport nodes also ensures services, facilities, education and employment opportunities are accessible to residents.

ENABLERS OF INCLUSIVE GROWTH

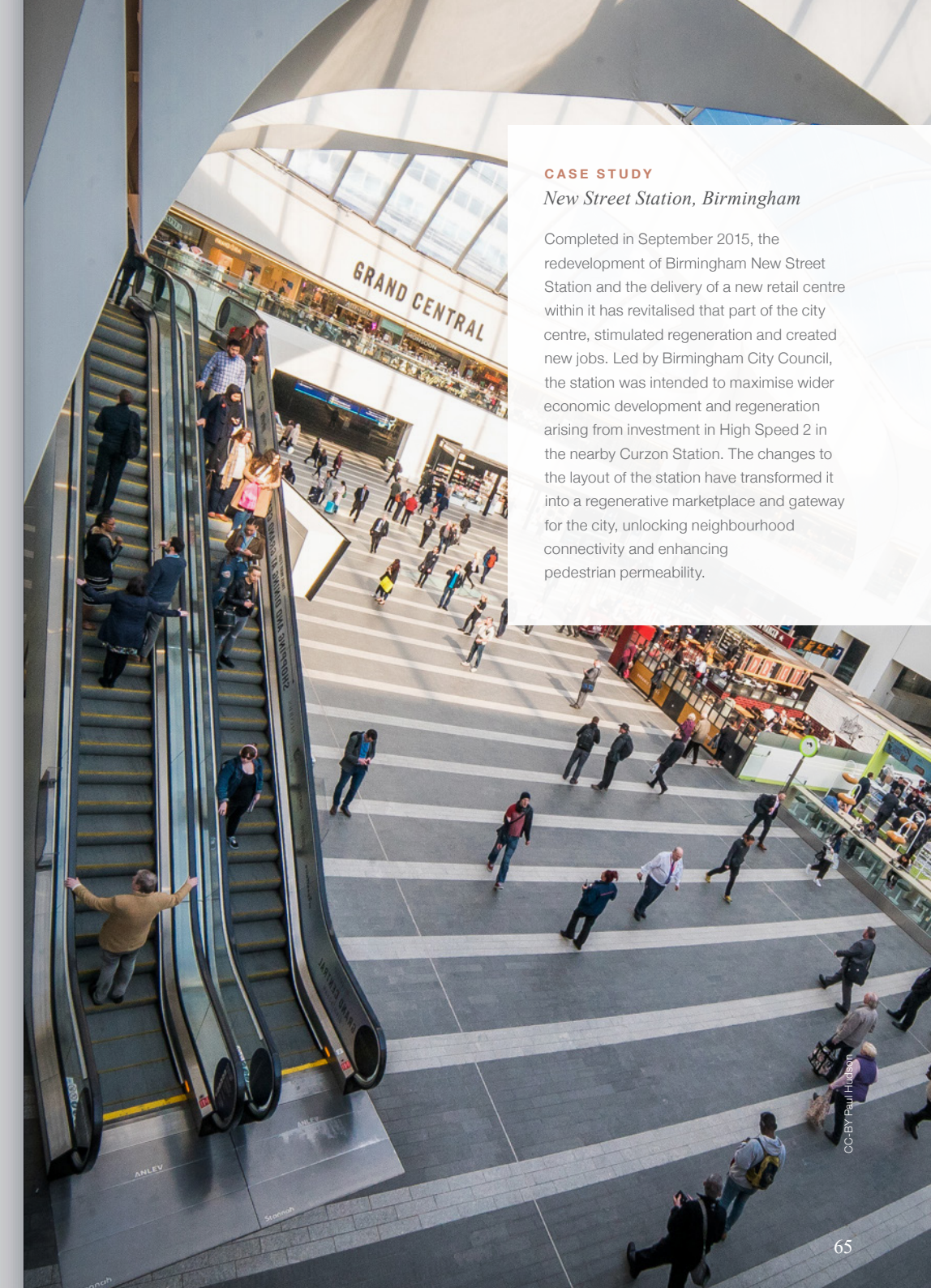
The high land values around stations attract investors and if station owners take on the mantle of estate managers and developers, they can maximise the economic and commercial value of their assets. This unlocks development potential and long-term value creation through a dynamic mix of uses and multi-functional spaces, establishing synergies with adjoining sites and developments that benefit from station connectivity.

