Management of Urban Air Mobility for Sustainable and Smart Cities.
The Case of a Vertiport Network in Lisbon, Portugal, Using a User-Centred Approach

(versão final após defesa)

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Dedicatory

To my parents Maria and Álvaro.

“*Aviation is proof that given the will, we have the capacity to achieve the impossible.*”

Eddie Rickenbacker

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Finally, this Dissertation ambitions to provide conditions and practical tools, contributing to enhancing lives for the better and reversing the global issue of climate change. Consequently, I firmly prosper this Dissertation to be used as a tipping point for future advanced discussions to bring on-demand UAM to Portugal. Besides that, this research vision resonates accurately with my will: to inspire others by driving meaningful change in the air transportation industry through the development and innovation of sustainable, safer and more simple solutions while tackling global climate change, humanizing technology, and empowering women worldwide. Thus, while this research's development has widened my technical and interpersonal skills, I have nurtured my personal growth and strengthened my character and potential.

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Resumo

Esta Dissertação foca-se na mobilidade urbana tridimensional (3D). Enquanto prioriza o desenvolvimento da mobilidade sustentável e cidades inteligentes, este estudo pretende fornecer condições e ferramentas práticas de modo a promover a mudança na vida das pessoas para melhor e reverter as alterações climáticas mundiais.

Atualmente, o sector do transporte é responsável por cerca de 16 por cento de todas as emissões anuais de gases de efeito estufa no mundo. Particularmente, o aumento do tráfego rodoviário urbano tem intensificado a poluição e o ruído nas cidades, deteriorando a qualidade de vida dos cidadãos que as habitam. Obviamente, é necessário promover uma mudança inovadora e rápida na mobilidade urbana. Neste sentido, o espaço aéreo poderia aliviar este aumento de movimentos urbanísticos ao complementar os sistemas tradicionais e emergentes de transporte terrestres. Inovação na mobilidade urbana poderia ocorrer ao integrar-se a mobilidade aérea urbana (UAM) em todas as cidades do mundo. Contudo, a UAM revela uma lacuna relativamente ao envolvimento desta tecnologia com as pessoas, o que curiosamente representa a chave para o sucesso a longo prazo. Deste modo, ao desenvolver uma UAM consistente e centrada nas pessoas, estimularíamos o progresso mundial ao mudar a forma como todos nós viajamos nas cidades. Ao mesmo tempo, estaríamos um passo mais perto de impulsionar uma terceira revolução da mobilidade global e um novo mundo de acessibilidade.

No entanto, as melhores oportunidades de inovação não estão só na criação de novas tecnologias que possibilitem a UAM, mas também no ecossistema que estas produzem juntas: as redes de *vertiports*. Assim, este estudo propõe incorporar redes de *vertiports* nas cidades usando um *design* centrado no utilizador. Sendo que existe falta deste tipo de investigação em Portugal, nesta Dissertação recorre-se a uma abordagem conceptual para analisar a logística e viabilidade da integração de redes de *vertiports* em cidades através da implementação de um *living lab* na capital deste país, Lisboa. Esta abordagem incorpora um *design* centrado no utilizador baseado no envolvimento contínuo dos cidadãos portugueses no processo de tomada de decisão a par de uma interacção paralela com cinco diferentes *stakeholders* (especificamente, a ANA Aeroportos de Portugal, a NAV Portugal, a ANAC Portugal, a Câmara Municipal de Lisboa e o Governo de Portugal). Como resultado, são propostas diretrizes de três etapas para a implementação de uma rede de *vertiports* na capital portuguesa. Esta proposta tem a virtude de apoiar futuras discussões avançadas para trazer a UAM para Portugal e de humanizar a tecnologia da UAM com o objetivo de reduzir a lacuna existente entre a comunidade científica,

autoridades públicas, atores profissionais (ou seja, a indústria) e consumidores (ou seja, as pessoas).

Por último, para impulsionar uma mudança global positiva e significativa na mobilidade urbana através da UAM, devemo-nos inspirar nas pessoas ao considerar as suas necessidades e preocupações e, de seguida, chamá-las para agir. Porque, no final das contas, tanto a mobilidade urbana sustentável como as cidades inteligentes começam principalmente com os hábitos diários de cada um de nós.

Palavras-chave

Mobilidade Aérea Urbana (UAM); Mobilidade Aérea Avançada (AAM); Gestão do Tráfego Aéreo Urbano (UATM); Gestão do Tráfego Não Tripulado (UTM); Espaço Aéreo Urbano; Logística Urbana; Mobilidade Urbana; Descolagem e Aterragem Vertical Elétrica (eVTOL) e Híbrida; Veículo Aéreo Não Tripulado (UAV); Sistemas de Aeronaves Não Tripuladas (UAS); *Drone*; Carro Voador; Mobilidade Sob Pedido (ODM); *Vertiports*; Mobilidade Sustentável; Cidades Inteligentes; Acessibilidade e Conectividade Urbana.

Resumo Alargado

Motivação

Atualmente, o sector do transporte é responsável por cerca de 8.16 mil milhões (isto é, aproximadamente 16 por cento de 51 mil milhões) de toneladas de gases de efeito estufa que são adicionados à atmosfera todos os anos. Particularmente, o aumento do tráfego rodoviário urbano tem intensificado a poluição e o ruído nas cidades, deteriorando a qualidade de vida dos cidadãos das mesmas. Este acréscimo de movimentos urbanísticos tem levado, por exemplo, ao consumo elevado de recursos e à degradação ambiental. Obviamente, é necessário promover uma mudança inovadora e rápida na mobilidade urbana. O espaço aéreo poderia controlar este aumento ao complementar os sistemas tradicionais e emergentes de transporte terrestres através da mobilidade aérea urbana (UAM) em todas as cidades do mundo.

Desta forma, a UAM surge como uma forma revolucionária para providenciar conexões urbanas ponto a ponto, uma rede de táxi aéreo e um serviço de mobilidade sob pedido (ODM) para pessoas, bens e prestadores de serviços (por exemplo, serviços de assistência médica, transporte cidadãos com mobilidade reduzida, operações de resgate, missões humanitárias, turismo sustentável, *etc.*), utilizando veículos híbridos e elétricos de descolagem e aterragem vertical (eVTOL). Estes veículos, no entanto, precisam de infraestruturas físicas para descolar, aterrar e para apoiar todas as outras operações projetadas para a UAM. Existem três tipos de infrestruturas, designadas por *vertipads, vertiports*, e *vertihubs*. Quando vários *vertiports* estão estrategicamente espalhados dentro de uma determinada área urbana, a conexão entre estes produz um ecossistema constituído por uma rede de *vertiports* através de pistas virtuais sobre o espaço aéreo de baixa altitude dessa área urbana com uma frota de aeronaves eVTOL a operar entre estas pistas. Inicialmente, estas infraestruturas podem ser localizadas em áreas operacionais da aviação tradicional (por exemplo, heliportos e pistas dos aeroportos), bem como infraestruturas civis urbanas que podem ser adaptadas para tal aplicação (por exemplo, telhados de prédios e estacionamentos). Além disso, para estas infraestruturas deverão ser planeados e providenciados espaços adicionais dedicados à manutenção, à reparação e às operações (MRO) dos “carros voadores,” bem como à monitorização e controle da frota e integração no espaço aéreo urbano.

Para além de representar um desafio técnico e regulatório complexo, a UAM apresenta um desafio social em paralelo de semelhante relevância. Apesar da humanização da tecnologia da UAM permitir o sucesso a longo prazo, existe ainda uma lacuna relativamente ao envolvimento desta tecnologia com as pessoas. Para contribuir na eliminação desta lacuna, nesta Dissertação utilizou-se uma abordagem conceptual onde se desenvolveu uma UAM consistente e centrada nas pessoas ao incorporar redes de *vertiports* nas cidades. Sendo que existe falta deste tipo de investigação em Portugal, Lisboa é escolhida como cenário nacional de operação para desenvolver e testar esta investigação devido ao seu congestionamento rodoviário, poluição sonora e poluição atmosférica, problemas estes intensificados pelo Aeroporto Humberto Delgado. Ainda, os principais pontos de interesse, as zonas de elevada densidade populacional e os nós de tráfego rodoviário (ou seja, as principais entradas da cidade, onde o tráfego é mais concentrado), poderiam servir como locais potenciais para a implementação de *vertiports*.

Objeto e Objectivo

Considerando que o objeto em estudo consiste na mobilidade urbana tridimensional, existem quatro objetivos principais a serem alcançados ao longo desta Dissertação:

1. Compreender como uma rede de *vertiports* nas cidades pode ajudar a reverter as alterações climáticas mundiais e melhorar a qualidade de vida das pessoas;
2. Identificar as lacunas, problemas e desafios associados à implementação de *vertiports* nas cidades;
3. Determinar formas possíveis e eficazes para permitir esta implementação em Lisboa, considerando constantemente a aceitação pública;
4. Fornecer diretrizes com base em dados reais e *feedback* para implementar uma rede de *vertiports* na capital de Portugal.

De forma geral, os cinco capítulos desta Dissertação em conjunto permitiram atingir o primeiro objetivo estabelecido. Já o capítulo 2 (ou seja, o estado de arte) reflete-se na concretização do segundo objetivo. O capítulo seguinte (ou seja, o caso de estudo) completa o terceiro objetivo. Por fim, com o penúltimo capítulo (ou seja, a análise dos resultados do caso de estudo) cumpre-se assim o quarto objetivo.

Metodologia

A metodologia utilizada envolve uma abordagem conceptual com objetivo de analisar a logística e a viabilidade da integração de rede de *vertiports* nas cidades através da implementação de um *living lab* em Lisboa, Portugal. Esta abordagem incorpora um *design* centrado no utilizador baseado no envolvimento contínuo dos cidadãos portugueses no processo de tomada de decisão a par de uma interação paralela com *stakeholders*. Isto permitirá tornar a UAM mais humanizada, garantindo que as pessoas façam parte da tomada de decisões e, consequentemente, tornar-se-ão mais dispostas a aceitar e usar a UAM no seu dia-a-dia.

Para tal, inicialmente foi realizada uma revisão da literatura sobre a mobilidade urbana, UAM e rede de *vertiports*, e ainda uma análise SWOT (isto é, os pontos fortes (*strengths*), pontos fracos (*weaknesses*), oportunidades e as ameaças (*threats*)) e uma análise PESTLE (isto é, os fatores políticos, económicos, sociais, tecnológicos, legais e ambientais (*environmental*)) relativamente à UAM em comparação com os sistemas de transporte terrestres, tradicionais e emergentes.

Seguidamente, implementou-se um *living lab* em Lisboa, o qual se divide em três elementos que são aprofundados durante o caso de estudo: o ambiente urbano, a percepção dos cidadãos e a política governamental. Após o estudo do ambiente urbano de Lisboa, iniciaram-se duas fases de análise à viabilidade social (isto é, fase 1) e viabilidade técnica (isto é, fase 2) onde as pessoas e os *stakeholders* são consultados, respectivamente. Por um lado, na fase 1 ambiciona-se identificar as necessidades e preocupações das pessoas relativamente à integração de uma rede de *vertiports* na sua cidade. Por outro lado, a fase 2 consiste em explorar as expectativas e requisitos demonstrados pelos *stakeholders* para, posteriormente, minimizar as suas preocupações de modo a providenciar sugestões para maximizar oportunidades. Depois dos resultados de ambas as fases terem sido recolhidos e, ainda, conectados, foram propostas diretrizes de três etapas para a implementação de uma rede de *vertiports* na capital portuguesa.

Análises e Resultados

Da implementação e análise do *living lab* em Lisboa foram concluídos os seguintes pontos:

- Relativamente à fase 1, de inquérito à população em geral, enquanto as principais necessidades das pessoas reflectem-se na poupança de tempo, contribuição para menos poluição, satisfação pessoal e envio e compra de mercadorias, as preocupações das mesmas consistem no custo das viagens, questões de segurança (*security*) e poluição sonora. Verificou-se também que quanto mais conhecimento as pessoas tiverem relativamente à UAM, maior é a probabilidade para que estas aceitem e utilizem aeronaves eVTOL para se deslocarem. Ainda, confirmamos que os locais potenciais para a colocação inicial de vertiports podem ser em três regiões de Lisboa: Belém, Olivais e Alvalade;
- Relativamente à fase 2, de inquérito aos *stakeholders*, os seus requisitos e expectativas residem na necessidade de uma adaptação do espaço aéreo e integração e capacidade terrestre, de tecnologias que possibilitem a UAM (por exemplo, biotecnologia, inteligência artificial, *blockchain*, *etc.*) e de uma atualização e compartilhamento de dados em tempo real (por exemplo, tecnologia da informação, tecnologia de quinta geração (5G), *etc.*). De modo a minimizar as suas preocupações, sugere-se a maximização de oportunidades tais como: melhorar/otimizar a arquitetura atual do espaço aéreo tal como aprimorar as operações atuais do mesmo; oportunidade para as *startups* e organizações desenvolverem tecnologias ODM, inovadoras e sustentáveis; e oportunidade para aumentar a oferta de trabalho na área de manutenção, controlo remoto, análise de dados e cibersegurança para acomodar os sistemas de aeronaves não tripuladas (UAS);
- Relativamente à conexão entre a fase 1 e a fase 2, verificou-se que a segurança (*safety*) e a sustentabilidade são preocupações partilhadas em ambas (as fases).

Os pontos referidos acima deram origem às directrizes propostas para a implementação de uma rede de *vertiports* na capital portuguesa. Estas dependem principalmente das pessoas, seguido do processo e, finalmente, do produto, e ainda explicam como gerir esses três elementos-chave com eficiência e eficácia. Acima de tudo, para que redes de *vertiports* incorporem um *design* centrado no utilizador é preciso cultivar e favorecer uma cooperação global e nacional sem negligenciar as pessoas do processo de tomada de decisão. Deste modo, na primeira etapa das diretrizes propostas está incluído um plano de ação para o envolvimento das pessoas neste processo de tomada de decisão que consiste em informar, envolver e colaborar diretamente com estas. Isto significa capacitar as pessoas diretamente na construção do futuro do nosso mundo. Porque, de facto, a inovação nasce do resultado da colaboração, da partilha de informações e da exposição de dados reais de forma aberta e constante.

Conclusões

A identificação e a gestão das preocupações das pessoas e dos *stakeholders*, permite que tanto as necessidades das pessoas como os requisitos dos *stakeholders* sejam resolvidos, como subprodutos. Essencialmente, devemos promover redes de *vertiports* que permitam que as necessidades fisiológicas das pessoas floresçam e que as preocupações das mesmas sejam consideradas no processo de tomada de decisão em conjunto com os requisitos dos *stakeholders*. A comunicação empática é, portanto, uma ferramenta fundamental para trazer a UAM para as nossas vidas diárias e para o nosso mundo.

É verdade que a UAM tem o poder para revolucionar o sector do transporte, contribuindo assim para prevenir uma crise climática mundial. No entanto, esta representa um dos maiores desafios alguma vez enfrentados pela indústria da aviação até aos dias de hoje. Neste sentido, esta indústria tem um longo e árduo caminho pela frente de pesquisa e desenvolvimento (R&D) até encontrar um equilíbrio dinâmico entre a comunidade científica, autoridades públicas, atores profissionais (ou seja, a indústria) e consumidores (ou seja, as pessoas) envolvidos e até garantir todas as condições necessárias de logística e viabilidade para se integrar a UAM em todas as cidades do mundo. Além disso, para a implementação da UAM deve-se ter em consideração a variedade de ambientes urbanos como também as necessidades de cada um destes. Curiosamente, o poder das diretrizes propostas nesta Dissertação projeta-se na sua aplicabilidade em qualquer área urbana.

Porém, é necessário agir agora! Sendo as alterações climáticas a nível mundial uma questão humana, a solução mais eficaz para estas está na mudança dos comportamentos de cada um de nós, e a tecnologia pode ajudar muito nisso. Complementarmente, em vez das pessoas competirem com a inteligência artificial e outras tecnologias atuais e emergentes, as pessoas podem colaborar no desenvolvimento destas. Pode ser assim relevante recorrer à antropologia em geral, e à antropologia digital em particular, nesta aventura de R&D.

Abstract

This Dissertation focuses on urban mobility three-dimensional (3D). Whilst prioritizing the development of sustainable mobility and smart cities, this study aims to provide conditions and practical tools to promote change in people's lives for the better and reverse global climate change.

Currently, the transportation sector accounts for roughly 16 per cent of all annual greenhouse gases emissions in the world. In particular, the increase in urban road traffic has intensified pollution and noise in cities, deteriorating the quality of life of the citizens who inhabit them. Obviously, it is necessary to promote an innovative and rapid change in urban mobility. In this sense, airspace could ease this increase in urban movements by complementing traditional and emerging land transport systems. Innovation in urban mobility could occur by integrating urban air mobility (UAM) in every city in the world. Yet, UAM reveals a gap regarding the involvement of this technology with people, which interestingly represents the key to long-term success. In this way, by developing a consistent, people-centred UAM, we would spur world progress by changing the way we all travel in cities. At the same time, we would be one step closer to driving a third global mobility revolution and a new world of accessibility.

However, the best opportunities for innovation are not only in creating new technologies that enable UAM but also in the ecosystem they together produce: vertiport networks. So, this study proposes to embed vertiport networks in cities using a user-centric design. As there is a lack of this type of research in Portugal, this Dissertation uses a conceptual approach to analyze the logistics and feasibility of integrating vertiport networks in cities by implementing a living lab in the capital of this country, Lisbon. This approach incorporates a user-centric design based on the ongoing engagement of Portuguese citizens in the decision-making process alongside a parallel interaction with five different stakeholders (specifically, ANA Airports of Portugal, NAV Portugal, ANAC Portugal, the Lisbon City Council, and the Government of Portugal). As a result, a three-step roadmap is proposed to implement a vertiport network in the Portuguese capital. This proposal has the virtue of supporting future advanced discussions to bring UAM to Portugal and humanizing UAM's technology in order to narrow the existent gap between the scientific community, public authorities, professional actors (i.e., the industry) and consumers (i.e., people).

Lastly, to drive positive and meaningful global change in urban mobility through UAM, we must inspire people by considering their needs and concerns and then call them to act now. Because, in the end, both sustainable urban mobility and smart cities start foremost with the daily habits of each of us.

Keywords

Urban Air Mobility (UAM); Advanced Air Mobility (AAM); Urban Air Traffic Management (UATM); Unmanned Traffic Management (UTM); Urban Airspace; Urban Logistics; Urban Mobility; Hybrid and Electric Vertical Take-Off and Landing (eVTOL); Unmanned Aerial Vehicle (UAV); Unmanned Aircraft Systems (UAS); Drone; Flying Car; On-Demand Mobility (ODM); Vertiports; Sustainable Mobility; Smart Cities; Urban Accessibility and Connectivity.

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List of Acronyms

AAM	Advanced Air Mobility
AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AI	Artificial Intelligence
ANAC	Portuguese Civil Aviation Authority
ANSP	Air Navigation Service Provider
APL	Lisbon Port Administration
ATC	Air Traffic Control
ATM	Air Traffic Management
BVLOS	Beyond Visual Line of Sight
CBA	Cost-Benefit Analysis
CREL	Circular Regional Exterior of Lisbon
CRIL	Circular Regional Interior of Lisbon
Csa	Hot-Summer Mediterranean Climate
CTR	Controlled Traffic Region
EASA	European Union Aviation Safety Agency
EC	European Commission
eVTOL	electric Vertical Take-Off and Landing
FAA	Federal Aviation Administration
FATO	Final Approach and Take-Off Area
FIR	Flight Information Region
IATA	International Air Transport Association
ICA	Instructions of Aeronautic Command
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IPMA	Portuguese Institute of the Sea and the Atmosphere
IT	Information Technology
MRO	Maintenance, Repair, Overhaul
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NAV	Portuguese Air Navigation Service Provider
NGO	Non-Governmental Organization
ODM	On-Demand Mobility

PANS	Procedures for Air Navigation Services
PAV	Personal Air Vehicles
PESTLE	Political, Economic, Social, Technological, Legal, and Environmental
PSU	Providers of Services for Urban Air Mobility
REH	Special Helicopter Route
R&D	Research and Development
SARP	Standards, and Recommended Practices
SDG	Sustainable Development Goals
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TLOF	Touchdown and Lift-Off
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UATM	Urban Air Traffic Management
UAV	Unmanned Air Vehicles
UML	UAM Maturity Levels
UTM	Unmanned Traffic Management
VAS	Vertiport Automation System
VFR	Visual Flight Rules
VTOL	Vertical Take-Off and Landing
WEF	World Economic Forum
WHO	World Health Organization
ZLT	Free Zones for Technology
3D	Three-Dimensional Space
4G	Fourth-Generation
5G	Fifth-Generation

Chapter 1

Introduction

1.1 Motivation

Today, roughly 51 billion tons of greenhouse gases are added to the atmosphere every year, where the transportation sector accounts for roughly 16 per cent of those gases [1]. With the Covid-19 pandemic, global traffic patterns plummeted, and greenhouse gases emissions decreased about 6 per cent (i.e., went down from 51 billion tons to about 48 or 49 billion tons) in 2020 due to travel prohibitions and economic slowdowns [2]. Unfortunately, this improvement is only temporary, and as soon as the global economy begins to recover from this pandemic, emissions will return to even more sobering levels [2]. As the world gets crowded, urban traffic has increased pollution and noise in cities, deteriorating citizens' quality of life. Obviously, it is necessary to promote an innovative and rapid change in urban mobility.

The airspace could ease this increase in urban movements by complementing traditional and emerging land transport systems. Imagine taking off and landing anywhere and anytime. Being incorporated in Advanced Air Mobility (AAM)[1], Urban Air Mobility (UAM) appears as a revolutionary way to provide urban point-to-point connections, an air taxi network, and On-Demand Mobility (ODM) service (see figure 1), for passengers, freight, and service providers, using hybrid and electric Vertical Take-Off and Landing (eVTOL) aircraft. These intracity connections offer a new travel solution to complement existing modes of urban public transport for service providers (e.g., emergency responses, mobility service for disabled citizens, rescue operations, humanitarian missions, sustainable tourism, etc.), air taxis, or private/executive transportation. Plus, UAM gives citizens more access to the urban airspace while simultaneously allowing them to cross cities safer and gives them the power to decide how to use their time effectively while decreasing their ecological footprint.

Yet, UAM reveals a gap regarding the involvement of its technology with people, which interestingly represents the key to long-term success. In this way, by developing a consistent, people-centric UAM, we would nurture world progress by changing the way we

[1] AAM consists of a new concept of air transportation using hybrid and electric vertical take-off and landing aircraft to move people and cargo between places. The application of AAM in urban areas is called urban air mobility.

all travel in cities. At the same time, we would be one step closer to driving a third global mobility revolution and a new world of accessibility. This rise in accessibility reflects the concept of the radius of life. This concept seeks to optimize the environment where people spend 90 per cent of their lives to encourage community transformation. The radius of life will get people moving faster even living further away from the city centres, i.e., in rural areas, resulting in more control of urbanization reduce in cost of living, and leading to longer lives.

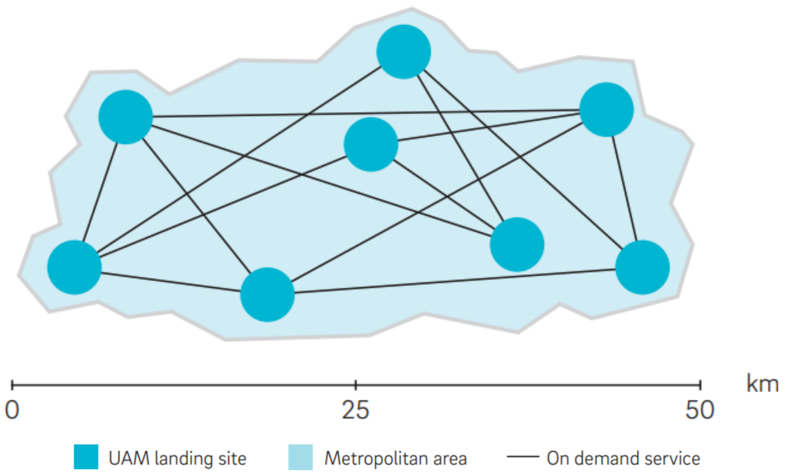

Figure 1 – A combination between urban point-to-point connections, air taxi network, and ODM service. Source: [4].

Indeed, innovation in urban mobility could occur by integrating UAM in every city in the world. However, the best opportunities for innovation are not only in creating new technologies that enable UAM but also in the ecosystem they together produce: vertiport networks. Vertipads, vertiports, and vertihubs, also known as take-off and landing sites, are UAM physical infrastructures to support eVTOL operations, must be carefully planned to provide passengers with a superb experience. Initially, these infrastructures can be placed in operational areas of traditional aviation (e.g., heliports and taxiways) and urban civil infrastructures that can be adapted for such an application (e.g., rooftops and parking lots). Furthermore, additional space must be planned and provided for maintenance, repair, and operations (MRO), monitoring the fleet of eVTOL aircraft, and integration into urban airspace. [5]. A vertiport network incorporates vertiports strategically scattered in cities connected via virtual lanes over the low altitude airspace and a fleet of air vehicles servicing between those infrastructures [6]. Whether this network is well planned will ensure that no other aircraft will mix with UAM operations.

