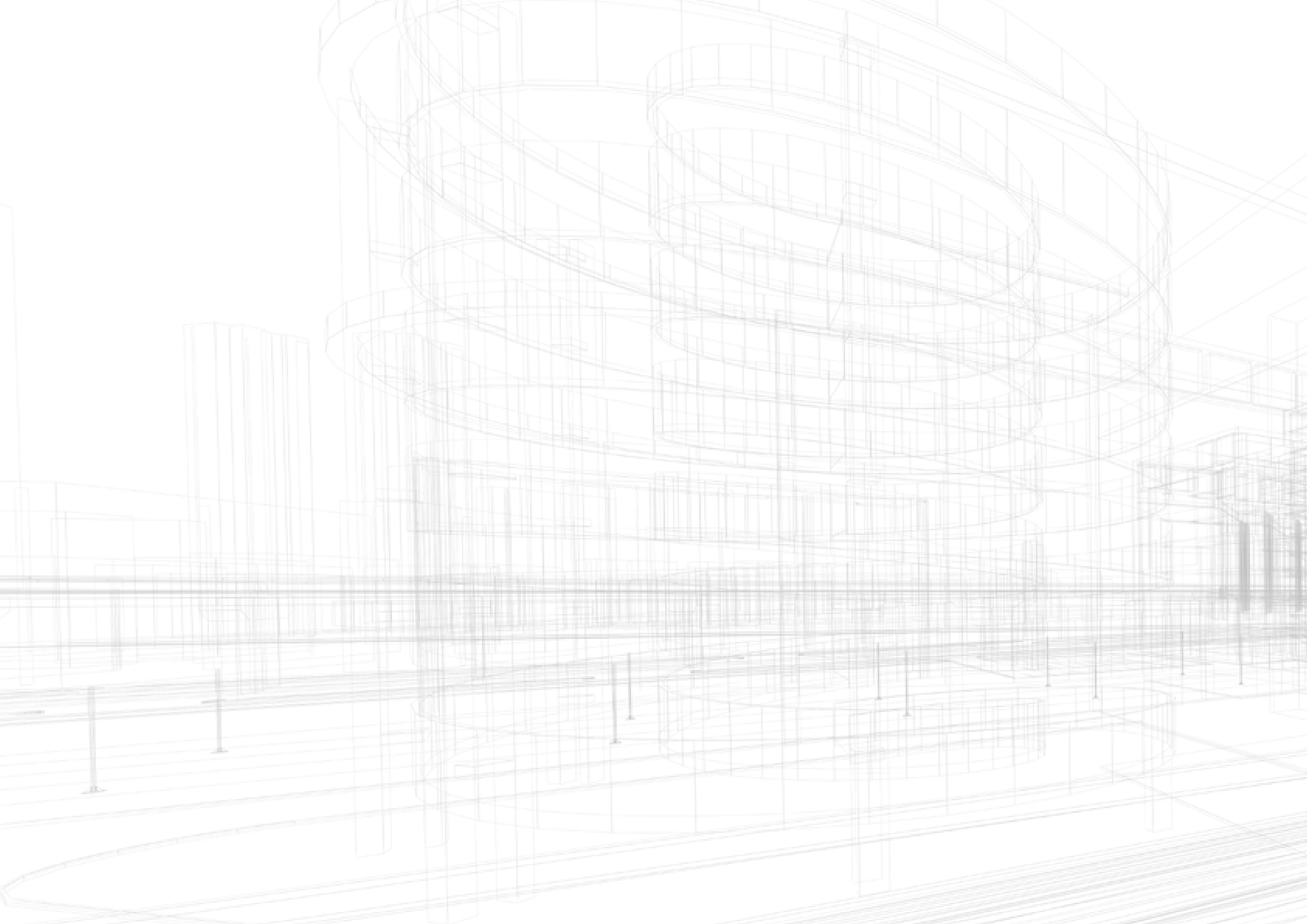
SKYCITIES. SKYWAYS. SKYTAXIS.
DREAM OR DESTINY?

A WHITE PAPER ON THE INFRASTRUCTURE IMPLICATIONS OF UAM

egis



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INTRODUCTION

As the urban population explosion and the growth of megacities continues, governments and private companies must address new infrastructure challenges associated with emerging, more innovative forms of transport and mobility. A particular challenge will be the impact of autonomous drones on the urban landscape.

Drones will be used for everything from surveying, asset management and deliveries, to passenger aircraft that can take off, hover, and land vertically. This is giving rise to the concept of Urban Air Mobility (UAM) and Advanced Air Mobility (AAM) which spans intra-city, suburban and rural passenger transport using drones and also package/cargo deliveries.

UAM (the term UAM is used to cover both UAM and AAM in this paper) offers the promise of faster low (or zero) emission journeys, smarter use of urban infrastructure and reduced congestion. However, UAM also poses challenges that touch on social acceptability, environmental policy (noise and emissions), public use, land use (ie for vertiports / terminals), and liability / insurance arrangements [1]. It also requires more advanced traffic management as well as stringent requirements to ensure safety.

These concerns span the skills and expertise across many parts of Egis. Our understanding of cities, transport, infrastructure and operations give us a wide and unique perspective from which to comment. This perspective also allows us to explain how multi-modal transport infrastructure will need to be better designed and integrated in order to accommodate UAM within the fabric of the city. We believe that this aspect of UAM has so far been insufficiently considered and as both a designer and operator of such infrastructure, we believe we are perfectly placed to address it.

SPECIFICALLY, THE AIM OF THIS WHITE PAPER IS TO:

- Present the state of UAM today: what is driving it, where the money is and what is holding it back.
- Set out a vision for UAM as an integrated form of transport of the future from the perspective of hypothetical characters living in two different UAM-enabled cities in 2035.
- Examine what infrastructure might be needed and how it could be delivered.

URBAN MOBILITY OF THE FUTURE

CITY MOBILITY NEEDS ARE CHANGING

Those planning tomorrow's cities know all too well that the urban landscape is constantly changing, particularly when it comes to the question of accommodating the mobility demands of growing populations (60% of world's population is estimated to live in cities by 2030 [2]). In an increasingly connected networked city environment, mobility is a key element in building a resilient and liveable city that can transport residents to their destination in the fastest, safest and most sustainable way possible.

Mobility solutions today are predominantly focused on land transport modes (eg car, metro, tram, bus, bicycle, walking) and to a lesser extent on marine or water transport (eg river shuttle, boat). Ground-based transport suffers from the congestion caused by insufficient infrastructure. Today, French roads are clogged with traffic congestion for on average 70 hours a week across the country [3]. In turn, congestion makes it difficult to undertake the major works required to implement new ground infrastructure, as the disruption makes the situation worse for months (sometimes years) and is unpopular. Underground transport helps to solve congestion issues, but the infrastructure costs per kilometre are very high and cause yet further disruption during extended periods of construction. Their need for maintenance hangars, storage depots and the like also increases the proportion of man-made infrastructure and leads to a decline in biodiversity. Mass transport solutions also struggle to match supply with demand, especially out in the suburbs where there is insufficient demand to justify the infrastructure needs.

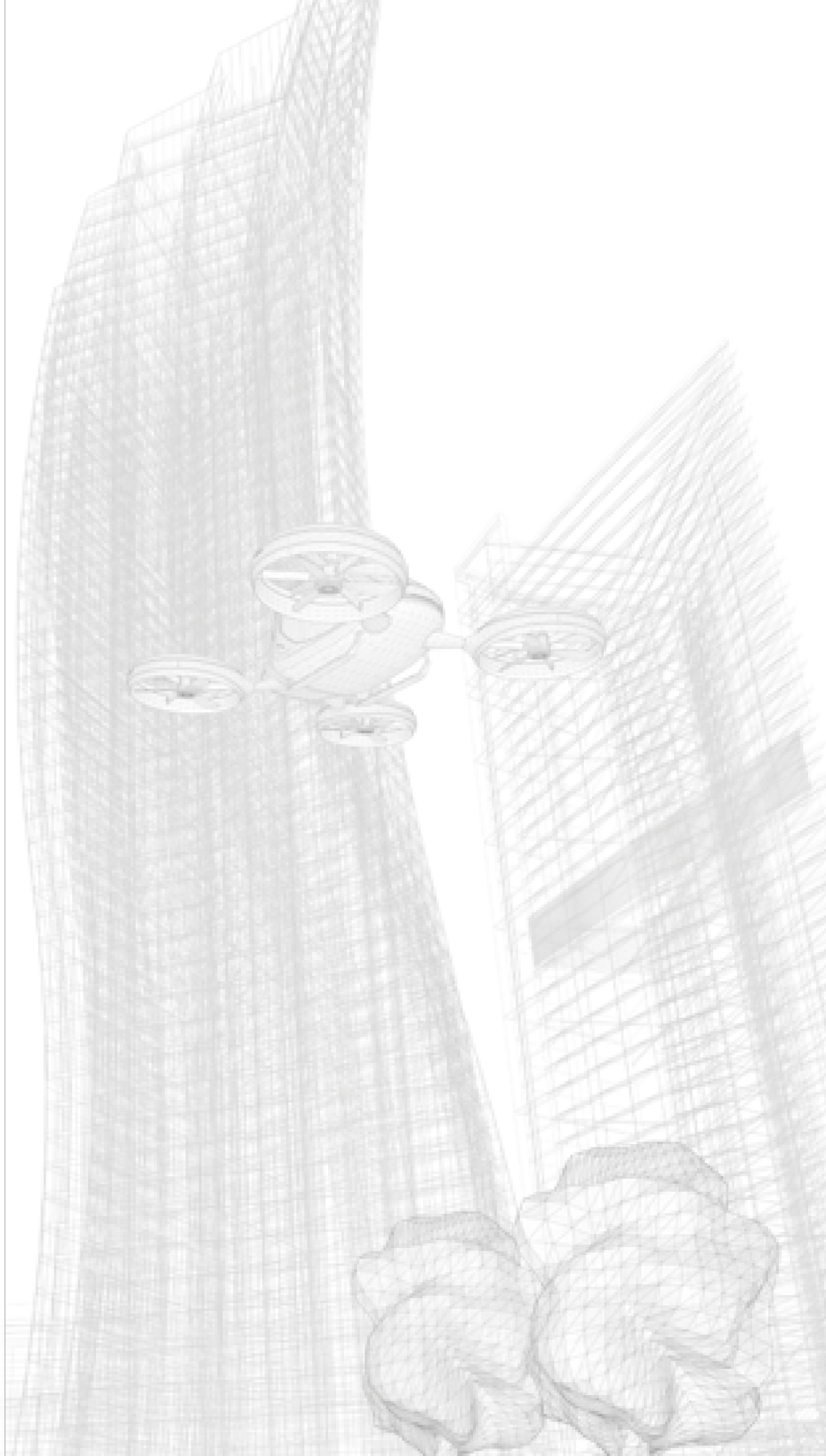
As of today, transportation is a significant producer of emissions and cities are putting a lot of effort into improving the local air quality. Fossil fuels are being phased out progressively in many countries and electrification is gaining wider support. However, electrification comes with infrastructure implications (electricity charging) and other solutions, eg hydrogen, need to be developed to accommodate decarbonisation initiatives.

An emerging answer to problems of congestion, demand imbalance, and decarbonisation initiatives is Urban Air Mobility (UAM) – taking urban mobility to the sky to make use of the invisible infrastructure that is airspace. Once the realm of science fiction, UAM has seen significant technological advances in electric propulsion, avionics, autonomous flight technology, artificial intelligence and 5G communication networks. It now looks set to become not only viable, but perhaps even a means to revolutionise the transport infrastructure of tomorrow.

THE ROLE FOR URBAN AIR MOBILITY

Helicopters are already flying routinely over cities, but UAM takes this to the next level by using eVTOLs (Electric vertical take-off and landing) that can be piloted remotely or even autonomously, though initial operations are likely to include an on-board pilot. UAM covers transportation of not only people – typically 2-4 passengers initially – but also packages/freight in the urban environment. This paper will predominately focus on passenger mobility.

UAM sits at the crossroads between different transport disciplines. The aviation industry is



taking an interest because of the opportunity to extend its reach into very low level (VLL) airspace where responsibilities are yet to be defined. It also fills gaps in the aviation network to link passengers to the airport for longer-haul and international travel, and may enable very short-haul trips (under ~20km) to find a profitable business model. The automotive industry could view UAM as a threat to its legacy car market, but also an opportunity to extend its work on driverless cars to the air. Most of the largest car manufacturers have already invested significantly in UAM [4]. UAM is also of interest to rail companies, with metro and railway stations offering prime locations for the start or end of UAM journeys, as well as flexible infrastructure that is less vulnerable to disruptions and delays, alongside considerably lower capital investment requirements.

UAM should not be viewed as a substitution to existing modes of transportation, rather as a new mode of transportation, offering distinct and complementary benefits to its users – notably shorter, more predictable travel times and the unique perspective of an aerial journey.

FIGURE 1

HOW UAM COMPARES WITH OTHER TRANSPORT MEANS (GENERALISED TIME VS DISTANCE)

As a generalisation, **UAM** travel time is likely to be similar to that of **high-speed rail** (assuming similar accessibility), with lower feeder/distribution times than **conventional aircraft**, and faster journeys than **conventional rail**. This means it will generally be most suited to journeys in the 45-300km range – as shown below, (where 'generalised time' includes the time to and from the station as well as the journey).

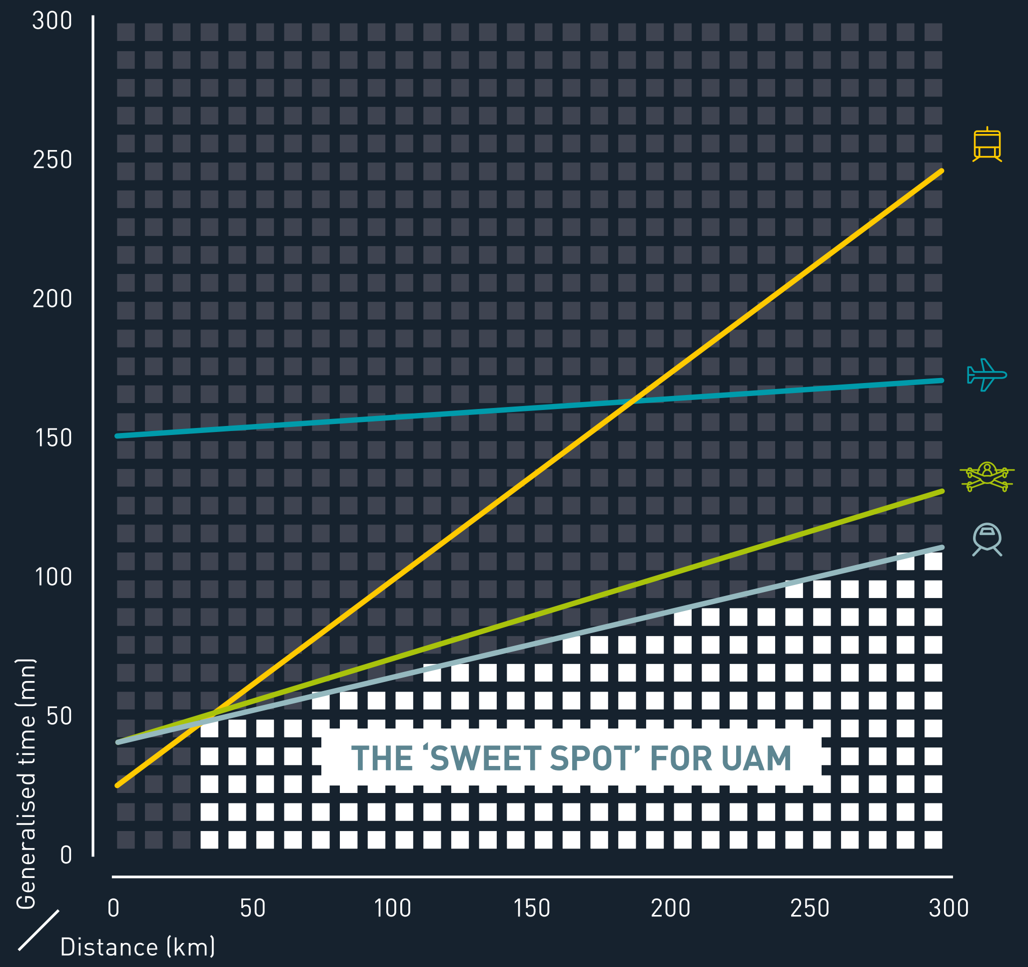


FIGURE 2

UAM USES AND ATTRACTIVENESS

	NON-PASSENGER	PASSENGER			
	LAST MILE DELIVERY	**REGIONAL AIR MOBILITY (RAM)**	**AIRPORT SHUTTLE**	**AIR METRO**	**AIR TAXI**
	Drones delivering light weight packages (up to 2.25 kg). Drones fall under EASA specific category (medium risk).	Transportation of passengers across medium to long distances (20km+). Fares comparable to Uber Lux.	Transportation of passengers from city to the local airport. Shorter distances, baggage occupying space – $.	Scheduled and shared flights within the city network (short distance up to 20 km).	On-demand taxi service within the city. Very short distance, extensive automation, higher fares.
	TODAY	+5 YEARS			+15 YEARS
FACTORS INFLUENCING UPTAKE:					
LEVEL OF SAFETY RISK	★★★	★★	★★	☆	☆
PROGRESS TOWARDS APPROVAL	★★★	★★	★★	☆	☆
TECHNOLOGY MATURITY	★★★	★★★	★★★	☆	★★
ECONOMIC CASE	★★★	★★★	★★	☆	☆
LIKELY TICKET PRICE	★★	★★★	★★	★★	☆
INFRASTRUCTURE READINESS	★★★	★★	★★	☆	☆
LEVEL OF AUTOMATION	★★★	★★	★★	★★	☆
CAPACITY CONSTRAINTS	★★	★★	☆	☆	★★★
SOCIAL ACCEPTANCE	★★	★★	★★	☆	☆
CURRENT ATTRACTIVENESS	Urban delivery might not be competitive in fares, but great benefits can be seen where infrastructure is underdeveloped (ie between islands). Current capacity is very low, but could aim at high value goods.	Transportation of people brings additional challenges across all fronts. Technology is however present and fares can be competitive with other modes of transportation (eg train).	Airport shuttle shares the same challenges as RAM, but fair amount of space will be occupied by checked baggage and thus fares will be higher.	Dense urban canyons pose more challenges across all areas. None of the areas is ready today.	Most complex use case. A great level of automation needs to be achieved. However, more than 4-seat capacity will not be needed.

CURRENT ATTRACTIVENESS

Excellent ★★★

Average ★★

Poor ☆

These regional/inter-city journeys are less integrated into the fabric of the city and therefore more likely to be the starting place for UAM passenger flights. Some (eg Lilium RAM [5]) consider regional flights to be a stepping stone to shorter range operations where there is a bigger market.

So far, there are a few uses that have emerged as viable for major metropolitan areas.
These are shown in Figure 2, which depicts a potential timeline of UAM use cases and their attractiveness. The use cases (assessed at the current level of advancement) are scored against factors influencing the uptake such as level of safety risk, economic case, capacity constraints, etc. The higher the score of the use case, the higher its readiness. Therefore 'last mile delivery' is most likely in the near-term with 'air-taxi' farther into the future.