Stations can also catalyse outward investment, where surrounding communities can benefit from investment in utilities, infrastructure and services in the stations' precincts. King's Cross and St Pancras in London and Birmingham New Street are good examples of station developments as epicentres of growth.

Measures need to be in place to ensure that existing communities do not get pushed out from redevelopment projects around stations, but benefit from them. The goal should go beyond affordable housing to affordable lifestyles. Land immediately outside stations that is less commercially attractive but still easily accessible can be used to support a thriving community, with integrated public services such as well-being centres, training hubs or police stations. Enabled through public ownership and/or public-private partnerships, these hubs could promote cross-sector collaboration for enhanced community well-being (see section 3). Stations can provide many employment prospects: from construction and development, to operation and service provision. And, of course, as transport hubs, they offer access to opportunities beyond the neighbourhood. Stations also have a role in enabling businesses of all sizes to flourish. For example, in the UK, stations work with local Business Improvement Districts to create thriving mixed-use communities, where small innovators can succeed alongside larger more established firms, and existing local businesses with high social value are given the chance to thrive.

£8bn
cost to the UK economy from road congestion in London

340,000
new homes a year need to be built a year in England to meet population growth



CC-BY Paul Hudson

CASE STUDY

New Street Station, Birmingham

Completed in September 2015, the redevelopment of Birmingham New Street Station and the delivery of a new retail centre within it has revitalised that part of the city centre, stimulated regeneration and created new jobs. Led by Birmingham City Council, the station was intended to maximise wider economic development and regeneration arising from investment in High Speed 2 in the nearby Curzon Station. The changes to the layout of the station have transformed it into a regenerative marketplace and gateway for the city, unlocking neighbourhood connectivity and enhancing pedestrian permeability.

CASE STUDY

Transit Oriented Development, Guangdong

To remain globally competitive, while meeting regional and local needs, Guangdong's Foshan City is using 104km of metro links to string together its townships and urban areas through the development of 52 stations. Five different models and associated land uses have been developed with the intention that these can be adapted in accordance with the local needs of each place: new city model; industrial/community integrated model; synergistic model; interchange hub model; and connection enhancement model.

STATION IDENTITY

Stations are often the first and last impression of a place; they serve a central role in developing the identity, and shaping the perceptions, of the city. Emphasis may be placed on architectural value, such as New York's striking World Trade Centre transportation hub, designed by architect Santiago Calatrava.

Alternatively, the life cycle of stations can be used to instil local and cultural identity through design to generate a stronger sense of place, as seen in the Metroselskabet's Cool Construction initiative in Copenhagen, that turns construction site hoardings into temporary public spaces for the benefit of neighbours and passers-by.[80] It may be more appropriate for some stations to embed themselves into their locality, taking account of context and local issues. Martin Place in Sydney, for example, has been designed to integrate with the historic heritage of its environments, as well as providing new commercial and public spaces, and opening up new pathways across the city.

TODs may take the form of decking over stations, building alongside a transit line, or throughout a broader neighbourhood. But in all cases, the design chosen to unite the station with its surroundings should create vibrancy during the day and a sense of safety at night.

By developing in a radial, open manner, stations become permeable environments that people walk through into the urban fabric and network of green spaces further afield. As extensions of city streets, guides such as the Healthy Streets indicators could be equally applied to stations, with a focus on elevating the pedestrian experience for all users.