Since there is a lack of research on UAM infrastructures, this raises a challenging question: How to incorporate vertiport networks in cities worldwide using a user-centric design? Thereby, we try to understand how a network of vertiports in cities can help reverse global climate change and improve people's quality of life. UAM is, therefore, forced to work harmoniously (i.e., in an insanely safe, secure, and reliable way) to address the needs and demands of each country and city [7]. To help answer the question posed, we look for the gaps, issues, and challenges currently faced in vertiports implementation in cities. Then, we figure out possible and effective ways to make this implementation work, always considering public acceptance. While representing a complex technical and regulatory challenge, the UAM presents a parallel social challenge of similar relevance. In this sense, keeping people at the centre of UAM is the key to success [8].

As there is an absence of this type of research in Portugal, Lisbon is chosen as the case of the national scenario of operation to develop and test this investigation. This choice is mostly due to Lisbon's road congestion, noise pollution, and atmospheric pollution, which are all intensified by the Humberto Delgado Airport. This local airport is located right in the middle of the city where noise and microparticles emitted by aircraft are highly harmful to the health of citizens. In 2020, despite the Covid-19 pandemic, moving within Lisbon meant losing, on average, about 30 minutes per day on city traffic, resulting in more than four days that year per person [9]. So, this investigation uses a conceptual approach to analyze the logistics and feasibility of integrating vertiport networks in cities by implementing a living lab in the capital of Portugal, Lisbon. In detail, this approach incorporates a user-centric design based on the ongoing engagement of Portuguese citizens in the decision-making process alongside a parallel interaction with five different stakeholders (specifically, *ANA* Airports of Portugal, *NAV* Portugal, *ANAC* Portugal, the Lisbon City Council, and the Government of Portugal). Still, a three-step roadmap is proposed to implement a vertiport network in the Portuguese capital.

Ultimately, whilst prioritizing the development of sustainable mobility and smart cities, this Dissertation ambitions to provide conditions and practical tools to promote change in people's lives for the better and reverse global climate change. Thereby, this Dissertation has the power to support future advanced discussions to bring UAM to Portugal and to humanize UAM's technology in order to narrow the existent gap between the scientific community, public authorities, professional actors (i.e., the industry) and consumers (i.e., people).

1.2 Object and objective

The object selected for this Dissertation is urban mobility Three-Dimensional (3D). This increase in urbanistic movements has led, for example, to high consumption of resources and environmental degradation, among other problems that need to be alleviated. Notably, it is necessary to promote an innovative and rapid change in urban mobility.

As stated previously, this Dissertation desires to provide guidelines based on real data and feedback for the integration of vertiport networks in Lisbon. For that, we try to understand how a network of vertiports in cities can help reverse global climate change and improve people's quality of life. Additionally, this investigation identifies the gaps, issues, and challenges associated with vertiports implementation. Also, this study determines possible and effective ways to make this implementation work, consistently considering public acceptance.

1.3 Methodology

The methodology followed embraces a conceptual approach to analyse the logistics and feasibility of the integration of vertiport networks in cities by implementing a living lab in Lisbon. This approach incorporates a user-centric design based on the ongoing engagement of people in the decision-making process alongside a parallel interaction with stakeholders. Using this design allows the humanization of UAM, ensuring that people are part of the decision-making process and, consequently, making them more willing to accept and use UAM in their daily commute.

This investigation starts by highlighting the gaps, issues, and challenges currently faced in vertiports implementation in cities through a literature review, a SWOT analysis (i.e., strengths, weaknesses, opportunities, and threats), and a PESTLE analysis (i.e., political, economic, social, technological, legal, and environmental) on future UAM operations comparing to traditional and emerging land transport systems.

After the study of Lisbon's urban environment (i.e., the scenario description), the case study goes through the scenario development, containing two distinct phases of analysis of social feasibility (i.e., phase 1) and technical feasibility (i.e., phase 2), where people and stakeholders are consulted, respectively. On the one hand, phase 1 identifies the needs and concerns of people regarding vertiport networks. On the other hand, phase 2 explores the expectations and requirements demonstrated by the stakeholders. Afterwards, we try to minimize their concerns to provide suggestions to maximize opportunities.

Then, we conduct a scenario validation. Lisbon is chosen as the case of the national scenario of operation to develop and test this investigation. Being the most populated city in Portugal, more pressure is placed on its road network. So, Lisbon's key points of interest, zones with high population density, and traffic nodes (i.e., the major entrances into the city, where traffic is more concentrated), could serve as optimal locations for vertiports implementation. After the results of both phases had been collected and further connected, a three-step roadmap based on real data and feedback is proposed to bring UAM to the Portuguese capital.

In conclusion, prospects for further research are given.

Briefly, the following workflow presents the methodology used in this Dissertation (see figure 2).

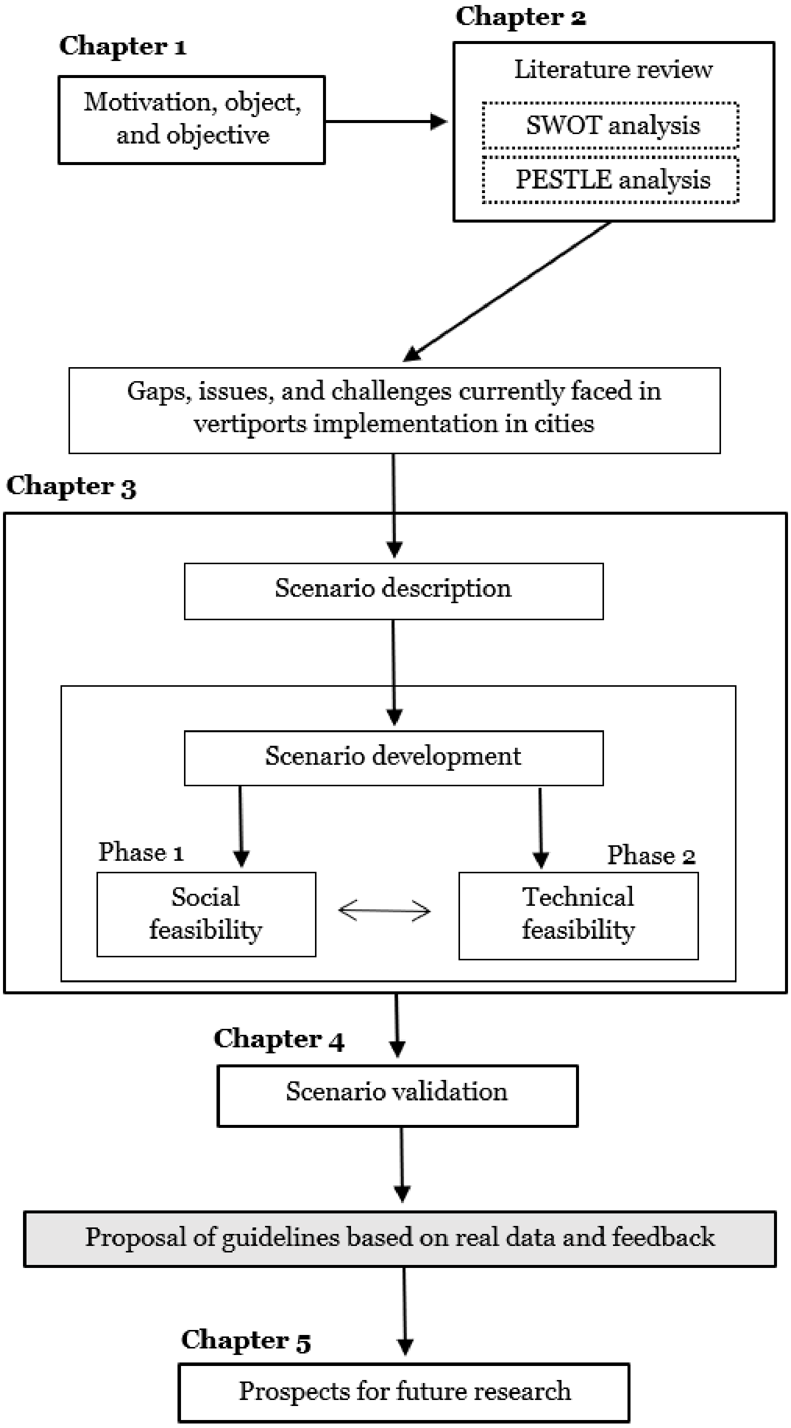

Figure 2 – Workflow of the methodology adopted. Source: Own elaboration.

1.4 Dissertation structure

The structure of this Dissertation is divided into five chapters: introduction, state of the art, study case, results analysis, and conclusions.

The introduction (i.e., chapter 1) includes this Dissertation's motivation, object, objective, methodology, and structure to simply and clearly, explain the investigation conducted.

Chapter 2 represents the state of the art, disclosing a review of relevant literature about urban mobility, UAM, and vertiport network. Plus, SWOT and PESTLE analyses are performed.

The implementation of the case of study and the results obtained from it comprises chapter 3.

Chapter 4 displays the scenario validation, i.e., analysis of the results' main findings.

Chapter 5 concludes with this Dissertation with a synthesis, limitations found, final considerations, and prospects for further research within the UAM market.

Chapter 2

State of the art

2.1 Introduction

Chapter 2 focuses mainly on the gaps, issues, and challenges concerning the implementation of vertiports in cities. For that, it discusses the current urban mobility and its logistics process and how could we upgrade it by complementing UAM into that process. This literature review illuminates the path ahead to wisely apply these concepts in the case of study and then creatively produce guidelines based on real data and feedback for the integration of UAM in Lisbon.

2.2 Urban mobility

2.2.1 Purpose and concept

Currently, most of the world's population is living in urban areas, and globally the United Nations (UN) predicted that 68 per cent of the population will live in these areas by 2050 [10]. Another study detached that roughly more than 73 per cent of the European public lived in urban areas, and it is expected urbanization to increase by about 85 per cent by de same year [11]. For these reasons, urban areas are considered key actors to achieve the UN Sustainable Development Goals (SDGs) [12].

Dominating the employment and economic output, urban areas, also called metropolitan areas or "greater" (e.g., Greater London), comprise the city itself as well as the surrounding areas, and it can refer to cities, towns, and suburbs [13]. In another sense, mobility contributes to the quality of life since it expresses the ability to move or be moved in a free and easy way. Simply put, urban mobility is all the movements in urban areas, i.e., all the daily trips by the inhabitants and freight in a city, and the logistics associated with such trips [14]. In detail, it represents a complex shared system that sights to satisfy short distance mobility demands and citizens' needs in cities. The three categories of urban mobility are: collective or public, individual, and freight transportation [15]. The most common modes of transport in urban mobility are:

- Road transport: car, taxi, van, bus, lorry, motorcycle, bicycle, and walking;

- Rail transport: tram, metro, and train;
- Maritime or fluvial transport: vessel;
- Air transport: helicopter, drone, and aeroplane.

Logistics has a transversal and multidisciplinary nature, and it refers to activities related to the production and distribution of resources for consumption. Briefly, logistics determine the operational conditions for urban mobility, contributing to the quality of life. It turns out that the connection between transport and logistics has become increasingly important in the development, organization, and operation of urban areas [16].

Already with is the purpose and concept of urban mobility introduced, we describe then how its ecosystem works nowadays and who is involved in it.

2.2.2 Ecosystem framework

Representing all the movements in urban areas, the urban mobility ecosystem is conceivable through the collaboration of multiple actors and stakeholders[2], composed of [17], [18], [19]:

- Public authorities:
  - Regional or local authorities: road, traffic, and city authorities;
  - Higher governments: the national government, the European Commission in some cases.
- Professional actors:
  - Resource supply stakeholders: infrastructure providers and operators, landowners;
  - Shippers: manufactures, retailers;
  - Transport operators: freight carriers, couriers;
  - Receivers: residents, shopkeepers, offices.
- The consumers (i.e., those affected by the urban mobility ecosystem, whereas not directly involved in it):
  - Other traffic participants: vulnerable road users, passenger vehicles;
  - City residents and users: citizens who live, work, study, and shop in the city;
  - Visitors and tourists.

[2] Actor refers to an abstract notion - one or more physical users can be in the role of one actor – while stakeholder refers to the one who has a decisive role with regards to the payment for creating the application or has an interest in it.

The framework shows how the urban mobility ecosystem works (see figure 3), considering the urban mobility values that must be preserved and the costs and benefits involved.

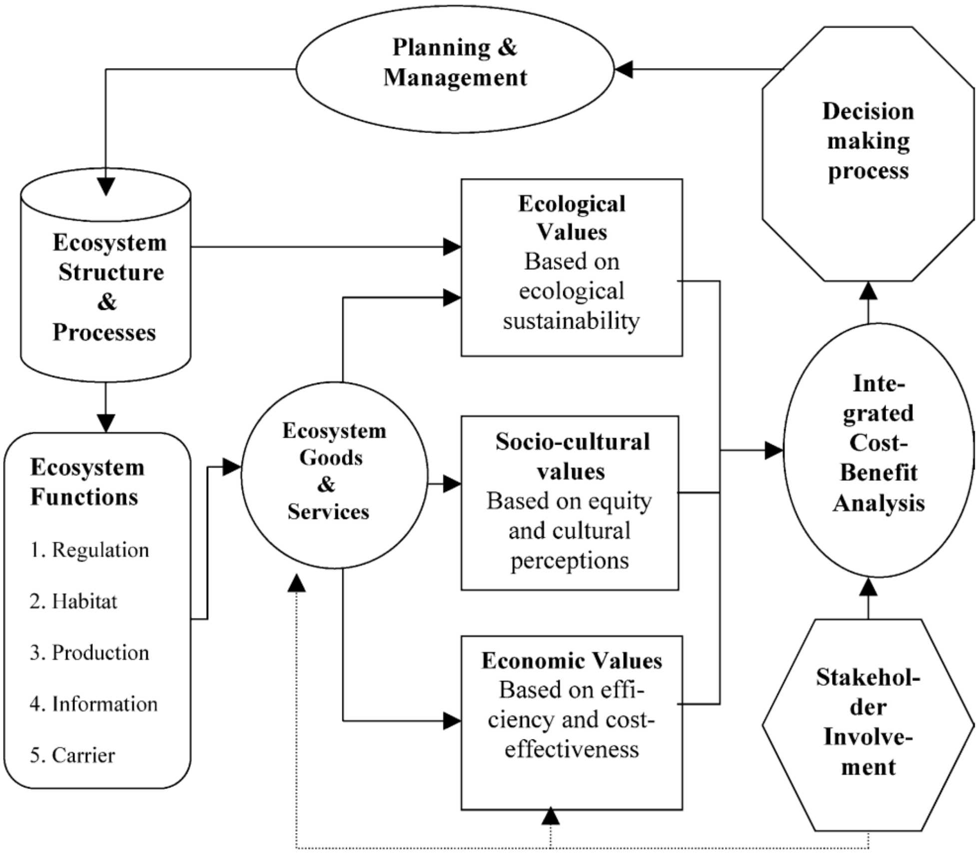

Figure 3 – Urban mobility ecosystem framework. Source: [20].

The urban mobility ecosystem functions can be divided into five categories [21]:

- Regulation functions: represent the legislation and regulation imposed by public authorities;
- Habitat functions: contain specific features about the city's layout (this function has a strong influence on all the other functions since it cannot be easily modified);
- Production functions: include all the transportation activities and processes required to enable the mobility of citizens, freight, and service providers;
- Information functions: use lots of information which is crucial to maintain communication among all actors and stakeholders involved, enhancing the mobility coordination;
- Carrier functions: express the effects caused by the transportation activities, e.g., noise, air pollution, traffic accidents, inequality.

Knowing now who is involved and the way it works, the urban mobility ecosystem presents challenges and solutions that are explored next.

2.2.3 Challenges and solutions

According to the World Health Organization (WHO), exposure to air pollution causes 4.2 million deaths per year [22]. Urban mobility is of the biggest accountable for air pollution, like many other present concerns.

Urban freight transportation (making part of urban logistics[3]) represents a significant percentage of urban mobility [23]. Derivative to the highly inherently complexity of freight transportation, several challenging hurdles hold back the development of innovative solutions: freight transportation acts essentially for the private sector, and consequently, this sector will not engage in more sustainable solutions if it brings about an increase in costs [24]; the daunting task of gathering, update, and share data from a large number of actors and stakeholders is necessary (with often divergent goals and perspectives); Shippers and transport operators are unwilling to share information about their operations [11].

Naturally, citizens prefer simplicity which is the ultimate efficiency. So, several European cities have been putting into practice some measures so far to simplify the urban mobility ecosystem, striking its challenges, and coming up with innovative solutions. Some of these solutions rely on infrastructure measures (e.g., building new infrastructures or adapting the existing ones), territorial management measures (e.g., allocating lands to be used for urban mobility operations as parking spaces), access restrictions measures (e.g., accessing time or spatial restrictions), traffic management measures (e.g., re-organizing and optimizing traffic flows in congested areas), and promotion measures (e.g., promotion tools to be used by the local authorities to support best practices without imposing them) [25].

There is an emerging concern to achieve a shift towards sustainable urban mobility. With sustainable urban mobility, it is possible to improve accessibility and quality of life and make urban areas more attractive. Being a goal of the UN by the year 2030, the urban areas of the future will have a vast majority of citizens making their daily urban trips sustainably [12]. A framework developed by McKinsey & Company (see figure 4) contains seven factors for making cities move cleanly and efficiently to help actors and stakeholders

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[3] Urban logistics refers to the freight distribution in urban areas and the strategies that can improve its overall efficiency.

begin to design and implement the appropriate interventions to achieve sustainable urban mobility [26].

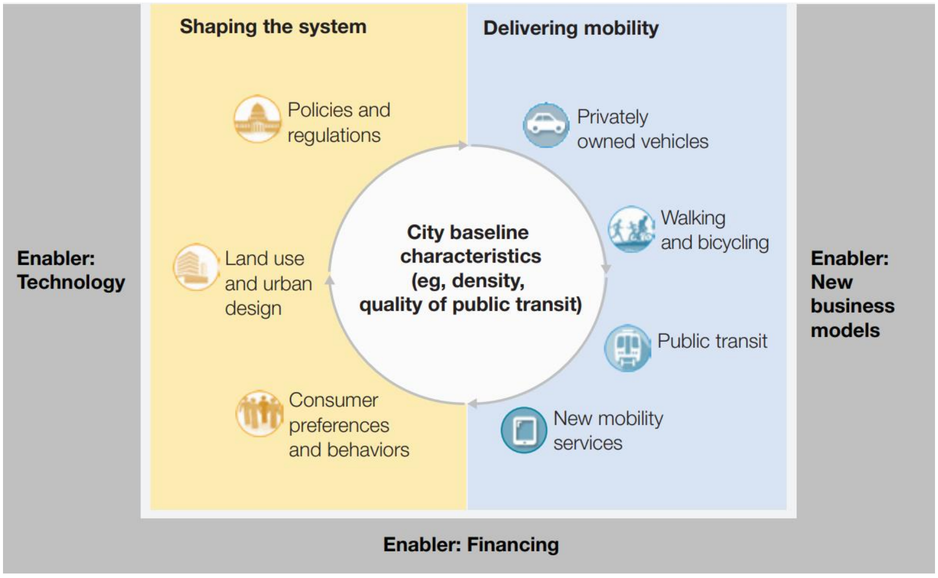

Figure 4 – Seven factors affecting the urban mobility ecosystem. Source: [26].

These seven factors include privately owned vehicles (i.e., in-vehicle connectivity combined with real-time analytics and data on traffic conditions, electric power trains, car-sharing services, and advanced driver-assistance systems); walking and bicycling (i.e., bike-sharing systems and closing more areas to vehicle traffic and implement other pedestrian areas and roadways for cyclists); public transit (i.e., improve public transit performance and develop software to help riders plan trips on mass transportation); new mobility services (e.g., e-hailing, shared e-hailing, car sharing, on-demand private shuttles, and private buses); policies and regulations; land use and urban design; and consumer preferences and behaviours [26].

Still, urban mobility has a long way lied ahead until it meets a dynamic equilibrium between all actors and stakeholders involved and develops better solutions. One solution that is under the spotlight recently and might have the potential to revolutionize the current urban mobility: UAM.

2.3 Urban air mobility

2.3.1 Purpose and concept

As a booster for future urban mobility, UAM can increase accessibility into cities as well as decrease emissions and commuting times. UAM is an aviation transportation system composed of on-demand urban air services using eVTOL vehicles for the transportation of passengers, freight, and services providers (e.g., emergency responses, mobility service for disabled citizens, rescue operations, humanitarian missions, tour guides for tourism sightseeing, and so on) at lower altitudes within urban areas [7], [27].

Recently, worldwide engineers, scientists, and researchers are putting lots of effort into bringing on-demand air mobility to cope with the increase in urbanization, consumption patterns, and global supply chains. Overall, the UAM market is on fast-paced growth, and the following years will unfold an exciting new chapter in urban mobility. The historical development of UAM started with the idea of helicopters flying in urban areas that consequently introduced the Vertical Take-off and Landing (VTOL) concept. However, the helicopters' low technology at that time, high noises, and high operational costs led helicopters to cease almost all their operations years later [28]. Presently, UAM with helicopters exists in some cities, e.g., São Paulo (with hundreds of daily helicopter flights), New York, Monaco, Mexico City, and so forth. A cleaner VTOL vehicle, i.e., an eVTOL, is being under massive development. Since 2015 and with the wave of designs of Personal Air Vehicles (PAV) – aircrafts capable to provide on-demand urban air services –, companies as EHang, Airbus, Volocopter, and SureFly were the first conductors for UAM with their eVTOL vehicles [29]. Besides these stakeholders, others are contributing to the development of other UAM fields and can be consulted in figure 34 from annexe 1 [30]. Shortly, the relevant UAM research fields are composed of [28]:

- Social considerations:
  - Public acceptance;
  - Potential users.
- Technical, regulatory, and economic considerations:
  - Vehicles;
  - Infrastructures:
    - Ground infrastructure;
    - Urban Air Traffic Management (UATM).
  - Market actors;
  - Operations;
  - Integration;
  - Regulation;
  - Modelling.

Developed by NASA, the UAM Maturity Levels (UMLs) represent levels of maturity of the UAM ecosystem (see figure 5). These levels provide a generalized vision of the future with UAM with high-level requirements for airspace design and management, aircraft development and operations, and community integration [31]. It begins with low-risk, low-tempo, and low-density UAM operations and at each stage, new lessons will be learned and applied to achieve high-tempo and high-density mature UAM operations [32]. The UML-6 represents the ubiquitous integration of UAM into citizens' daily life.

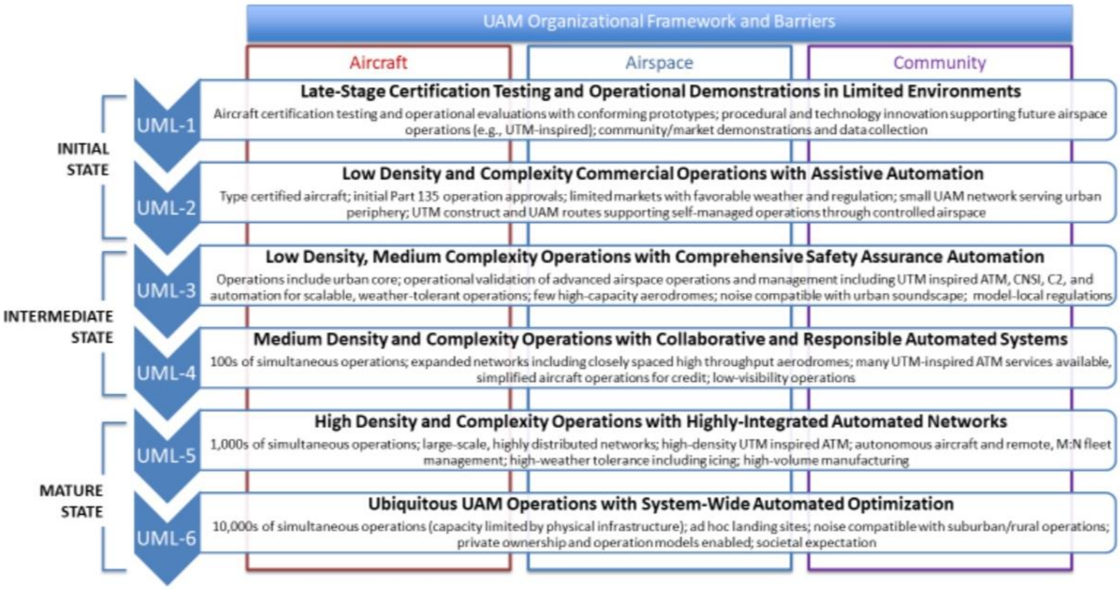

Figure 5 – NASA's UMLs. Source: [31].

Released by The World Economic Forum (WEF) and the City of Los Angeles, the following seven guiding principles serve to support the development of UAM policies and infrastructures [33]:

- Safety: UAM must achieve levels of safety performance consistent with conventional aviation operations;
- Sustainability: UAM must attain more sustainable behaviours by improving environmental outcomes and embracing innovation;
- Equity of access: UAM should provide equitable access to mobility for disadvantaged communities and businesses;
- Low noise: UAM noise disturbances should be measured and mitigated by a public-first approach to vehicle design, infrastructure siting, and route planning;
- Multimodal connectivity: UAM should connect to existing forms of transport and mobility hubs to offer seamless customer experience;
- Local workforce development: UAM should create more employment opportunities on the ground and in the air;

- Purpose-driven data sharing: constant data sharing to providers to quickly respond to the needs of passengers, communities, and market demands.