KEY PLAYERS

OVERVIEW:

VEHICLE MANUFACTURERS

There are ~300 different vehicle concepts worldwide including start-ups and well-established companies (Boeing, Airbus, Lilium, Hyundai, Volocopter, EHang to name a few). Their focus is on certifying vehicles, optimising manufacturing (eg to scale up) and securing social acceptance in terms of issues such as noise reduction.

VEHICLE OPERATORS

PASSENGER CARRYING: UAM operators sell rides to passengers much like a 'city airline'. UAM may initially appear only as a competitor to the niche market of helicopter rides, but as costs per hour reduce (lower fuel and maintenance costs, lower pilot costs) it will expand.

PACKAGE CARRYING: Package delivery will most likely be developed before passenger transportation as the safety risks are considerably lower. Several companies are already today operating delivery drones, transporting goods and high value medical supplies.

Currently, it is not clear who the UAM operators will be. However, it is speculated that established companies from the mobility sector such as Uber (though at the time of writing they have just sold their UAM division to Joby aviation) are in pole position to operate eVTOL.

INFRASTRUCTURE DESIGN / DEVELOPERS

These are providers and developers of infrastructure (such as landing/take-off platforms, storage, and charging) to accommodate UAM operations. They include dedicated private companies like Skyports, who are engaged in vertiport design and development. As for other types of capital-intensive infrastructure, vertiports present an interesting opportunity for public private partnership (PPP) schemes.

INFRASTRUCTURE OPERATORS

Providers of digital platforms and services to integrate, manage and supervise air mobility offerings/services including airspace and information management (eg UTM). This group includes traditional Air Navigation Service Providers (ANSPs), airports and Unmanned Traffic Management (UTM) providers. However, there remains debate over the benefits of a centralised command and control UAM planning model (EHang white paper[6]) versus a freer 'Uber' type model (Uber white paper[7]), whilst Airbus (Altiscope blueprint) describes a wide variety of microservice design options that are theoretically possible for different service needs.

CITY COUNCILS AND LOCAL AUTHORITIES

Region, department/county/locality, metropolis/city, other local authorities in charge of mobility. Whilst standards may be set at national or international level (as per traditional aviation) UAM will require significant local governance to address UAM's impacts (local nuisances, vertiport construction) and authorize UAM network development. This is similar to governance for bus/metro/underground transport systems.

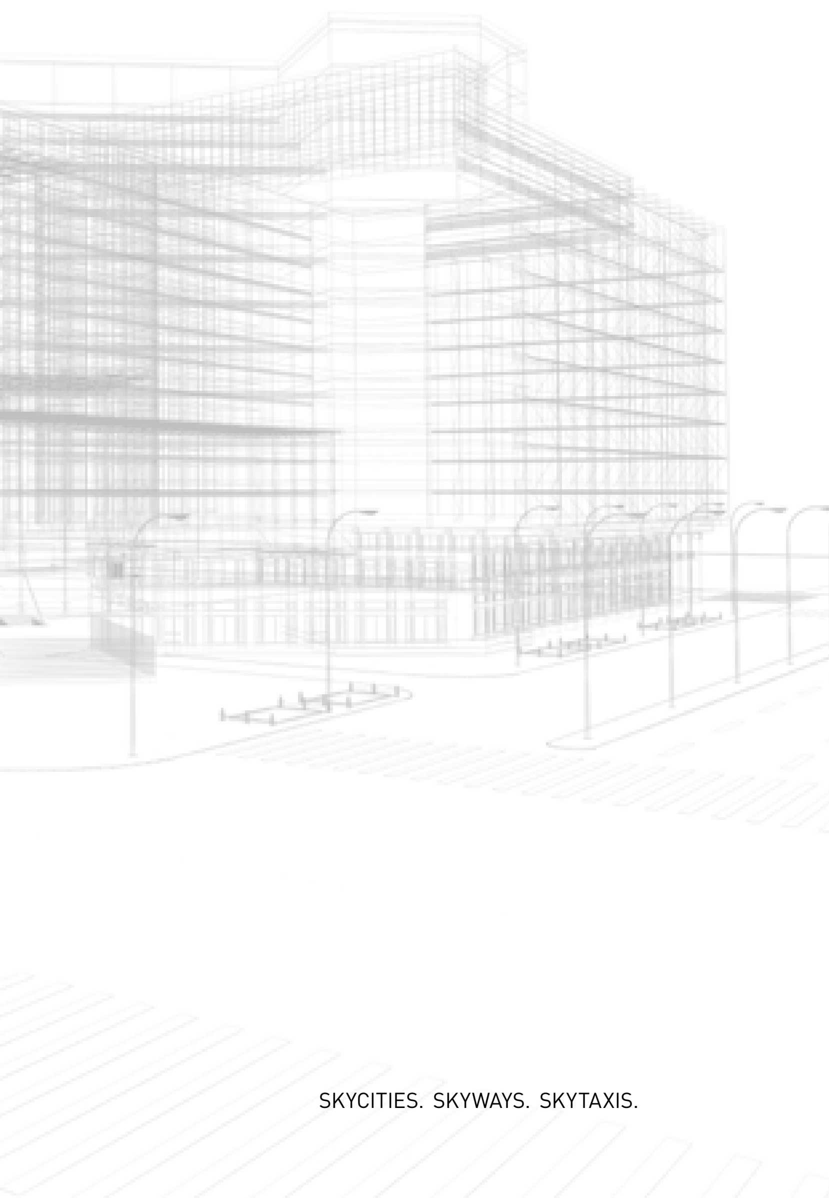
City authorities will also be interested in a form of control and some cities will be interested in operating UAM/infrastructure by themselves.

Singapore aims to be the first UAM provider by the end of 2023. Infrastructure is being built with support from Volocopter and Skyports and 2023 as a target 'go live' date seems achievable. In China, UAM has penetrated national strategies and China is expected to become the world's largest UAM market [8], [9].

STATE AND REGULATORY AUTHORITIES

Regulatory authorities have struggled to keep up with the growth in drone operations. Early regulations have needed to adapt to emerging use cases like infrastructure inspection, farming and mapping. Existing regulations are adapting but as UAM grows, tailored regulation and standards can be expected.

UAM is a novel mode of transportation still under development and will emerge differently across various countries. To allow for cross-border operations and to adopt best practices, transport authorities should cooperate with relevant state and regional authorities. A close cooperation with cities is also foreseen as significant overlap of responsibilities and interests exists. The emphasis should be on ensuring appropriate expertise and understanding to decide whether a concept or vehicle is acceptable for operation in the local environment.



WHERE THE MONEY MIGHT BE

Only a few years ago UAM was still a very futuristic concept which lacked potential for profitable business. Today more investment is forthcoming on the back of more realistic business plans. Some initial market studies even predict that the market will be valued at $20 billion by the end of the decade and will continue to expand to support more than 100,000 vehicles in service by 2050 [10]. There is however considerable uncertainty and fragility in the business outlook for UAM, as was evidenced in February 2021 when more than 60% of the share value of EHang was lost after a short seller, Wolfpack Research, published a report questioning their sales relationships, technology and regulatory approvals [11].

Looking again at the key players in the UAM market, what are their revenue sources or business models likely to be? These questions will be key to answer for potential investors.

BUSINESS MODEL / REVENUE STREAM:

VEHICLE MANUFACTURERS

eVTOL manufacturers will sell vehicles directly to operators, or via leasing companies. In some cases, they may themselves decide to be an operator.

Big players like Airbus, Boeing, Embraer, or Hyundai are exploring solutions by testing both automatic flights and different aircraft concepts from multicopters to fixed wing. Despite the Covid-19 pandemic, investment in eVTOL aircraft has continued growing at the rate of around $1 billion per year [12] with 24 companies now flying multi-passenger eVTOL aircraft.

Manufacturers are looking to sell aircraft for between $300K and $1 million per vehicle and aiming for the ability to produce thousands of units per year [13]. Production is expected to be slower than for a car but quicker than for a helicopter, with a supply chain that will be shorter and more flexible than for conventional aircraft, using extensive automated manufacturing processes and 3D printing technology. Once certification is achieved, production lines will be quick to react provided the demand is there. Regions with an established automotive or aeronautical industry will benefit from this new market and will be able to attract eVTOL manufacturers.

VEHICLE OPERATORS

Passenger carrying: UAM operators buy or rent eVTOL vehicles and sell tickets to passengers. The price of tickets will cover capital costs (like vehicles, booking systems) and operating costs (insurance, maintenance, etc). Operating costs will achieve economies of scale as the number of flights increases.

Package carrying: In rural or remote areas last kilometre delivery will be more economical via drone, though may still require subsidy. It will however be an issue in the urban environment due to the complexity of delivering in dense environments. To date, loads are also typically limited to a maximum of 350 kg.

INFRASTRUCTURE DESIGN / DEVELOPERS

UAM infrastructure spans landing/take-off points (also known as vertiports) or zones, energy/charging provision, storage and maintenance. It is capital intensive and could be a city asset or developed through private-public partnerships (PPP). The vertiports would typically be located on the roof of railway stations, car parks or existing buildings. In densely populated areas it may be a challenge to acquire enough locations to build a useful network. But if successful, it will bring major benefits as real estate owners that could offer vertiports where eVTOL vehicles can (for a fee) take-off or land.

Real estate asset managers focus on maximizing a property's value for investment purposes. A real estate portfolio typically mixes different types of properties and includes tower buildings for mixed-use properties that cater to both businesses and residential tenants or retail properties such as storefronts. Having a vertiport on the rooftop could offer a new and lucrative way to value a part of the building often disregarded. Firstly, as a steady form of rental revenue and secondly through secondary revenue via passenger traffic (eg advertising, retail, commercial services such as Click&Collect, or even coworking).

Air taxi or cargo companies will also require communications services and electricity to operate vertiports. These services will need to be provided by the UAM infrastructure.

INFRASTRUCTURE OPERATORS

The integration, management and supervision of air mobility offerings/services is a significant market segment in itself and likely to require a control model, as part of a 'system of systems design'. The market will very much depend on whether a centralised command and control model applies or a more liberalised 'uber' type model with multiple infrastructure operators. For example, ANSPs who control upper airspace on behalf of a State, are arguing for the right to control (and presumably take revenue for) traffic – partly on the basis that they see a need for integration with existing air traffic*. Other key players include the communications providers (eg telecommunications companies) who hold a powerful position as the only ones able to locate and communicate with the vehicles. There are also emerging UTM Service Providers (eg AirMap and Altitude Angel) who are developing tools such as UTM systems to control and organise unmanned traffic.

* Current air traffic control concepts are considered unsuitable for urban operations, so today's ANSPs would have to evolve significantly to provide this service.

CITY COUNCILS AND LOCAL AUTHORITIES

Cities and local authorities will want to ensure public safety while enabling economic growth and mobility. They may aim to limit the number of eVTOLs and will probably engage in PPP arrangements to ensure vertiports are in line with city planning. PPP arrangements will initiate the capital-intensive business to design and develop UAM in multiple dimensions like real estate management, technical and operational management (eg power grid, air traffic management or safety and security).

Municipalities who are developing smart city concepts might want to integrate UAM networks to better interconnect the urban grid once the inner city use case is deemed feasible.

STATE AND REGULATORY AUTHORITIES

The authorities responsible for a safety of the environment will have to take UAM into account when setting national safety standards. In cross-border operations like in MAHHL cities (Maastricht, Aachen, Hasselt, Heerlen, Liège) [14], standards should be aligned.

BARRIERS TO SUCCESS

Technological advancements have seen UAM mature significantly over recent years. For example:

- The concept of Distributed Electric Propulsion (DEP) has matured. DEP uses electrically driven propulsors which are only connected electrically to energy sources. They offer several benefits over conventional propulsion systems: vertical take-off and landing performance, significantly higher efficiency than jet or piston engines and simpler propulsor design resulting in increased safety and easier maintenance.

- Higher battery performance* provides the ability to fly longer distances and carry more load/passengers. Batteries are also becoming more accessible. Currently, the price of 1 kWh is 80% lower than it was ten years ago.

- Autonomy has been greatly explored in the automobile industry in recent years and is established for military drones.

- Improved connectivity also plays an important role in UAM deployment. The urban environment and Very Low Level (VLL) airspace create new challenges for the aviation industry meaning that vehicles will need to adapt in the same way as fish adapted to living in the ocean. This mostly concerns signal coverage and interference. Manufacturers are looking at using mobile networks to support a command and control (C2) communication link rather than conventional means which might be proven unsuitable. The introduction of 5G networks promises much better connectivity between vehicles. Additionally, new augmentation systems and High Accuracy Positioning (HAP) services provide navigational and surveillance benefits which are essential in such a dense environment.

* Battery capacity increases on average by ~3% each year.

However, availability of technology alone is not sufficient to ensure a market will emerge and there are numerous challenges that remain to be tackled. This section outlines some of the most significant of these barriers to success.

SOCIAL ACCEPTABILITY

Public acceptance of UAM is one of the greatest obstacles to overcome, particularly in Western societies where citizens have been less accepting of drones [15]. Some worry about creating a divide between the beneficiaries of UAM (those passengers who gain time) and those most impacted (the people 'stuck' on the ground, who will be impacted by the noise and visual pollution). Other types of urban transportation (car or mass transport) do not so clearly divide the two populations. Innovative solutions may be needed to balance this out – for example travel vouchers to those impacted on heavily used air corridors. Before the UAM business can take off, regulators will have to work hard on developing acceptable standards for both operators and citizens bearing the noise.

Innovations will be needed to monitor and track key indicators. For example, integrating new sensors and monitors into a new (or already existing in the most modern cities) 'mobility observatory', to check the noise pollution of these new types of vehicles. Air corridors will have to be designed to provide safe overflight of dense areas on the one hand, but on the other to ensure that the noise of these flying vehicles melts into the background hum of land traffic – itself expected to become quieter due to the growth in electric vehicles.

It will also be necessary to accommodate visual pollution concerns. This will not be a fixed process but a dynamic one as air corridors, buildings, and security gateways will continually change. The compatibility of air corridor use and the integration of local transportation networks, including noise sensitivity planning and equitable access, will be the tools of tomorrow for communities to accept UAM deployment.

SAFETY AND SECURITY RISKS

Aviation has a strong safety record based on concerted and continual efforts to improve safety performance across all aspects of the industry. This includes costly certification processes applied to aircraft manufacturing, operation and maintenance, licencing and training requirements for flight crews and high performing safety-critical systems. The business case for UAM is founded on accessibility, cost-effectiveness, hyper-convenience and these are all attributes more closely associated with car travel than current air travel. It remains to be seen whether the public will accept a corresponding (higher) risk level.

Safety performance rests on multiple diverse foundations that include technical, human and operational safeguards, all of which are subject to rigorous oversight from regulators and other governance organisations. It is important to consider how all these aspects are affected by the introduction of UAM:

- In a congested, urban environment, reliance on See/Detect and Avoid rule alone is not feasible to maintain safety and UAM will have to apply the airspace and traffic management principles that conventional aviation uses to safely handle dense traffic. However, if these defences are to be provided by non-human, autonomous or highly automated systems then high reliability across all feasible operating scenarios must be assured and proven.
  To accommodate all these capabilities, ATC concepts as we know them today, may be insufficient for UAM.
- The increasing use of advanced materials in eVTOLs, new propulsion and energy storage technologies, and the prevalence of autonomy will have significant implications for certification processes, which will need to be flexible to adapt to these changes and keep pace with the development of the technology.
- The Communication, Navigation and Surveillance infrastructure used by conventional aviation must undergo significant changes to provide the same level of performance as today, let alone the improvements that will be necessary to manage high volumes of UAM traffic in urban canyons. The challenge extends to meteorological information which must be provided hyperlocally to enable accurate weather predictions and protection against micro-scale variations in weather that can significantly affect the flight performance of eVTOL aircraft.

Finally, the entire aviation system and its constituent elements, especially with the advent of autonomous technology, must be adequately protected against all threats including cyber threats. The implication from an operational and safety perspective of a sustained cyber-attack that affects large parts of the aviation system cannot be understated. This will undoubtedly require an integrated approach to system design, system operation, threat monitoring and attack response to provide adequate mitigation. Military or sensitive assets will also need to be protected, and military and police authorities must be considered among the stakeholders in any UAM project.

In the short-term, developers and operators of UAM technology will be subject to existing regulations whether those are from a certification, training and competence or planning perspective. Infrastructure developers such as vertiport designers will be subject to the same planning regulations as exist today and air routes will need to follow those that exist today for rotary-wing operators. The challenge to enable UAM to realise its economic and societal benefits will be to safely and securely accommodate the introduction and integration of new technologies and operations without undermining the hard-won reputation for safety that aviation has built up over the past 50 years. This requires a clear roadmap for development and integration of UAM that is supported by all key stakeholders, including governments, regulators and other governance organisations.

AN ECONOMIC CASE FAVOURING THE ELITE

The current cost per passenger is fairly high compared to other modes of transportation and may therefore be limited to only the wealthiest portion of the population. According to a NASA report [16], a 5-seat piloted eVTOL will cost about $6.25 per passenger mile, compared to the cost of driving a car, which today is about $0.50 per mile, and an Uber taxi which is between $1-2 per mile. The performance of eVTOL (capacity, range, speed, etc.) is linked to energy performance such as battery capacity or efficiency. Further technological advancement will be needed to increase the maximum capacity and decrease operating costs, resulting in lower fares and more feasible use cases.

SUSTAINABILITY – COMPARED TO THE ELECTRIC CAR

Sustainability is one of the arguments for UAM development. Nevertheless, eVTOLs will not compete with a small electric car in terms of energy efficiency. eVTOLs will emit much less CO_2 than a helicopter but are likely to emit more than an electric car. An eVTOL is expected to need between 0.2 and 1 kWh/mile [17] (and in an urban trip context, around 0.5 kWh/mile [18]) compared to a 0.3 kWh/mile for cars (0.2 for a small car in urban environment) [19]. Furthermore, it is not evident how eVTOLs will avoid, shift or improve [20] trip efficiency in a sustainable way (compared to public mass transport and/or an electric car).

BALANCING COSTS, SAFETY AND RESPONSIBILITIES IN A NEW REGULATORY FRAMEWORK

Across the world, several leading cities are showing an interest in the potential of UAM, but given the high stakes, governments are also nervous.

After a slow start, regulatory frameworks for drone and UAM operations are now coming online. For example, several countries have published concepts of operations dedicated to UAM, like Australia at the end of 2020 [21]. The recent initiatives in defining drone regulation have however highlighted the difficulty in developing a regulatory framework that does not stifle an emerging market by imposing unbearable costs on manufacturers and operators, while still ensuring that they will achieve an acceptable level of safety, including in future operations that have not yet been imagined.

From the vehicle perspective, airworthiness will have to account for new challenges linked to new technology such as electric propulsion or Artificial Intelligence as an autonomous embedded pilot, where little prior experience exists. The UAM market can develop under current conditions but a tailored regulatory framework will allow greater scaling in the future.

Another question to answer is who will be in charge of the airspace*. The principles and rules of sharing the very low level (VLL) airspace below 500ft are still under development, with most drone flights performed on an exception basis. The next step will be to develop that further for passenger-carrying eVTOL vehicles. Technical and procedural challenges will be linked to how humans and autonomous systems interact and cooperate.