REGIONAL AND SOCIAL CONNECTIVITY

Stations have a growing role in promoting local urban mobility and meeting the needs of urban centres, by connecting previously disjointed districts and improving access to opportunities. Leeds station in the UK, for example, developed a growth strategy as part of a requirement for all High Speed 2 stations. This looked first at the needs of the city to determine its function and typology that, in turn, would unlock and optimise economic and social mobility.[81]

Long-term growth plans for cities and regions necessitate locally-specific but regionally-integrated development, and for that, they need to be physically well connected. This will become more important as inter-regional travel promises to become faster with the expansion of high speed rail globally, or even the introduction of new modes such as Hyperloop. Models such as those used in the Foshan Transit Oriented Development project in China could be adopted and adapted for different locations.

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CASE STUDY

Free public transport, Luxembourg

Luxembourg is set to become the first country to make public transport free. Initially it was free for children and young people under the age of 20, but by 2020 it will be free to all. Fares on trains, trams and buses will be lifted in an effort to curb some of the worst congestion in the world. More than 180,000 people living in France, Belgium and Germany cross the border to work in Luxembourg, increasing the country's population by almost a third.

NON-FARE FUNDING AND FINANCING MECHANISMS

The benefits of stations go well beyond the provision of transport. Initiatives such as the UK Rail Safety and Standards Board's Common Social Impact Framework for Rail measures its social impact value as a system. As these wider social, economic and environmental benefits are recognised, governments and local authorities may rethink their budget planning and benefits appraisals and seek opportunities for cross-sector financing.

Station developments stimulate a rise in property values, and stations will capture and redistribute land value uplift for the benefit of the community. Stations can look to alternative financing models such as tax increment financing – the primary tool used in the Hudson Yards TOD in New York – to forward-fund investment and stimulate economic activity. Alternative non-fare revenue streams can also be pursued through different development models, such as the Station Redevelopment Programme adopted by India Railways that uses a 'hybrid model' where stations are developed, but commercial land is monetised separately.

Stations could capture financial returns as the uses and functions of stations evolve. With the integration of space-as-a-service models, stations could develop innovative usage-based charges, licensing and fees, and cross-subsidisation through targeted premium offers from both people and goods.

CHAPTER 6

Key takeaways

NEIGHBOURHOOD INTEGRATION

Station environments should integrate with the personalities of the cities in which they are located; public spaces should seek ways to express the local identity and adapt to changes over time.

INCLUSIVE GROWTH

City authorities should adopt inclusive growth strategies and social equity tools to ensure urban regeneration potential is optimised, and that the existing community is the primary benefactor.

DYNAMIC VALUE CREATION

Stations should seek ways to dynamically capture and create value from their assets and from adjoining sites to promote long-term financial sustainability – whether as developers, estate managers or as catalysts for investment.

NEW REVENUE STREAMS

The evolution of the mobility landscape, new station uses and the ability to quantify savings through investment provides opportunities for new revenue streams and cross-sector funding.

CONNECTED NETWORK

Stations should be viewed as part of an integrated and connected network of hubs, where the core objectives and functions of each station are identified to optimise investment.

ONE GOVERNING BODY

All strategic functions – including social, economic and environmental factors as well as mobility – should be streamlined into one governing body coordinating decisions across a consistent geography.

COVID-19

Adapting in times of a global pandemic

While public transport has been hailed as the most environmentally and economically sustainable mobility solution, COVID-19 nearly brought the system to a halt. Yet, throughout the pandemic and even during stringent lockdowns, public transport remained an essential piece of civic infrastructure for many. This has led to the rapid adoption of new hygiene and safety measures and innovations to keep the network operational and safe. Meanwhile, many transitioned to personal cars or active and micro-mobility options including cycling and walking. As restrictions reduced passenger numbers the amount of goods being transported increased, challenging existing freight and logistics networks.