With the UAM's concept and purpose covered in detail, we can then analyse the three biggest challenges that UAM faces: public acceptance (social challenges), UATM (technical challenges), and regulation (regulatory challenges). Of all challenges, social challenges are the toughest case for UAM.

2.3.2 Public acceptance

Doubtless, one of the biggest challenges of UAM is foremost in getting the people to accept and adhere to this new reality of "flying cars". Bearing in mind that the entire passenger experience must ensure simplicity, consistency, and be user-centred, the way UAM will impact the people must be carefully deliberated and strategically planned, i.e., the lower impact on them comes the higher willingness. Figure 6 summarizes the four components for public acceptance.

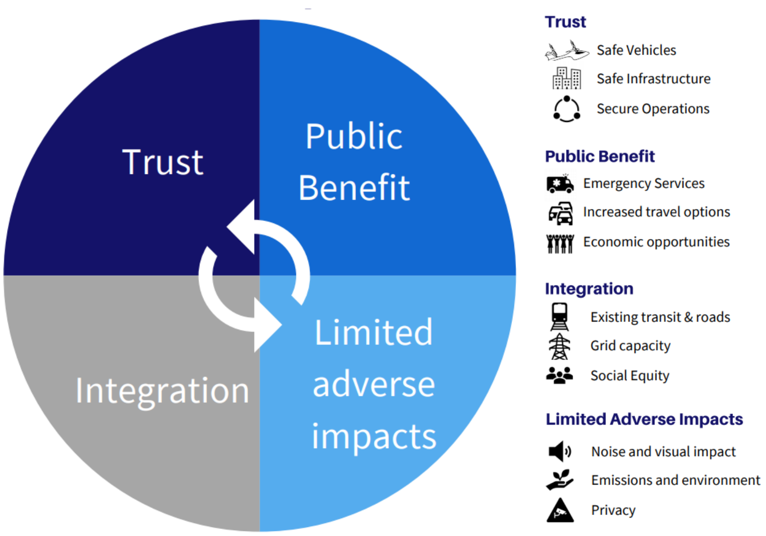

Figure 6 – Components for public acceptance. Source: [34].

It is noteworthy that people trust does not come only by demonstrating that vehicles, infrastructure, or operations are safe and secure. It comes primarily from their belief that the people can improve their life with UAM, or UAM operations may be at stake of never being successful.

A study made in Stuttgart by Volocopter [35] found that people's knowledge about eVTOL vehicles has a significantly positive influence on public acceptance. So, a plain UAM knowledge management and disclosure must reach the people to help them overcome their fear barrier. UAM infrastructures are preferred to be at the local airport and railway station, followed by park and ride parking and the city centre. Interestingly, the people expect a positive effect on the overall mobility with UAM introduction, as well they also will see the city as an innovative hub. Figure 7 illustrates the nine social acceptance factors collected by Volocopter in Stuttgart.

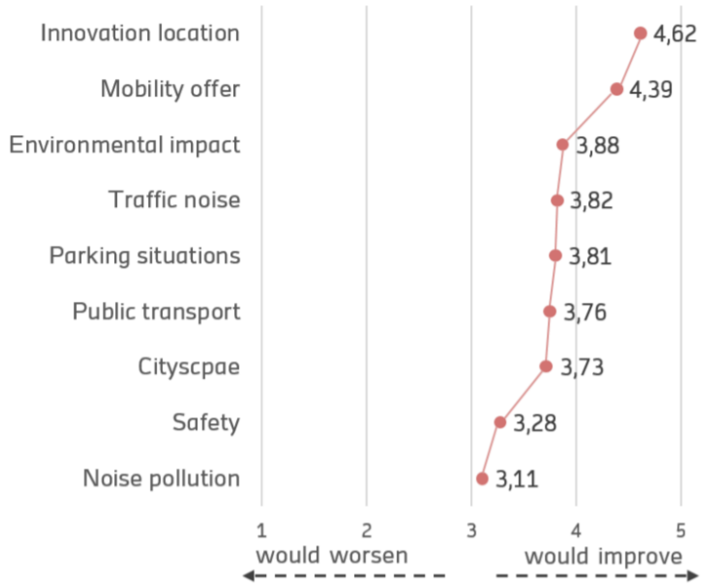

Figure 7 – Social acceptance factors. Source: [35].

The people will desire to perceive how UAM will address concerns as [36], [37], [38], [39]:

- Noise: many eVTOL vehicles are electrically powered and use multiple rotors (this minimizes the noise due to high rotational swiftness);
- Safety and security: safety assurance for UAM requires collaboration between regulatory authorities, service providers, UAM operators, and government stakeholders. Concerns associated with accidents are inevitably present in people minds due to past disasters with helicopter operations in cities. The more knowledge and awareness the people has about UAM, the more likely they are to get on board in an eVTOL vehicle since their perception of safety increases. As well, allow people to experience an eVTOL flight by virtual-reality simulations. Beyond safety, high-security levels, including cyber and physical security, must be guaranteed with a very reliable security system to avoid cyber-attacks or terrorism, causing both urban and air chaos;
- Visual pollution: to protect areas of natural beauty and cities skyline, visual pollution could be addressed by modification of routes or having flight operations above existing road traffic corridors, e.g., highways;

- Privacy: flight over less sensitive areas or at higher altitudes, meanwhile considering airspace restrictions, could solve privacy concerns.

Moreover, a study on public acceptance [40] shows inequity, i.e., unequal access to urban airspace influenced by citizens' wealth, as other prevailing concerns, along with the time of the day and altitude for UAM travels. Still, the biggest study of public acceptance in Europe is the one done by European Union Aviation Safety Agency (EASA) [41].

Besides social challenges, there are still technical challenges to manage, e.g., urban air traffic which is explained in the following section.

2.3.3 Urban air traffic management

Each city's airspace has specific constraints, laws, and regulations that will impact the way each UATM is planned. One option would be to integrate UAM operations into the airspace and current Air Traffic Control (ATC).

The airspace has six categories - Class A, B, C, D, E, and G - with different operational requirements and different levels of ATC service provision [42]. Being Class A the most restrictive one in terms of operational requirements, and due to its high altitudes (between 18,000 ft (5.49 km) and 60,000 ft (18.29 km) Mean Sea Level ((MSL)), it is out of scope for UAM. Note that all Classes, except Class A (conducted only under Instrument Flight Rules (IFR)), both IFR and Visual Flight Rules (VFR) are permitted [43]. For airports far from urban areas, UAM operations will prevail either in Class E or Class G. In the case of airports near urban areas, Class B (from the surface to 10,000 ft (3.05 km) MSL) is more appropriate for large-sized airports, Class C for medium-sized airports (from the surface to 4,000 ft (1.22 km) MSL), and Class D for small-sized airports (from the surface to 2,500 ft (762 m) MSL) [32], [44]. The Lisbon Flight Information Region (FIR) is classified as Class C, D, and G [45]. Lisbon's Controlled Traffic Region (CTR) is a Class C, extending from the surface to 2,000 ft (610 m) [46], so we give more emphasis to the operational requirements of this airspace category.

Compared to the helicopter, eVTOL vehicles are four times less quiet, fifteen times more reliable, two times safer, and ten times cheaper [29]. The difference between eVTOL aircraft and traditional helicopters and aircraft resides mainly in the innovative control systems and the planned degree of autonomy. Initially, UAM operations are likely to follow the existing rules and routes for helicopter operations (i.e., eVTOL vehicles will fly in cities at low altitudes, operating under VFR with human pilots [32], adding several more from the fundamental principles of aviation). Air laws are based on the Chicago Convention, Standards, and Recommended Practices (SARPs), Procedures for Air Navigation Services (PANS), and specialized guidance manuals [47]. The International Civil Aviation Organization's (ICAO) Rules of the Air tackles general flight rules, VFR, minimum heights over cities and cruising levels, limit proximity between aircraft, among other considerations essential to be considered for UAM operations. The relevant ones for this Dissertation are summarized below [48]:

- "Except when necessary for take-off or landing (...), a VFR flight shall not be flown: a) over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a height less than 300 m above the highest obstacle within a radius of 600 m from the aircraft (...)";
- For Class C, "(...) VFR flights shall be conducted so that the aircraft is flown in conditions of visibility" of 5 km and "distance from clouds equal to or greater than" 1500 m horizontally and 300 m vertically for altitudes below 10,000 ft (3.05 km) and above 3,000 ft (914 m) MSL; "(...) VRF flights shall not take off or land at an aerodrome within a control zone, or enter the aerodrome traffic zone or traffic pattern: a) when the ceiling is less than 450 m; or b) when the ground visibility is less than 5 km.";
- "Aircraft should not fly in a prohibited area, or in a restricted area, (...)";
- A landing area is defined as the "part of a movement area intended for the landing or take-off of aircraft."

Air Traffic Management (ATM) is a complex system that addresses (safely and efficiently) the demand for flight through the airspace. Figure 8 illustrates a typical ATM system where air traffic demand is the input, traffic flow as the output, capacity as the system resource that allows traffic to flow is another input, and, lastly, disturbances as unwished inputs.

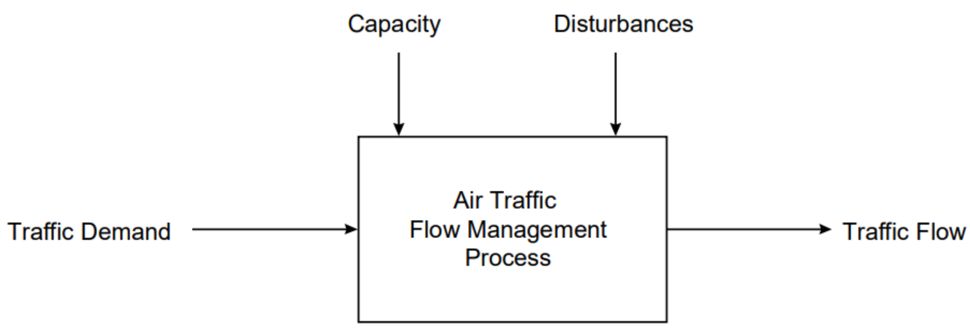

Figure 8 – ATM system. Source: [42].

An ATC, representing an Air Navigation Service Provider (ANSP) by ground air traffic controllers, has the primary purpose of preventing collisions between aircraft. The introduction of UAM could dramatically change the way the airspace is used, and the way ATC works, so a robust UATM system is required. Being aware of the possibility of elevating even more complexity to ATM system (which is already work loaded and so is not suited to address air vehicles density growth), six airspace integration principles for UATM were imposed by NASA [32]:

- "Does not require additional ATC infrastructure;
- Does not impose additional workload on ATC;
- Does not restrict operations of traditional airspace users;
- Will meet appropriate safety thresholds and requirements;
- Will prioritize operational scalability;
- Will allow flexibility where possible and structure where necessary."

Ideally, the ATC should not be involved in UAM operations. The existence of Providers of Services for UAM (PSUs) will exchange information with other PSUs through a network that enables safe and efficient operations within the UAM corridors [49]. UATM could be positioned between Unmanned Traffic Management (UTM) below and ATM above (see figure 9). Most importantly, UATM must be maintained as simple as possible.

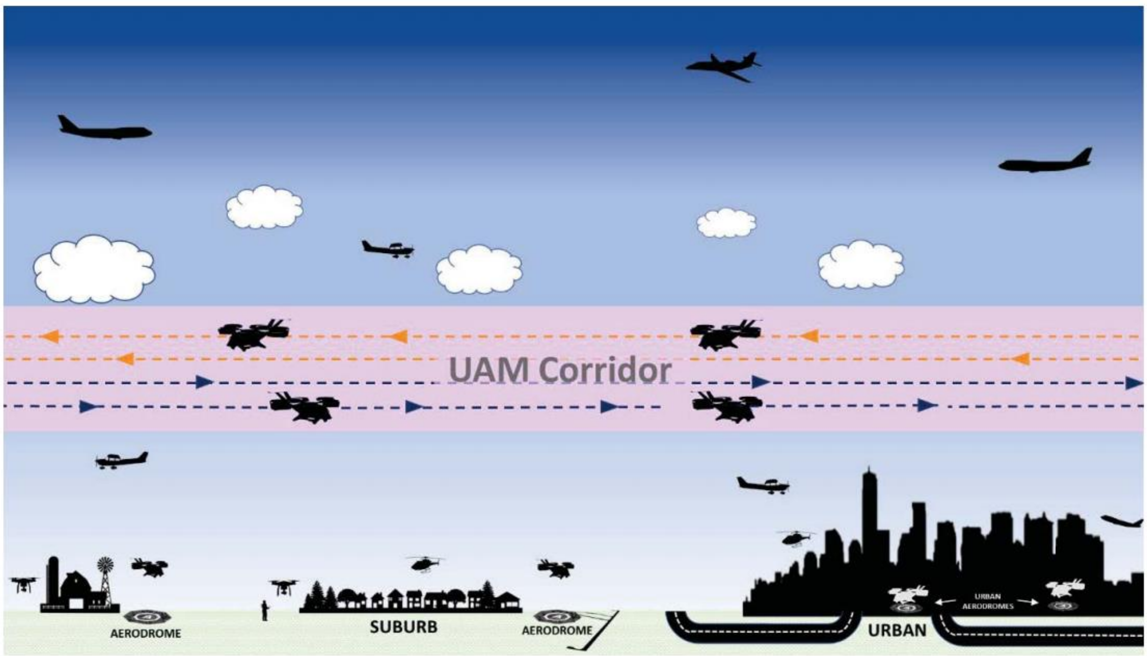

Figure 9 - UAM integration into airspace. Source: [49].

A UAM corridor is a more sophisticated and flexible airspace volume defining a 3D route segment with specific rules, procedures, and performance requirements where tactical ATC separation services are not provided. Within the UAM corridor, eVTOL vehicles will exchange information with other users of this corridor. However, ATC will have access to all available real-time information about UAM operations. It will be responsible for declaring whether a UAM corridor is open or closed, whereas it does not generally control UAM operations [49].

UAM is envisioned to have operations at altitudes between 1,500 ft (457 m) and 4,000 ft (1.22 km) Above Ground Level (AGL). Bird strikes happen mostly below altitudes of 3 km, so UAM might therefore interfere with the natural environment, disturbing wildlife and risking fatalities to both humans and animals.

Finally, with two out of three UAM's biggest challenges, the regulatory challenges are the only missing approach.

2.3.4 Regulation

Regulatory authorities are responsible for shaping standards for UAM. NASA predicts regulation will be in place for scalable operations between the next two and five years for last-mile delivery operations and more than ten years from now for air taxi operations [50].

Relative to the eVTOL certification, air laws for manned aircraft dictates that aircraft must be type certified according to initial and continuing airworthiness, registered, and maintained according to a program, pilots must be licensed, and operators must be certified [47]. UAM vehicle manufacturers need to develop and gain certification established by the regulatory authorities. In the quest to grapple with regulations related to UAM, several regulations developed by regulatory authorities like the Federal Aviation Administration (FAA), the EASA, and the Portuguese Civil Aviation Authority (ANAC) are below:

- FAA [27], [49], [50], [51]: Currently, the FAA is working on five regulatory categories: aircraft, airspace, operations, infrastructure, and community. It has already developed the UAM Concept of Operations version 1.0[4] (released in June 2020), and it is recently collaborating with NASA on its AAM National Campaign.

[4] This document describes the envisioned operational environment for UAM that supports the predicted evolution of flight operations in and around urban areas, focusing on ATM, Unmanned Aircraft Systems (UAS), and UTM, to support initial UAM operations.

Relative to the eVTOL certification, FAA plans to avail the flexibility of Part 23 Amendment 64, with the special conditions listed in the G1 certification (yet will be released in 2021 and EASA's equivalent of a G1, i.e., (CRI)-AO1, is close to being completed). It includes small aircraft under 19 seats or 19,000 pounds (8,618 kg) of maximum take-off weight. Lastly, FAA foresees the future of UAM regulation as being likely a marriage between evolutions of UAS (Part 107) and manned commercial rules (Parts 135 and 91). Until 2025 and through the Agility Prime program launched by the U.S. Air Force, the civil certification for eVTOL vehicles will be accelerated for future military purposes;

- EASA [28], [52], [53], [54]: UAM in Europe is expected to become a reality within 3-5 years. Alike FAA but using a completely different approach, EASA is paving the way to enable safe UAM. First and foremost, the Agency is minded to consider the safety of the European citizens, being mindful as well of the effects on all stakeholders. In May 2020, it established the Proposed Means of Compliance with the Special Condition VTOL (SC-VTOL-01) based on CS-23 Amendment 5, integrating elements of CS-27 and containing the safety and design objectives to guide UAM vehicle manufacturers. This document has defined the number of passengers as limited to 9 and a maximum certified take-off mass of 3,175 kg. Also, it introduces two certification categories:
  - Category Enhanced: aircrafts intended for operations over congested areas or for commercial flights must be capable of continued safe flight and landing after a failure (aircraft are required to encounter catastrophic failure conditions similar to the failure rate required for commercial airliners, that is, less than 10^{-9} per flight hour);
  - Category Basic: aircraft must be capable of a controlled emergency landing.

  This approach's choice allows the Agency to focus where clarification from the aircraft manufacturers is ultimately more urgently required and where the greatest safety impact will be accomplished. It is also dealing with the regulations for UAM air taxis operations at low-altitude airspace below 150 m (the Agency has released the U-space concept which supports routine UAS/UAM operations). By 2025, EASA expects to publish certification of the first Artificial Intelligence (AI)[5] for aircraft systems;
- ANAC [28], [45], [55], [56]: ANAC has already regulated conditions for Unmanned Air Vehicles (UAV). UAV operations are only permitted during daylight and below altitudes of 400 ft (122 m) AGL (the same applies to the UAV's operations in Brazil). The Portuguese regulation is vague in the sense of dealing with the type of

[5] AI refers to the simulation of human intelligence processes by machines, especially computer systems.

operations allowed, and it did not limit the maximum UAV weight. By contrast, the VFR flights for helicopters during daylight are defined with the total number of passengers limited to 9 and a maximum certified take-off mass of 3,175 kg. These flights allow helicopters to be licensed to operate above urban areas with a minimum altitude of 500 ft (152 m) AGL (the same applies to the helicopter's operations in Brazil) and a height above 985 ft (300 m) over the congested areas of cities. However, and being mostly in hands of ANAC, the Authority has still a long way to allow the introduction of UAM in Portugal (these regulations should include flight crew licensing and training, landing areas, maintenance regulations, requirements for operating organizations, and their certification, ATM, and Air Navigation Service Provider (ANSP) especially for low altitudes, databases for obstacles and terrain in high quality, and security regulations for passengers).

Beyond these three regulatory authorities, there are still other relevant regulators in the Integrated Airspace (e.g., EUROCONTROL and NAV).

Interestingly, many current helicopter services are planning to transition their operations to eVTOL operations in the future, e.g., Uber Copter and the Airbus VOOM (unfortunately, this last one had to cease its operations due mostly to the Covid-19 pandemic. It had provided on-demand helicopter services in three of the most populous and congested metropolitan areas in the world: São Paulo, Mexico City, and San Francisco [57]). Particularly in São Paulo, Brazil, traffic jams can last for hours. A complement to minimizing road congestion, this city has the biggest helicopter fleet in the world. Legislation for these helicopter operations can be consulted in the Instructions of Aeronautic Command (ICA) no. 100-4 [58]. Chosen by clients, heliports of São Paulo are situated in convenient spots, e.g., airports, hotels, and corporate buildings, with helicopters operating in the Special Helicopter Route (REH) and taking place from Monday to Friday between 7 a.m. to 8 p.m. [59]. It is important to share that helicopter's operations in Brazil can not be mixed or confused with future UAM operations and thus cannot be used as a reference for discussions while projecting UAM. Besides that, differing from a Portuguese perspective (and European perspective), from a Brazilian point of view, future UAM operations are intended to be conducted in order to provide individual transportation instead of sustainability purposes, as there are severe urban mobility problems in cities (e.g., São Paulo) that need to be eased first and foremost.

Right now, we have the three UAM's biggest challenges characterized which leads us to move to a strategic analysis of UAM, using two business planning techniques as SWOT and PESTLE analysis.

2.3.5 SWOT/PESTLE analysis

Both SWOT and PESTLE analyses are executed to be aware of what to expect to be encountered during the case of study. SWOT and PESTLE analyses are equally strategic analysis tools widely used for business goals planning. While SWOT analysis allows to capitalize the business' strengths, minimize weaknesses effects, make the most of opportunities, and reduce threats impact, PESTLE analysis considers the environmental context that affects the business and the possible changes in this context [60]. The latter has a special focus on identifying trends that help to think proactively by anticipating potential changes that may occur in any business.

When both analyses are merged, it powerfully enables the identification of key internal factors (i.e., factors in the control of the business as strengths and weaknesses) and their classification associated with external factors (i.e., factors outside the control of the business as opportunities and threats). A closer parsing is made below [61], [62]:

- SWOT:
    - Strengths: internal factors that help achieve the business goals, e.g., advantages, capacities, and authentic or lowest-cost resources;
    - Weaknesses: internal factors that hinder achieve the business goals, e.g., disadvantages, limitations, improvement areas, and factors for losing business;
    - Opportunities: external factors that could help achieving the business goals, e.g., chances of improvement areas, competitors' vulnerabilities, current trends, and good opportunities to spot;
    - Threats: external factors that could hinder achieving the business goals, e.g., external risks, weaknesses, threats, hurdles, and competitors' business.
- PESTLE:
    - Political: opportunities or threats related to the government body, their policy and initiatives, financial support for businesses, taxation;
    - Economic: opportunities or threats related to inflation, rates, labour and energy costs, changes in customer demand;
    - Social: opportunities or threats related to public, lifestyle, trends, culture, education;

- Technological: opportunities or threats related to emerging technologies, information systems, communication systems;
- Legal: opportunities or threats related to regulations, employment, government law, and standards;
- Environmental: opportunities or threats related to weather, natural disasters, pollution, waste.

For complex systems and a need for extensive analysis of external parameters, a SWOT/PESTLE analysis turns out to be the most popular tool [63]. Given the fact that UAM operations may be quite complex and encompasses various distinct parameters, a SWOT/PESTLE analysis is applied to highlight internal factors and external factors related to the UAM market, either with positive effect (i.e., strengths and opportunities) or negative effect (i.e., weaknesses or threats). Table 1 clusters a wide range brimming of these factors that may impact and influence future UAM operations.

Table 1 - SWOT/PESTLE analysis related to the UAM market. Source: Own elaboration.

SWOT/PESTLE analysis	**Internal factors** (strengths and weaknesses)	**External factors** (opportunities and threats)
Political	• Innovative mode of urban mobility, and hence innovative city hub; • Higher public acknowledgement; • Existence of few or no policies for UAM.	• Government initiatives to raise the adherence to friendly environmental transportation; • Positive effect on the overall urban mobility; • Funding from higher governments (e.g., European Commission (EC)) due to innovative initiatives; • Low resilience from the government to support long-time decisions.
Economic	• Traffic flow optimization; • Multimodal integration; • Higher electrification; • High investment in initial acquisition.	• Higher employment opportunities; • Innovative opportunities for businesses; • Increased demands on local gip capacity; • City's economic situation degradation.
Social	• People flow optimization; • Higher swiftness and adaptability to emergency response, mobility service for disabled citizens, rescue operations, humanitarian missions, and deliveries distribution; • Lower commuting times; • Easier access to airspace for the people; • Lower privacy; • Higher difficulty of people's willingness and acceptance.	• Increase of tourists and visitors; • New trend launching that could facilitate public willingness and acceptance; • Risk of incidents and accidents; • Passenger interference with UAM operations and passenger illness during flight; • Cyber and physical security-related threats as sabotage and terrorism; • Higher inequality; • Unsafe proximity to people and structures; • Potential privacy violation.
Technological	• Higher safe and secure system compared to helicopter operations; • Advanced technologies are still under development for	• Higher automation for on-demand businesses; • System failure or loss of control; • Aircraft's collisions and bird strikes;

	cybersecurity, sense-and-avoid, fight control, contingency management procedures, cooperative route planning, weather consideration, localization with high-precision, and automated flight; • Higher airspace congestion.	• Cybersecurity-related risks; • Potential UAM route conflicts with existing ATM and increase of ATM workload.
Legal	• Existence of few or no regulations at all UAM fields; • Existence of prohibited or restricted urban areas for vertiport placement; • Existence of prohibited or restricted airspace areas for UATM.	• Overview opportunity for optimizing airspace; • Need for people and passenger protection laws; • Regulation could never allow UAM implementation.
Environmental	• Environmentally friendly (vehicles are electric-powered); • Small footprint for ground infrastructures; • Higher visual pollution.	• Competitive advantage due to green practices; • New environmental laws; • Vulnerability to weather conditions; • Potential interference with birdlife.

With the most relevant UAM strengths, weaknesses, opportunities, and threats already unveiled, we are more aware of what it could take to accomplish guidelines based on real data and feedback that could be applied to a vertiport network in Lisbon. Still, we must first look at some features of this network before moving to its conceptual implementation (chapter 3).