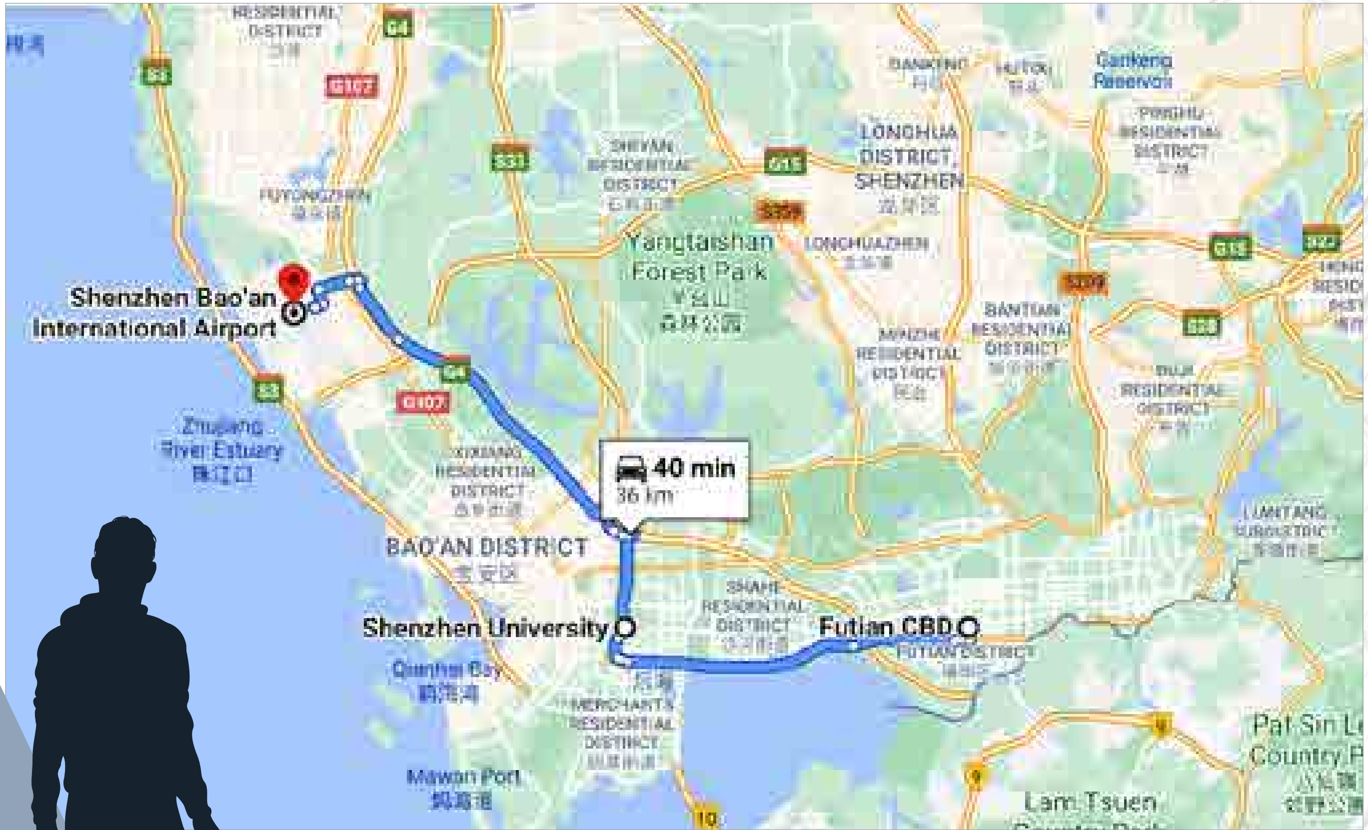
* For a wider view of airspace management of the future, see our Airspace Guardian white paper

UAM IMAGINED IN A NEW CITY

From the discussion so far, it is clear that whilst there are strong drivers for UAM, there remain several barriers to overcome before it becomes an everyday reality. If and when it becomes reality, what might it actually look like? To explore this question, we've imagined two candidate cities in 2035 and how the lives of particular fictional residents within them might be impacted.

- The first city (this chapter) is a 'new' city: modelled on Shenzhen, China. This city is relatively new, which allows for UAM to be built in to the infrastructure and city fabric from the start.
- The second city (next chapter) is an 'old city': modelled on Paris, France. This city is well established and so UAM has to be integrated into an already very constrained fabric.

LEE
the student



© Google Map data 2021.

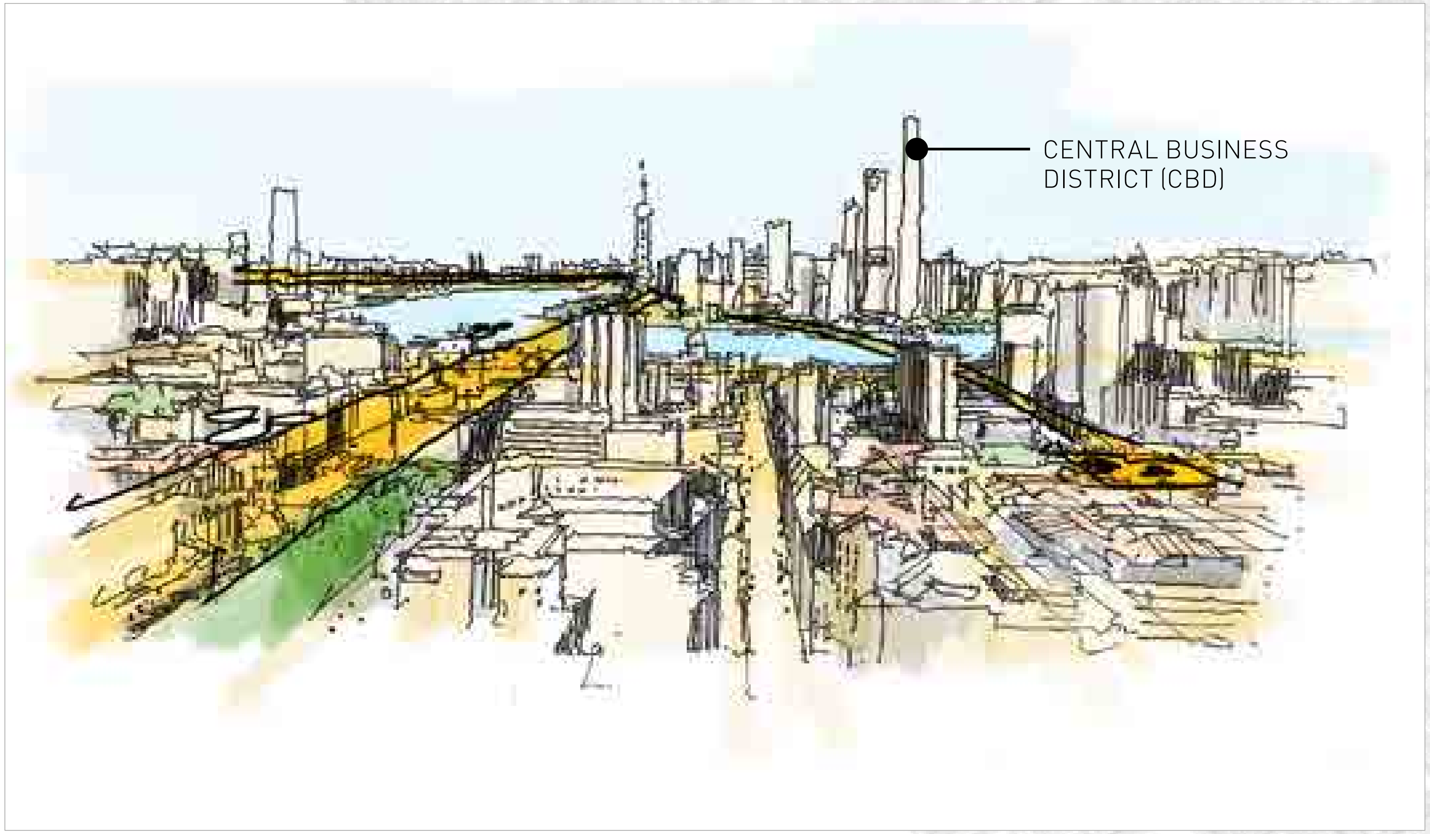
1 Lee is a student living on the University campus, 30 minutes by road from the airport, where he has a part-time job with a logistics company. His girlfriend lives in a Central Business District (CBD) two hours away by road. He is a big user of public transport and does not own a car or bike himself.

Lee's watch wakes him at 8am, with a reminder that his lecture starts at 9:30, he has a trial for the football team at 2pm and he needs to start his shift at the airport at 4pm. He picks up an e-scooter outside his building to get to his lecture (the e-buses are too busy).

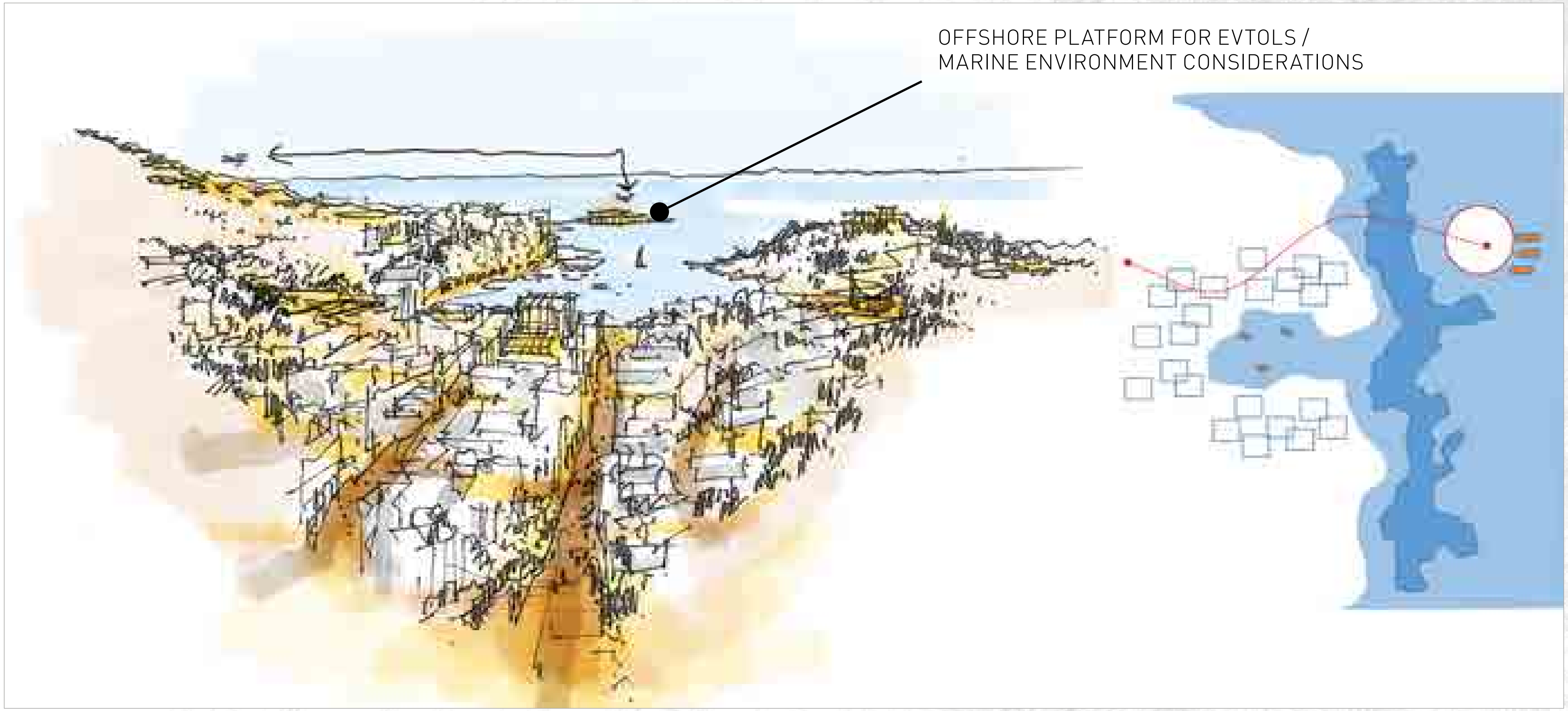
2 Once his lecture has finished, he walks to the sports ground where he grabs a high-energy meal from the vending machine – he sent his order through during his lecture to make sure he got exactly what he wanted.

After the trial, Lee catches the e-bus out to the airport to start his shift at the logistics company. It's his job to load delivery drones taking urgent packages to and from the CBDs around the city and into the city itself.

At the weekend, Lee plans to visit his girlfriend Sofi. She lives in an area not well served by rail but e-buses, EVs and eVTOL air shuttles provide coverage of the gaps.



AERIAL CORRIDORS

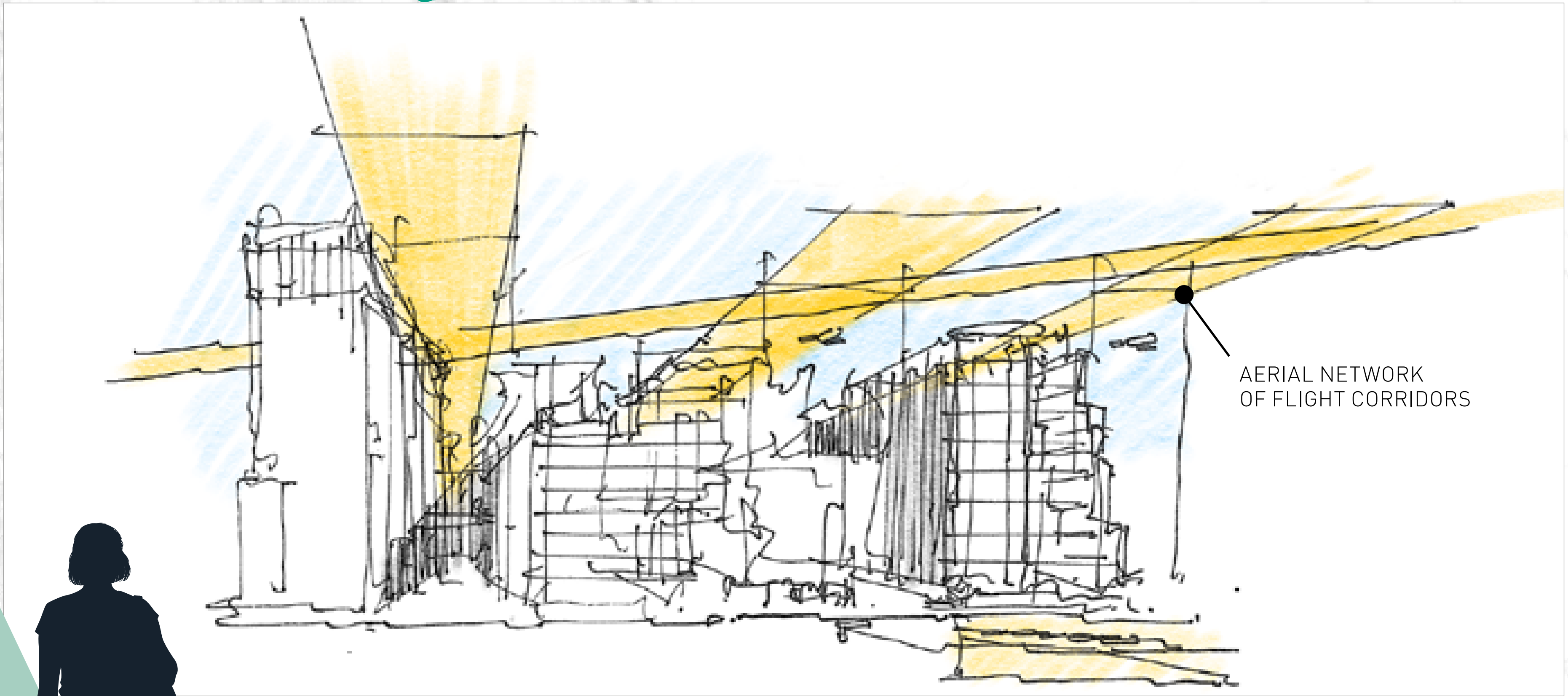


3 An integrated transport app for the city offers real time information on all the different transport modes and dynamic pricing. Sometimes the Air Shuttle can cost less than a conventional taxi – especially when air quality indicators trigger city subsidies for greener journeys.

4 This weekend it's Sofi's birthday and Lee has a surprise for her – a boat trip around the bay. They'll get to it via the latest autonomous air taxi, designed to protect the marine conservation area from too much water traffic. He's pre-booked it to pick them both up from her building and it will drop them directly on onto the boarding pontoon for the boat trip. A treat to look forward to!

AERIAL CORRIDORS

AMAL
theworkingmum

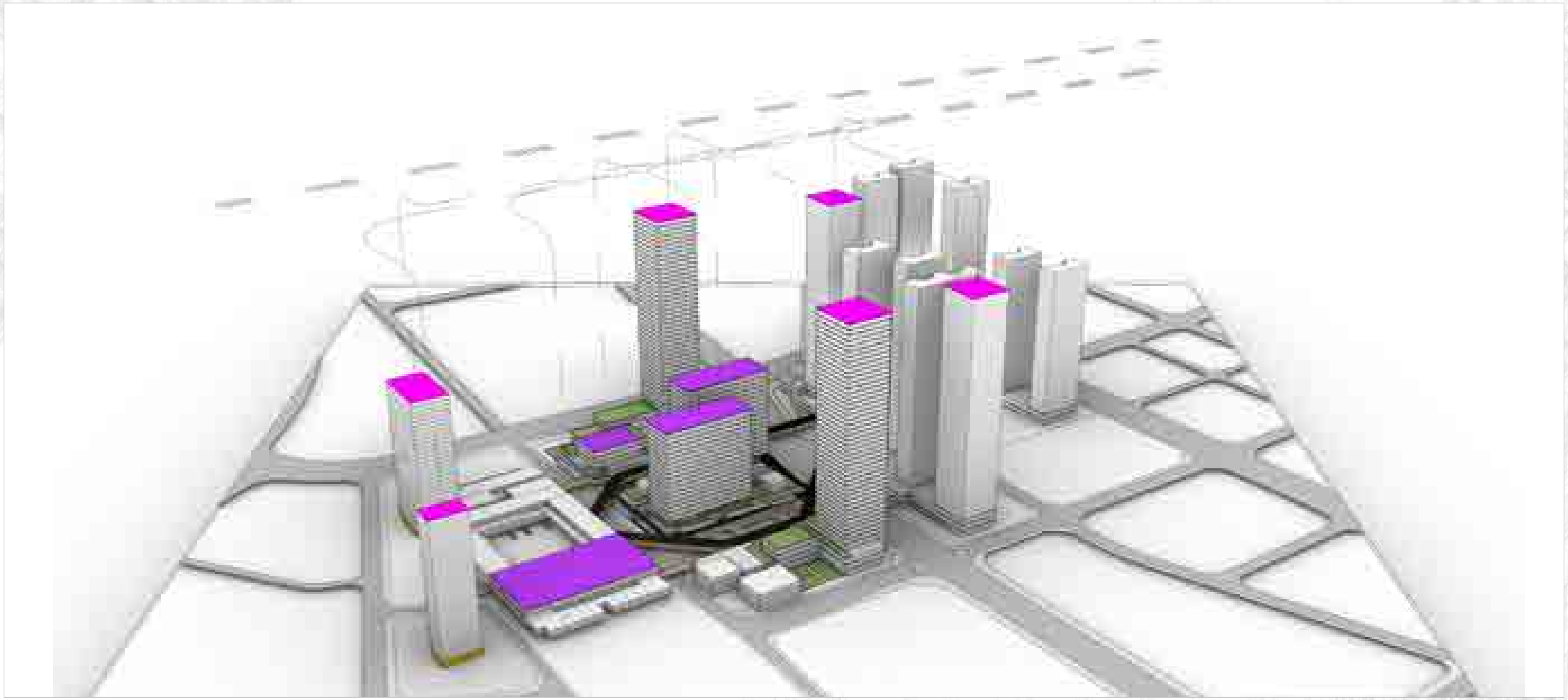


1 Amal is CEO of a large events company in Shenzhen. She lives in a new greenfield suburb with her family. By road, the journey into Shenzhen can take between 50 to 90 minutes depending on the time of day, so she blends car travel with commuting by air shuttle, especially when she has an early start or late finish ahead.