As we transition into a world where life amidst a pandemic may be the new normal, we ask ourselves how our society and the systems we depend upon can adapt and build resilience to future shocks. It will be essential to find solutions that strike a balance between human, economic and planetary health. In some ways the specific COVID-19 responses in transport can be seen as a reflection and a fast-forward to the visions of future stations described in the previous chapters.

Pandemic induced lifestyle changes and technological advances will create longer term shifts that will shape stations and the transport network beyond immediate emergency responses and solutions. Similarly, mitigation responses can play an important part in a green recovery and a longer-term shift towards more sustainable, integrated and inclusive transport systems. Every disruption, while challenging, brings the opportunity to rethink the status quo and make the necessary changes towards a better future.

> "Our current situation offers us a chance to explore the most significant transport behaviour change since the mass-produced private car became a reality. It's time for an informed debate, to review our priorities and develop a shared vision for the future of our public transit networks."
>
> Richard de Cani
> Global Planning Leader

The following interactive illustration outlines the specific implications of the pandemic for station environments, ranging from temporary interventions to long-term adaptation. It addresses crowd management, hygiene and sanitation, active mobility and logistics and finally the emergence of new uses and adaptations.

Photo by Victor He

COVID-19

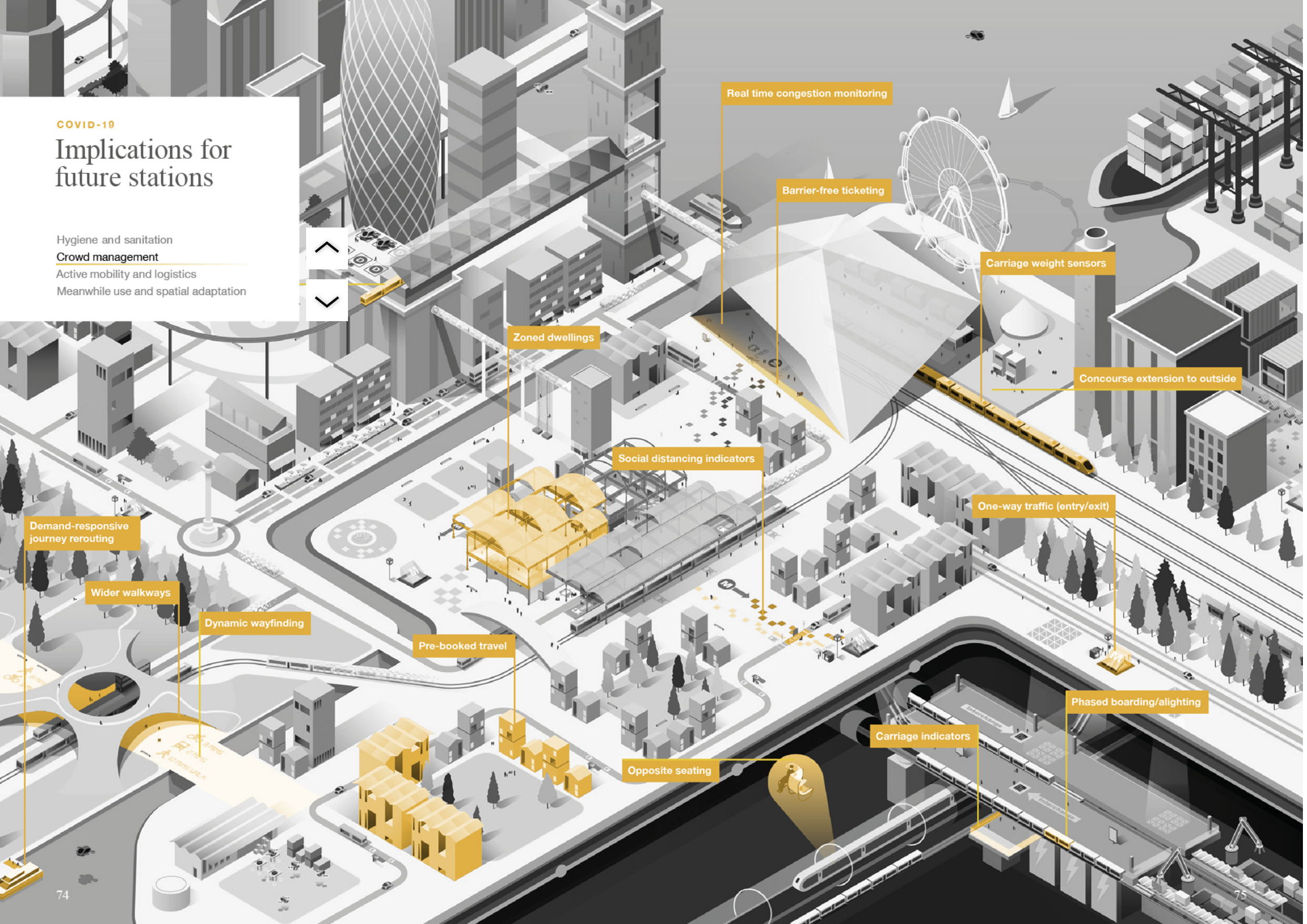
Implications for future stations

Hygiene and sanitation

Crowd management

Active mobility and logistics

Meanwhile use and spatial adaptation



© Luca Bravo

VISION

Welcome to the future station

The future station is a diverse, evolving and porous part of the city. It is a place of interchange, and a strategic location for public services and city amenities that dissolve into the surrounding urban fabric. It is a place of continuous movement and interaction, 24 hours a day.

Multiple transport modes circulate into, out of, above and around one another, autonomously responding to demand, and maximising the flow and experience of people. Travellers are guided by a digital sensing layer that combines real-time data from multiple networks and hubs. Pedestrian routes are intuitive, with personalised support for all ages and abilities where needed.