2.4 Vertiport network

2.4.1 Purpose and concept

UAM needs infrastructures that enable multimodal connectivity as well as take-off and landing operations for eVTOL vehicles [5], [64]. These infrastructures are key enablers for the integration of UAM into urban areas, and wise UAM infrastructures placement creates opportunities to integrate UAM into other systems and technologies, such as public transportation, sharing economy modes (e.g., bike-sharing), or private modes. Their strategic placement can also enable other infrastructure to provide mutual support for UAM and other transportation options, such as parking garages that can serve both rail stations and co-locate with another UAM infrastructure [31]. The three types of UAM infrastructures are (figure 10) [65]:

- Vertihub: the biggest type, it can be built in the city centre or periphery areas, and MRO are carried here;
- Vertiport/Vertibase: the intermediary type, it can be built in the city centre, and small maintenance and repair operations are carried here;
- Vertistop/Vertistation/Vertipad: the smallest type and it can be built everywhere.

Figure 10 – Types of UAM infrastructures. Source: [8].

The five main areas necessary for these three types of infrastructures to function are [66]:

- Communication facilities;
- Statics and construction;
- Vertiport placement;
- Vertiport space requirements;
- Vertiport passenger process.

Since our primary focus is on vertiports, these infrastructures must include 1-2 take-off and landing pads, taxiways, 2-3 parking gates with charging batteries or refuelling tanks facilities, and a small space for passenger processes. Key areas such as points of interest, zones with high population density, and traffic nodes (i.e., the major entrances into cities, where traffic is more concentrated) serve as optimal locations for vertiports placement. Vertiports can be constructed over water (e.g., floating barge vertiports), on the ground (e.g., highways cloverleaves/turnabouts, private company campuses, airports), or elevated (e.g., rooftops, the top level of parking garages) [36], [65]. Albeit vertiports do not necessarily have to be newly constructed. Initially, these infrastructures can be placed in operational areas of traditional aviation (e.g., heliports and taxiways) as well as urban civil infrastructures that can be adapted for such an application (e.g., rooftops and parking lots), considering additional space with a minimum area of 1,000 m^2 [67].

Being the world's first full-scale passenger air taxi vertiport across Singapore, VoloPort was the outcome of an existing collaboration between Skyports and Volocopter. Its design can be easily adapted to fit different sizes, heights, and climate zones (i.e., flexible to all kinds of locations (figure 11)). Typical VoloPort requirements are [68]:

- Available footprint bigger than 25,000 square feet (2,323 m^2);
- Clear rooftops or multi-storey car parks;
- Clear approach and departure paths free from obstacles;
- Sites located close to other transport modes.

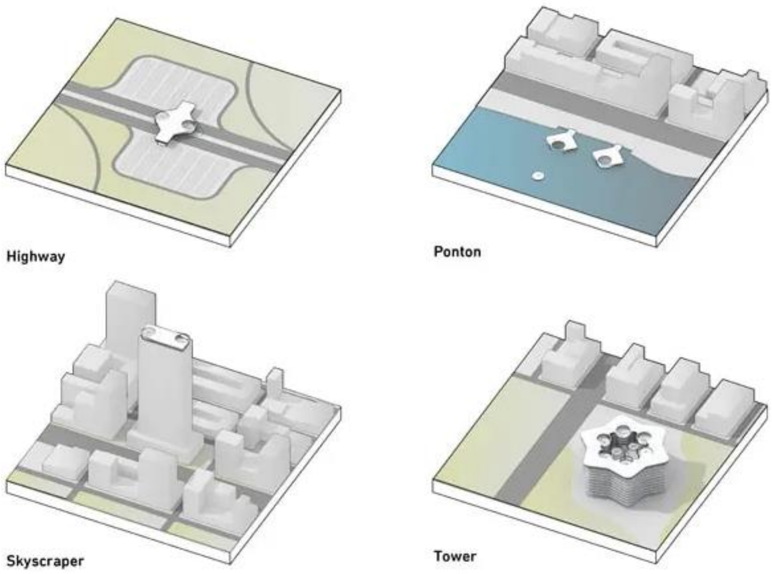

Figure 11 – Different VoloPort designs for urban areas. Source: [67], [68].

Despite that, UAM is believed to require little to no infrastructure. For example, Varon Vehicles Infrastructures Networks will provide transportation services in Latin American cities without the need for physical construction [6]. A set of vertiports strategically scattered in cities connected via virtual lanes over the low altitude airspace and a fleet of air vehicles servicing between those infrastructures features a vertiport network. All UAM fields together must build an ecosystem of simplicity to ensure an effective and efficient vertiport network. Potential market actors for this ecosystem to work include the platform provider, service provider, ground infrastructure provider, UATM provider, communication infrastructure provider, MRO company, vehicle manufacturer, and vehicle owner [28].

Besides, these networks need to englobe all demand trips within one network rather than be separated by trip purpose. The number of UAM routes rises with the number of vertiports (figure 12) [66] and UAM is expected to have a strong positive impact on long routes.

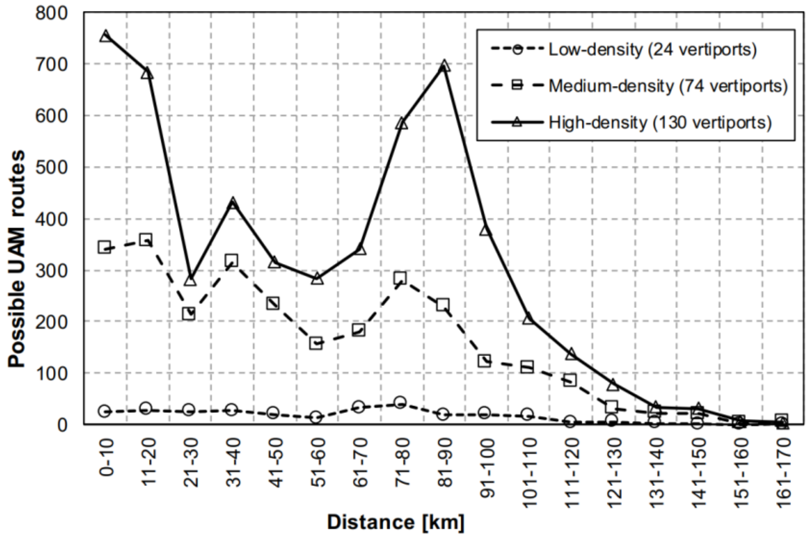

Figure 12 – Distribution of possible UAM routes by distance for different levels of density network. Source: [66].

Enabling both multimodal connectivity and take-off and landing operations for eVTOL vehicles, vertiports development and placement in cities still requires bearing in mind some considerations and regulations.

2.4.2 Considerations and regulation

Vertiports must engage the government, local communities, and the private sector, and its development requires an understanding of diverse factors like:

- Existing transportation;
- Land use/zoning;
- Physical infrastructure;
- Fuelling.

A high ranking factor for infrastructures placement prevails on the access or closeness to major transport hubs (e.g., airports, train stations) and closeness for a passenger home because of the greater potential for time savings [5]. Connections times to other public transport must be held, whereas UAM services can also be on-demand. It is also indispensably to take into account no-fly zones, existing air routes, critical infrastructures, city obstacles, weather conditions, and topography [6].

Another important consideration resides in the type of propulsion used in eVTOL vehicles (e.g., battery, hydrogen, or fuel) and energy storage must be deliberated [65]. From a vertiport point-of-view, vehicles driven by batteries[6] are more favourable and much easier to handle compared to tanks for hydrogen or fuel. Conversely, to reduce the number of vertiports, these infrastructures must be equipped with hydrogen or fuel (both with superior energy density than batteries) because vehicles could take either energy source for multiple trips with them. [66].

At last, data intelligence must be part of vertiports to leverage high levels of dynamic autonomous UAM operations. These operations will be englobed by a vertiport automation system (VAS) (see figure 13). This system consists of a vertiport operations system capable of supporting high-throughput operation capabilities under conditions defined as NASA's UML-4 (see figure 5). While PSUs manage air traffic from departure vertiport to arrival vertiport in coordination with VAS operators, the latter manage surface operations within the vertiports [69].

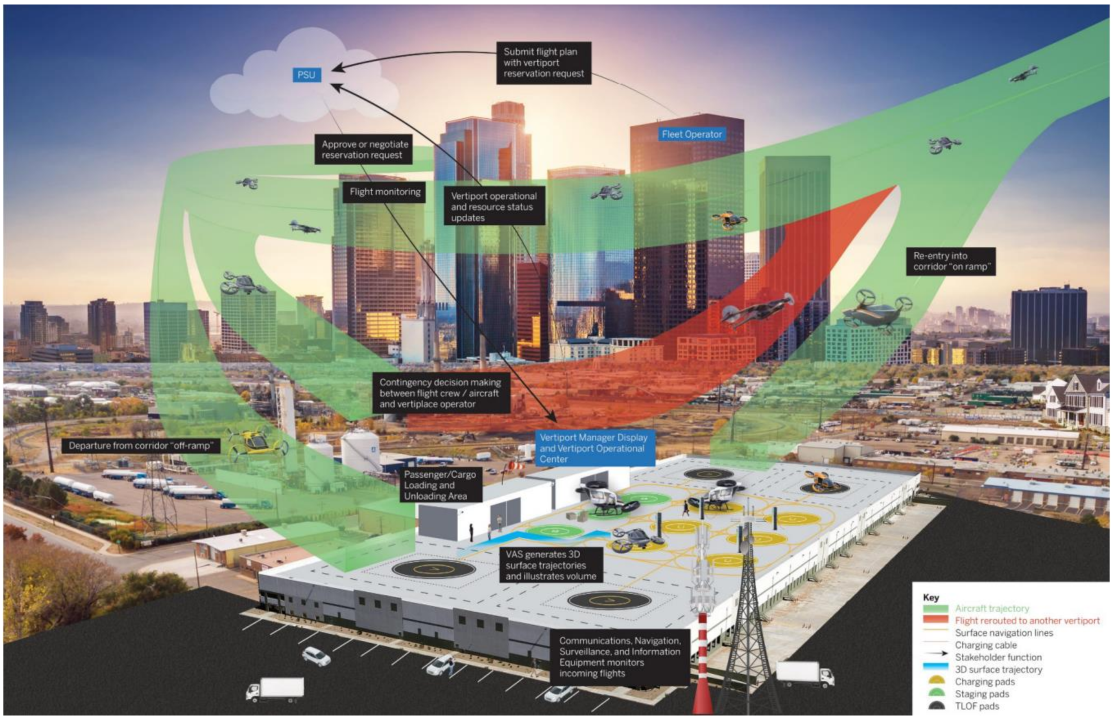

Figure 13 – VAS Diagram. Source: [69].

Enabling technologies will boost the development of vertiport networks like automation, sensors, software, radar, fuel cells, and flight simulators. These next-generation

[1] The recommended storage temperature for most batteries in the market is 15°C, and the maximum allowable temperature is between −40°C and 50°C for most battery chemistries. Being that lithium-ion batteries are the most prevalent for commercial and industrial applications, these batteries should be stored in a charged state, ideally at 40 per cent, ensuring all safety requirements.

technologies will produce a network blockchain[7] and AI system with a mix of Fifth Generation (5G) network communication and Automatic Dependent Surveillance-Broadcast (ADS-B)[8]. As a result, more situational awareness for UAM operations like Beyond Visual Line of Sight (BVLOS) in urban areas [70]. Firstly, with blockchain and AI systems, transactions are transparent on the network, meaning no paper records and almost zero transactional friction in that network. Secondly, communications vertiports will use 5G network communication. Experiments on communication networks have proven that while the Fourth Generation (4G) network provides only coverage below 300 m, the 5G network can allow operations to heights of 1000 m. Thirdly, although commercial aviation utilizes ADS-B, it lacks frequency bandwidth to be used by UAVs. However. in the initial phases, the ADS-B technology with radio-based voice communication support manned operations [71]. Finally, because of a network blockchain and AI system with a mix of 5G network communication and ADS-B, UAS will have the ability to fly BVLOS. For instance, Honeywell is working on a radar technology RDR 84K to allow BVLOS for UAV that uses a digitally active phased array which allows the radar to be "steered" and detect objects in the urban airspace or on the ground [72].

Now from a regulatory perspective, there is merely little and unclear research on vertiports and no explicit regulations for design and placement were yet presented. However, since vertiports have some similarities with heliports (they must be also subject to approval or certification), some researchers have been orientating themselves on infrastructure requirements for helicopters operations (ICAO's Annex 14 Volume II Heliports [73]) and adjusting them according to the level of throughput that is expected at vertiports, eVTOL vehicles characteristics and cities' specifications. In heliports, the size of a landing pad is determined by the Final Approach and Take-off area (FATO) and safety area of at least 2 D, where D is the largest overall dimension of the helicopter when the rotors are turning (figure 14). For vertiports, the Touchdown and Lift-off area (TLOF), FATO, and safety area dimensions are shown in figure 15.

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[7] Blockchain technology is a system of recording information in a way that makes it impossible to edit it. Hence, this technology could deliver a framework that can be used by stakeholders in UAM, as it can ensure security, provide for identity management, assume a supporting role in UATM, UAS conflict management and flight authorisation.

[8] ADS-B is a tracking and surveillance technology used by aircraft to determine its position via satellite navigation or other sensors and periodically broadcasts it, enabling it to be tracked.

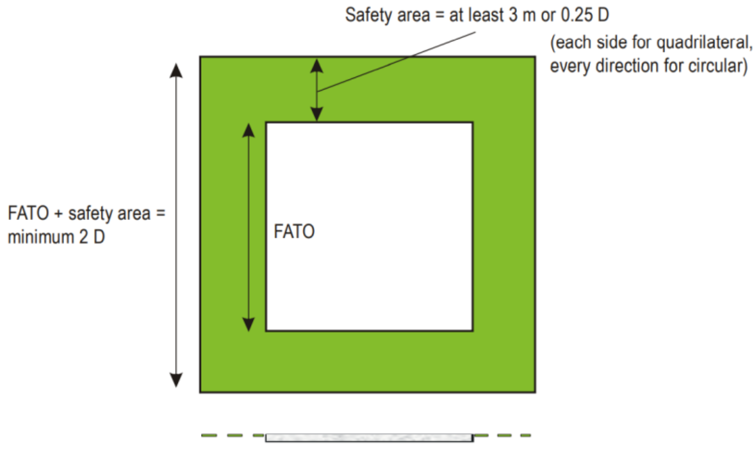

Figure 14 – FATO and associated safety area. Source: [73].

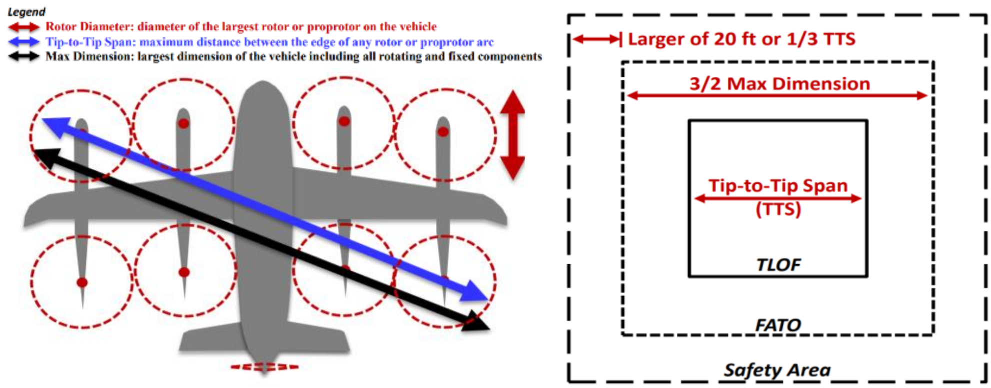

Figure 15 – Vertiport design dimensions for an example eVTOL. Source: [64].[9]

In addition, current regulations for heliports that can serve as support for vertiport regulations are presented in the FAA's Advisory Circular (AC) 150/5390-2C [74], EASA's Regulation (European Union) No 139/2014 [75], and the ANAC have the conditions for heliports in Portugal established in the Decree-Law no. 55/2010 (released on 31 May 2010) [76]. Nevertheless, all these regulations contain gaps related to eVTOL vehicle recharging or refuelling, the landing and take-off of autonomous vehicles and fire hazards in both vehicles and vertiports.

Lately, progress with new regulations for vertiports has been carryout out by national and international regulators. For example, the FAA Technical Centre is in the process of developing Vertiport Design Standards (on the other hand, the FAA's AC 150/5390-3 "Vertiport Design" was cancelled due to incompatible eVTOL vehicles use). Concurrently, the EASA has established the Vertiport Task Force to develop a Vertiport Design Manual (Rule Making Task 0230) [77]. Other specifications for vertiport designs are in progress by

[9] Vertiports with multiple pads for take-off and landing to support simultaneous operations require to present a minimum of 61 m separation distance between its FATO areas. The minimum width and length of a FATO can't be less than 30.5 m and 61 m, respectively.

EUROCAE with its WG112 VTOL SG5 Ground and American Society for Testing and Materials with its Committee F38.

Vertiports development will depend on the regulatory timeline and technical capability. Figure 16 displays the four system-level processes that may constrain vertiport throughput by limiting either aircraft or passenger throughput: airspace, airfield, terminal, ground access capacities. Unfortunately, regulation for vertiports will not fit all cities since these infrastructures may have a variety of configurations depending on the level of throughput that is expected at these infrastructures, the specifications of the eVTOL vehicles they plan to support, and the characteristics of each city.

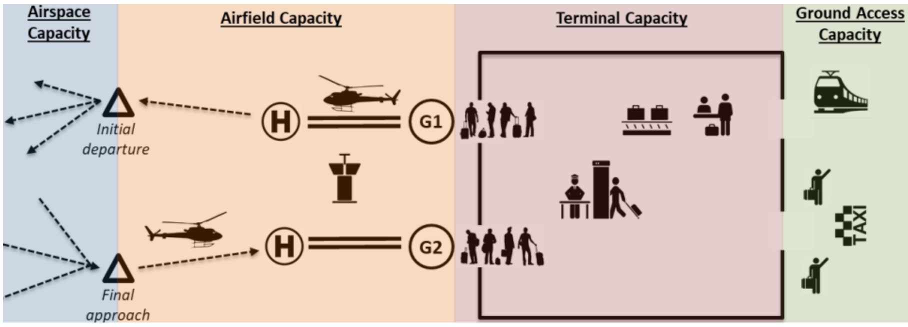

Figure 16 – Four capacity limiting processes of vertiport (or airport) operation. Source: [64].

Despite all these considerations and regulations to take into account, there are also several gaps, issues, and challenges that cannot be forgotten along with the development and placement of vertiports.

2.4.3 Gaps, issues, and challenges

Spatial, temporal, economic, political, legal, technological, physiological, social, and environmental barriers are some examples that could delay the implementation of vertiports in cities. Solutions for these barriers must be tailored to meet a wide array of urban environments and their needs [78].

The location of vertiports is challenging in urban environments because it could have huge implications on equity, e.g., gentrification, displacement, affordability of services, access for people with disabilities, vertiport vicinity, fight paths, and so on [50]. Finding the optimal vertiport locations and creating seamless interfaces to existing urban mobility options are the keys to providing genuine-time savings to potential users [67]. However, the lack of locations in cities to place vertiports is the greatest operational barrier. Other constraints include rooftops that may not have been constructed such that they can be retrofitted or surrounding high-rise buildings that may create micro-climates (e.g., wind tunnels) and may necessitate increased rates of vertical climb at take-off, and consequently, increasing power demands [36].

As eVTOL vehicles will use electric propulsion, these will require considerable energy for all operations and high-power charging infrastructures, forcing urban areas to require significant upgrades to power grid elements and building facilities to mitigate equipment overloads during peak charging periods. Plus, energy storage has to be charged from the grid (i.e., without onsite storage) to help reduce energy and demand charges. The most appealing places to accommodate vertiports consist of at-grade (e.g., regional airports) structures and multistory and high-rise structures (e.g., existing parking lots) [79]. Besides that, using hydrogen fuel cells (produced using solar or wind power) as the power source for eVTOL vehicles poses opportunities (e.g., increasing range, endurance, and others). But, it also represents the biggest challenge for vertiports: hydrogen is a highly flammable fuel creating significant hazardous for use in rooftop-based vertiports because it is logistically difficult and expensive to transport to such heights. Fire hazards may be concerned if the refuelling of the vehicle is not performing in a safer manner that is allowable under the fire regulations [80].

Until issues related to power source generation, storage, and transportation are addressed, the use of eVTOL vehicles for commutes between 30 miles (48.28 km) and 200 miles (322.87 km) range is the optimal flight range (figure 17).

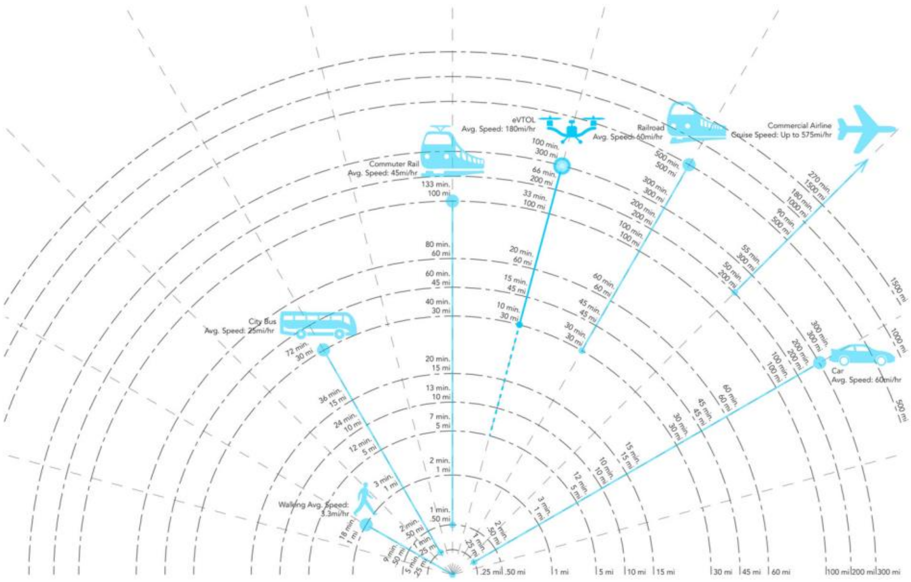

Figure 17 – Comparative efficiencies in various modes of urban transport. Source: [81].

Table 2 summarizes some of the main gaps, issues, and challenges currently faced in vertiports implementation in urban areas.

Table 2 - Gaps, issues, and challenges of vertiports. Source: Own elaboration.

Gaps	Issues	Challenges
• Regulation for vertiport design and placement; • National and local legislation; • Ground support equipment; • Roles, processes, systems (e.g., safety management system); • Enabling technology; • People perception of electrification and fully autonomous technologies.	• Technology and infrastructure development cycles are not in sync; • Different city characteristics (no size does not fit all); • Power sources generation, transportation, and storage; • Limited space in cities for vertiport placement.	• Vertiports funding; • Vertiports placement; • Ensure equity; • Ensure safety and security; • Determine who will plan regionally; • Public acceptance; • Adapt to the birdlife and wildlife; • Adapt to the varied weather adversities; • Multimodal integration (e.g., alignment of timelines); • Airspace and ground integration and capacity; • Privacy, noise, and visual pollution; • Real-time update and share of data.

Finally, with several gaps, issues, and challenges listed together is easier to simulate a vertiport network in the city chosen for the development of this Dissertation's case study, a living lab is carried out in the city and portrayed in chapter 3. To integrate UAM into their daily lives, the people must be at the centre of the solution design. In this regard, it is possible to reach and nurture society's trust which is the key to fostering an innovative mobility solution for cities. This strategy represents a user-centred approach, based on systematic people engagement in the decision-making process along with stakeholders [82]. Remind that we know that most citizens will initially reject this new concept of "flying cars", we pursuit to understand their existing fear barrier and then creatively discover optimal locations for vertiports placement based on their concerns and needs. Figure 18 shows a living lab broken down into urban environment, citizen perception, and government policy.

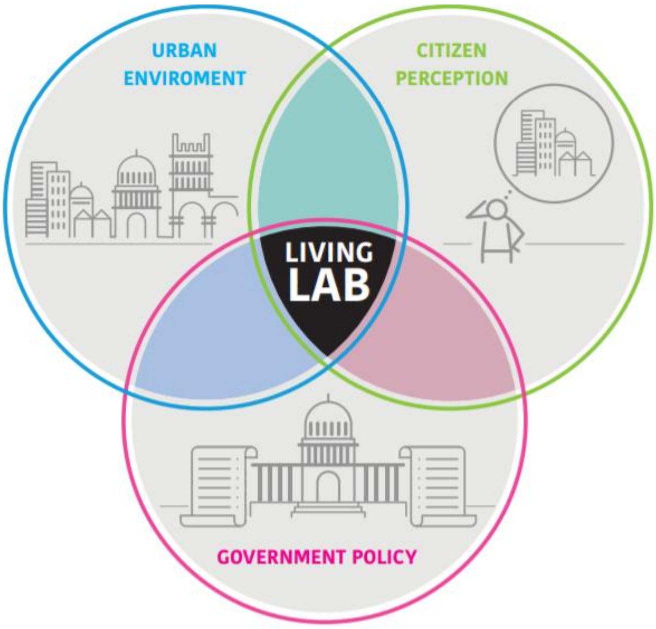

Figure 18 – Three key areas of a living lab in cities. Source: [82].