AERIAL CORRIDORS

2

She drops the children at their school in the neighbouring building, using the convenient air bridge, no need to descend to street level, then takes the elevator to the Sky Lobby where the Vertiport is located. She pre-booked her commuter flight using the Shenzhen Shuttle App – it costs a little more than usual today because demand is high and it's rush hour, but it will take her to a floating air shuttle pontoon right next door to her city centre office in under 20 minutes.



3 Top of her agenda for today is a meeting with the City Transport team to plan for an upcoming concert. The city is expecting hundreds of thousands of visitors for one night only and she's meeting with the Vertiport and Air Shuttle providers to look at optimising drop off and pick up points that night. It will need to integrate with parking and rail/metro transport nodes, but they have a digital twin of the whole transport system – called their 'Mobility Observatory' and this helps enormously with planning and real time management, so she's not expecting any problems. She's meeting them at her favourite spot in the city, the prestigious Vertitower Forest, where all the VIPs arrive to experience nature in the city. The top deck has discreet landing docks offering maximum privacy, and dedicated meeting rooms that can be booked through the Elite Shenzhen members only club app.

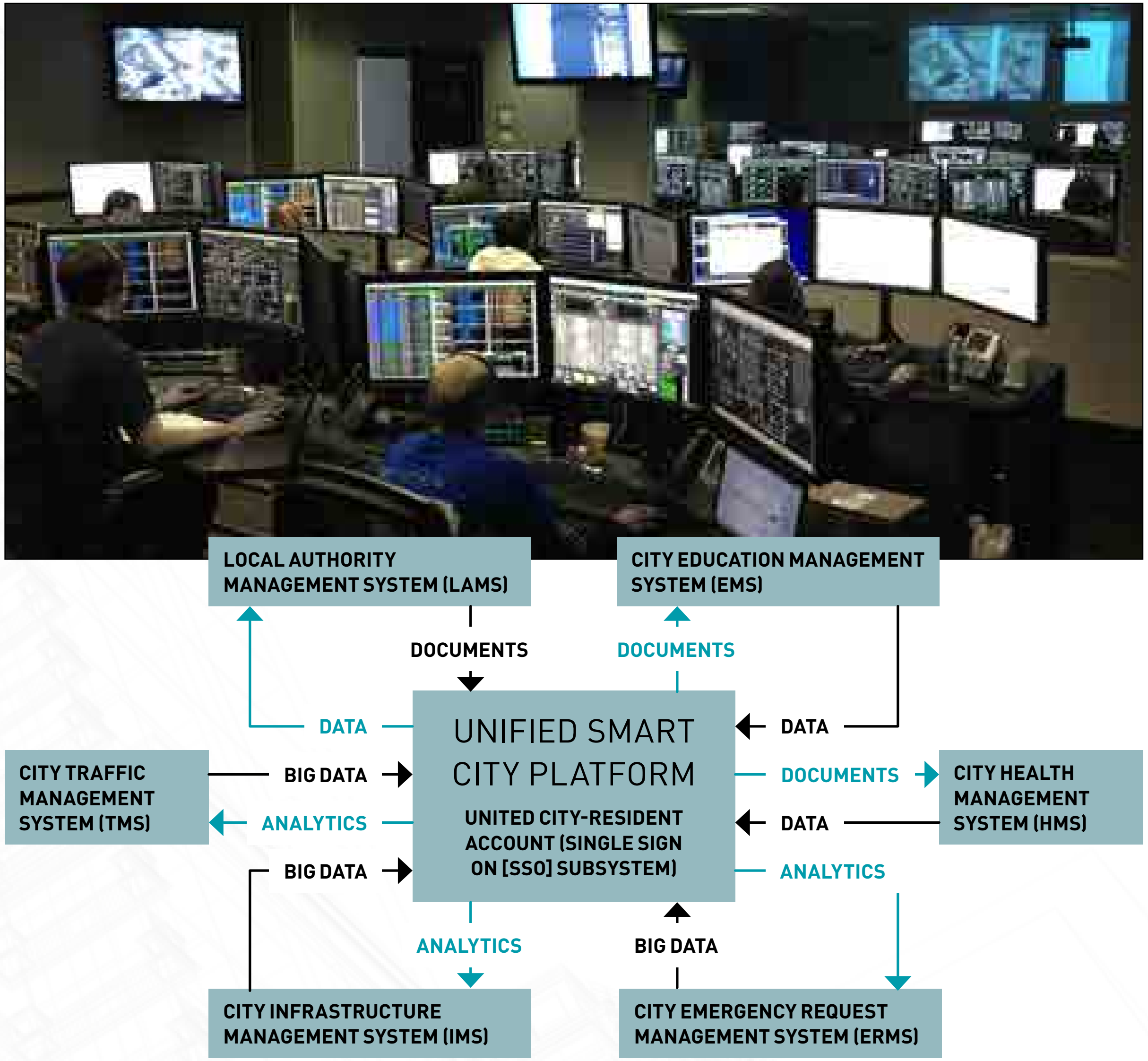
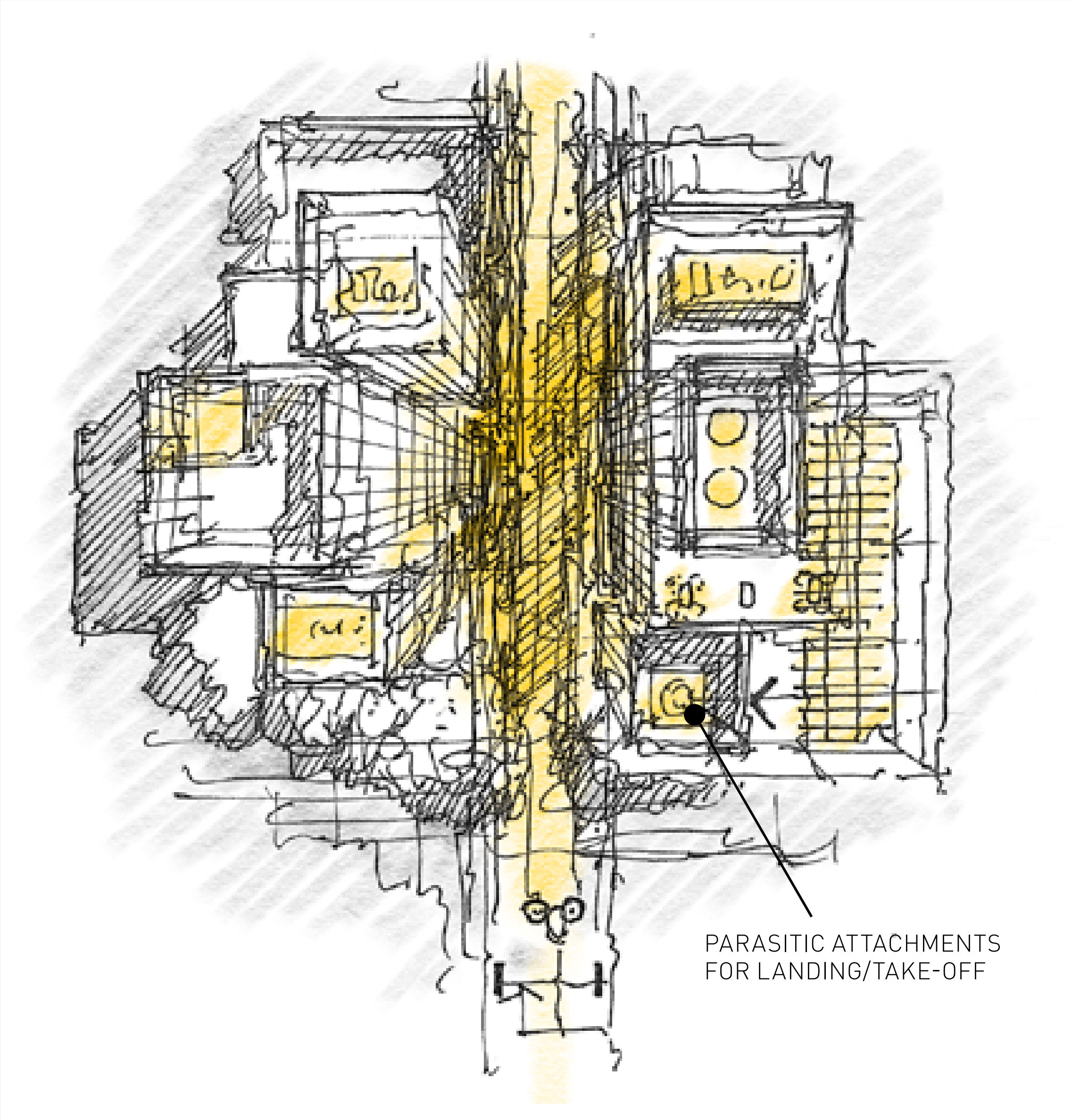


FIGURE 9

EXAMPLE OF A MOBILITY PLATFORM ARCHITECTURE (REAL PROJECT EXAMPLE)



4

It's been a long day; Amal has one more appointment before heading home – time for a haircut! Her hairdresser is based in a nearby suburb. This time she takes the metro – it's more cost effective, and anyway the dynamic weather alerts are showing delays on air shuttle flights due to high winds. But she takes the opportunity to book a flexible air shuttle pick up for 7pm. The app will guide her to the nearest available air shuttle operating at the time.

Happily, the wind has dropped by the time she leaves the hairdresser, because the city is busy again and she is keen to fly home. She follows the audio instructions in her earpiece to the Vertiport two blocks away, stops by the city farm in the basement to pick up some fresh vegetables and then makes her way to the Sky Lobby, and home … as the aircraft comes in to land the rooftop advertising shines bright in the night sky, a new restaurant has opened in the neighbourhood; maybe the children would like it?

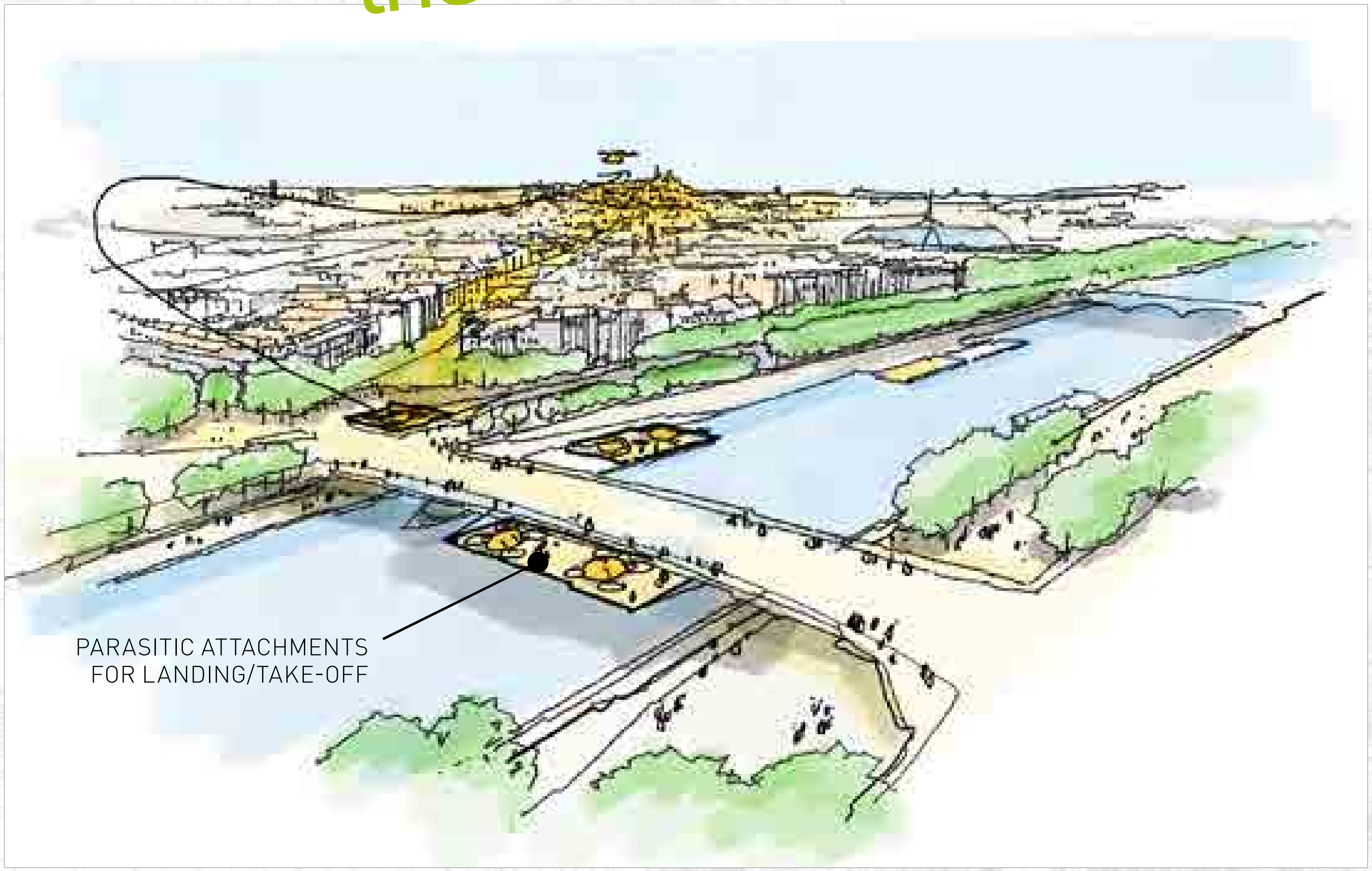
AERIAL CORRIDORS

UAM IMAGINED IN AN OLD CITY

How might UAM look in a well-established and already very constrained city like Paris? This section explores the possible role of UAM through the eyes of a pair of tourists and a company executive.

JAN AND NOOR, the tourists

1 Jan and Noor are visitors in Paris. Jan visited about 15 years ago but missed out on so many things that he wanted to come back. He is also keen to discover how the 2024 Olympics have changed the city. Noor is a first time-time visitor and mostly wants to see the main tourist sites of the city. They have rented a studio within Paris and plan to rely on public transport for their journeys during their stay.

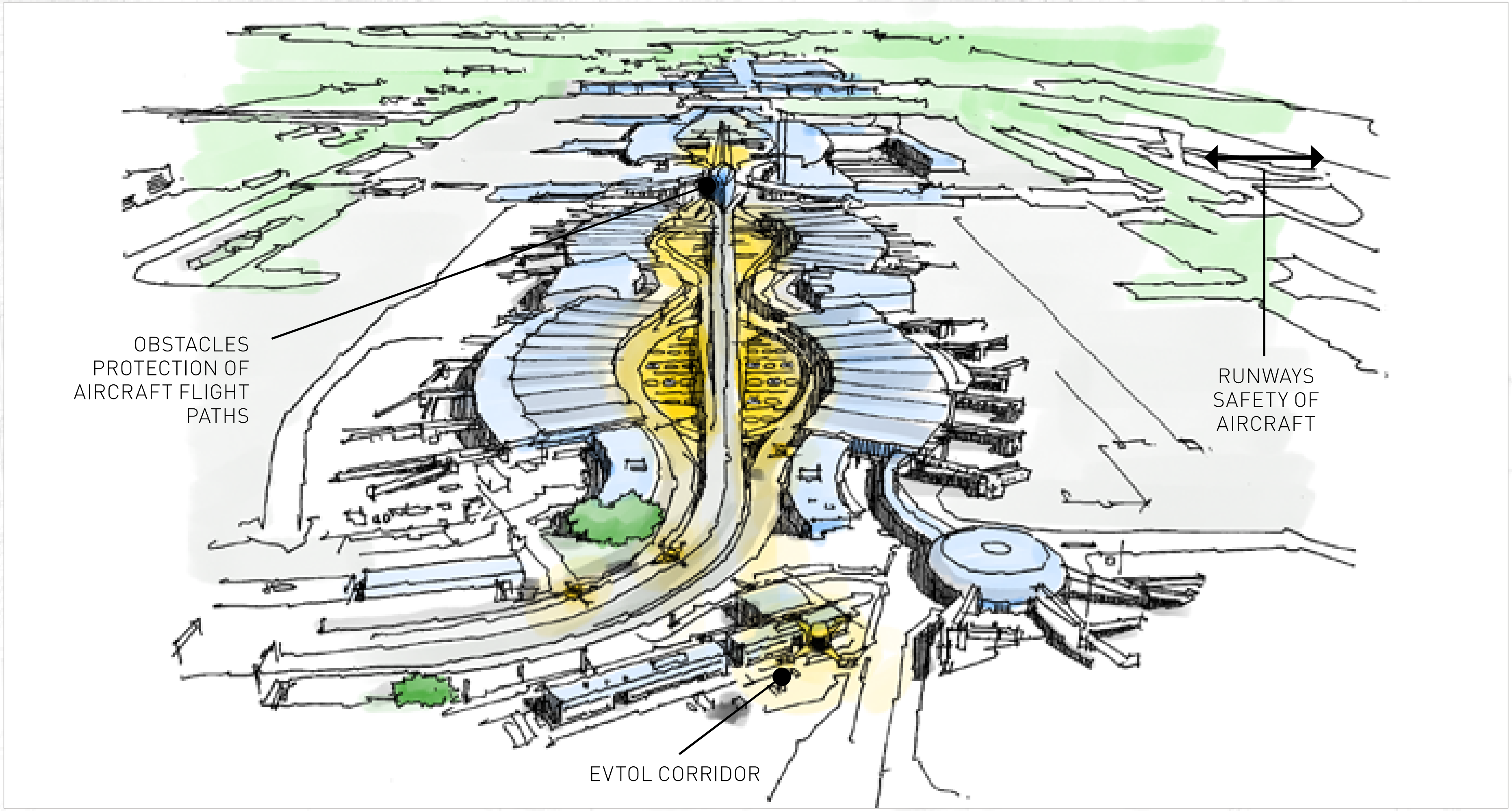


AERIAL CORRIDORS

2 After arriving at Charles de Gaulle airport, they make their way to their rented studio using a specialised mobility app for tourists and receive the QR codes for their tickets. The app guides them out of the airport terminal to the CDG Express station. They scan their QR codes at the station's entrance and access the platforms where a train takes them to Gare de l'Est station. From there, the app leads them to a bus stop where they will catch a bus to their studio.