Interchange between transport modes is seamless. High-speed passengers arrive in a location that best suits their onward journey, whether next to an underground metro or among the green spaces and shops of the public realm. Cyclists hop on fully-charged e-bikes and move freely into and out of the city in a continuous two-way flow. Pick-up points for autonomous vehicles appear when and where needed, before reverting to a walkable streetscape.

Those not travelling are attracted by a quiet, convenient and accessible environment.

The community of users is diverse, with residents, workers, students and visitors taking advantage of complementary amenities and services. Retail space responds to desire and demand, expanding and contracting throughout the day. A health centre caters to locals as well as commuters, while a community arts space attracts new audiences and provides space for people to explore, innovate and make. A human presence supports all station users, from the provision of personalised travel plans to guides for local experiences.

The future station is the heart of its district, with arteries extending out into the surrounding neighbourhood. A circular resource network distributes renewable power, heat and goods. It consumes less energy than it produces, and its fabric is made-up of modular, sustainable materials that are part of a continuous cycle of use and reuse.

The future station succeeds because of integration, investment and partnership. The city, transport operators, station owners, developers and local communities work together to design, assemble and evolve a reciprocal relationship of uses and functions. This benefits the environment, the economy and local people. Rather than just a platform for travel, the future station is a catalyst for a resilient, sustainable and inclusive city.

TICKETLESS AND BARRIER FREE

Vanishing boundaries

5G connectivity, facial recognition, secure digital passports and faster data processing speeds will simplify ticketing and payment even further, supporting gateless transport hubs. This will enable seamless connectivity between modes and blur the boundaries between the city and the station.

DIGITAL TWIN

Real-time demand management

Digital twins of transport networks will enable greater efficiency by combining multiple digital models into a single integrated system. A control centre will help to monitor, predict and alert station operators to any issues, as well as autonomously responding – whether deploying cleanbots, increasing metro frequency or balancing energy consumption.

INCLUSIVE WAYFINDING

Accomodating different uses

Wayfinding through the station will combine digital and analogue layers to support navigation by a broad spectrum of users. This will range from intuitive graphics and colour zoning to embedded digital signage. Circulation spaces will vary to benefit different groups, including children and wheelchair users.