2.5 Conclusion

Current urban mobility has a long way laid ahead until it meets a dynamic equilibrium between all actors and stakeholders involved and integrates a safe, secure, and reliable UAM in cities. UAM must be tailored to meet the wide array of urban environments and their needs.

In summary, Chapter 2 overviewed the current urban mobility in cities and its logistics process and analysed how we could integrate UAM into that process (including a SWOT/PESTLE analysis of this new mode of transport). The last part of this chapter reinforces how vertiport networks in cities could help to reverse climate change and elevate citizens' welfare. For that, in the first place, we laid out the purpose and concept of vertiports. Afterwards, a few considerations, the existent regulation, and the absent regulation associated with the implementation of vertiports were bolstered. To sum up, we clustered mainly on the gaps, issues, and challenges concerning the employment of vertiports in cities. In the next chapter, we analyse this implementation in a particular city and reveal the results.

Chapter 3

Case of study

3.1 Introduction

The deployment of a vertiport network in Lisbon and the results obtained are presented in this chapter. The strategy used in this chapter is divided into two distinct phases (but both are always connected): the social feasibility (phase 1) and the technical feasibility (phase 2). Since the strategy represents a user-centred approach, the first phase gives guidance to the following phase. The focus here is to tailor UAM in human terms, making people be part of the decisions and, hence, make them more willing to engage with UAM. For that, a living lab is conducted where the people and stakeholders involved are consulted as this project unfolds. Lastly, it is awaited the results to uncover possible and effective ways to make vertiports implementation work, consistently considering public acceptance for this new reality of “flying cars”.

3.2 Scenario description

The city of Lisbon, in Portugal, is chosen to be the operation scenario mostly due to its road congestion, followed by noise and atmospheric pollution concerns to the people (intensified by the Humberto Delgado Airport located right in the middle of the city where aircraft noise and microparticles emitted by aircraft are highly harmful to citizen's health.) As a secondary reason, Lisbon is the author’s hometown, meaning more personal knowledge about the city's characteristics. Furthermore, this city already envisions to leverage itself as a smart city that places its citizens and their needs at its core, which meets this Dissertation’s user-centred approach.

Simply put, in this section we look forward to the urban environment through the “living lab.” Here, an analysis of the optimal locations that could serve as for vertiports placement in Lisbon was conducted, i.e., zones with high population density, key points of interest, and traffic nodes. For that, we describe the demography, land use/zoning, weather conditions, birdlife, existing transportation, accessibility of Lisbon. By then, we create the operation outline used in chapter 4.

3.2.1 Demography and land use/zoning

According to the most recent census, the city of Lisbon has the following demography [83], [84]:

- Area: 100.1 km²;
- Population: 552,700 habitants;
- Population density: 6,436 habitants/km²;
- Metropolitan area: 2,821,876 habitants.

Figure 19 represents the demography distribution across the city of Lisbon, where the darker zones are the ones with the highest population density.

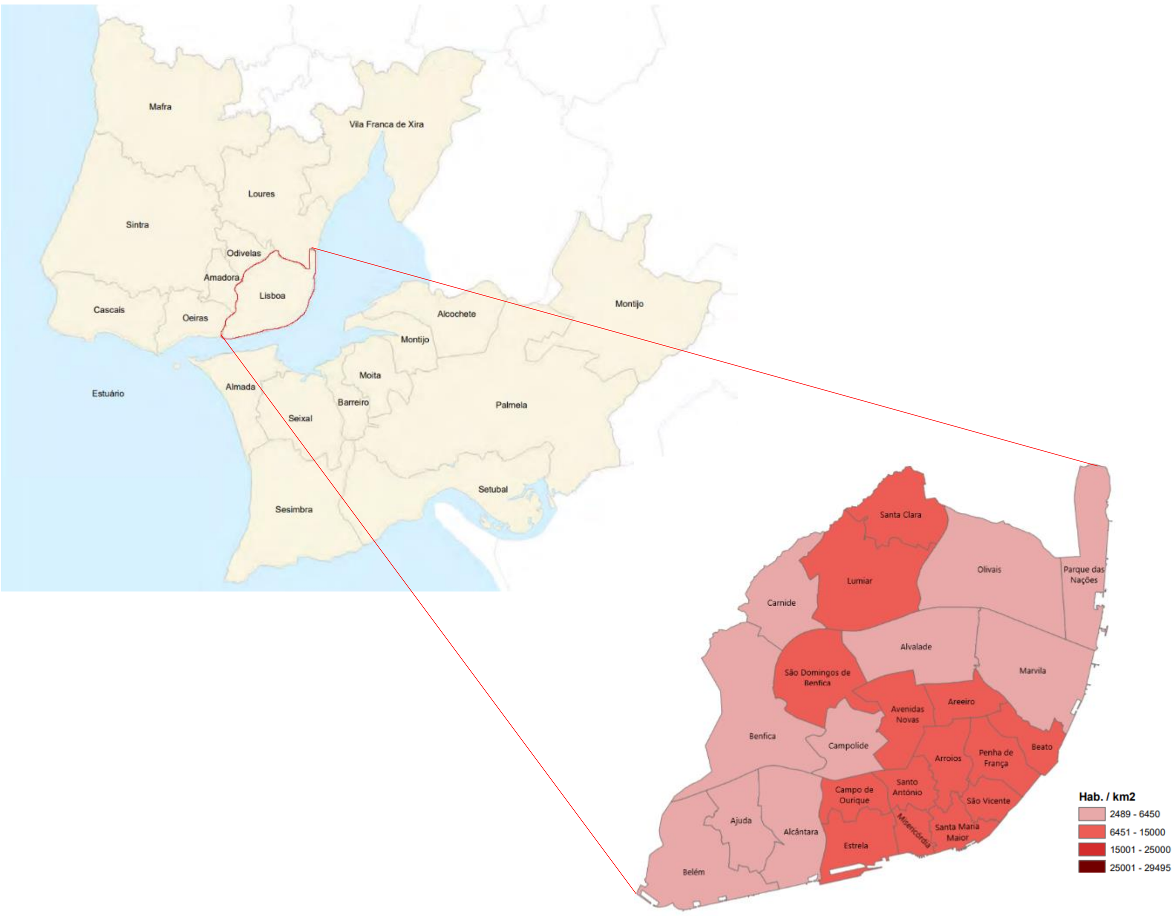

Figure 19 – Lisbon Metropolitan Area and population density of the city of Lisbon. Source: Own elaboration based on [83].

Apart from being the most populated city in Portugal, Lisbon is included in the main tourist and historic districts. Figure 35 from appendix 1 reveals the locations of the key points of interest in the city of Lisbon. The most touristic zones have great accessibility conditions for all kind of citizens, e.g., Belém, Parque das Nações, Rossio in Santa Maria

Maior, Cais de Sodré in Misericórdia, and the famous "baixa de Lisboa" in Santa Maria Maior.

In any case, the historic nature of its buildings raises challenges to integrate UAM, attaching with several challenges ranging from the city's irregular topography to its aged population. Regarding this latter challenge, it appears that the highest concentration of the elderly population resides in the oldest areas of the city, e.g., São Domingos de Benfica, Alcântara, Belém, Ajuda, and Alvalade. By contrast, given to its irregular topography dominated by hills and valleys of variable dimension, Lisbon is known as the city of the seven hills [85]: "Colina de São Jorge", "Colina de São Vicente", "Colina de Sant'Ana", "Colina de Santo André", "Colina das Chagas", "Colina de Santa Catarina", and "Colina de São Roque". The highest point with 745 ft (227 m) MSL is in the Monsanto Forest Park, which will not leverage concerns, at first, since UAM is envisioned to have operations at altitudes above 1,500 ft (457 m) AGL, as mentioned in the previous chapter. Figure 20 shows this point and other forestry zones of the city.

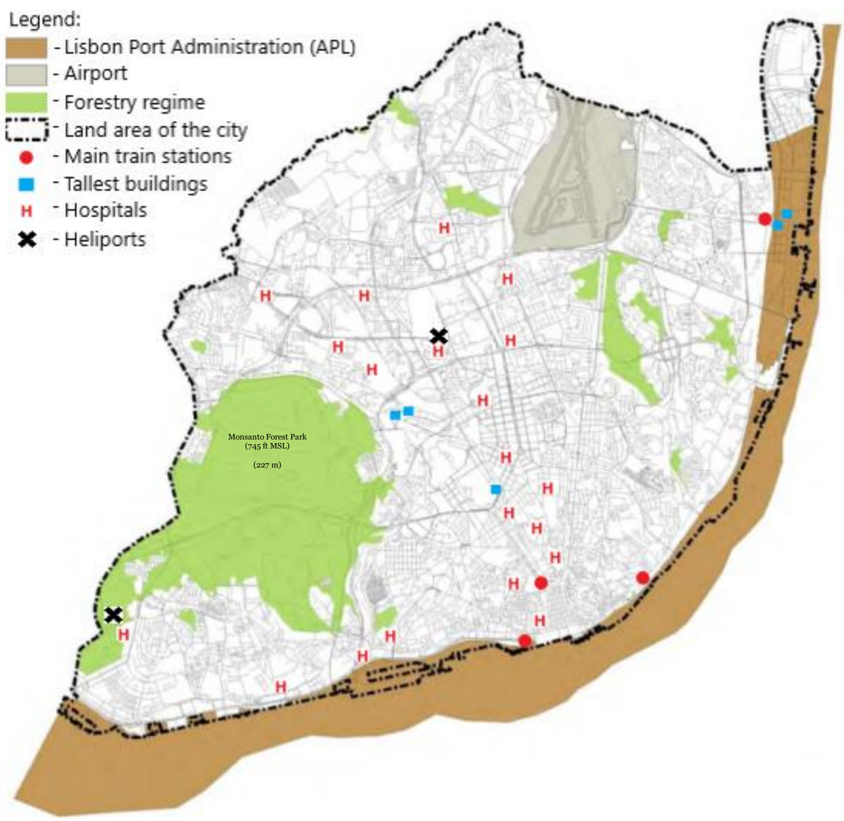

Figure 20 – Land use of the city of Lisbon. Source: Adapted from [83].

The city has a vast area of the coast (represented as the Lisbon Port Administration (APL)) which could be a potential zone to place vertiports over.

The tallest buildings in Lisbon are the Saint Gabriel Tower and the Raphael Tower, both in Paque das Nações and with 361 ft (110 m). These two buildings are followed in high by the Sheraton Lisboa Hotel & Spa in Avenidas Novas with 315 ft (96 m), the Twin Towers in Campolide with 295 ft (90 m), and the Corinthia Lisboa Hotel in Campolide with 272 ft (82.9 m) [86].

Regarding air transport, the airport of the city in Olivais is known as the Humberto Delgado Airport (location indicator: LPPT (ICAO) or LIS (International Air Transport Association (IATA)) and it is located 7 km northeast from the city centre. Regarding the rail transport, the main train stations of the city are the Rossio Station (located in Santa Maria Maior and it is where trains to Sintra depart from), Cais do Sodré Station (located in Misericórdia and it is where trains to Cascais depart from), Santa Apolónia (located in Santa Maria Maior), and Gare do Oriente (located in Parque das Nações).

The industrial and logistical market areas[10] in the city of Lisbon have been vanishing over the years, where many of the spaces with industrial characteristics have given rise to new residential developments, commerce, or offices [87].

Lastly, Lisbon possesses lots of hospitals (private and public), scattered around the city. The Hospital Santa Maria in Alvalade and the Hospital São Francisco de Xavier in Belém are the only ones that include heliports, turning both hospitals a potential location for vertiports placement for emergency responses. For initial vertiports placement, the existing landing pads (e.g., helipads) and taxiways (e.g., airports and aerodromes) could be used. Even though there are no other heliports in the city of Lisbon, other cities within the Lisbon Metropolitan Area contain a wide variety of them. Table 8 from appendix 1 presents all the aerodromes and heliports in the Lisbon Metropolitan Area.

Existing helicopters' air routes (represented in figure 36 from appendix 1), for example, routes already used by helicopters for service providers (e.g., emergency responses, mobility service for disabled citizens, rescue operations, and humanitarian missions), could be used for initial UAM operations.

Besides these routes, the initial UAM operations could also follow the rules and procedures for tourism sightseeing and passenger transport already carried out by the company Lisbon Helicopters [88], whereas in a sustainable way. Only then, the operations

[10] The industrial and logistical market in Lisbon Metropolitan Area is divided into 6 zones: zone 1 (Alverca-Azambuja); zone 2 (Almada-Setúbal); zone 3 (Loures); zone 4 (Montijo-Alcochete); zone 5 (Sintra-Cascais); and zone 6 (Lisbon City).

could extend to more complex and ODM operations like air taxis and private/executive transportation, for which routes are missing. It is also indispensable to take into account no-fly zones. Within the city of Lisbon, a special fly zone to pay more attention to (once it covers the boundary defined by the coast of the city) is the non-airspace management cell[11]. This one is a restricted area named LPR26A MONTIJO, it is used for air exercises, and its airspace classification is Class D [45].

All told about Lisbon's demography and land use/zoning, we now evaluate Lisbon's weather conditions and its birdlife.

3.2.2 Weather conditions and birdlife

Briefly, two important external factors, i.e., factors that cannot be controlled, are considered for the UAM operations: the weather conditions where the eVTOL vehicles will operate and the birdlife that UAM will be very likely to interfere with.

Table 3 describes the annual variation of the weather conditions for the city of Lisbon that was collected by the Portuguese Institute of the Sea and the Atmosphere (IPMA) [89]. According to Köppen's climate classification[12], Lisbon has a temperate climate with a rainy winter and a dry and hot summer (i.e., Hot-summer Mediterranean climate (Csa)). The table below shows that, throughout the year, wind ranges from roughly 50 km/h to 80 km/h utmost and temperature generally varies from nearly 7°C to just above 29°C, precipitation suffers sudden changes between zero millimetres and slightly below 107 millimetres.

[11] An airspace management cell is a joint civil/military cell responsible for the day-to-day management and temporary allocation of national or sub-regional airspace under the jurisdiction of one or more State(s).
[12] The Köppen climate classification, sometimes called the Köppen–Geiger climate classification system, is one of the most widely used climate classification systems worldwide. This classification divides climates into five main climate groups, and each group is divided according to the seasonal precipitation and temperature patterns.

Table 3 – Weather conditions from November 2020 to October 2021 collected by the IPMA's meteorological station Lisbon – Gago Coutinho (nº 579). Source: Own elaboration based on [89].

	Average minimum temperature [°C]	Average maximum temperature [°C]	Total precipitation [mm]	Max daily rainfall [mm]	Max wind velocity [km/h]
November 2020	12.2	18.6	80.6	23.5 (day 25)	55.1 (day 3)
December 2020	9.1	15.6	95.9	25.4 (day 19)	79.2 (day 4)
January 2021	7.1	13.5	58	31.6 (day 20)	68.4 (day 20)
February 2021	10.7	16.7	106.7	46.2 (day 20)	67.7 (day 9)
March 2021	10.3	19.8	15.7	15.4 (day 4)	55.1 (day 20)
April 2021	12.6	21.2	69.3	14.2 (day 24)	50.4 (day 23)
May 2021	13.0	23.3	17.6	8.4 (day 9)	57.6 (day 9)
June 2021	15.0	25.9	6.4	3.2 (day 20)	58.3 (day 22)
July 2021	16.9	28.4	0.3	0.3 (day 3)	58.7 (day 31)
August 2021	17.5	29.2	0.0	-	59.0 (day 16)
September 2021	17.8	27.1	26.6	9.9 (day 15)	54.4 (day 22)
October 2021	15.9	25.3	52.5	27.5 (day 30)	65.5 (day 29)

Regarding birdlife, it is important to note that bird strikes happen mostly below altitudes of 3 km where UAM operations will occur. Lessons can be learned from the proposed new airport in Montijo to expand the Lisbon airport (that was afterwards rejected). This new airport was projected to be located right at the Tejo River Estuary and therefore, negatively impacting its sensitive fauna. This estuary is currently a haven for migratory birds between the period from October 1 until the end of February. Overflying these areas during that period is prohibited up to 1,000 ft (304.8 m). For prevention, UAM must not operate in these areas of sensitive fauna. Otherwise, it would be extremely hazardous, impacting nature and passenger safety altogether [90]. Figure 37 from appendix 1 shows the bird migration and areas with sensitive fauna.

The weather yearly and birdlife is already analysed. Then, we look at the existing transportation and accessibility of Lisbon.

3.2.3 Existing transportation and accessibility

To better understand the optimal locations for vertiports implementation in Lisbon, we must overlook the existing transportation and the access to the city (by road, rail, maritime or fluvial, and air transport). According to EASA, vertiports must be integrated within the local mobility network [91]. Besides closeness to other transport modes, connection times to them must be held as well. Complementary, we must define where the traffic nodes are, i.e., the major entrances into the city, where traffic is more concentrated.

The access into the city of Lisbon is quite extensive with several highways and national roads as represented in figure 21. The interval between 7 am and 10:30 am is quite congested as well as the interval between 5 pm and 8 pm (sometimes even worse compared to the morning period). Ordered in a descending way regarding traffic density, the major entrances into the city of Lisbon are the A2 highway (also known as the 25th of April Bridge (height of 624.9 ft (191 m)) which connects Alcântara (within the city) to Almada (outside the city)); A5 highway; A1 highway; IC19; A12 highway (also known as Ponte Vasco da Gama Bridge (height of 486 ft (148 m)) which connects Parque das Nações (within the city) to Alcochete (outside the city)); A8 highway; IC22; IC16 highway.

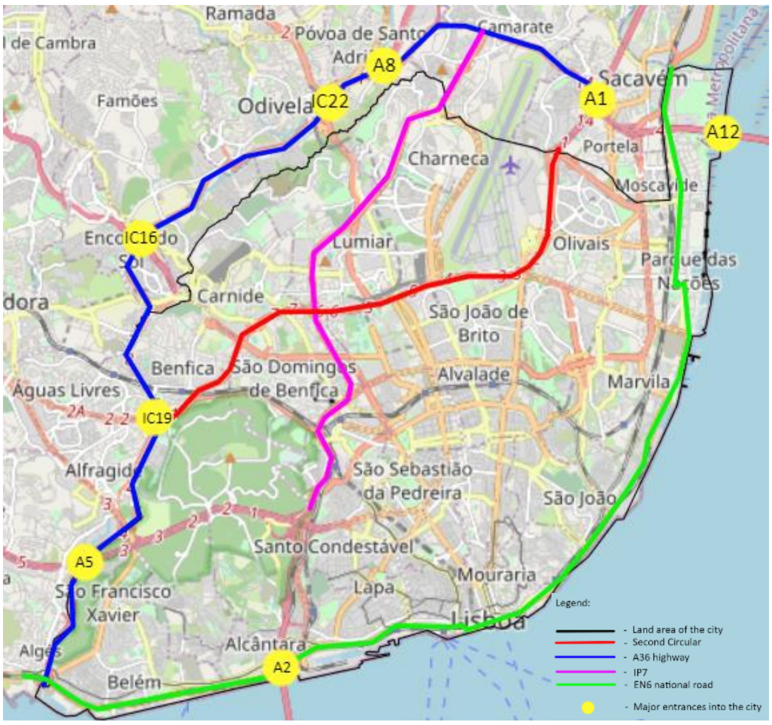

Figure 21 – Major entrances into the city of Lisbon. Source: Own elaboration based on [92].

One of the Portuguese roads with the highest traffic density at rush hour is the Second Circular which is an urban road that connects the eastern part of the city (A1 highway) to the western part (IC19). The airport of the city generates more than 15 per cent of the traffic of this urban road [93]. The IP7, also called as North-South Axis, is a highway that runs through the city from north to south and it connects the A2 highway to the Circular Regional Interior of Lisbon (CRIL). This latter one is also called the A36 highway or IC17 and it is a road along the periphery of the city in its interior. The circular that goes along the periphery of the city in its exterior is called the A9 highway (also known as the Circular Regional Exterior de Lisboa (CREL)) and it is not represented in the figure above. Contrary, the road that goes along the coast of the city (the marginal zone) is the EN6 national road, also called the Avenue Marginal, that connects Parque das Nações (close to the A12 highway) to Cascais (outside the city). Together with the marginal zone, two zones within the city are equally difficult regarding traffic density: the Campo Grande in Alvalade and the Marquis of Pombal Square in Santo António.

Potential locations for vertiports could be in car parks of public access that are scattered in Lisbon and presented in figure 38 from appendix 1.

As referred above, the accessibility into and within the city is quite extensive, even for disabled citizens. Unfortunately, the irregular topography of the city makes it harder for disabled citizens to move around, especially in the old and high zones of the city, e.g., Alfama in Santa Maria Maior, Chiado in both Santa Maria Maior and Misericórdia, and Bairro Alto in Misericórdia.

Lisbon has a satisfactory mobility service with a wide range of modes of transport like bus, metro, tram, taxi/uber, train, tourist bus, car, bicycle, motorcycle, vessel (ferry, catamaran, and cacilheiro), and cable cart. Besides that, the city has elevators to allow reaching its seven hills. Figure 39 from appendix 1 shows the current transport distribution network of Lisbon. Through the "Zona de Emissões Reduzidas" project, significant changes in the existing transportation are being made by the Câmara Municipal de Lisboa. This revolutionary project prioritizes the improvement of quality of life and reduction of pollution and congestion in Lisbon. It limits the circulation of light and heavy vehicles on working days, where residents, public transport, and rescue vehicles are the only ones authorized to circulate in this new reduced emissions zone of *Avenida-Baixa-Chiado*.

Concerning the power grid in Portugal for electric transportation, electricity is generated using different technologies and primary energy sources, e.g., coal, natural gas, fuel oil, diesel, water, wind, sun, biomass, and waste. The Portuguese electricity grid is connected with Spain's. The *Rede Eléctrica Nacional S.A.* is the energy sector company that is responsible for the Portuguese national electricity grid system. It contains six circuits of 400 kV and three circuits with 220 kV, totalling 8,907 km of circuit length [94].

Up to now, we look in particular to the demography, land use/zoning, weather conditions, birdlife, existing transportation, accessibility of Lisbon. Consequently, we now can start the projection of the operation outline.

3.2.4 Operation outline

This section presents the operation scenario for the vertiport network implementation in Lisbon. As stated earlier, we have resorted to the places established for initial placement in operational areas of traditional aviation (e.g., heliports and taxiways) as well as urban civil infrastructures that can be adapted for such an application (e.g., rooftops and parking lots). Vertiports can be constructed in the city centre, whereas their placement must possess additional space with a minimum area of 1,000 m^2 for MRO and the monitoring and control of the fleet and integration into urban airspace. Table 4 shows the modes of transport available and roads close to each optimal location for vertiports placement. Vertiport no. 5 could be in the airport or near it to alleviate the Second Circular road. To decrease the time of emergency responses, vertiport no. 7 could be in the heliport of Hospital Santa Maria and vertiport no. 1 in the heliport of Hospital São Francisco de Xavier. Being close to Gare do Oriente train station, vertiport no. 4 could be on the rooftop[13] of Saint Gabriel Tower or Raphael Tower or over water as a floating barge vertiport. Vertiport 6 could be near the Estádio José Alvalade. The vertiports no. 3 and no. 6 cover locations of high population density. Finally, vertiports no. 2, 3, and 8 could be initially placed in parking lots, the top level of parking garages, floating barges, or highway cloverleaves/turnabouts, considering additional space.

[13] Only if rooftops are already prepared for helicopters or will have to be further adapted, i.e., they will not be of immediate use.

Table 4 – Closeness between other modes of transport and roads to optimal locations for vertiports placement. Source: Own elaboration based on [95].

Vertiport no. **Location**	Modes of transport							**Roads**
	Road transport	Rail transport			Maritime or fluvial transport	Air transport		
	Bus	**Tram**	**Metro**	**Train**	**Vessel**	**Helicopter**	**Airplane**	
1 **Belém**	✓	✓		✓	✓	✓		A5 EN6
2 **Alcântara**	✓	✓		✓				A2 EN6 IP7
3 **Misericórdia | Santa Maria Maior**	✓	✓	✓	✓	✓			EN6
4 **Parque das Nações**	✓		✓	✓				A12 EN6
5 **Olivais**	✓		✓				✓	A1 Second Circular
6 **Lumiar**	✓		✓					IC22 Second Circular IP7
7 **Alvalade**	✓		✓			✓		Second Circular
8 **Benfica**	✓			✓				A5 IC19 IC16 Second Circular IP7

Concerning the eVTOL vehicles, table 5 specifies some characteristics of the most popular aircraft in the UAM market. Not autonomous vehicles were privileged in this selection to get faster initial public acceptance.