3 Once settled, they plan their visits for the next few days. Among some offers suggested by their mobility app, Jan notices a discount for a company proposing eVTOL tours in Paris skies. Even with the offer, the price will make a dent in their holiday budget, but this would be an unforgettable experience. He takes the plunge and purchases the flight, booking it for a day when the weather looks promising.

4 After several exhausting days of treading the Paris streets and visiting monuments, Jan and Noor check in for their eVTOL tour, conveniently located by the river a few blocks from their studio. The flight is smooth, quieter than they expected thanks to the electric motors, but not silent like a hot air balloon. They both enjoy the unobstructed views of all the city's main sites, but the highlight is landing in the park at the Palace of Versailles – that wonderful memory will stay with them for years to come!

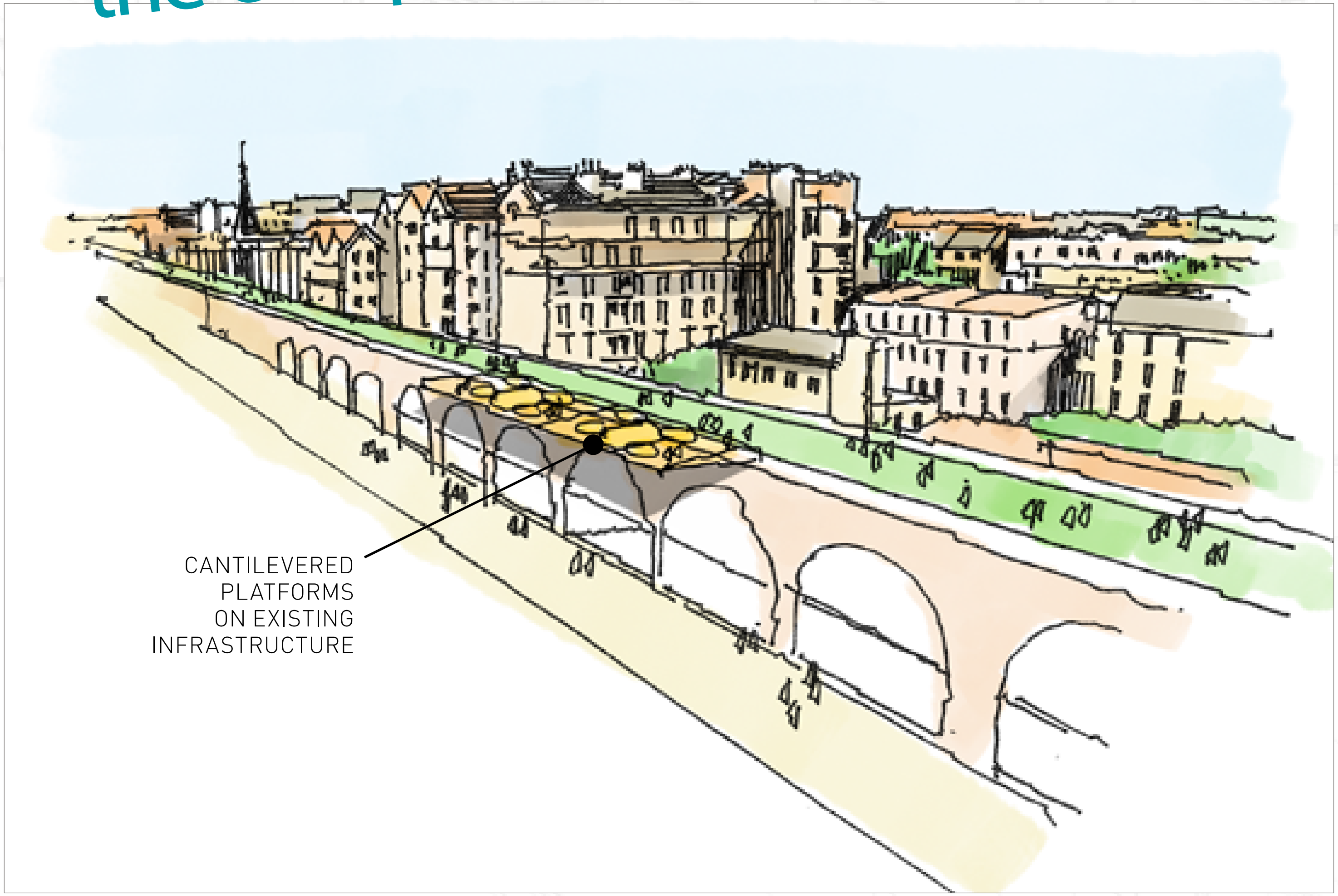


5 The eVTOL experience was so enjoyable that when they reach the end of their stay and have to decide on their trip back to the airport, they choose to take the UAM shuttle from Gare de Lyon station direct to Charles de Gaulle. Their last memories of Paris will be like birds, from the sky.

AERIAL CORRIDORS

LUDIVINE
the company executive

1 Ludivine works in La Défense business district and has chosen to live in Paris as she likes going out and taking advantage of the city's cultural offering. As part of her work, she sometimes travels abroad and has access to the convenient UAM shuttle service from La Défense to CDG airport or to Gare du Nord railway station.

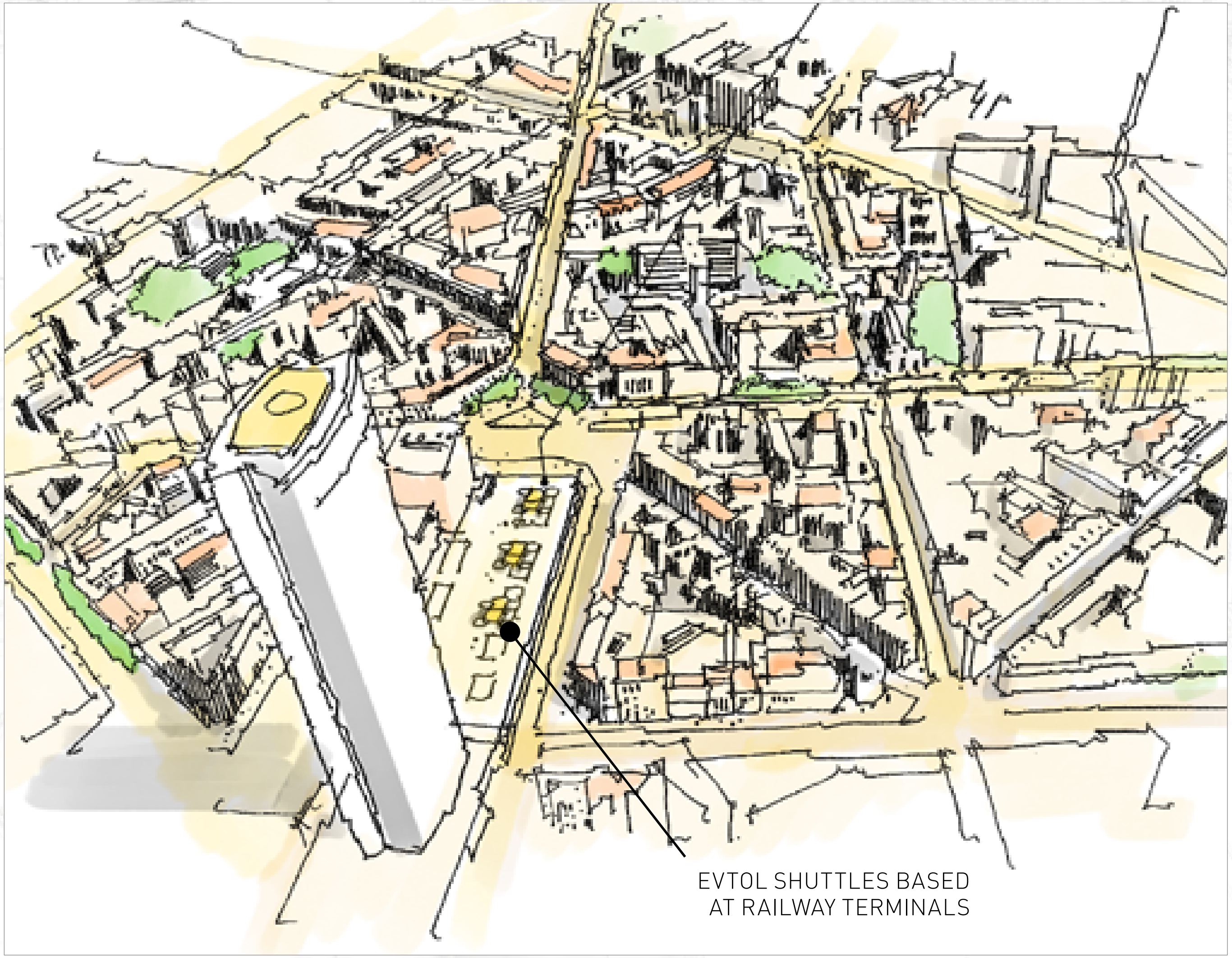


AERIAL CORRIDORS

2

For her intra-city trips, she has subscribed to a mobility service to help optimise her travel time. This morning, she starts working from home but at 09.15 am, she receives a notification on her phone that she has to leave for an urgent meeting, attached with a proposed itinerary and the fastest combination of transport modes. She accepts the proposal, which automatically triggers the various bookings and payments.

She leaves from the nearby metro station towards the périphérique. Once out of the metro station, her mobility app guides her toward a carpool pick-up point for a shared car ride to La Défense and informs the car driver that she is about to arrive. About halfway through her journey, she receives a new notification from her mobility app – traffic is building up ahead because of a road accident and she will be late for her meeting. She decides to leave her shared ride and hops onto a nearby eVTOL for the final section of the journey to arrive in time for her meeting.



3 In the evening, after a long day, she wants to get back home as rapidly as possible. At this time, road traffic is still dense and metros crowded, so she opts for a more expensive UAM shuttle to the railway station closest to her home. Enjoying the city sights from the sky makes up for the extra cost and these journeys are always an opportunity to strike up a conversation with the other passengers, which rarely happens when riding the metro.

AERIAL CORRIDORS

PREPARING FOR THIS KIND OF FUTURE

PREPARATION BY URBAN PLANNERS

UAM offers city leaders the chance to reimagine the city – reshaping land use, progressing territorial development through a forward-looking project, repurposing existing assets, reversing decline and improving quality of life for citizens. For those responsible for planning the urban environment, the addition of airspace to the urban landscape creates a new dimension. It will require new tools and expertise, create new opportunities and require new decisions to be made.

Questions that planners will need to answer will span community engagement, social acceptance, environmental and economic sustainability, regulatory compliance, urban zoning, traffic management and inter-modality. City density will also play a key role. The planning decisions made by 'new' hyper dense cities such as those in Asia and the Middle East (with distributions of individual towers housing around 10,000 people per square km [22]) will differ from those European compact and polycentric mid-rise cities like Barcelona, Paris, Berlin or Athens (with traditional perimeter blocks of 3,000 to 6,000 people per square km).

- Very low-density urban models, reminiscent of Frank Lloyd Wright's Broadacre City (1932), will become more technologically sustainable with UAM offering an alternative to road transport.
- In medium density environments, mixed use, socially varied housing and commercial fabric, designed as a proximity neighbourhood, would be the site of a dedicated, multimode vertiport.
- In very high-density environments vertical zoning will become the norm. In the world's megacities building size is expected to move towards 'cities in a building' where UAM is a prime design factor and real estate value driver (as per the example for Amal presented earlier in this paper).

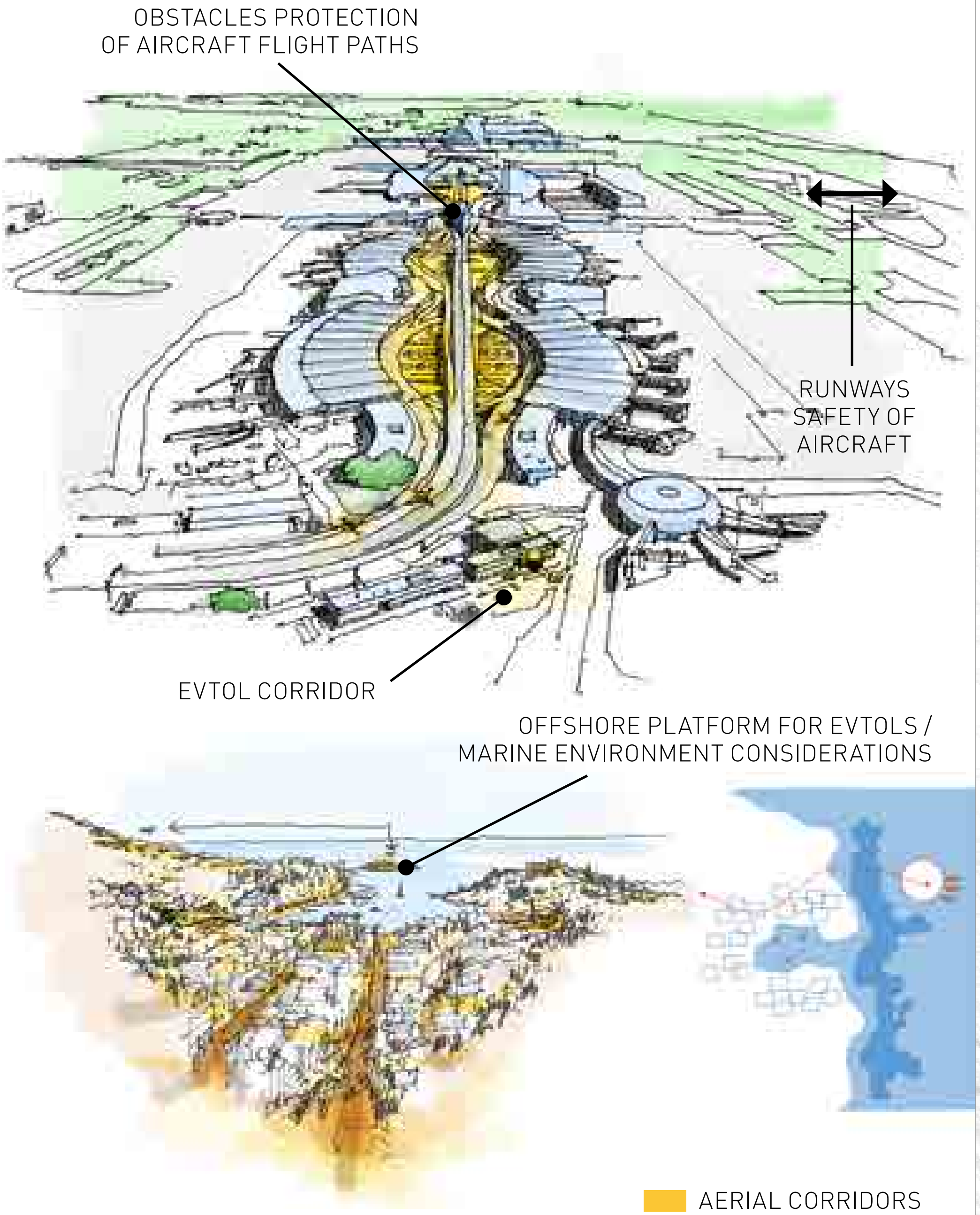
IMPACT ON LAND USE

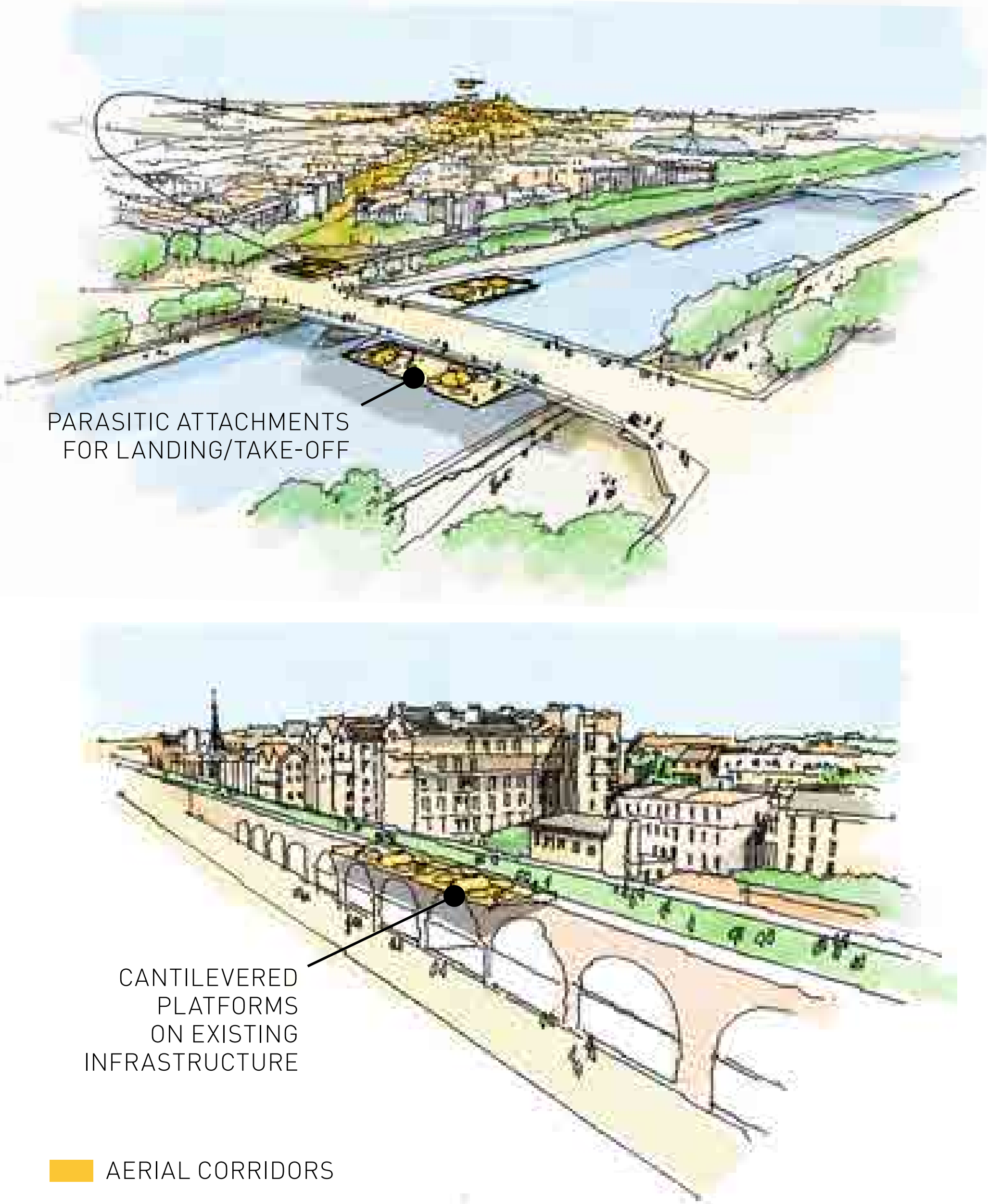
In the short term UAM will predominantly use existing infrastructure such as rooftops, but over time will require an array of vertiports and these must be integrated with existing land uses and concentrations of activity, particularly with:

- Existing airports.
- Mass transit intermodal nodes / Transit-Oriented Development (TOD) [23] for metro, high speed rail, etc. either creating new opportunities for TOD or consolidating existing TOD areas.
- Edge city 'commuter ports' in various types and densities of residential and mixed-use fabrics.
- Tourism, leisure and events areas.
- Exurban business parks and research campuses.
- Logistics hubs and industrial areas.