SPACES FOR WELLBEING

Active design

Stations will integrate spaces that support users' mental and physical wellbeing, including safe and convenient cycling and pedestrian routes. Nature will be brought into the station, while redundant spaces will be repurposed for community use, including climbing walls, medical centres and creative hubs.

PERSONAL ASSSISTANCE

Automation and human touch

A human presence will combine with digital systems to provide the best of both: emotional and physical support when needed, and monitoring and efficiency optimisation at the whole-station level. This will support individual autonomy and customer experiences.

FLEXIBLE STATIONS

Spaces that evolve over time

Flexible spaces will allow the fast adaptation of station environments informed by predictive systems. Cafes could expand to make use of underutilised concourse space during quieter periods, while adaptable platforms could be remodelled over time as ridership numbers change.

INTEGRATED MICRO-MOBILITY

Seamless cycle transfers

Active modes will be prioritised in and around station spaces and transport networks. Cycle routes will extend from the city to the platform, with the integration of bike storage within carriages standardised across networks to ease transfer.

RENEWABLE CHARGING

On-site energy generation

Stations will integrate renewable energy generation where relevant. This will help to power their own operations, connect to on-site charging points for electric cars, scooters and bicycles, and form part of district-wide energy networks.

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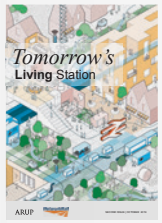
Future of Labs provides an overview of the key trends shaping the future of scientific research that will be of use to planners, designers and administrators involved in laboratory design projects. Science and research are key to addressing humanity's biggest challenges, now and in the future. Creating the right spaces and environments for research to thrive is essential.



There is a huge opportunity for stations to become bustling, multi-modal hubs that are at the centre of movement for people, support inclusive, sustainable and economic growth, and improve the wellbeing of the communities they serve. *Tomorrow's Living Station*, a report created by Network Rail and Arup, explores and identifies the future role stations will play in our towns and cities

Designing for Ageing Communities identifies the specific needs of older people and proposes strategies and actions that cities can take to make communities more age-friendly. The vision shows how communities around the word can achieve this vision and empower their older residents to live happy and fulfilling lives.

Future of Schools examines the key trends changing our understanding of learning and shaping schools of the future. The findings are a synthesis of research and trends across the education sector, with global examples of best practice and insight from industry experts.

ABOUT ARUP

Arup is the creative force at the heart of many of the world's most prominent projects in the built environment and across industry. We offer a broad range of professional services that combine to make a real difference to our clients and the communities in which we work.

We are truly global. From 80 offices in 35 countries our 15,000 planners, designers, engineers and consultants deliver innovative projects across the world with creativity and passion.

Founded in 1946 with an enduring set of values, our unique trust ownership fosters a distinctive culture and an intellectual independence that encourages collaborative working. This is reflected in everything we do, allowing us to develop meaningful ideas, help shape agendas and deliver results that frequently surpass the expectations of our clients.

The people at Arup are driven to find a better way and to deliver better solutions for our clients.

We shape a better world.

Stations are critical pieces of national and urban infrastructure. They are central nodes for inter- and inner-city mobility, provide easy access to facilities and services, and are enablers of economic growth, regeneration and the development of new communities.

The transport ecosystem goes far beyond the physical spaces of stations. This report considers a future in which station boundaries blur – between public and private, physical and digital, the building and the city – and where stations are an enabler for sustainability, well-being and opportunity. Only by recognising the extent of this ecosystem can we begin to understand the complex interactions between its people, spaces and contexts, and how the spaces we create can respond meaningfully to these diverse requirements and desires.

This report provides a review of key trends shaping the future of station design that will be of use to planners, designers, administrators and developers of stations. Our research builds on Arup's recent *Transformative Rail* report to consider the impact of multiple trends on the future design, role and experience of multi-modal stations, informed by conversations with experts across industry and academia.

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