Table 5 – eVTOL vehicles. Source: Own elaboration based on [96].

eVTOL Company	**Range [km]**	**Capacity**	**Autonomy [minutes]**	**Weight [kg]**	**Vehicle price**	**Cruise speed [km/h]**
S4 Joby Aviation	241.4	1 pilot + 4 passengers	N/A	1,814	$1.3 million	322
VoloCity Volocopter	35	1 pilot + 1 passenger	27	700	$330,000	110
Lilium Jet Lilium	300	1 pilot + 4 passengers	60	490	$4 million	280
CityHawk Urban Aeronautics	150	1 pilot + 5 passengers	N/A	1,170	$3.2 million	234
VA-1X Vertical Aerospace	161	1 pilot + 4 passengers	N/A	750	N/A	325

Unfortunately, some relevant values like autonomies neither prices for travel tickets were not unveiled by the companies. The Lilium Jet eVTOL has the highest range and the lowest weight, whereas its eVTOL is the most expensive one. It is noteworthy that the CityHawk from Urban Aeronautics has the highest capacity, and it is the most versatile eVTOL due to its ease to take-off and land everywhere and its suitability for all weather conditions (unlike the Lilium Jet which can only fly in daylight with good weather conditions), turning the CityHawk an appealing and mighty option (see figure 22) [97].

In order to make a parallelism between eVTOL travel and car travel (which is the mode of transport most used in Lisbon, according to Statistics Portugal [84], whereas not the most efficient one). The bestselling car in Portugal, Renault Clio (see figure 23), as having an average consumption of 5.2L/100km, a price of 20,850 €, and a weight of 2,503 kg [98]. For recurring costs, we considered an average fuel cost of 1.75 €/L [99] and the operating costs for a car representing roughly 4,032 €/year, including monthly fee, motor vehicle tax (called "Imposto Único de Circulação" in Portugal), insurance, car inspection, overall maintenance, fuel, and tolls.

Figure 22 – CityHawk. Source: [97].

Figure 23 – Renault Clio. Source: [98].

Moreover, UAM operations will be under the legislation of the national government and the regulation of the national aviation authority, ANAC. As we have mentioned in chapter 2, ANAC follows the same guidelines established by EASA, which defined the UAV operations to occur during daylight and below altitudes of 400 ft (122 m) AGL and helicopters operations above urban areas with a minimum altitude of 500 ft (152 m) AGL and a height above 985 ft (300 m) over the congested areas of cities. EASA has also restricted UAM operations to a number of passengers limited to 9 and a maximum take-off mass of 3,175 kg. Wind limits and other weather conditions limitations for UAM operations have not yet been specified by the eVTOL companies.

To assess the logistics and feasibility of the integration of UAM in Lisbon, two distinct phases (but both are always connected) were executed: the social feasibility (phase 1) to decode the citizen perception by consulting the people, and the technical feasibility (phase 2) by working together with the stakeholders involved. Figure 24 presents the methodology followed for both phases, including the objectives and operation outline of the scenario development. Recalling that this strategy represents a user-centred approach, based on systematic people engagement in the decision-making process along with stakeholders. This is possible by conducting a living lab, already presented in figure 17, which is broken down into three key areas: urban environment, citizen perception, and government policy. The urban environment is explored in this scenario description section and the citizen perception (phase 1) and government policy (phase 2) are examined in the scenario development section.

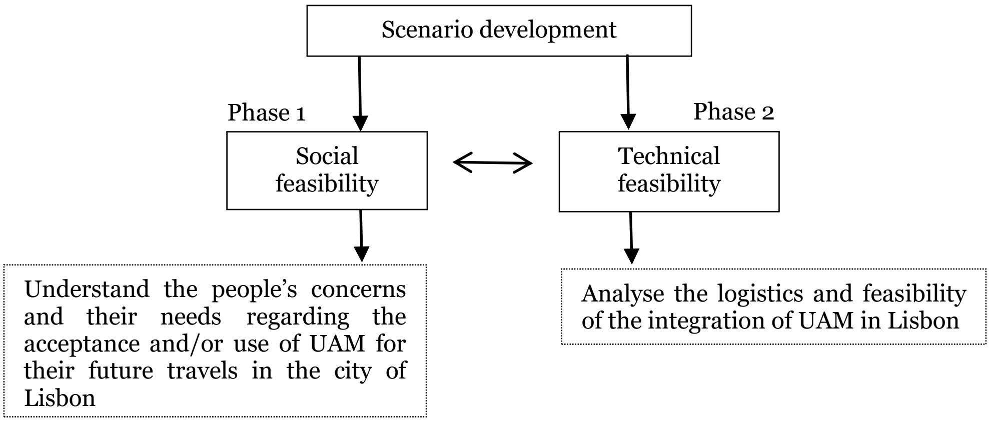

Figure 24 – Workflow of the methodology adopted for scenario development (phase 1 and phase 2). Source: Own elaboration.

Considering the scenario description presented above, we move toward scenario development and its results.

3.3 Scenario development

3.3.1 Phase 1

UAM integration goes beyond technical considerations where public acceptability plays a key role. Unfortunately, there is still an enormous gap in seeking the engagement of the people with the UAM. Recapitulating from chapter 1, we believe that making UAM consistent and user-centred, i.e., connecting directly to humanity and reflecting its values, pushes the world forward by changing how we travel in cities.

In the first phase – the social feasibility – the strategy used gears towards a user-centred approach. With that said, we pursuit to understand their concerns and needs regarding the acceptance and/or use of UAM for their future travels in the city of Lisbon, and then creatively discover optimal locations for vertiports placement based on their concerns and needs. The focus here is to tailor UAM in human terms, making people be part of the decisions to make them more willing to engage with UAM. This tailoring results in better integration of UAM into their future daily mobility.

For this first phase, we look forward to the citizen's perception. For that, the citizens of Lisbon are consulted with internet-based communications (e.g., an electronic survey). We disseminate electronic survey no. 1 (see figure 40 from appendix 2 [100]) to the population that lives, works, and studies within Lisbon. This dissemination comprises getting in touch with the city of Lisbon's parish councils, non-governmental organizations, educational establishments, companies, and the like. According to statistics, in 2020, 425,747 people enter Lisbon to work or study, while 47,521 city residents leave to work or study in the neighbouring towns. The balance is thus of 378,000 individuals. So, the resident population plus the population that enters Lisbon to work or study, excluding those that leave this city to work or study, represent a population size of 926,000 individuals [101]. The sample size is set to 85 survey responses, using a confidence level of 90 per cent and a margin of error of 9 per cent.

The electronic survey no. 1 is adapted into more human terms to be easier to understand (since UAM is a new technology for most of us) and connect with the people (by identifying with them through their concerns and needs). After all, sustainable urban mobility and smart cities start with an interaction with the people.

The original survey is in Portuguese as the official language in Portugal. Yet, it is translated and presented in English in this Dissertation to make it plainer and consistent. The electronic survey no. 1 serves to comprehend:

- To what extent does the sample of the population feels satisfied with the current urban mobility in Lisbon;
- What is their prior knowledge of UAM;
- To what extent are they willing to try out UAM;
- What are the reasons for them to try out UAM, i.e., their needs;
- What are the reasons for them to reject UAM, i.e., their concerns;
- Where do they prefer the vertiports to be placed;
- Demographics (e.g., gender, age, and type of citizen, i.e., if it is a citizen who lives, works, or studies within the city of Lisbon);
- Further insights about UAM.

In the meantime, this survey could give the sample of the population the possibility to learn about:

- The advantages that UAM will bring to their life;

- The technological advances around the world regarding the urban mobility of the future, from which they will be able to take advantage of new business and work opportunities and contribute to minimizing climate change;
- The report of the survey.

Followed and connected by phase 1 is phase 2, consisting of the technical feasibility of UAM.

3.3.2 Phase 2

Stakeholders influence the UAM and vertiports integration outcomes, and each stakeholder will have their expectations and requirements for this integration.

The first phase gave guidance to the second phase – the technical feasibility. Falling back on the same "living lab," for phase 2 we look forward to the government policy to assess the logistics and feasibility of the integration of UAM in Lisbon. The strategy used gears towards three steps:

1. Define stakeholders;
2. Identify the reason for their resistance through their expectations and requirements;
3. Explore and find ways to minimize concerns and maximize opportunities.

For that, the stakeholders involved in the decision-making process of urban mobility in Lisbon are consulted with electronic surveys. Related to step 1 of the strategy used, the main stakeholders (i.e., the national entities) as the Portuguese ANSP ("NAV Portugal" [102],) the airport authority of Portugal ("ANA - Aeroportos de Portugal, SA" [103],) the ANAC Portugal [104], the Lisbon City Hall [105], and the Government of the Portuguese Republic (specifically, the Ministry of Infrastructure and Housing [106]). For each stakeholder is created an electronic survey which dissemination comprises sending requests for participation via phone and electronic mail (email). One of the stakeholder's electronic surveys can be consulted in figure 41 from appendix 2. Likewise phase 1, the original surveys are written in Portuguese and then translated and presented in English in this Dissertation.

The electronic surveys for stakeholders serve to comprehend:

- What are the stakeholders' expectations for this integration;

- What are their requirements for this integration.

With the overview made for the strategies used in each of the two phases, the results obtained are then presented.

3.4 Results

3.4.1 Phase 1 results

For survey no. 1, we collected 89 responses. Table 6 lists data on the demographics in three different categories such as gender, age, and if the citizen lives, works, studies, or visits the city of Lisbon. Units are measured in percentage, except for bar graphs for which are in the number of individuals. Overall, men totalled slightly below 70 per cent of responses and women just above 30 per cent. Furthermore, the group aged 18 to 29 reveals almost 50 per cent of all responses, while the elder group with up than 65 years of age only represent roughly 1.1 per cent. Citizens living, working, and studying in Lisbon represent nearly 41.6 per cent, 21.3 per cent, and 12.4 per cent, respectively. Lastly, a quarter of the total responses came from regular visitors or/and tourists.

Table 6 – Demographics of the sample of the population. Source: Own elaboration based on [100].

Category	**Subcategory**	**Per centage [per cent]**
Gender	Male	69.7
	Female	30.3
Age	18-29	49.4
	30-49	32.6
	50-65	16.9
	>65	1.1
Type of citizen	Resident	41.6
	Worker	21.3
	Student	12.4
	Visitors and tourists	24.7

Next, the results obtained are in three pie charts and three bar graphs.

The pie chart (figure 25) displays the degree of satisfaction among the population related to the current urban mobility in Lisbon. From this chart, we can perceive an overall satisfaction, whereas a significant number of citizens are either unpleased or indifferent with it According to figure 26, the number of people that have previously heard about UAM is almost similar to those who possess good knowledge of it. Controversy, a huge percentage of people have at least some knowledge on this matter but not sufficient to confidently discuss it. The analysis of the willingness to try out UAM is in figure 27. In general, a considerable number of the total responders expressed some or vast interest in using it.

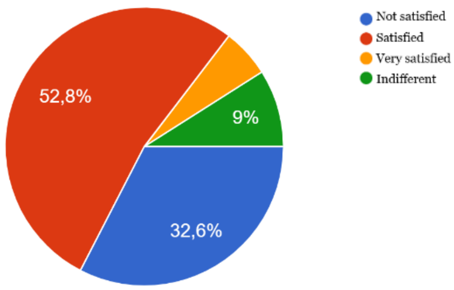

Figure 25 – Degree of satisfaction related to the current urban mobility of Lisbon. Source: Own elaboration based on [100].

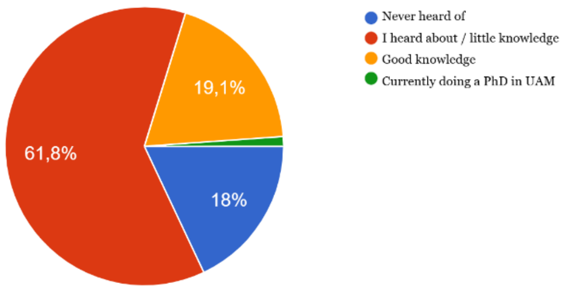

Figure 26 – Prior knowledge about UAM. Source: Own elaboration based on [100].

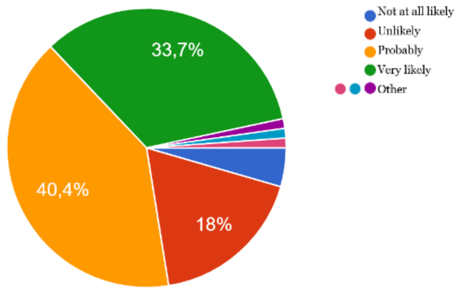

Figure 27 – Willingness to try out UAM. Source: Own elaboration based on [100].

Reasons for both to try out and reject UAM are shown in figures 28 and 29, respectively. The former is related to what people want, i.e., their needs, and the latter plots the major external and internal problems of people related to UAM, i.e., their concerns. Additionally, people could select more than one reason. Notably, people seek time savings the most, compared to using UAM for either the status symbol or to access the airspace. Yet, the major concerns lay in the worries of air crashes and the cost of eVTOL travels.

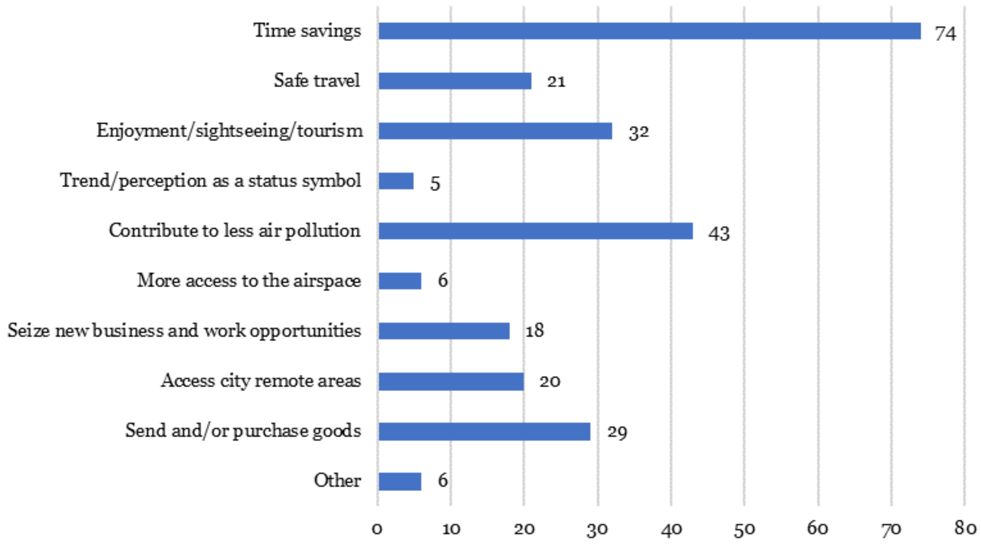

Figure 28 – Reasons for trying out flying cars (people's needs). Source: Own elaboration based on [100].

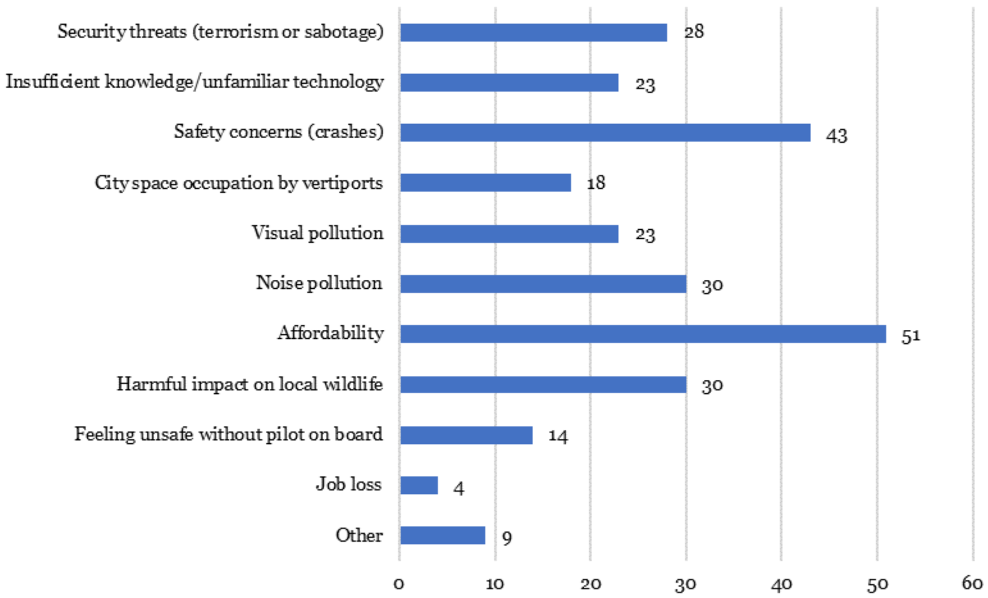

Figure 29 – Reasons for rejecting flying cars (people's concerns). Source: Own elaboration based on [100].

The last survey no. 1 question embraced people's preferred places in Lisbon for vertiports placement. The bar graph from figure 30 illustrates the most convenient locations. Likewise, people were free to select more than one vertiport placement option. People prefer vertiports to be in opener spaces like parking lots and existing helipads/heliports. Despite that, a significant preference resides on the closeness of these infrastructures to the Humberto Delgado Airport.

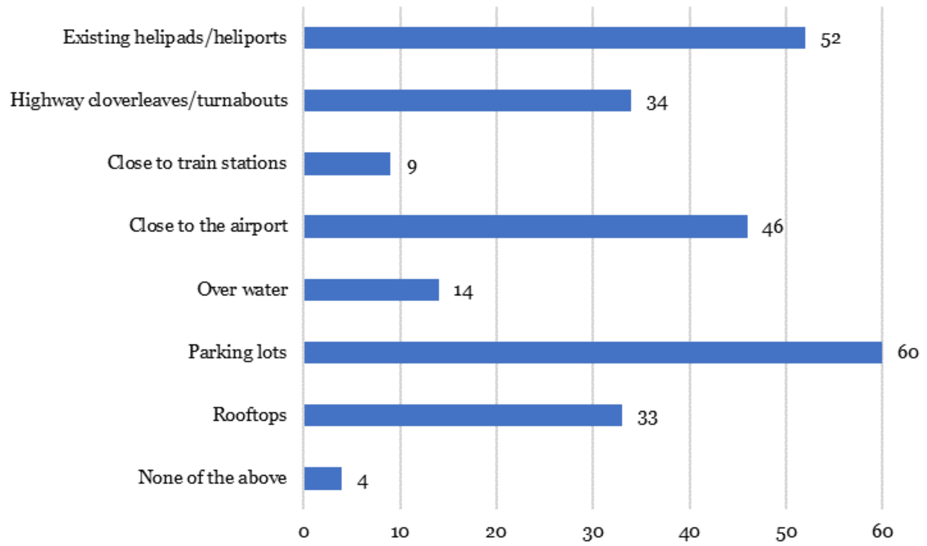

Figure 30 – Preferred places for vertiports placement. Source: Own elaboration based on [100].

In complement, responders shared further insights about UAM, being the meaningful ones who are bear in mind during the analysis of the results presented in Chapter 4. While some citizens show to be against this new innovative mobility, others shared further suggestions on this matter as:

- Transpose UAM to reality since it is still the realms of science fiction for many. Examples provided include making presentations at seminars or trade fairs to make it well known and promote UAM work opportunities and changing the mentality and customs of today's societies by educating people about electrification and fully autonomous technologies through books, lectures or television programs can help them cooperate with and accept the outcomes;
- Make a separation in two types of air traffic (freight and people). The latter might have to stay on the city periphery and combine with other modes of urban transport;
- Build vertiports where people's mobility is facilitated, e.g., near bus stations;

- Make it accessible to more people and not for the richest. Consider being careful not to harm the poorest, who will have less access to UAM but will continue to suffer downward consequences, e.g., noise and visual pollution.

Now with the phase 1 results presented, let us go into the results obtained from phase 2.

3.4.2 Phase 2 results

Already with the five stakeholders defined in step 1 for phase 2 strategy, step 2 consists in identifying the reason for their resistance through their expectations and requirements to assess the logistics and feasibility of the integration of UAM in Lisbon. Stakeholders' answers are strictly confidential, and data is only used for statistical purposes and therefore, we present just an overview of all their answers. Their meaningful insights are in table 7. Overall, stakeholders assume a positive initial attitude and a firm willingness to actively contribute towards the integration of UAM in Lisbon.

Table 7 – Expectations and requirements from the stakeholders contacted. Source: Own elaboration based on [107], [108], [109], [110], and [111].

Stakeholders' expectations and requirements
• The development of UAM will be one of the biggest challenges facing the aviation industry, not so much in terms of the development of future aircraft, but rather in terms of navigation systems prepared to sustain high-density air transportation with the operational safety requirements that citizens take for granted concerning this air mode;
• Urban airspace is currently used mostly for take-offs, landings, search and rescue missions, security missions, and other activities. It is not suitable for UAM operations yet, therefore is a need for reconfiguration. After this new reconfiguration, it will be necessary for service providers to guarantee safe operations and operators and pilots who make available the various services for urban airspace. This integration will be phased in and reach its fullness when all the conditions from a regulatory, safety, training, and market point of view are met for this new reality;
• There may be the eventuality of flights where there is no predefined route, but a volume of airspace that will be used (air photography, search, and rescue, urgent delivery of medicines to specific locations, among others) requiring immediate adaptation to such an operation;
• It will also be necessary to ensure the compatibility of these systems with existing aviation. For example, specialized missions must always have a human pilot, although he may not be on board the aircraft;
• The need to maximize the autonomy of these aircraft, combined with the complexity of managing a 3D, will lead to progressively removing human pilots. On the other hand, these aircraft will probably be equipped with active systems to detect and avoid obstacles, using location systems and 5G telecommunications networks to transmit their position, speed, and route in real-time to processing centres that do the management of automated traffic in real-time. Meanwhile, this data network will have to be high resiliency and low latency (less than one-second response) for all systems to work properly (e.g., remote identification, the separation between unmanned and manned aircraft, detecting and avoiding collisions, geospatial reconnaissance, authorization flight information, traffic information, and so on);
• The network where all data will be processed, in this context, cybersecurity will be essential to guarantee the safety and security factors of the operations;
• ANSP and respective support services might have to start a "reskilling" process as the system will be based on a strongly digitized architecture where automation will have a role preponderant and the procedures will be a little different from those used today. ANSP should adopt this integration as a natural evolution of air transportation;
• There is still no infrastructure capable of accommodating take-off and landing sites (vertiports). In other words, it will have to be built from scratch or using existing infrastructures such as heliports, vacant or unused public spaces, and the urban buildings that allow the construction of these vertiports. At the same time, the environmental impacts and the adequacy factor of the energy networks will have to be analysed.

3.5 Conclusion

To conclude, the living lab employment was successfully achieved, even though having found problems in reaching people above 65-years-old and not receiving feedback from at least two out of five stakeholders.

Overall, this chapter describes in detail the urban environment of Lisbon to discover optimal locations that could serve as for vertiports placement. By then, in the scenario development section, the people and stakeholders are consulted in phase 1 (the social feasibility) and phase 2 (the technical feasibility), respectively. The results are finally presented, which are expected to uncover possible and effective ways to make vertiports implementation work. Before proposing guidelines for this integration, we need to analyse these results in the following chapter.

Chapter 4

Results Analysis

4.1 Introduction

The scenario validation is conducted in Chapter 4, which displays a detailed analysis of the main findings of the results obtained in the previous chapter, connecting both phases of the social feasibility (phase 1) and technical feasibility (phase 2). This chapter also provides UAM guidelines based on real data and feedback to introduce a smart, innovative, and sustainable mobility solution, i.e., UAM, in Lisbon, Portugal. For purposes of clarification, through the humanization of its technology, UAM has the power to point the way toward a new world of accessibility.

4.2 Scenario validation

4.2.1 Phase 1 results analysis

The key results from survey no. 1 are detailed below:

- Overall, more than half of all responders are satisfied with the current urban mobility in Lisbon, whereas approximately 32.6 per cent of people are unpleased with it and under 10 per cent shown to be indifferent to this matter (see figure 25);
- 60 per cent of them are slightly familiar with the UAM concept and purpose. Controversy, barely 18 per cent of responders scarce of knowledge about it (see figure 26);
- The more people know about this emergent technology, the more likely they are to experience an eVTOL flight across Lisbon. Even though less than 25 per cent affirmed not to be willing to use UAM in their future commutations, a significant percentage of about 74.1 per cent expressed some and abundant interest in using it (see figure 27);
- The top 3 people's needs relative to UAM (see figure 28) include time savings, contribution to less air pollution, and pleasure which scored 74, 43, and 32 responses, respectively. Additionally, the interest of nearly 30 responses is on sending and purchasing merchandise, expressing a sizeable tendency to the appearance of new future business and work opportunities;

- The top 3 people's concerns (see figure 29) consist in the travel costs with 51 responses, safety concerns with 43 responses, and noise pollution and environment concerns that both amount to the identical level of concern (with precisely 30 responses each). In addition, security concerns represent just about 30 responses and hence should be taken also as a priority;
- The top 3 places for vertiports placement (see figure 30) include parking lots with the highest rank of 60 responses, followed by existing helipads or heliports which total for 52 responses, and airports in third place with 46 responses. From these results, we confirm the potential of the vertiports no. 1 (Belém), 5 (Olivais), and 7 (Alvalade), described in table 4 from chapter 3, because they contain either a heliport or airport. For parking lots within the city, consult figure 38 from appendix 1. Furthermore, performing the facilities' location problems, also known as location analysis, might be a compelling task to find the optimal locations of vertiports to diminish travel costs.