FIGURE 5

EXAMPLES OF SETTING LAND ASIDE FOR DEDICATED VERTIPORT DEVELOPMENT





Decisions made on vertiport locations, their operations and transport connectivity will be crucial and may also change the balance between public and private sector investment. In particular, vertiport integration will require either:

- Setting land aside for dedicated vertiport development typically in lower value suburban or edge urban areas (as in Figure 5); or
- Adapting existing land (or water) uses and buildings (such as the bridges and waterway pontoons (as in Figure 6); or
- Flexibly planning and embedding the required floor-space, cantilevers, high-speed elevators etc. in buildings from the start (also as in figure 6).

FIGURE 6

EXAMPLES OF ADAPTING EXISTING LAND / WATER USES AND BUILDINGS

FIGURE 7

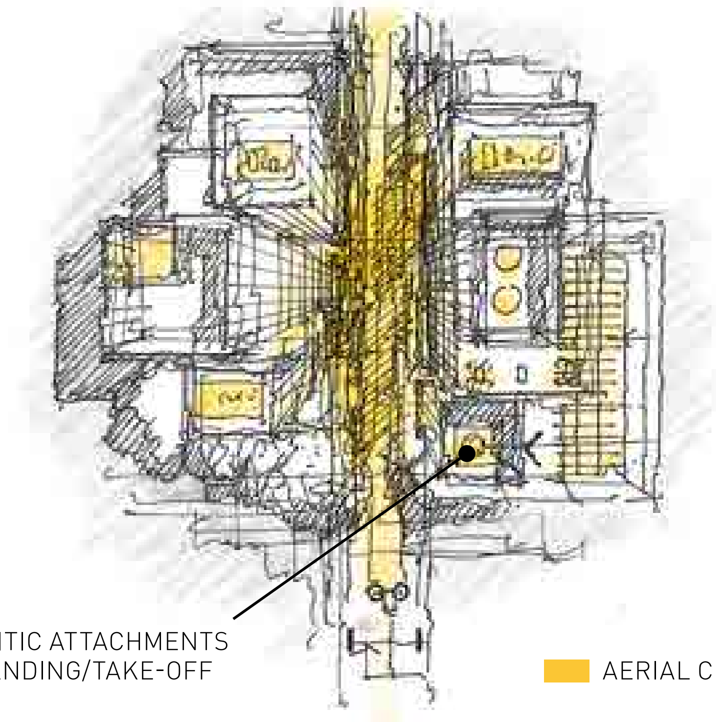
EXAMPLES OF FLEXIBLY PLANNING AND EMBEDDING VERTIPORTS FROM THE START

UAM has the potential to shape a huge secondary real estate market. In land transport, multimodal hubs have tended to increase land values in the area immediately around them.
This may also occur with UAM networks: access to new low altitude air-corridors, especially at key points of intersection with land transport will probably be the places where real estate values increase. This could apply, for instance, to:

- the main CBD vertiport hub in large cities, plausibly on top of a major land transport hub
- the vertiport at the airport, or
- a multimodal freight logistics vertiport.

But it may also apply to generalised increases in 3D floor area values for all accessible floors along the vertical air routes*. This is essentially a new market segment.

* much like real estate values increased when Haussmann cut new boulevards through medieval Paris. It is a less well known fact that the entire modernisation was a real estate driven operation and was highly profitable.



UAM will also provide the opportunity to connect hilly or mountainous terrains surrounding cities where geographic barriers make rail/ underground transport uneconomic. Hillside villages previously hard to access could become new real estate hot spots.

Metropolitan administrations and private sector business alliances which identify these opportunities early and secure land, floor area, and air route access rights will be well placed to profit from increased land and floor area values in the intensified 3D geography of prime locations. Emerging imaging and data technologies may be required to help correlate population density and income, real estate values, actual building heights and possible air-corridors (eg figure 8, right).

3D URBAN ZONING

Metropolitan areas will need to take a fresh look at zoning. In a sense, the classical 2D multimodal integrated transport plan goes 3D (links upwards). Access to air corridors could rapidly become as important as road accessibility is today. The passage from a 2D 'nuclei and land line' (or 'hub and spoke' in aviation speak) network to a 3D 'polycentric, mixed point, air corridor and land route integrated network' is a major shift.

In time, the UAM network itself will be functionally differentiated. Airbus and MVRDV studies [24] suggest an overlap of specialised networks (business, R&D, tourism leisure, logistics etc.)

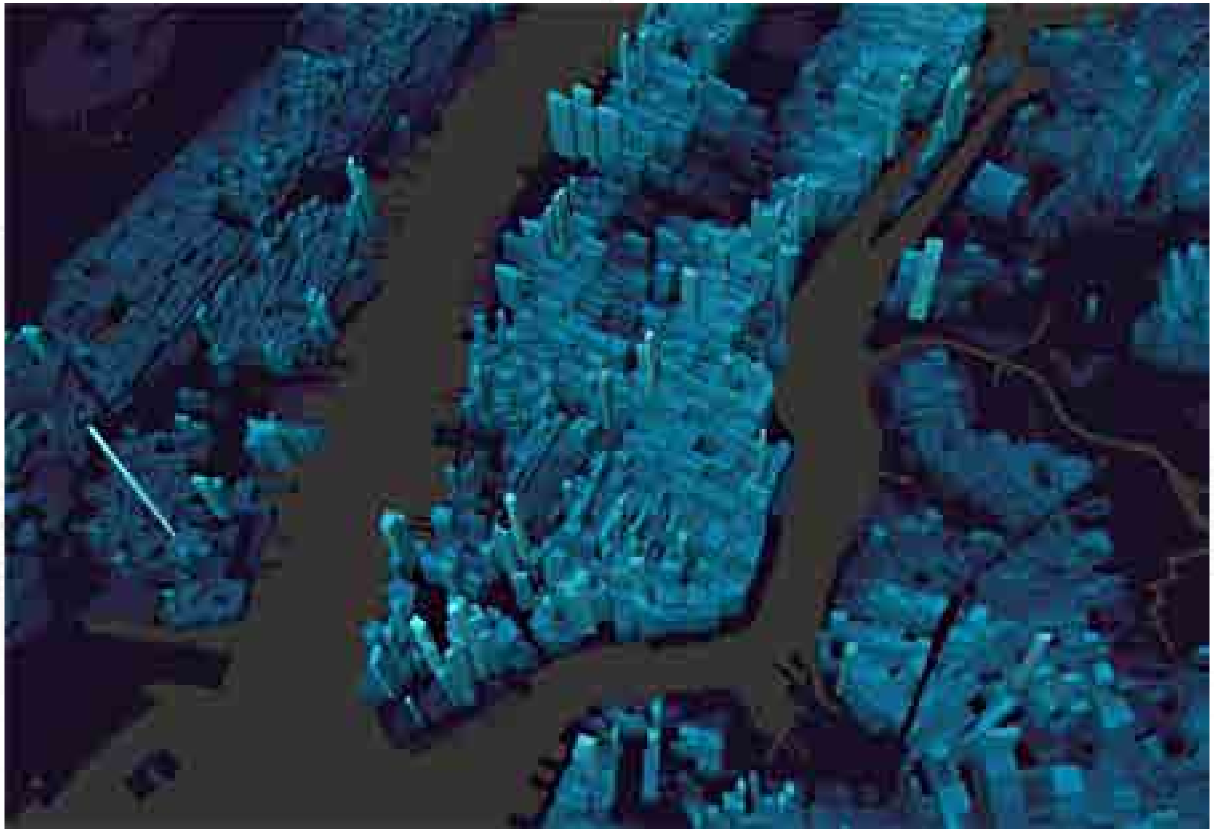
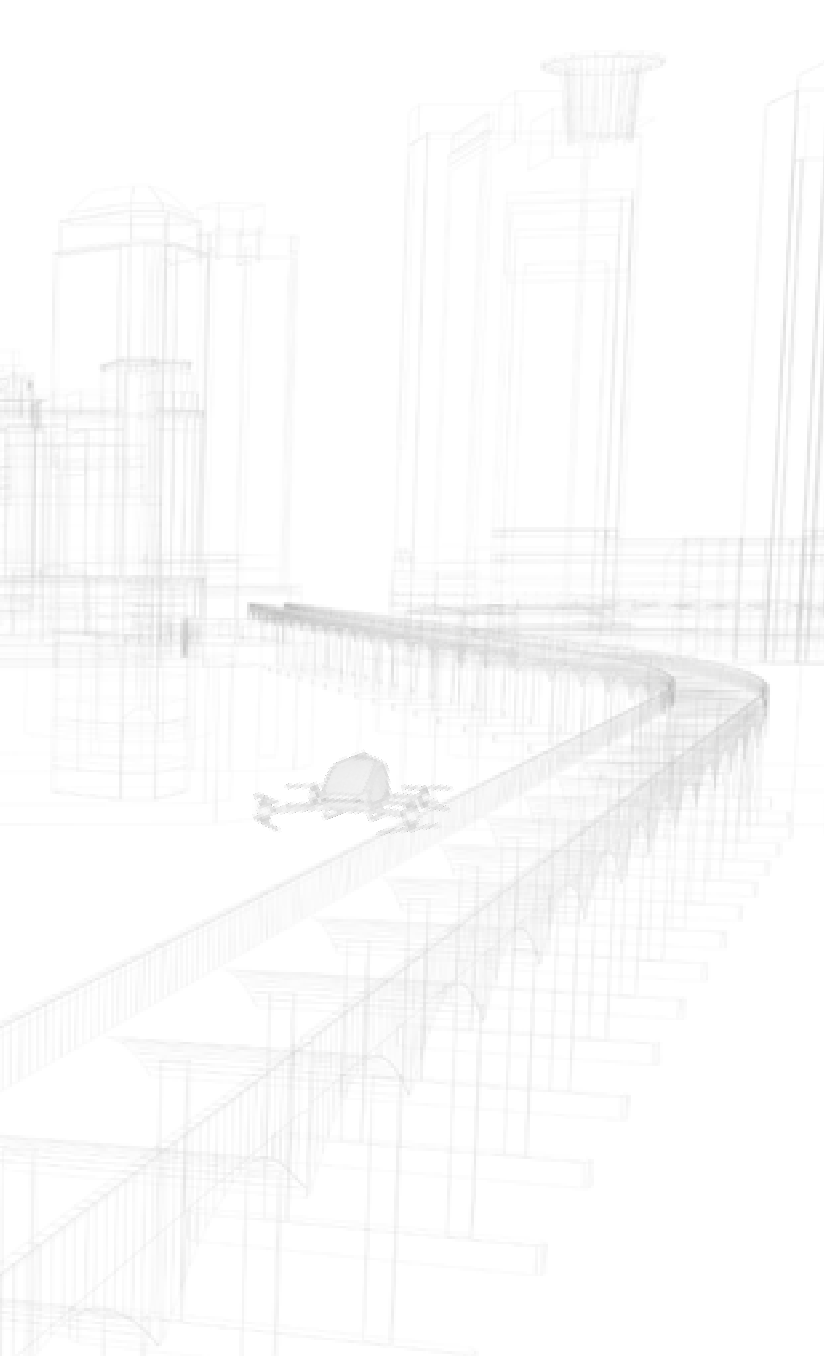


FIGURE 8 ▲

AN EXTRUDED POPULATION DENSITY MAP OF MANHATTAN (NOT ACTUAL BUILDING HEIGHTS)



each with specific origins and destinations, differently distributed over the 2D and 3D space of the metropolitan region.

To integrate the variety of needs and users, a three-dimensional air-routes plan, specific to each metropolitan region, will be required to establish the corridors, sharing mechanisms, management and control of the urban sky. However, this should not be considered in isolation of 2D multimodal land transport planning.

The 3D geography of prime UAM air corridors, integrated with existing multimodal land transport nodes will be one indicator of the prime location opportunities for vertiports. Urban planners need to start looking forwards into potential UAM scenarios in which vertiports can be best located in their cities, recognising environmental, social and practical factors. The plan could identify possible areas for vertiport locations and transport integration options. The plan needs to be flexible as there are many unknowns both in UAM developments and other areas of city planning. It can then be used to inform infrastructure and investment decisions in the transition towards UAM.

COMMUNITY ENGAGEMENT

To address community concerns about visual and noise impacts of UAM, cities will need to engage with communities, including local businesses, to foster social acceptance. Many aspects of social acceptance, such as safety, will also have to be considered at a national level and this is considered in the 'Preparation by regulators' section (on page 46). Urban planners will want to focus on local issues and topics (eg noise nuisance to residents or potential disruption for businesses close to vertiports) that are a priority for their own communities. They will consequently need to organise local engagement, to understand the local priorities that will fit within a national framework. Many local measures, such as community consultation panels, could be imagined to guide the introduction of UAM into the city.

Social acceptance is not just a matter of individual feelings and perceived risks and benefits, but is predominantly a social process [25]. Public acceptance may depend on the views and information made available by experts (and the media) who will often use terminology and language that is difficult for the lay person to comprehend. As a result, people will rely on others to gather and interpret information. This is where trust becomes especially important.

A lack of trust in decision makers, authorities or regulators regarding the protection of citizens, the fair allocation of risks and benefits or the stated impacts may discourage public cooperation and hamper adoption of UAM. Conversely, the existence of trust can lead to greater tolerance of uncertainties, willingness to explore opportunities, and openness to new information. It allows people to make decisions and enjoy the benefits of new technologies without having to understand all the details.

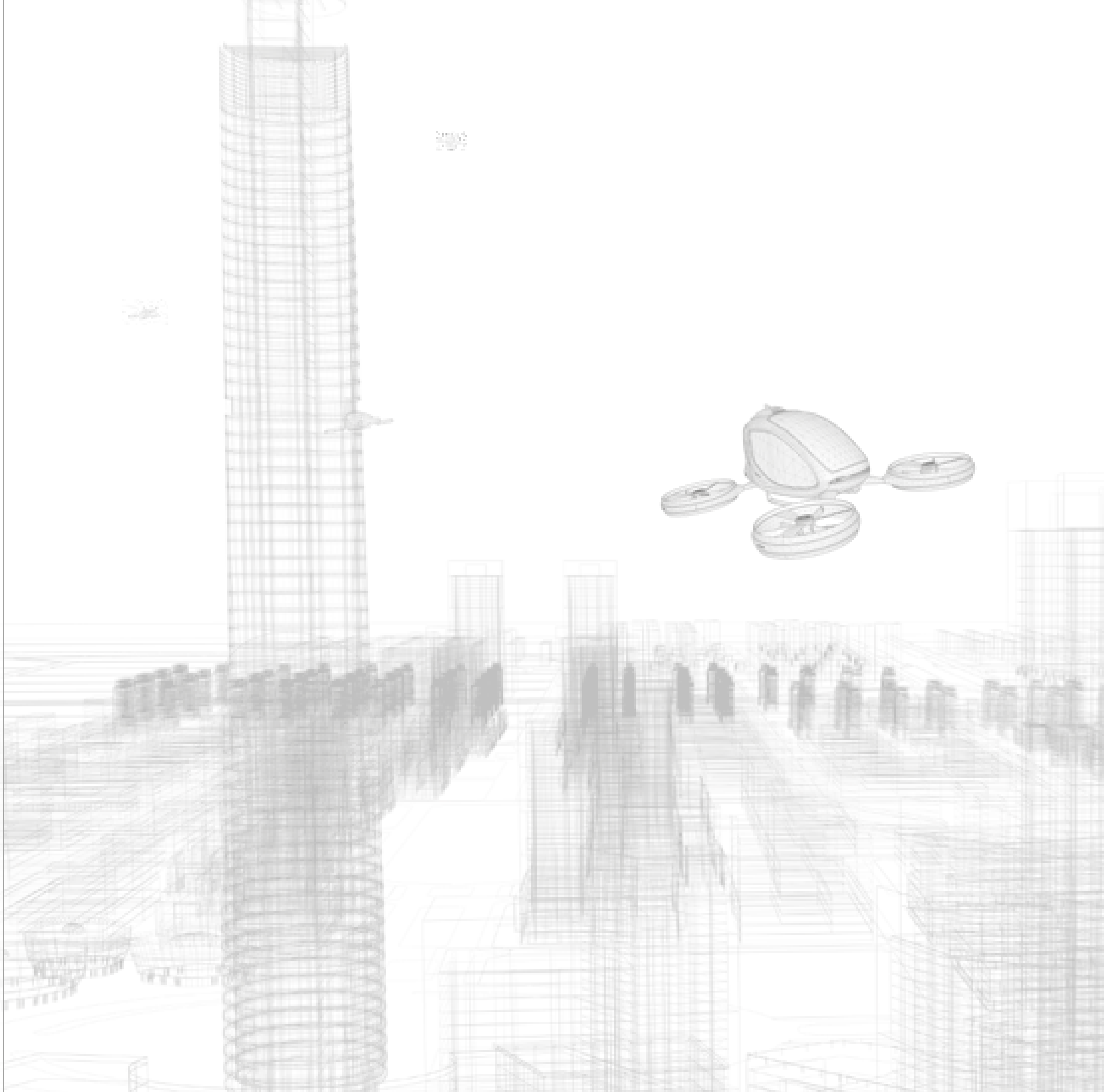
Therefore, part and parcel of the advent of UAM will be the need to build trust with communities, open channels of dialogue and education, and use accessible language.

PREPARATION BY INFRASTRUCTURE PROVIDERS

Although not as physically extensive as road or rail, UAM infrastructure still remains a capital-intensive investment. Building a network of vertiports around densely populated cities requires detailed planning and acquisition of land can be challenging. Vertiports will have particular infrastructure requirements like access to power for recharging, and 5G for communications. They may also have to take account of micro-weather aspects such as wind patterns in the take-off and approach zones by delaying flights or warning passengers of sudden gusts of wind.

LOCATING AND BUILDING VERTIPORTS

Some vertiports currently exist for VTOL aircraft and, in the US at least, are legally the same as heliports, although no refuelling, maintenance, repair or storage of helicopters is permitted. The design of these vertiports is thus covered by International Standards [26],



while other standards also influence the height of nearby buildings.

Infrastructure providers will need to take account of these standards but also monitor for changes to them and for the publication of new regulations. Meeting design and build standards will be easier in new cities where it can be planned in from the start. In old cities, it will be necessary to carefully research areas that are able to comply with the standards.

Although existing vertiports are based on heliport standards, this will change over time as vertiports get their own specific standards. Vertiports have some key differences: UAM aircraft will be lighter and often smaller, and the space and load bearing requirements will not be the same; UAM will require additional facilities for recharging electric vehicles, handling cargo as well as passengers, or hosting remote pilot stations.