A quick note related to travel costs: because today's green technology is not cheap enough compared to its fossil-fuels counterparts, we should strive to keep Green Premiums[14] as low as possible for everyone to pay for it in the years ahead [1]. These Green Premiums highlight where we need to innovate, giving lots of room for green tech improvement. For example, to decarbonize the atmosphere, innovation might help to bring prices down by deploying zero-carbon alternatives [1]. In short, the focus should be on creating affordable innovations for zero-carbon fuel for UAM operations. Moreover, a cost-benefit analysis (CBA)[15] (see figure 31) might be an interesting systematic approach to achieve benefits and preserve savings whist.

[14] The Green Premium is the additional cost of choosing a clean technology over one that emits more greenhouse gases.
[15] CBA refers to the systematic approach to estimating the strengths and weaknesses of alternatives used to determine options that provide the best approach to achieving benefits while preserving savings.

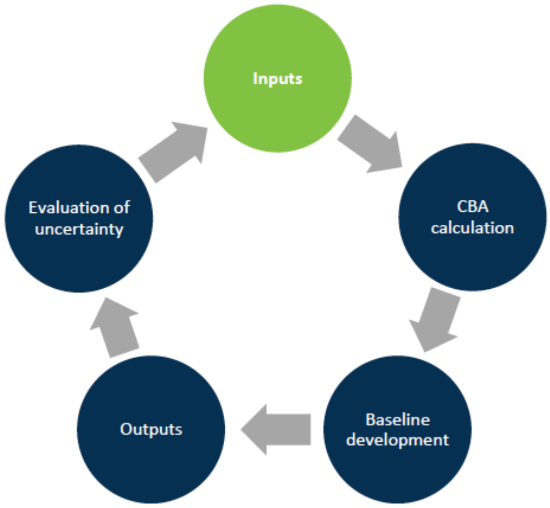

Figure 31 – Cost-benefit analysis. Source: [112].

Other essential points are related to the urge to protect wildlife and foster an acceptable noise level of decibels[16] and travel prices. Besides that, given the safety and security concerns expressed by the people, the UAM market needs to build confidence and trust in them, and for that, it must address their needs and concerns. As a result, public acceptance increases, leading to shifting human pilots for remote ones. Human beings cannot trust rules or technology, no matter how sophisticated, but we can only rely on them because it simply reacts to a set of variables. Otherwise, we trust people because they know how to follow and break the rules, when necessary, to save and protect us. For example, service providers, operators, and pilots do everything to avoid plane crashes, and so people board aircraft with trust because they know some experts know what rules to break if something goes wrong. Today's technology has not yet that sort of flexibility.

Having collected and analysed data from phase 1, we then can assess the logistics and feasibility of the integration of UAM in Lisbon through the analysis of phase 2 results.

4.2.2 Phase 2 results analysis

In the previous chapter, we identified five stakeholders involved in the decision-making process of urban mobility in Lisbon (step 1) and the reason for their resistance through their expectations and requirements (step 2). The following step (step 3) explores and discovers ways to minimize stakeholders' concerns and maximize opportunities.

[16] Today's urban life sustains an average background noise level of 60 decibels, which is loud enough to raise one's blood pressure and heart rate, and cause stress, loss of concentration, and loss of sleep. Therefore, people living in cities are regularly exposed (against their will) to noise above 85 decibels from sources like traffic, metro, industrial activity, airports, and so on. Concerning the noise level, eVTOL vehicles are estimated to have about 70 dB of noise from a distance of 152.4 m.

After analysing the insights provided by stakeholders that are summed up in table 7, we notice three major concerns among them like the need for:

- Adaptation of the airspace and ground integration and capacity. This concern englobes the development of new laws and regulations for urban airspace reconfiguration and phased integration with the existing aviation and the advanced training with a "reskilling" process for service providers, operators, and pilots deal with the different roles, processes, systems;
- Enabling technology. So, progress must be made in biotechnology[17], AI, and blockchain technology;
- Real-time update and share of data. The data network must be high resiliency and low latency, allowing to manage automated air traffic in real-time. For that, information technology[18] and 5G network communication has to be heftily advanced.

By resorting to table 1 and 2 from chapter 2, we get support for the diverse opportunities that the UAM market can bring to stakeholders to help to mitigate their concerns. These leave us with leeway to maximize opportunities, including:

- An overview opportunity for optimizing the airspace architecture and enhancing current airspace operations. By doing it, the complexity of managing a 3D with high-density air transportation might be decreased and all operational safety requirements guaranteed;
- Chance for businesses to develop on-demand, innovative, and green technologies. While there is an urge to create and roll out breakthrough technologies, companies, and industries that cooperate with this zero-carbon technology might lead the national economy in the coming years. In another perspective, they can use the 3D in ways never imagined possible in the past. For instance, there is currently a high demand to maximize the autonomy of eVTOL aircraft and even higher demand on the design and integration of networks of vertiports for these aircraft in cities. The sooner we all think about how we can adopt new green technologies into our lives and recognize it is going to happen in a matter of few

[17] Biotechnology refers to the technology that utilizes biological systems and living organisms (or parts of these organisms) to develop or create different products.
[18] Information technology (IT) refers to the use of any computers, storage, networking and other physical devices, infrastructure, and processes to create, process, store, secure and exchange all forms of electronic data.

years, without being in resistance, but in a place of embracing it, the least our lives will be shaken by it;

- Higher employment opportunities. The switch from manned to unmanned aircraft will forever vanish some of today's jobs, whereas lots of other work opportunities will be created in maintenance, remote control, data analysis, and cybersecurity. To be clear, the goal here is to protect people, not jobs. Still, these new jobs will require an advanced individual specialization and so, there is an urge to invest in people to equip them with new technical and interpersonal skills beforehand.

Moreover, the remaining concerns also pointed out by stakeholders are looked at in detail in the next section because those concerns are the same demonstrated by the people (e.g., safety and environmental concerns). Thus, an interconnection of phase 1 with phase 2 is performed in the next section.

4.2.3 Connection between phase 1 and phase 2

Reinforced by one of the interviewed stakeholders, UAM is "one of the biggest challenges facing the aviation industry." UAM integration must cultivate and nurture global and national cooperation, without neglecting people to be part of the decision-making process. By the way, this cooperation is notoriously hard but not impossible if we equally respond to the interests of all parties.

Starting by analysing their interests, the people and stakeholders share two similar worries about the UAM integration. With this information, we can connect both insights.

As the top priority for stakeholders, safety concerns are also common among citizens. These can divide into internal or external safety concerns. External concerns represent the actual problem (e.g., collisions) and internal ones refer to how the external problem makes them feel (e.g., for stakeholders is the responsibility to provide safe and secure operations, and for the people is the feeling unsafe without a pilot onboard). Since problems should be solved starting from the root, the primary focus should be to find solutions for internal concerns. A risk management cycle assessment[19] (see figure 32) might be a helpful process to recognize fundamental actions that need to be taken and learn from those actions to make continuous improvements in UAM.

[19] The risk management cycle assessment refers to the framework for the actions that need to be taken to manage risk.

Figure 32 – Risk management cycle assessment. Source: [113].

Also, about safety measures: it is mandatory the develop standardized infrastructure specifications that would secure the highest level of safety for vertiports. As one of the stakeholders mentioned, there is a lack of infrastructures capable to accommodate vertiports in Lisbon. Alternatively, both the people and stakeholders referred their preference to using existing heliports, vacant or unused public spaces (e.g., parking lots) for vertiports placement, confirming the potential of the vertiports no. 1 (Belém), 5 (Olivais), and 7 (Alvalade), described in table 4 from chapter 3. For parking lots within the city, consult figure 38 from appendix 1.

The other similar concern among all parties focuses on the environment. About one billion tons of CO_2 and its equivalents represent the carbon footprint of air transportation. Notably, the aviation industry must assume its responsibility to the earth and emit more carbon-free emissions while working economically. The impact that UAM would have on the environment will displace the birdlife and wildlife and require the adequacy factor of the energy networks. In the perspective of birdlife and wildlife, there will be a need for the latest data on the risks for those animal species and projections from computer models that predict the impact of UAM on them. In other words, an adaptation of UAM on birdlife and wildlife must go through three stages: first, reduce risks posed by UAM; second, get ready for and respond to emergencies (e.g., bird strikes that might cause fatalities to both humans and animals); third, after the disaster, plan for services for animals and people who have been displaced or affected in some way. On the other way, UAM is propelled by electricity to reduce carbon footprint, and there is nothing wrong with using more energy as long as it is carbon-free (e.g., zero-carbon energy). A life cycle assessment[20] (see figure 33) for UAM operations is a useful resource to analyse its environmental impacts, from production until the end of life. Finally, another relevant point is in the fact that today's environmental laws and regulations are outdated. We need changes in policy by coming up with policies that make a big difference in the environment. Local and national governments should create policies and incentives to help reduce emissions without wrinkling the economy while making that adaptation an attractive investment in everyone's lives. However, to be truly sustainable, people must first want to fly electric, and so, elected officials should support best practices without imposing them.

Figure 33 – Life cycle assessment. Source: [114].

To conclude, UAM should use innovation to release zero-carbon emissions and make eVTOL vehicles and vertiports safer and trustworthy. Up to this point, we have gathered sufficient conditions to propose guidelines for UAM integration in Lisbon based on real data and feedback obtained from phase 1 and phase 2.

4.3 Proposal of guidelines

Completed the scenario validation, we can hence move into production of guidelines for UAM integration in Lisbon. These guidelines strive to implement vertiport networks using a user-centred approach in urban areas, enabling UAM to meet the needs and concerns of all its customers and guarantee the absolute best user experience for everyone. By creating

[20] A life cycle assessment evaluates the environmental impacts associated with all the life cycle stages of a commercial product, process, or service.

such a user-centred design, we obtain an ongoing people engagement in the long term. This engagement will promote more innovation, more profitability, time-saving, and build greater loyalty and credibility.

Bearing in mind the UAM's will of changing lives for the better through innovation in urban mobility towards sustainable mobility and smart cities implementing urban air mobility in cities worldwide, below, we propose a three-step roadmap with lean[21] practices for UAM integration in Lisbon:

1. People: Create a marketing plan [115] based on citizen perception:

   1.1 People's needs:

   - Time savings;
   - Contribute to less air pollution;
   - Enjoyment, sightseeing, and tourism;
   - Sending and buying merchandise.

   1.2 People's concerns:

   - Travel costs;
   - Safety and security concerns;
   - Noise pollution;
   - Environment concerns.

   1.3 Express empathy and authority by resonating UAM's will with people and sharing real data with them (e.g., UAM testimonials and statistics), respectively.

   1.4 Give them a plan of action [116]:

   - Inform: provision of information from stakeholders to people;
   - Involve: exchange of information between both parties;
   - Collaborate: exchange of information and consider it over the decision-making process.

[21] Lean refers to the set of management practices to improve efficiency and effectiveness by eliminating waste.

1.5 Call them for action.

1.6 Test this marketing plan and reflect on its successful and tragic results.

1.7 Identify, record, and share people's transformation (i.e., before and after visual illustrations to make daily and continuous improvements).

2. Process: Adapt and reinforce this marketing plan by interconnecting the three key areas of the living lab (see figure 17):

- Citizen perception;
- Urban environment;
- Government policy.

3. Product: Deploy and expand a vertiport network in Lisbon. Potential vertiports are no. 1 (Belém), 5 (Olivais), and 7 (Alvalade) – see table 4 from chapter 3.

UAM ecosystem depends on people, followed by the process, and finally by the product. This roadmap orientates the understanding of how to manage these three key elements efficiently and effectively.

The first and foremost UAM's key enabler is people. Curiously, people tend to buy the products/services that are easiest to understand. That is to say, by creating this marketing plan for UAM with a simple, clear, easy strategy, more customers will engage.

After managing people's needs and their internal and external concerns, the proposed plan of action thinks about how people feel about UAM and identifies with them, using empathy and authority. To win people over before they even experience UAM, we should think about how the experience looks, how it feels, how it makes people feel. With that said, this plan of action gives people a clear vision to solve their concerns through a three-step process for people engagement of informing, involving, and collaborating directly with the people. The UAM market must initiate this engagement early, exchange information in a continuous, understandable, and transparent way, prove to the people that their concerns and needs are being taken into account in the decision-making process, and ensure that the process is as inclusive and collaborative as possible [116].

The collaboration with communities should empower people by giving them the freedom to share their ideas (e.g., through working groups, public meetings, targeted meetings, mail-outs, print, broadcast, and so on). This means involving people directly in building together with our future. In truth, innovation is the result of cultural collaboration and sharing. Empathic communication is, therefore, an integral tool for UAM integration to support the people in overcoming their psychological hurdles and giving them a clear vision of UAM. Essentially, we must create environments to enable these physiological needs to flourish, while those same environments must expose freely real data for people to be part of the UAM ecosystem. Indeed, the opportunities in UAM will not be in creating new technologies themselves, whereas in the ecosystem they create. Instead of people competing with AI, they can focus instead on collaborating with, while improving it. Nonetheless, it might be helpful to resort to anthropology and digital anthropology[22].

Plus, armed with the latest information about UAM, people can make better decisions and come up with better solutions. Going a little further, we suggest moving from a data presentation position to predicting data (e.g., showing evolution in future milestones, such as in people's lives and the UAM market within one year, two years, five years, ten years, and so on.) In this context, empathic predictions that incentivize people to act now must be created (e.g., through modelling, simulation, and visualization technologies, to show people their direct upwards and downwards effects on themselves, their relatives, and other lives, including potential environmental impacts). Furthermore, people tend to desire interactive experiences (e.g., the Danish company “Lego Group” and the Swedish company “IKEA”), so we should do not forget to make UAM joyful, innovative, and engaging like an enrich and fulfilling on-hand eVTOL flight experience.

What each of us could do? Of course, it is not enough to give people a plan for UAM integration, we must inspire them by calling them to act on it and so contribute and be part of a larger cause than themselves (i.e., changing their and other lives for the better through innovation in urban mobility). Consequently, there are two potential outcomes from this marketing plan: benefit or adverse effects. These must be analysed for the sake of UAM’s continuous improvement and success.

The last point mentioned in step 1 of the roadmap proposed refers to getting an audio-visual record of people’s transformation. In other words, comparisons of before and after

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[22] Anthropology refers to the study of what makes us human (e.g., on the origin, development, and behaviour of humans). Digital anthropology refers to the anthropological study of the relationship between humans and digital-era technology.

the marketing plan testing, especially when helped people experience success, should be shown.

The second key is the process. It calls to adapt and reinforce the previous marketing plan by interconnecting the three key areas of the living lab. The urban environment concerns the demography and land use/zoning, weather conditions and birdlife, and existing transportation and accessibility. In particular, collaborating with urban planners might be helpful since they possess essential tools of form-based code, overlay zoning, and high limitations. Besides that, cooperating closely with non-governmental organizations (NGOs) and professional actors is also fundamental for the urban environment. For political hurdles, it is required to work with public authorities (e.g., political leaders, aviation regulators, ANSP, and respective support services). To facilitate this cooperation, this Dissertation has collected some stakeholders' prevailing worries about UAM which refer to the need for adaptation-related to airspace and ground integration and capacity, enabling technology, and real-time update and share of data. Anyway, breakthroughs in technology might help overcome some of these political hurdles, maximizing opportunities. To conclude, this living lab could be extended in future times.

The final key to focus on is the product itself which we move from a conceptual approach to a concrete one. Vertiports no. 1 (Belém), 5 (Olivais), and 7 (Alvalade), described in table 4 from chapter 3, are potential ones to deploy and expand a vertiport network in Lisbon.

4.4 Conclusion

In summary, chapter 4 incorporates all data analysis got from all survey respondents. Hereupon, a roadmap with good practices is proposed considering the key results.

From the implementation and analysis of the living lab in Lisbon, the key results obtained are:

- (Phase 1) People's main needs are reflected in saving time, contributing to less pollution, enjoyment, and sending and purchasing goods. Still, people's concerns are the cost of travel, security issues, and noise pollution. Essentially, we must promote networks of vertiports that allow people's physiological needs to flourish, and that people's concerns are considered in the decision-making process together with stakeholder requirements. Empathic communication is, therefore, an integral tool to bring UAM into our daily lives and our world. It was also found that the more knowledge people have regarding UAM, the greater the probability that they will accept and use eVTOL aircraft to commute. This finding reinforces the same conclusions got from other studies conducted around the world on social acceptance factors and, therefore, it is crucial to share information openly and constantly with every citizen). Furthermore, we confirmed that the potential places for the initial placement of vertiports can be in three regions of Lisbon: Belém, Olivais and Alvalade;

- (Phase 2) Stakeholders' requirements and expectations reside in the need for an adaptation of airspace and integration and ground capacity, technologies that enable UAM (e.g., biotechnology, artificial intelligence, blockchain, etc.) and an update and real-time data sharing (e.g., information technology, 5G technology, etc.). To minimize their concerns, it is suggested to maximize opportunities such as the opportunity to optimize the current airspace architecture such as improving its current operations; the opportunity for startups and organizations to develop innovative and sustainable ODM technologies; and the opportunity to increase labour supply in the area of maintenance, remote control, data analysis, and cybersecurity to accommodate UAS;
- (Connection between phases) Safety and sustainability are shared concerns in both phases. Shortly, the management of people and stakeholders' concerns related to vertiport networks implementation might address people and stakeholders' needs as by-products.

The key points mentioned above gave rise to the proposed guidelines for the implementation of a network of vertiports in the Portuguese capital. These guidelines based on real data and feedback aim to humanize the UAM technology, depending mainly on the people, followed by the process and finally the product and further explain how to manage these three key elements efficiently and effectively. These guidelines also suggest implementing a three-step plan of action for people engagement in the decision-making process. This plan of action consists of informing, involving, and collaborating directly with people, meaning empowering them directly in building the future of our world. Because innovation is born from the result of collaboration, sharing information, and exposing real data openly and constantly. Finally, this plan of action calls people for action!

Nonetheless, UAM represents one of the biggest challenges ever faced by the aviation industry. Therefore, this industry has a long and arduous path ahead of research and development (R&D) to find a dynamic balance among all actors and stakeholders involved and even ensure all necessary logistical and feasibility conditions to integrate UAM in every city in the world.

The next chapter encourages the implementation of these guidelines by revealing limitations encountered during the development of this Dissertation and meaningful prospects for future research to drive a positive and meaningful change in urban mobility.

Chapter 5

Conclusion

5.1 Introduction

Chapter 5 concludes this Dissertation by providing a synthesis of it, along with limitations found, prospects for further research within the UAM field, and final considerations in the conclusion section. Again, how to incorporate vertiport networks in cities worldwide using a user-centric design? Let us see next how simply and clearly.

5.2 Dissertation synthesis

The Dissertation is detached into five chapters: introduction, state of the art, case of study, results analysis, and conclusions.

The introduction (chapter 1) seeks to contextualize the reader with the investigation done. Here, we introduce the object in the study: urban mobility 3D. Plus, the four main objectives are also presented in this chapter. Fortunately, all objectives were achieved:

1. Understand how a vertiport network in cities could help to reverse the global issue of climate change and improve people's quality of life;
2. Identify the gaps, issues, and challenges associated with vertiports networks implementation in cities;
3. Determine possible and effective ways to make this implementation work, consistently considering public acceptance;
4. Provide guidelines based on real data and feedback for the integration of a vertiport network in Lisbon.

Overall, all chapters together have allowed us to strike objective no. 1. The state of the art (chapter 2) aims for objective no. 2. So, this chapter contains a review of relevant literature about urban mobility, UAM, and vertiport network. This chapter also compiles a SWOT and PESTLE analysis, functioning as filters to increase the awareness of what to expect to be encountered during the case of study. Here we clustered some of the mainly on the gaps, issues, and challenges concerning the employment of vertiports in cities.

Next, the case of study (chapter 3) deploys a conceptual vertiport network in Lisbon through a living lab composed of the citizen perception, urban environment, and government policy. In more detail, the scenario description describes the urban environment of Lisbon (e.g., demography, land use/zoning, weather conditions, birdlife, existing transportation, and accessibility). As well within the scenario description, we created the operation outline used over the scenario development. Regarding the scenario development, this is slipped into the social feasibility (i.e., phase 1) and the technical feasibility (i.e., phase 2) to complete objective no. 3. Phase 1 seeks to understand people's concerns and needs regarding vertiport networks. Phase 2 explores the logistics and feasibility for UAM integration in this urban area according to stakeholders' expectations and requirements. Related to phase 2, we start by defining five stakeholders involved in the decision-making process of urban mobility in Lisbon. In the second place, we identified the reason for their resistance through their expectations and requirements. Finally, we explored and discovered ways to minimize stakeholders' concerns and maximize opportunities. By after that, the results for both phases are obtained and presented in this chapter. In conclusion, the living lab employment was successfully achieved, even though having found some problems along the way.

The analysis of the results of the case study (chapter 4) wishes to attain objective no. 4 and incorporates all data analysis got from all survey respondents plus the main lessons learned from it. It reflects on the results obtained from both phases, specifically an individual analysis of both phases with regards to the UAM integration in Lisbon. With all this information gathered, a connection between both parties' insights is made. Therefore, this chapter proposes a three-step roadmap with lean practices for UAM integration in Lisbon considering the analysis of the key results. This roadmap includes a three-step plan of action for people engagement in the decision-making process, consisting in informing, involving, and collaborating directly with the people. By then, it calls people for action! To clarify, we have thrived to humanize UAM through this roadmap.

The conclusion (chapter 5) finishes this Dissertation by encouraging and supporting the implementation of the proposed roadmap by providing a synthesis of this Dissertation, along with limitations found, meaningful prospects for future research to drive a positive change in urban mobility, and final considerations in the conclusion section.

5.3 Limitations

All four goals were accomplished, though some hurdles were faced throughout the development of this Dissertation, whereas they have only slightly affected since we have still come by substantial outcomes. For instance, the Covid-19 pandemic swift the initial strategy to conduct phase 1 and phase 2 from chapter 3. Instead of face-to-face interviews to collect a wide scope of insights from citizens and stakeholders, these approaches were conducted virtually through internet-based communications. Luckily, we obtained sufficient and significant responses that enabled us to design simple guidelines.

Nonetheless, spreading survey no. 1 was the main force that pushed the number of responses to be below the ideal one. For the same population size of 926,000 individuals that live, work, and study within the city of Lisbon, by using a confidence level of 95 per cent and a margin of error of 5 per cent, the sample size is set to 385 survey responses and, as a result, more accurate and precise results might be obtained. It was also tough to receive feedback from more people above 65-years-old, having only collected one response from that age group. Concerning phase 2, on the other hand, it was unachievable to reach two out of five stakeholders whom insights are hefty for the decision-making process in urban mobility.

5.4 Prospects for future research

Further research would reinforce this Dissertation. Studying and performing the following suggested tasks might strengthen this Dissertation and contribute to breakthroughs in UAM:

- Facilities location problems (i.e., vertiports location analysis to seek for the optimal placement of these facilities to minimize transportation costs while considering factors like avoiding placing hazardous materials near housing, and competitors' facilities);
- The Free Zones for Technology (ZLT) - Framework for Regulatory Sandboxes [117];
- Enabling technology for vertiports;
- Vertiports design;
- Vertiports and Humberto Delgado Airport integration;
- Vertiport network's passenger flow and traffic prediction;

- Vertiport network impact and integration with Lisbon's transport network (see figure 39 from appendix 1);
- Vertiport network worthiness analysis (i.e., make parallelism of the ins and pos regarding eVTOL travel over car travel);
- Anthropology and digital anthropology;
- Data visualization tools (i.e., modelling, simulation, and visualization technologies);
- Environmental laws and regulations updating;
- Cost-benefit analysis (i.e., analyse the economic feasibility (see figure 31 from chapter 4));
- Risk management cycle assessment (see figure 32 from chapter 4);
- Life cycle assessment (see figure 33 from chapter 4);
- Extend the living lab implemented throughout this research.
- Physical infrastructure suitability assessment (i.e., the study of types of city infrastructures that need to be repurposed, renovated, or redeveloped to incorporate vertiports);
- Fuel capacities assessment (e.g., electricity generation, transmission, distribution, and storage).

5.5 Conclusion

Earlier in chapter 1, we have alerted that an innovative and rapid change in urban transportation needs to occur. Innovation in urban mobility could happen by integrating UAM in every city in the world. And, for example, by having all its operations propelled with zero-carbon energy just as cheap, reliable, and safe as what we get from fossil fuels [1], UAM might revolutionize transportation worldwide and prevent a climate catastrophe.

However, the best opportunities for innovation are not only in creating new technologies that enable UAM but also in the ecosystem they together produce: vertiport networks. Yet, UAM reveals a gap regarding the involvement of its technology with people, which interestingly represents the key to long-term success. In this way, by keeping people at the centre of UAM we would nurture world progress by changing the way we all travel in cities and be one step closer to driving a third global mobility revolution and a new world of accessibility.

For the sake of simplicity and clarity, to incorporate vertiport networks in cities worldwide using a user-centric design, it is necessary to cultivate and nurture global and national cooperation without neglecting people in the decision-making process. Because, in the end, urban mobility is all about people. Hence, people must be inspired by considering their needs and concerns in the decision-making process and then call them for action. However, we must take action now. Both sustainable mobility and smart cities start foremost with the daily habits of each of us. Likewise, since the climate change issue is a human issue, the most important solution consists of changing behaviours, and technology can strikingly help with that. Anyway, the integration of vertiport networks should be gradual since it will tremendously shake up people's life.

Indeed, UAM operations will definitely occur. It is now a matter of when they will occur. Even though this Dissertation privileges the European perspective for UAM, it is important to reinforce that both the European authorities and North-American ones are working together to make these operations a reality soon. For example, the EASA and the FAA are working on the horizon 2025 and horizon 2030 for the initial commercial operations with manned vehicles and operations with autonomous vehicles, respectively [118].

In conclusion, while it prioritizes the development of sustainable mobility and smart cities, this Dissertation envisions providing conditions and practical tools to promote change in lives for the better and reverse global climate change. Thus, this investigation has the power to support future advanced discussions to bring UAM to Portugal and to humanize UAM's technology in order to narrow the existent gap between the scientific community, public authorities, professional actors (i.e., the industry) and consumers (i.e., people).

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Annexe 1 – Urban Air Mobility

Figure 34 – Market map of UAM. Source: [30].

Appendix 1 – Scenario Description

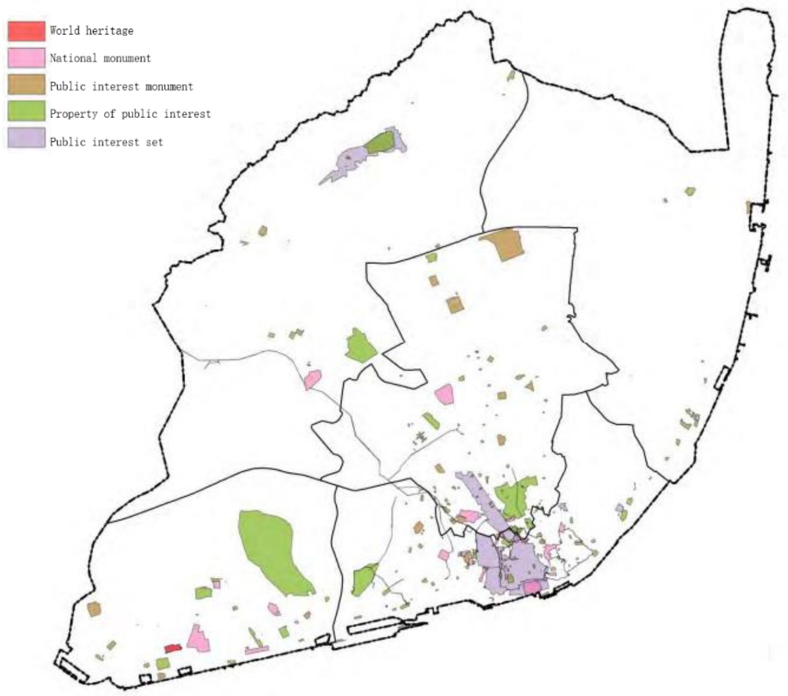
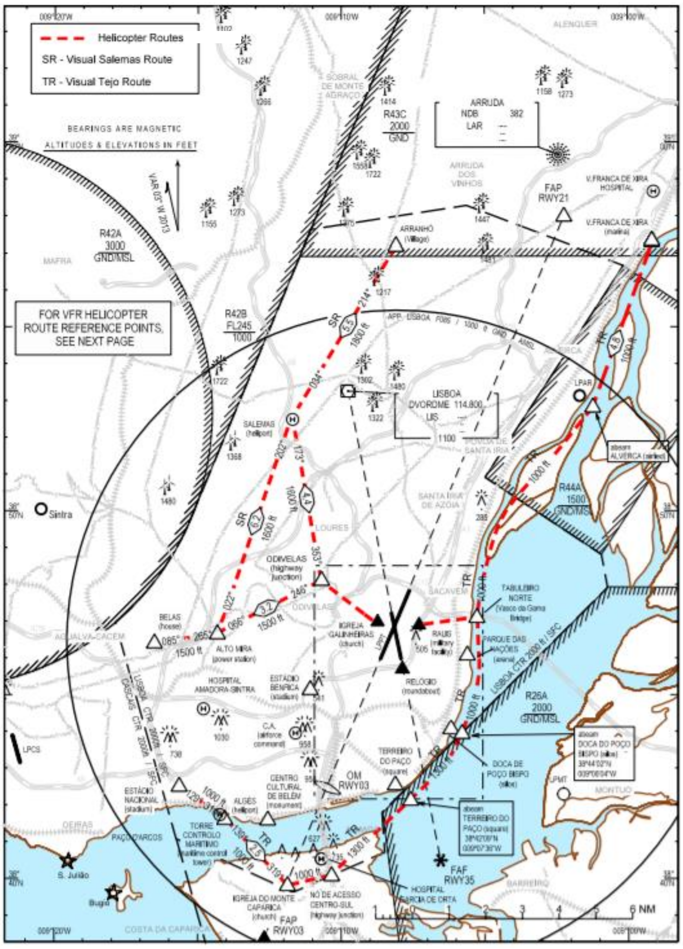


Figure 35 – Location of the key points of interest of the city of Lisbon. Source: [83].

Table 8 – Aerodromes and heliports in Lisbon Metropolitan Area. Source: Own elaboration based on [45][23].

Name	ICAO's location indicator	Type of infrastructure	Type of traffic permitted
		Aerodromes	
Santa Cruz	LPSC	National	VFR; Non-schedule; Private
Sintra	LPST	Military	N/A
Cascais	LPCS	National	IFR/VFR; Non-schedule; Private
Ota	LPOT	Military	N/A
Alverca	LPAR	Military	N/A
Lisbon	LPPT	International	IFR/VFR; Schedule; Non-schedule, Private
Montijo	LPMT	Military	N/A
		Heliports	
Torres Vedras	N/A	Other	VFR; Medical emergency
Mafra	LPMP	Other	VFR; Medical emergency; Firefighting
Amadora Hospital	LPAS	Other	VFR; Medical emergency
Carnaxide Hospital de Santa Cruz	LPFX	Other	VFR; Medical emergency
Alfragide	LPAF	Other	VFR; Non-schedule; Private
Cascais Hospital	LPHC	Other	VFR; Medical emergency
Algés	LPJB	Other	VFR; Non-schedule; Private
Almada Hospital	LPGO	Other	VFR; Medical emergency
Lisboa Hospital Santa Maria	LPSM	Other	VFR; Medical emergency
Salemas	LPSA	Other	VFR; Medical emergency; Private
Vila Franca de Xira Hospital	LPXR	Other	VFR; Medical emergency

[23] There is also a heliport at the top of Lisbon's Judiciary Police building in Arroios. However, for safety reasons (it is not certified since it does not meet requirements regarding fire-fighting means), we do not consider this heliport for the sake of this Dissertation.



VFR HELICOPTER ROUTE REFERENCE POINTS

Belas (house)	384625N0091631W
Alto Mira (powestation)	384640N0091419W
Salemas (heliport)	385230N0091142W
Arranhó(village)	385712N0090806W
Vila Franca de Xira (marina)	385719N0085909W
Abeam Alverca (airfield)	385248N0090114W
Tabuleiro (Vasco da Gama bridge)	384707N0090517W
Odivelas (highway junction)	384807N0091042W
Igreja das Galinheiras (church)	384700N0090836W
RALIS (military facility)	384659N0090713W
Abeam Doca do Poço Bispo (silos)	384402N0090604W
Abeam Terreiro do Paço (square)	384209N0090736W
NóAcesso CentroSul (highway junction)	384005N0091021W
Igreja do Monte da Caparica (church)	383950N0091153W
Torre de Controlo Marítimo	384137N0091404W
Estádio Nacional (stadium)	384232N0091539W
Hospital de Vila Franca de Xira	385840N0085906W
Parque das Nações (MEO Arena)	384606N0090538W
Terreiro do Paço (Square)	384229N0090812W
Estádio do Sporting (Stadium)	384540N0090938W
Estádio do Benfica (Statium)	384510N0091105W
Praça Marquês de Pombal	384331N0090900W
Centro Cultural de Belém	384144N0091228W
Túnel do Grilo	384811N0090832W
Doca do Poço Bispo (silos)	384404N0090611W
NóAcesso Ponte Vasco da Gama	384726N0090652W

Figure 36 – VFR helicopter routes in Humberto Delgado Airport CTR and respective reference points. Source: [45].

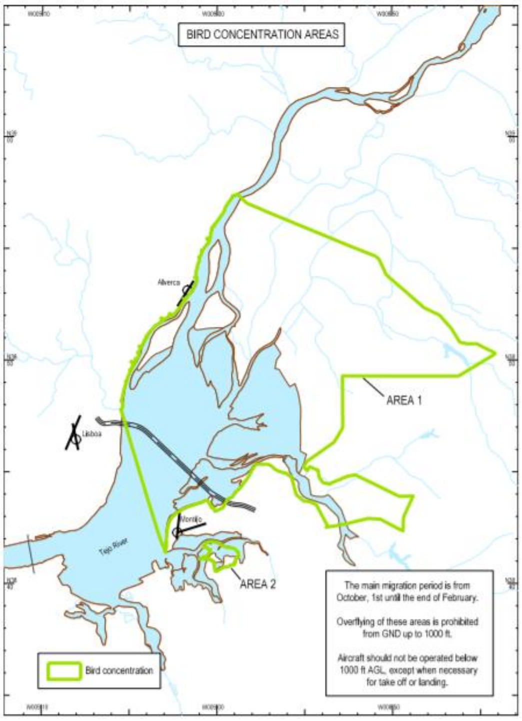


Figure 37 – Bird migration and areas with sensitive fauna. Source: [45].

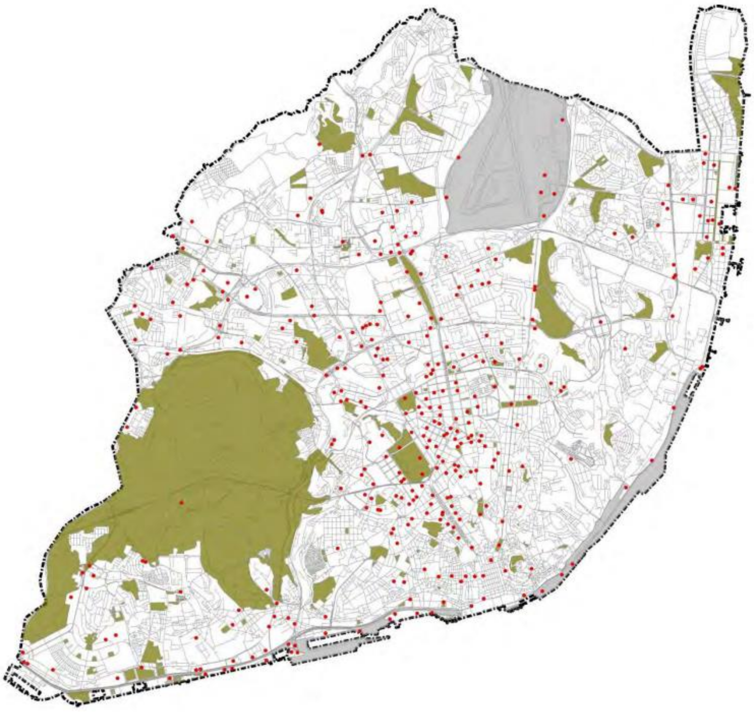


Figure 38 – Location of public access car parks. Source: [83].

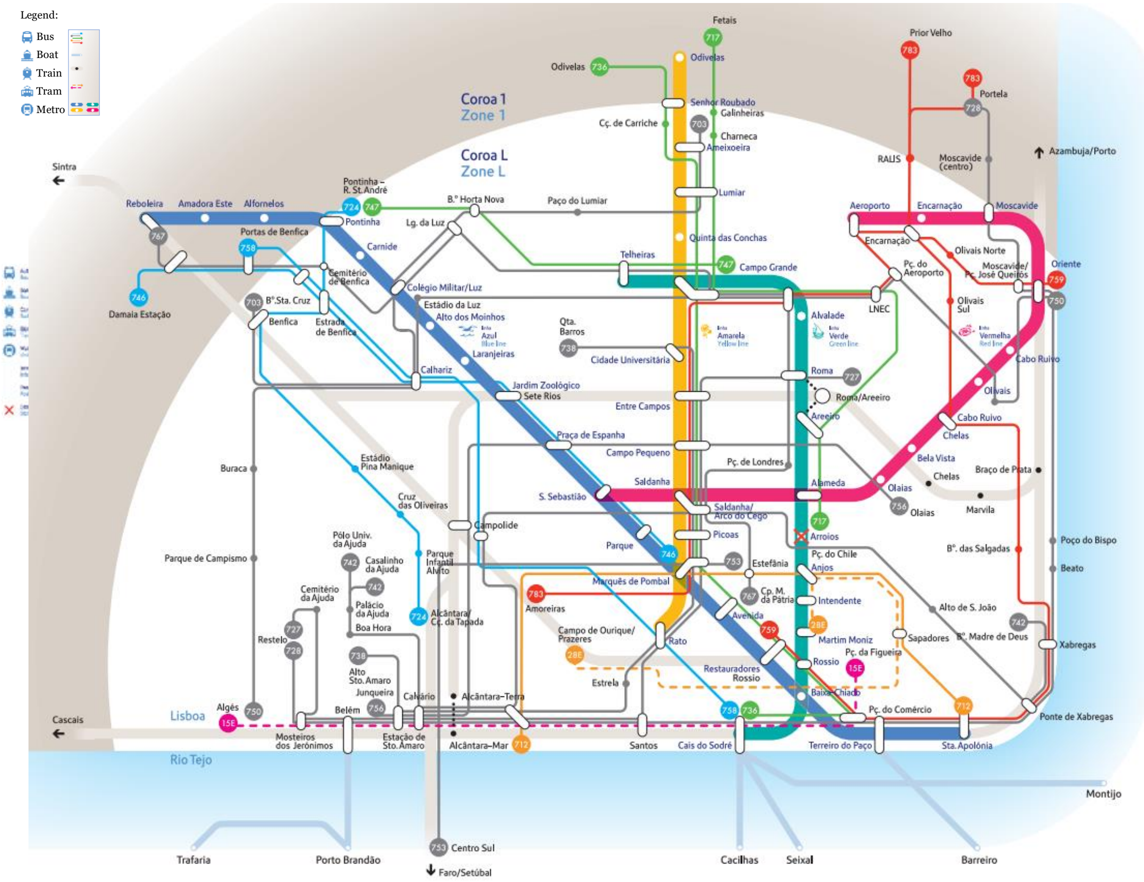
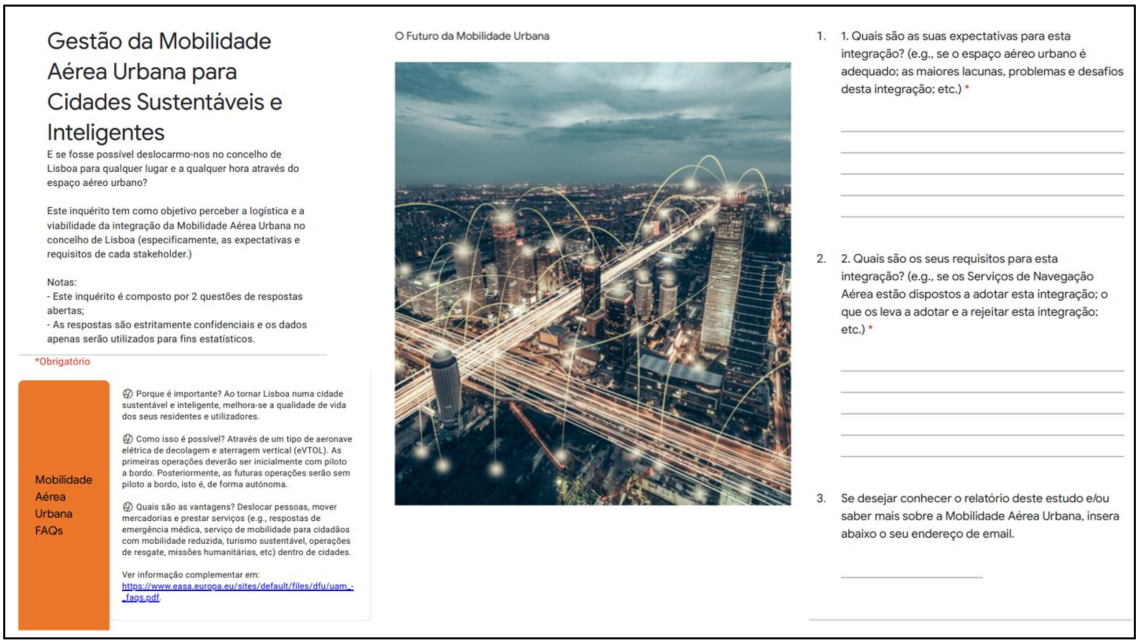


Figure 39 – Transport network diagram of the city of Lisbon. Source: [95].

Appendix 2 – Electronic Surveys

Figure 40 – Electronic survey no. 1. Source: [100].


Gestão da Mobilidade Aérea Urbana para Cidades Sustentáveis e Inteligentes

E se fosse possível deslocarmo-nos no concelho de Lisboa para qualquer lugar e a qualquer hora através do espaço aéreo urbano?

Este inquérito tem como objetivo perceber a logística e a viabilidade da integração da Mobilidade Aérea Urbana no concelho de Lisboa (especificamente, as expectativas e requisitos de cada stakeholder.)

Notas:
- Este inquérito é composto por 2 questões de respostas abertas;
- As respostas são estritamente confidenciais e os dados apenas serão utilizados para fins estatísticos.

*Obrigatório

Mobilidade Aérea Urbana FAQs

Porque é importante? Ao tornar Lisboa numa cidade sustentável e inteligente, melhora-se a qualidade de vida dos seus residentes e utilizadores.

Como isso é possível? Através de um tipo de aeronave elétrica de decolagem e aterragem vertical (eVTOL). As primeiras operações deverão ser inicialmente com piloto a bordo. Posteriormente, as futuras operações serão sem piloto a bordo, isto é, de forma autónoma.

Quais são as vantagens? Deslocar pessoas, mover mercadorias e prestar serviços (e.g., respostas de emergência médica, serviço de mobilidade para cidadãos com mobilidade reduzida, turismo sustentável, operações de resgate, missões humanitárias, etc) dentro de cidades.

Ver informação complementar em: https://www.easa.europa.eu/sites/default/files/dfu/uam_-_faqs.pdf.

O Futuro da Mobilidade Urbana

1. 1. Quais são as suas expectativas para esta integração? (e.g., se o espaço aéreo urbano é adequado; as maiores lacunas, problemas e desafios desta integração; etc.) *

2. 2. Quais são os seus requisitos para esta integração? (e.g., se os Serviços de Navegação Aérea estão dispostos a adotar esta integração; o que os leva a adotar e a rejeitar esta integração; etc.) *

3. Se desejar conhecer o relatório deste estudo e/ou saber mais sobre a Mobilidade Aérea Urbana, insera abaixo o seu endereço de email.

Figure 41 – Stakeholder's electronic survey sample. Source: [107][24].

[24] For the sake of simplicity, we only showcase one of the stakeholders' electronic surveys since the other ones are similar, differing on the name of the stakeholder for whom the survey concerns. The others can be consulted virtually in [108], [109], [110], and [111].

Appendix 3 – Articles Submitted

a) Article submitted to the Journal of Airline and Airport Management (JAIRM)

MANAGEMENT OF URBAN AIR MOBILITY FOR SUSTAINABLE AND SMART CITIES: VERTIPORT NETWORKS USING A USER-CENTRED DESIGN

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Purpose: Urban mobility is all about people as well as the climate change issue is a human issue. Thus, this research envisions to provide conditions and practical tools through the innovation in urban mobility by bringing urban air mobility (UAM) to cities worldwide, contributing to change lives for the better and reversing the global issue of climate change.
Design/methodology/approach: This study goes through two phases: social feasibility and technical feasibility. Moreover, it incorporates a user-centred design based on the systematic engagement of people in the decision-making process alongside a parallel interaction with several stakeholders. An innovative roadmap based on real data and feedback is obtained to implement a vertiport network in Lisbon, Portugal.
Findings: By tackling people and stakeholders' concerns related to vertiport networks implementation (e.g., safety, security, environmental, travel costs, and noise pollution concerns), the people's needs (e.g., time savings, contribution to less air pollution, enjoyment, and sending and purchasing merchandise) and stakeholders' needs (e.g., adaptation related to airspace and ground integration and capacity, enabling technology, and real-time update and share of data) might be addressed, as by-products. Plus, we could minimize concerns by maximizing opportunities, like optimizing the airspace architecture and enhancing current airspace operations, a chance for businesses to develop on-demand, innovative, and green technologies, and higher employment opportunities. Finally, we have discovered that driving positive global change requires inspiring others by addressing people's needs and concerns and, by then, calling them to action.
Originality/value: UAM's market reveals a gap in engaging this technology with the people, which is the key enabler to success in the long run. Empathic communication is, therefore, an integral tool to bring urban air mobility to our lives and our world. So, this investigation thrives on humanizing technology to narrow the gap between the science community, public authorities, the industry, and consumers.
Keywords: Urban Mobility; Urban Air Mobility (UAM); Vertiport Network; Sustainable Mobility; Smart Cities.

b) Article submitted to the *Revista Portuguesa de Estudos Regionais* (RPER)

URBAN AIR MOBILITY FOR SUSTAINABLE AND SMART PORTUGUESE CITIES: A LIVING LAB IN LISBON

MOBILIDADE AÉREA URBANA PARA CIDADES PORTUGUESAS SUSTENTÁVEIS E INTELIGENTES: UM *LIVING LAB* EM LISBOA

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ABSTRACT/RESUMO

This article focuses on urban mobility three-dimensional, aiming to provide conditions and practical tools to improve lives and reverse climate change through the innovation of urban mobility by implementing a living lab in Lisbon, Portugal. As urban mobility is about people, like climate change issue is a human issue, urban air mobility's technology humanization is the key to obtaining success in the long run. As a result of the ongoing engagement of Portuguese citizens alongside interaction with stakeholders, guidelines are provided to bring urban air mobility to the city of Lisbon. These guidelines could backbone future advanced discussions and narrow the gap between the science community, public authorities, professional actors (i.e., the industry), and consumers (i.e., people).

Keywords: Urban Air Mobility; Urban Mobility; Accessibility; Sustainable Mobility; Smart Cities.

JEL codes: L93, O18, Q01, Q55, Q56, R4.

Este artigo foca-se na mobilidade urbana tridimensional, com o objectivo de fornecer condições e ferramentas práticas para melhorar a qualidade de vidas e reverter as alterações climáticas através da inovação da mobilidade urbana implementando um *living lab* em Lisboa, Portugal. Como a mobilidade urbana diz respeito às pessoas, assim como a questão das alterações climáticas é uma questão humana, a humanização da tecnologia da mobilidade aérea urbana é a chave para obter sucesso a longo prazo. Como resultado do envolvimento contínuo dos cidadãos portugueses a par da interacção com *stakeholders*, são providenciadas directrizes de modo a trazer a mobilidade aérea urbana para a cidade de Lisboa. Estas directrizes poderão apoiar futuras discussões avançadas e reduzir a lacuna entre a comunidade científica, autoridades públicas, atores profissionais (ou seja, a indústria) e os consumidores (ou seja, as pessoas).

Palavras-chave: Mobilidade Aérea Urbana; Mobilidade Urbana; Acessibilidade; Mobilidade Sustentável; Cidades inteligentes.

Código JEL: L93, O18, Q01, Q55, Q56, R4.

c) Article submitted to the Journal of Air Transport Management (JATM)

Management and Logistics of Urban Air Mobility Ecosystem Towards Sustainable Air Transport: How a Customer-Focused Network Will Drive World Progress?

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Abstract

This article focuses on urban air mobility (UAM). Whilst prioritizing the expansion of sustainable and autonomous air transport industry across the globe, this investigation strives to provide conditions and practical tools to promote change in people's lives for the better and reverse global climate change. Thus, a conceptual approach is used to analyse the logistics and feasibility of a UAM ecosystem in Lisbon, Portugal, as the national scenario of operation, by incorporating a customer-focused network based on the ongoing engagement of citizens in the decision-making process alongside a parallel interaction with key stakeholders. The results obtained from this analysis will illuminate the path to develop a UAM ecosystem successfully, consistently considering people's needs and concerns and the stakeholders' expectations and requirements for this integration, by exploring ways to mitigate concerns and maximize opportunities. As a result, a three-step roadmap with lean practices is proposed for the management of the UAM ecosystem using a customer-focused network concept in cities worldwide. This ecosystem depends foremost on people, followed by the process and finally, by the product, and so, this roadmap orientates how to manage these three key elements efficiently and effectively. To drive positive and meaningful global change in urban transportation through UAM, we must inspire people by considering their needs and concerns and then call them to act now. Because, in the end, sustainable air transportation starts foremost with the daily habits of each of us. Ultimately, this study has the virtue of supporting future advanced discussions to bring UAM worldwide and humanizing UAM's technology to reduce the existent gap between the scientific community, public authorities, professional actors, and consumers.

Article Info

keywords:

Urban Air Mobility
Urban Air Traffic Management
Air Traffic Management
Sustainable Air Transport
Community Engagement Policy