Vertiport design will be subject to regulations to ensure that UAM operations reach a high level of safety, for example considering and mitigating safety hazards that are specific to eVTOLs, such as battery fires caused by thermal runaway. A particular aspect of this safety work will be minimising the risk of an eVTOL hitting a building or structure during landing or taking off in the city. Another aspect is the location of emergency parking sites in the city should the need arise, or the temporary closure of the vertiport. A specific assessment (known as a 'safety case') will be required to demonstrate the safety of all aspects of the operation. Early consideration of the safety aspects of the operation will smooth its later deployment into service.

A variety of vertiport designs can be imagined (for example those developed by Skyports [27] or Urban Air Port [28]) depending on the services provided by the eVTOL operator(s) and the urban environment. For example, in high density vertical cities there may be more use of vertiports on existing high buildings. These will likely have only one or two landing pads and will not be high-throughput transit centres. Where larger flat spaces are available, perhaps in some of the older lower-rise cities, there may be more 'multipad' vertiports say with six to ten landing ports. These will be for higher density transit hubs and may be best located near existing infrastructure hubs, such as railways or convention centres. Infrastructure providers need to prepare for both types of deployment.

A single vertiport may be implemented to serve a local area, or many vertiports can be placed in a large urban area and be used by different UAM operators. Depending on the future regulation on vertiports, some could also operate as heliports and provide services to a more varied range of aircraft. Vertiports can be envisaged to serve different purposes: a stop on a passenger route, adjoined to a loading zone for cargo handling, or a maintenance area next to an eVTOL depot.

Another consideration is the energy requirements of UAM operations. 'Rapid charge' solutions will require significant power. Vertiport constructors may need to consider the power grid capabilities and alternative energy sources to ensure that sufficient power is available. Energy planning, as with several other factors here, will require close engagement with the city authorities.

As with airports, vertiport design, building and operation will benefit from the digital transformation taking place in the field of construction. Building Information Modelling (BIM) will enable good choices to be made thanks to interactive simulation and the reversibility of all chosen solutions. The interoperable software of BIM fosters collaboration and communication between all parties involved, provides digital data integration and 3D visuals to increase productivity (cost and time management), and improves the technical and energy performance of infrastructures. Infrastructure providers should already be investigating how BIM might accelerate the later rollout of vertiports.

DIGITAL INTEGRATION

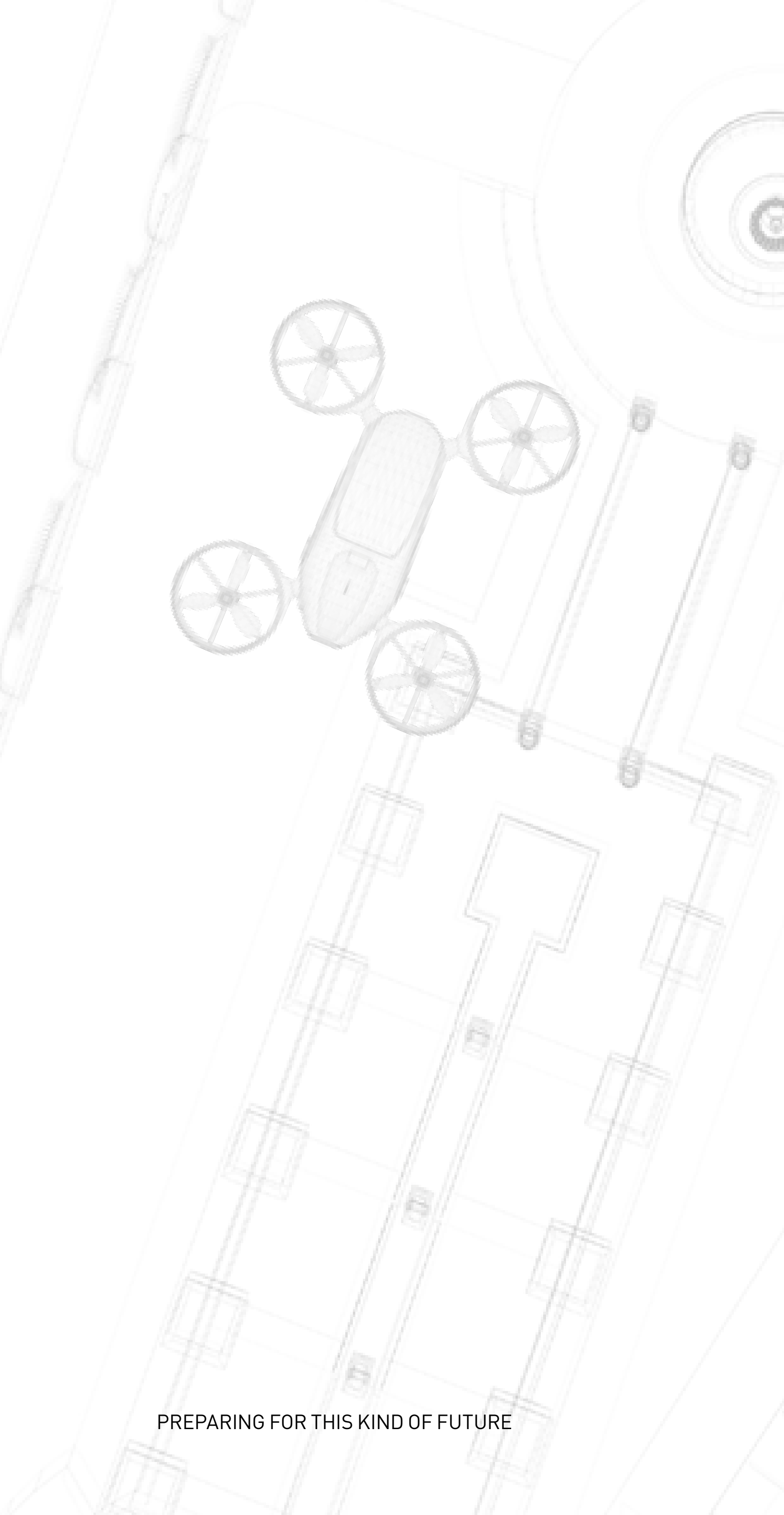
The digital platform for smart infrastructure will be created by integrating not only legacy systems but also all information related to mobility. This is the key to integrating UAM into a larger urban transportation network; data flows between operators will allow new mobility services for city residents that increase the efficiency of the transport network and reduce reliance on personal vehicles. Through the interoperability of different transport operators' systems, digitalisation will give rise to the development of platforms such as MaaS (Mobility as a Service), ie the implementation of digital systems according to a service-based approach. It will enable smart connections with existing transportation systems, especially if the vertiports are close to underground stations, bus stops, car parks or other transport terminals.

In new cities, it may be possible to achieve greater coordination of different transport modes since the city can be designed with this in mind. Apps are already available which offer access to city transport and they are gradually integrating more elements of the networks. These apps will be the main interface for citizens to access the UAM network as one element of multi-modal journey planning (as we envisaged with the Shenzhen and Paris examples).

Infrastructure providers should be preparing their services with both digital and physical integration in mind.

COMMUNICATIONS AND THE ROLE OF 5G

High integrity and low latency communication networks will be a key infrastructure for the operation of UAM vehicles. On paper, 5G is not suited to supporting UAM operations. It is largely planned for frequencies that are too



short range, and its core market will require infrastructure targeting the ground (not the air). Even if the antennas are adapted to reach UAM vehicles, the network will need to be extremely dense, so from the air too many cell towers will be visible making handover a potential problem. Finally, the core selling point of 5G: its extreme data rates, will be completely unnecessary for most UAM (and particularly UTM) use cases. 4G, or even 3G have already been shown to be adequate [29]. So why is 5G so often associated with UTM as a key enabler? The answer is underpinned by three reasons:

1. As 5G is rolled out, 2G is retired, making the frequencies used by 2G (which have much better propagation characteristics from an aviation viewpoint) available for re-use.

2. 5G uses beamforming directional antennas, which only function because 5G has a built in, independent and highly accurate positioning capability.

3. 5G is built to deliver extremely low latency for automotive Vehicle to Everything (V2X) use cases.

If infrastructure operators can offer a service that combines all three of these 5G features, and do so with guaranteed performance, it will become a key enabler for UAM.

PREPARATION BY OPERATORS

eVTOL operators and UAM services providers will also need to exchange data with the local airspace manager. In an environment where the airspace above urban areas is filled with all types of manned, autonomous and automatic aircraft, some form of regulation and control will be required to ensure the safe and smooth management of traffic flows. The principles that have structured air traffic management for conventional aviation will be applied locally to the urban airspace.

From an infrastructure perspective, the urban environment has an advantage over the sparsely populated areas or oceans above which traditional aircraft operate as there is an abundance of possibilities to support operations, with 5G wireless networks and the Internet of Things becoming a reality. Traditional air traffic control technology (eg radar surveillance, VHF voice communication), will not work in a dense urban environment, so new standards are required. However, 5G may not meet traditional safety standards so either way, new thinking will be needed.

GOING 'SMART'

To accommodate UAM efficiently, cities will need to 'go smart'. This involves digitalisation not just in the building or operating of infrastructure. The infrastructure itself has to be smart to improve its performance and increase its value as an asset. By combining physical infrastructure such as roads, railways, and buildings with digital infrastructure (sensors, wireless networks, BIM), smart infrastructure will allow transport assets to become providers of information, and thus to support more efficient decision-making and to improve the performance of existing assets.

Future city platforms will no longer be considered as simple traffic management platforms but as mobility management platforms and will include public transport, pedestrians, bicycles as well as aerial vehicles.

A future mobility management platform must also offer a mobility observatory. Creating a digital twin of the mobility management platform (or "hypervisor") will enable interoperability between tools and digital continuity in information exchange processes. It will enable cities to use artificial intelligence to be able to simulate and predict traffic flows and plan for special events such as festivals, concerts and processions.

Hypervisors have become a staple equipment in transport operations centres, allowing supervisors to have a holistic view of both the vehicle flows and the status of the

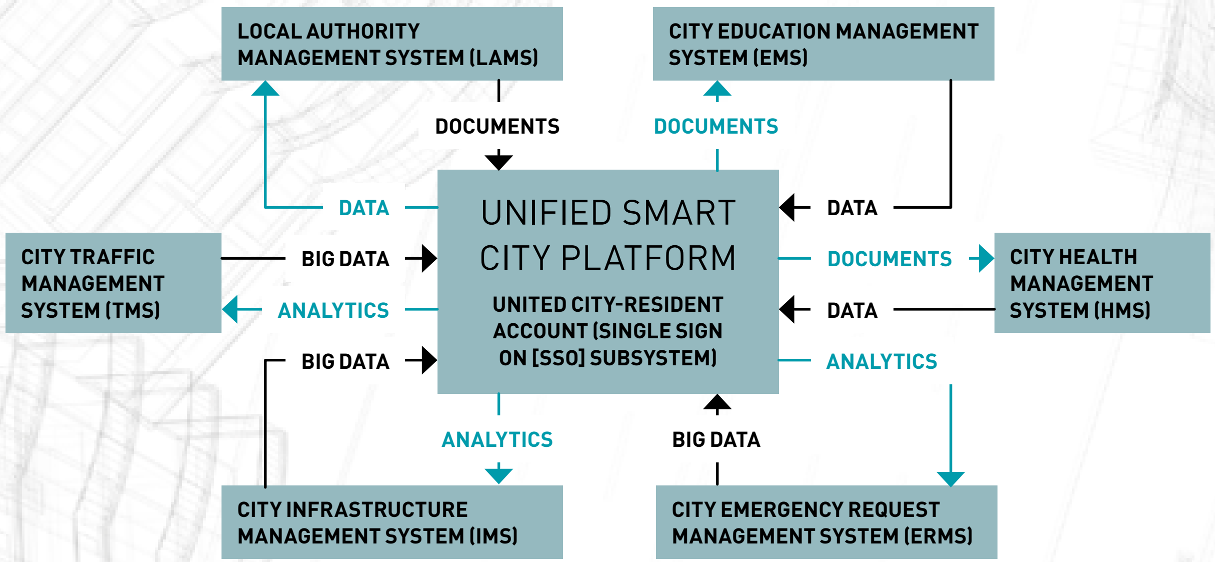


FIGURE 9

EXAMPLE OF A MOBILITY PLATFORM ARCHITECTURE (REAL PROJECT EXAMPLE)

infrastructure through remote sensors and cameras. Geographic Information Systems (GIS) will provide an accurate 3D model of the urban environment in which eVTOLs operate, enriched with spatial data which will improve the efficiency of operations and maintenance.

Coupling GIS and BIM technologies allows envisaging tools which will provide a holistic view of the transport infrastructure and operations in a city by providing a complete digital twin of the transport network. Data science and AI will allow supervisors to navigate and understand the massive amount of data they will be able to access and will support decision making when they face issues.

With UAM, the mobility observatory will have to integrate the regulatory and structural constraints of the city by including the overflight zones and securely integrate these air corridors with land infrastructure whose different land transport flows (car, public transport, pedestrians, bicycles) will synchronize with these air flows.

To provide services, the cities of tomorrow will not only have to have this type of architecture, but will also utilise a multi-purpose IP unifying network, interoperable yet distinct equipment, drivers for connected objects, or application interfaces (APIs), which ensure the exchange between software.

PREPARATION BY REGULATORS

Regulators will need to address airspace and air traffic management, vertiport design and build, as well as issues such as noise management, cyber security and privacy protection.

SOCIAL ACCEPTABILITY

Social acceptance of UAM operations is essential for widespread deployment. People may be uncomfortable with drones manoeuvring close to their apartments or flying over them at low level as they walk. They may perceive risk more acutely if accidents occur in the city, compared to aviation today where most accidents are away from populated areas. They may perceive UAM operations as an enabling an invasion of privacy. As noted above, they may oppose the construction of vertiports in their neighbourhood if they are seen as only for the wealthy elite.

Regulators need to understand these concerns and develop suitable regulatory frameworks to support social acceptance. One way that social acceptability could be increased, for example, is by prioritising medical and emergency uses of UAM (e.g delivery of transplant organs) to supplement ambulances on the roads.

At this time, regulators need to be engaging with the public to explain the possible future scenarios and to gather feedback. From this they can propose options for regulation and test them with the public, alongside UAM operators, city planners and infrastructure providers.

MANAGING NOISE

A particular and specific aspect of social acceptability is related to aviation noise. Standards for traditional aviation noise certification are based on the Effective Perceived Noise Level, or EPNL, which is applied to both aeroplanes and helicopters and described by ICAO as a "single number evaluator of the subjective effects of aircraft noise on human beings." Near airports, noise is often assessed with different measurements such as L_{DEN} which integrates loudness over a 24-hour period with different times of day given a different weighting in the calculation. Other measures are also available, and it is not clear if either of these (or others) will be appropriate for UAM measurements. EPNL is designed to reflect the annoyance of an aircraft 'whine' but it is designed around jet engines, not electric ones. L_{DEN} measures the cumulative effect of noise throughout the day but may be unsuitable for drones which operate within hundreds of metres of living accommodation.

Additional complexity exists with UAM because there is the real prospect of multiple eVTOL vehicles flying in one area. That scenario could

give someone on the ground a sense that noise is coming from all directions, bouncing off buildings, even if the absolute noise levels, measured in decibels, of individual aircraft might be acceptable.

Regulators will need to design noise control regimes for UAM considering the above factors and others. It would be helpful for regulators to start engaging industry and academia now to better understand the impacts of UAM noise and inform future plans. Even if eVTOL aircraft are significantly quieter than existing aircraft, there may still be challenges in gaining their acceptance.

ENSURING SAFETY AND SECURITY

When autonomous vehicles operate at vertiports, there will be new safety requirements. The current regulation will thus need to evolve to address these gaps, define the requirements that vertiports have to meet and provide the acceptable means by which vertiport designers and builders can demonstrate the conformity of the infrastructure with these requirements.

As noted above, public perceptions of risk may be different with UAM compared with traditional operations. This is partly due to the locality of operations (inside a city in highly populated areas) and partly due to the potential for apparently high accident rates if there is a dramatic rise in the frequency of operations. Therefore, safety standards may have to be quite different in the future and perhaps much higher than today.

A high rate of innovation in the UAM market (which is already happening and can be expected to continue) will also challenge safety standards. The standards are usually written reflecting current operations, materials and procedures. Standards can take years to prepare and agree. In a rapidly and fundamentally changing market it will be a challenge for regulators to keep up. A good example is the introduction of artificial intelligence and autonomous aircraft. In a few years, aircraft may be capable of self-flight but there are no regulations for this at present.

Regulators need to consider how they will oversee this future environment and engage with industry on the most challenging topics, such as how to manage safety with a high rate of innovation.

AIRSPACE MANAGEMENT

The management of the airspace over the urban area has to be considered as a resource shared by various stakeholders, and requiring rules and an arbitration body for efficient use. The management of the urban airspace will also have to look at issues that go beyond the mere allocation of portions of the airspace to the aircraft operators, such as reducing the effect of noise on communities, maintaining the privacy of residents, and ensuring the security of sensitive sites within the urban area. Given the density of obstacles and the dynamic nature of the urban environment, it will not be possible to transfer the technologies currently used by ATC. New sensors, communication networks and data networks will be needed.

Although it is expected that drones flying in an urban environment will have to be able to detect and avoid other aircraft on their own, full automation of these functions will not be achieved in the short term and urban airspace will see autonomous drones co-exist with manned helicopters and eVTOLs. In this environment, air traffic controllers will be necessary to manage the traffic and they will need support tools to communicate with pilots and track aircraft.

Faced with congestion in some parts of the airspace, conventional aviation has developed skills, tools and procedures to regulate the flow of aircraft as efficiently as possible and to balance the demand from airlines with air traffic control capacity. In the context of UAM and MaaS, flow management takes on a whole new dimension as air transport will only be one component in the overall mobility offering, and will also have to enable a high level of punctuality for seamless connections.

SHAPING OUR DESTINY

The concept of UAM offers the promise of fast, low (or zero) emission journeys and reduced congestion. Implemented successfully, it will offer an innovative mobility service that complements ground transport and connects distant suburbs in a demand-responsive way.

UAM hype seems to be at its peak, with many commentators concerned about whether the promises will match with reality. Right now, UAM raises as many questions as it answers and requires many challenges to be overcome. These include the economic case, social acceptability, environmental policy (noise and emissions), public use, land use and liability, and insurance arrangements.

The barriers to UAM market growth can be overcome, particularly as early uses of drones (for inspection purposes, aerial photography etc) have already helped to address some of the challenges. We do see UAM as more of a destiny than a dream, though it is difficult to be confident in the scale or timeframe of market maturation; some predictions seem overly optimistic. The UAM market is most likely to 'take-off' in parts of Asia first, where government and industry are well aligned and well organised and the conditions for new pioneers are favourable. It is also perhaps the area where demand is strongest, due to fast population and urban growth. The region is increasingly adopting the Transit-Oriented Development (TOD) concept with mixed use developments that lend themselves well to UAM services. Centres of interest will be linked and passengers will find retail, services, leisure and public transport all neatly integrated together. It is perhaps no surprise that some of the most substantial progress in flight demonstrations, manufacturing and certification are in this region. Other ambitious and fast developing parts of the world, like the Middle East, are also forging ahead with plans and will likely be among the front-runners.

Whilst no-one can predict what the market will look like in the years to come, in this white paper we have endeavoured to develop a vision that takes onboard the perspectives of potential users and the demands it will place on urban infrastructure. This has been considered in two quite different environments: first a modern city, akin to Shenzhen in China, where growth is rapid and new infrastructure is emerging out of nothing; and secondly for an old city, akin to Paris, where UAM would be another dimension to an already mature and complex urban fabric.

Our vision is based on a tailored, collaborative and technically sound approach that defines the service offer best suited to the context of each area. Whether it is a tourist service for Paris or a flexible infrastructure gap filler for Shenzhen, urban air mobility has a future that will need to be adapted to local needs and the built environment. We expect the development path to begin with cargo drones, extend to regional air mobility and airport shuttles, reaching the urban environment in 2030+, though the path will vary by region.

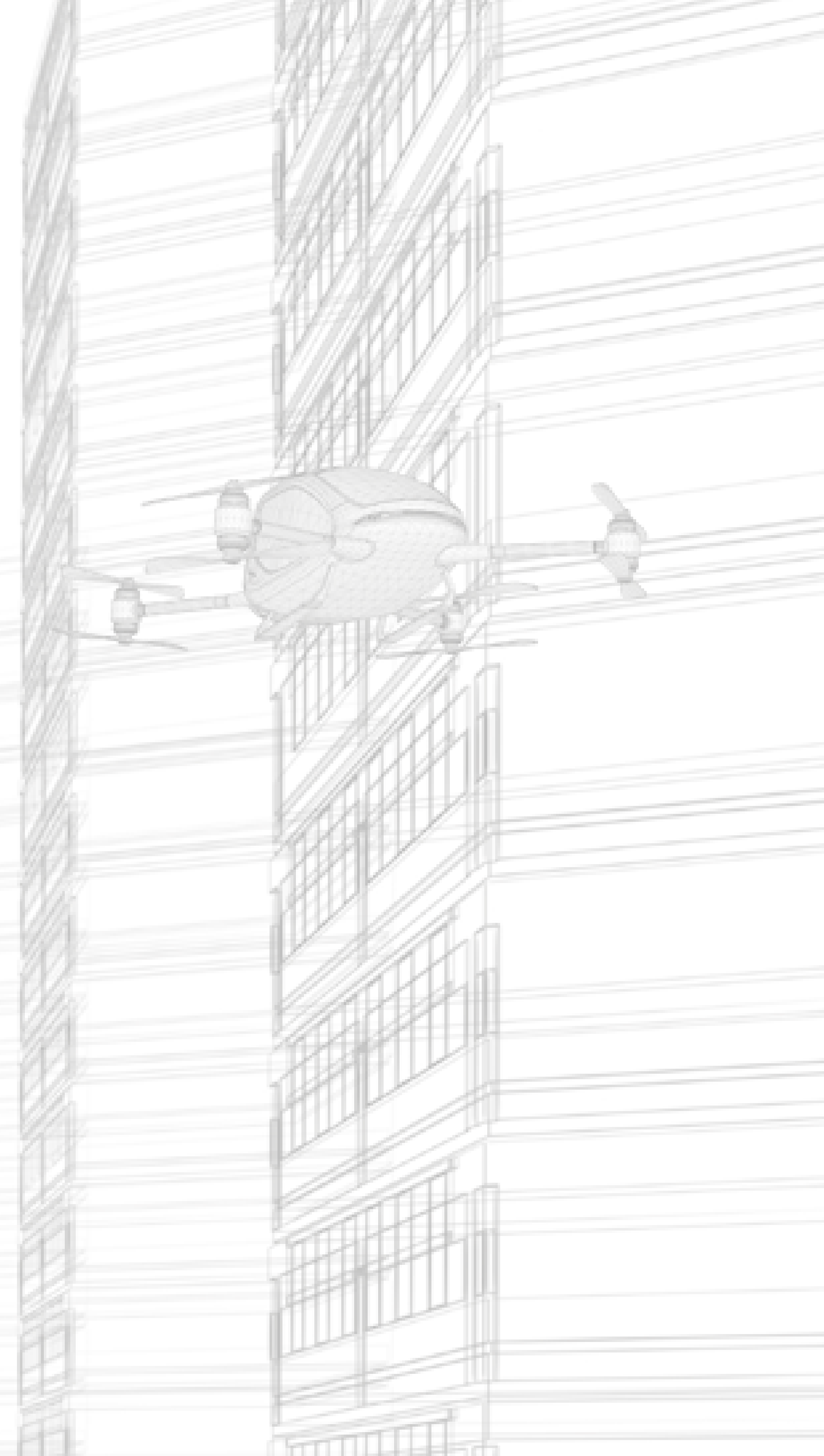
Of course, the eventual reality will almost certainly look different to our vision, but by offering possible scenarios, we can then imagine how to prepare. While preparatory steps need to be taken by many stakeholders, we have focussed on urban planners, infrastructure providers, operators and regulators. Key actions will include:

- The development of a collaborative ecosystem from both a technological perspective (vehicle x infrastructure x digital platform x exchange hub) but also from a governance perspective to oversee increased collaboration among all stakeholders involved (including those still yet to emerge).

- Integrating vertiports, by either setting land aside, adapting existing land (or water) uses or flexibly planning and embedding it into designs from the start.

- Taking a fresh look at urban zoning in metropolitan areas as air corridors become as important as road accessibility and we move from a 2D network to a 3D polycentric, mixed point integrated network.

- Building trust with communities through open channels of dialogue, education, and use of accessible language. Local consultation panels could help guide the introduction of UAM into the city and prevent it from becoming an elitist, niche market that fails to achieve its potential.



- Using techniques like Building Information Modelling (BIM) to make good choices for vertiport locations taking account of requirements like access to power, communications, micro-weather management and the evolution of services as the market matures.

- Ensuring high integrity and low latency communication networks – a key infrastructure for the operation of UAM.

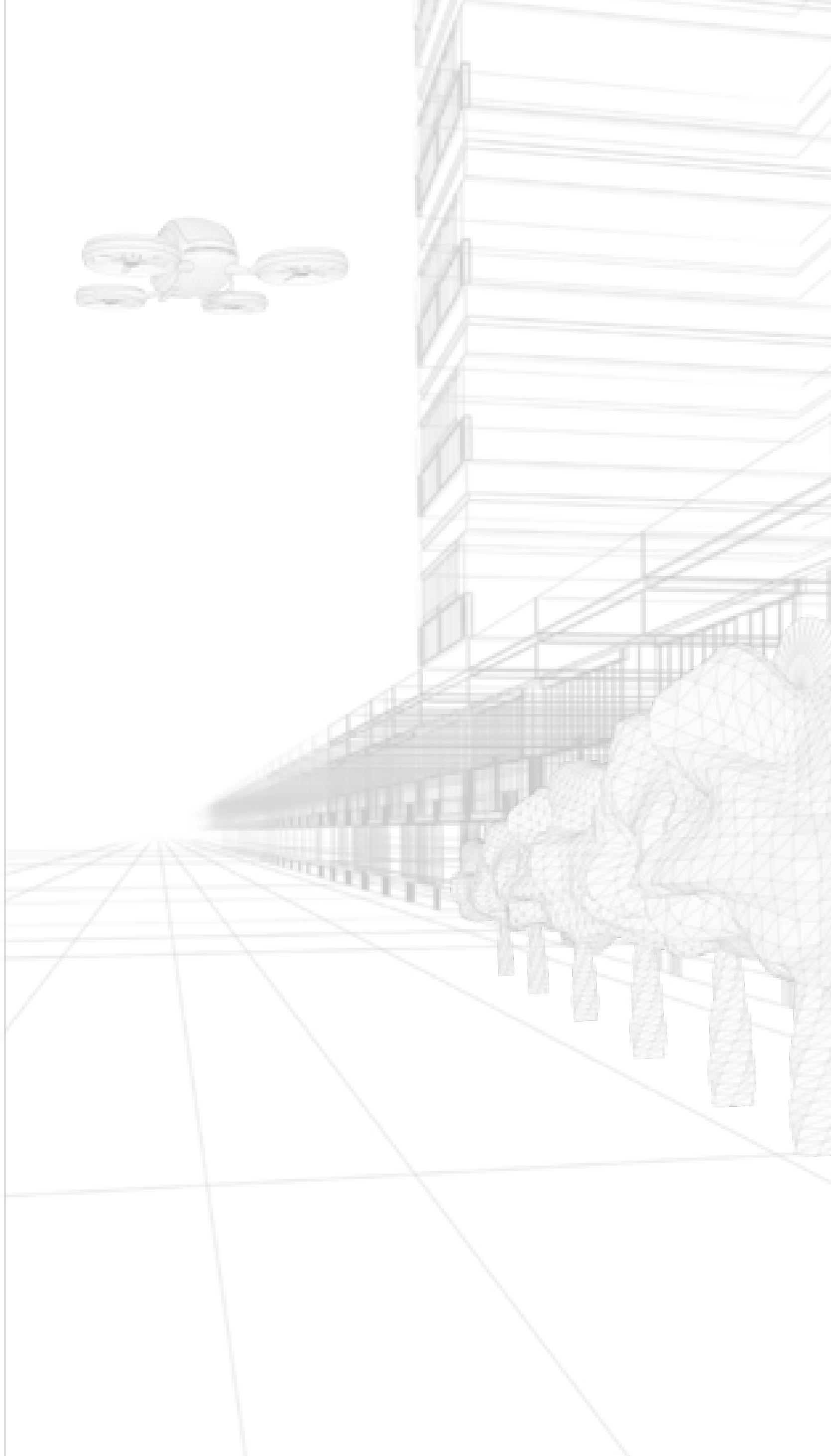
- Providing resilient Position, Navigation and Timing (PNT) solutions that overcome the challenge of urban environments and to support adaptive navigation routing.

- Coupling GIS and BIM technologies to create tools that provide a holistic view of the transport infrastructure and operations in a city, such as a complete digital twin of the transport network and aspects that impact it.

- The need for cities to 'go smart'. This involves digitalisation not just in the building or operating of infrastructure but the infrastructure itself. This will support more efficient decision-making, for example through a mobility observatory that could offer a management platform to enable cities to simulate and predict traffic flows and plan for special events.

- Regulators will need to address airspace and air traffic management, vertiport design and build, as well as issues such as noise management, cyber security and privacy protection. This means designing regimes for issues such as noise control and addressing gaps in safety regulations.

Our understanding of cities, transport, infrastructure and operations has given the contributors from across the Egis business a wide and unique perspective to reflect and comment on UAM – all with an independent standpoint. This perspective has allowed us to look at how multi-modal transport infrastructure will need to be better designed and integrated to accommodate UAM within the fabric of the city. The integration of aviation concepts into urban infrastructure is a significant challenge and one that we consider has been underestimated so far, although operators such as Volocopter acknowledge the need for an entirely new value chain [30]. Whether it is a new or old city, fully integrating UAM into the fabric of the city is the only way to deliver a shared, economically sound and politically supported concept that is both socially and environmentally acceptable.



EGIS CONTRIBUTORS AND CLOSING THOUGHTS

MOBILITY

"Egis is ahead of the curve and is working with its production teams on a new urbanisation of data and systems. UAM is another transport mode that requires real interaction between data and applications and, as it develops, it will be integrated into our models to better understand the interest and applications of a city."

Pascal Seum Souk, Yves Cohen

CITIES

"The integrated multimodal and AI-managed networks of today's land transport in cities require high-capacity multi-modal urban public transport. UAM will take its place and shape the existing integrated land transport system. How this occurs will certainly be very dependent on the feasibility of integrating eVTOL and will be different from higher capacity public transport vehicles."

Ion Besteliu, Isabelle Lopez

OPERATIONS

"Whilst it's early days in UAM, it raises new and interesting possibilities for the way in which privately owned buildings or public spaces can be used for a more complete mobility offer."

Patricia Yammine

BUILDINGS

"Buildings can be easily adapted to accommodate very light UAM vehicles, but the bigger constraint will be how to transfer passengers between roofs and street level city access. This is the reason we believe that lighter platforms on top of bridges or high traffic pedestrian facilities such as malls or convention centres will be a more preferable inner-city landing environment, together with out-of-town areas. The future urban environment is unlikely to radically change, but to slowly adapt from the reality we are already living in."

Matthieu Angenieux, Jason Easter, Leonard Milford

CONSULTING

"Identifying a location for UAM is only half the challenge, building the right teams and governance structures to launch the project is where the real difficulties lie."

Noemie Bercoff

RAIL

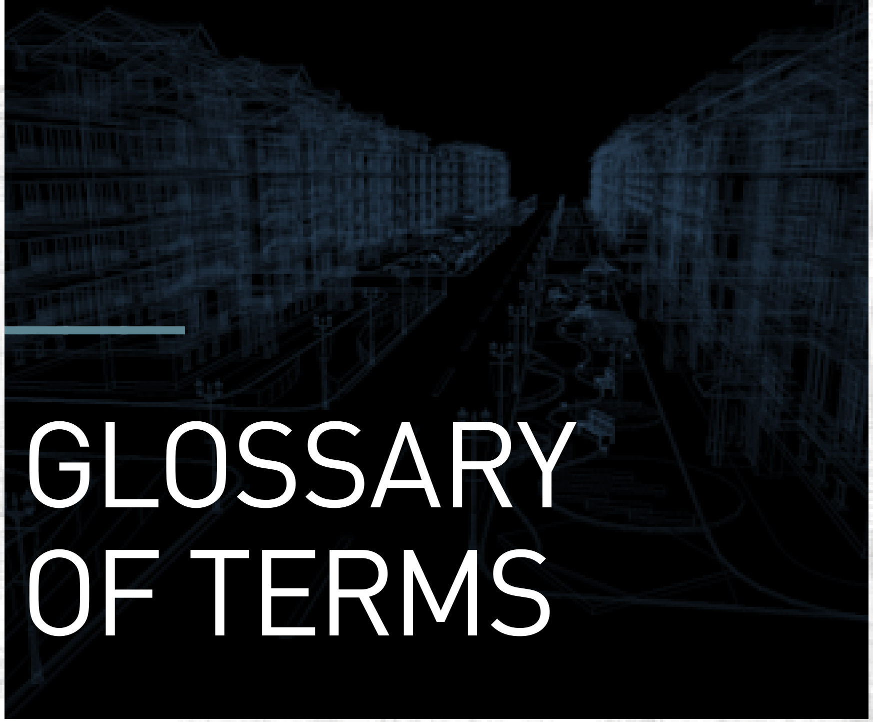
"By adding the 3rd dimension – the sky – I believe that UAM will become in the next years a smart complement to existing transportation systems in cities."

Stephane Dumarty

AVIATION

"UAM has the potential to transform cities radically. But more likely, it will transform them incrementally. Whilst there is an exciting dreamscape of a very different type of city to come, the most utility in the short term will come from organic growth."

Andrew Burrage, Jan Cernan, Eric Denele, Richard Derrett-Smith, Herve Drevillon, James Hanson, Nick McFarlane, Vincent Vimard



GLOSSARY OF TERMS

TERM	DEFINITION
AAM	Advanced Air Mobility. Concept of air transportation using eVTOL aircraft. AAM builds upon the UAM concept by incorporating use cases not specific to operations in urban environments.
AI	Artificial Intelligence.
ANSP	Air Navigation Service Provider. Organisation that provides the Air Traffic Management service (managing the aircraft in flight or on the manoeuvring area of an airport).
API	Application Programming Interface. Software that allows two applications to communicate.
ATC	Air Traffic Control. Service provided to aircraft on the ground and through controlled airspace and advisory services to aircraft in non-controlled airspace.
BIM	Building Information Modelling. Generation and management of digital representations of physical and functional characteristics of places.
Broadacre City	An urban or suburban development concept proposed by Frank Lloyd Wright.
C2	Command and Control Communication. A control and non-payload communication (CNPC) link between the remotely controlled aircraft and the pilot used to control the movement of the aircraft. The C2 link is not used for payload communication (ie sound, video, etc.).

TERM	DEFINITION
CBD	Central Business District
CDG	Charles De Gaulle Airport (Paris North)
CEO	Chief Executive Officer
CO2	Carbon Dioxide. One of the most important greenhouse gases linked to global warming.
Conventional propulsion systems	Machines powered by gasoline, diesel fuel, jet aircraft fuel and rocket fuel.
DEP	Distributed Electrical Propulsion. Electricity-powered flight propulsion system in which engines are distributed around the aircraft.
EPNL	Effective Perceived Noise Level. Instantaneous perceived noise level (PNL), corrected for spectral irregularities and for duration.
eVTOL	Electric Vertical Take Off and Landing. Electric or hybrid aircraft that can hover, take off and land vertically.
GIS	Geographic Information Systems. Computer system that analyses and displays spatial and geographic data.
HAP	High Accuracy Positioning. Positioning achieved by combining Global Navigation Satellite Systems (GNSS) with Real Time Kinematics (RTK) technology.
HMI	Human-Machine Interface. Interface that allows humans to interact with the machine.

TERM	DEFINITION
'Hub and spoke'	Network connecting every location through a single intermediary location called a hub.
Hypervisor	Digital twin of the mobility network, allowing to visualise and correlate in real time all the data produced by the underlying systems and to support an efficient management of operations.
ICAO	International Civil Aviation Organization. Agency of the United Nations, changing the principles and techniques of international air navigation and fostering the planning and development of international air transport to ensure safe and orderly growth.
IP	Internet Protocol. Set of requirements for addressing and routing data.
L_{DEN}	Descriptor of noise level which integrates loudness over a 24-hour period with different times of day given a different weighting in the calculation.
MaaS	Mobility as a Service. Integration of different forms of transport into one mobility service available on demand.
MAHHL	MAHHL-cities (Maastricht, Aachen, Hasselt, Heerlen, Liège) collectively joined the Urban Air Mobility Initiative to Improve public services and connectivity in the region.
Multipad	Multiple integrated landing ports.
NASA	US National Aeronautics & Space Administration.

TERM	DEFINITION
Périphérique	A controlled-access dual-carriageway ring road in Paris, France
PPP	Public Private Partnership. Form of cooperation between two or more public and private sectors.
QR code	Quick Response code. Type of barcode that can be read by a digital device, storing information as a series of pixels in a square-shaped grid.
R&D	Research and Development
RAM	Regional Air Mobility. Aviation transportation system using highly automated drones to transport passengers/cargo at lower altitudes within a region.
TOD	Transit-Oriented Development. Planning and design strategy maximising the number of different types of space (residential, business and leisure) within walking distance of public transport.

TERM	DEFINITION
UAM	Urban Air Mobility. On-demand and highly automated urban transportation system using passenger drones. The term often also encompasses package/cargo delivery drones too.
UTM	UAS (Unmanned Aircraft System) Traffic Management. Air traffic management system for remotely controlled and autonomous operations of Unmanned Aircraft System.
V2X	Vehicle to Everything. Technology allowing vehicles to communicate with moving elements of the traffic system around them.
Vertiport	A landing pad for UAM types of drones which land and take off vertically.
VIP	Very Important Person
VLL	Very Low Level. Volume of airspace below 500ft above (non-built-up) ground level.
VTOL	Vertical Take-Off and Landing. Aircraft that can hover, take off, and land vertically.

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