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On the understanding of the current status of urban air mobility development and its future prospects: Commuting in a flying vehicle as a new paradigm

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ABSTRACT

Urban Air Mobility (UAM) has the potential to disrupt air transportation, providing disruptive innovation not only to aviation but also to mobility systems and urban planning. Underpinned by technological advances in batteries, as well as in electric and distributed propulsion that facilitate the design of novel aircraft types with the capability for Vertical Take-off and Landing (VTOL), the UAM is attracting the attention of an extensive list of stakeholders, institutions and companies. It also covers a broad range of different areas of interest that have to be considered by a holistic and multidisciplinary approach in order to derive its full potential. This paper aims to provide an in-depth qualitative analysis of relevant aspects of UAM development and implementation. The added value of this paper is in assessing the current status and prospects of the most important UAM areas by analysing them from the literature and practice point of views. The paper also deals with the main challenges and multidisciplinary constraints that might slow down the pace towards the successful application of the subject concept.

1. Introduction

1.1. Motivation

Due to the rapid urbanisation, more than 70% of the European population and more than 80% of the North American population could live in urban areas by 2050, being nearly 80% of the inhabitants of the more developed areas (United Nations, 2018). As a consequence of such tremendous growth, the large cities around the globe are persistently facing growing mobility and infrastructure problems. Moreover, the urbanisation causes congestion, pollution and conflict (Turok, 2017) exerting a damaging impact on the health of the people and the environment. However, it also entails costs, notably in congestion accounting for 130 billion euros per year in Europe only, according to the European Institute of Innovation and Technology (EIT Urban mobility, 2021). For instance, large metropolises such as New York, London, Paris and Tokyo already reported a significant economic loss with the excess fuel and vehicle operating cost (Downs, 2005; Schaller, 2010; Ikeuchi et al., 2019). However, one must consider not only the economic cost (including the cost of time) of traffic jam but also the environmental cost in regards to pollution (Kelly and Fussell, 2015).

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Therefore, there is a need to explore new mobility concepts and paradigm in order to shorten commute times, bypass ground congestion, and enable point-to-point flights across cities (Kelly and Fussell, 2015). Urban Air Mobility (UAM) has the potential to disrupt air transportation, providing disruptive innovation not only to aviation but also to mobility systems and urban planning, The concept is underpinned by technological advances in batteries, as well as in electric and distributed propulsion that facilitate the design of novel aircraft types with the capability for Vertical Take-off and Landing (VTOL), very often referred as Personal Air Vehicle (PAV). Many companies such as AIRBUS, LILIUM, and KITTY HAWK compete with each other to advance VTOL technologies and prototypes and mass-produce the generation of VTOL vehicles that will leverage the development of air taxi service. In addition, the companies as ZEPHYR Airworks, AIRBUS, and VOLOCOPTER GmbH already conducted extensive test flights with their Electrical Vertical Take-off and Landing (eVTOL) demonstrators (namely Cora, Airbus-Vahana and Volocopter 2x) in several countries across the world, such as the USA, Japan, Singapore, New Zealand, France, and India (Rajendran and Zack, 2019).

UAM is anticipated to have huge potential to change the market rules, although there are still several challenges and multidisciplinary constraints that might slow down the pace towards successful application. While technology enablers are already available, or it is expected to be available soon, the social acceptance, costs, and other drawbacks have to be carefully analysed and properly solved to succeed. In addition to social acceptability and technological barriers, there are a number of other important issues that make the feasibility of this concept complex and questionable. Some of the most important are environmental sustainability, regulatory constraints, insurance and liability appointments, operational safety, affordability, and changes in movement and urbanisation patterns (Cohen, 2009).

Also, in the context of urban mobility actions and multi-modal strategies, it should be considered a particular or complete level of integration of this emerging transportation modality with other existing transportation options. With its innovative business models, UAM may be a suitable solution for high-speed mobility and user-oriented services.

This research aims to provide an in-depth qualitative analysis of the relevant aspects of UAM development and implementation. Although there are several overview papers dealing with the UAM concept (Straubinger et al., 2020a; Rajendran and Srinivas, 2020; Cohen et al., 2021; Garrow et al., 2021), the added value of this paper is assessing the current status and prospects of the most important UAM components by analysing them from the literature and practice point of views. The paper is more than a merely literature review and case study register since it scrutinises the most valuable sources and gives a detailed analysis of the most important areas of UAM development.

In order to gather as much information as possible, the body of knowledge that we used in our UAM research procedure consisted of scholarly articles, project reports and policy documents. One line of the exploration is from internet searching, where information about prototypes, demonstrations and current experiments in the field of urban air mobility can be found. In order to explore relevant scientific papers, various valid academic databases were exploited (e.g. EBSCO, ScienceDirect, Web of Science, Scopus, IEEE Xplore, Google Scholar). The following list of keywords, among the most relevant ones, and their combination and acronyms, were used: *"urban air mobility", "advanced air mobility", "on-demand aviation", "on-demand services", "electrical vertical take-off and landing vehicles", "infrastructure", "air traffic management", "passenger transportation", "societal issues", "Concept of Operations", "ConOps", "Drone Communications", "RPAS integration"*, as the most relevant. After a detailed review of search results, we were able to identify hot topics in the UAM field, set up primary research areas and categorised collected sources. In total, more than 170 different sources, searched from autumn 2020 and updated in April 2022 have been included in the analysis.

1.2. UAM - conceptual definition

UAM covers a broad range of different areas of interest that have to be considered by a holistic and multidisciplinary approach in order to derive its full potential. With UAM being a relatively novel and emerging topic, there are still a large amount of uncertainties and undefined items that have to be properly addressed. One of the first items worth mentioning is the fact that UAM term may equally refer to several different fields such as the application of drone (also referred as Remote Piloted Air Systems (RPAS)) technology into urban last-mile logistics and the future passenger transport in an intra-urban and inter-urban environment. While this paper mainly deals with passenger transport applications, the close relationship between the two concepts will be maintained as many disruptive technologies that will be initially developed for small RPAS may be later applied to larger devices and vehicles. Substantial progress has already been performed towards defining how future UAM operations could look like. UBER Elevate document (Holden and Goel, 2016) proposes the concept for air taxi services by analysing the feasibility of using eVTOL vehicles, the economics of the air taxi market, and the ground infrastructure (e.g., vertiports, charging systems) required for air taxi operation. It also provides a detailed discussion on airspace integration challenges for UAM like sequencing and scheduling aircraft into/out of vertiports and inter-operability between vehicles. In contrast to UBER Elevate white paper that focuses only on air-taxi services and operations, NASA document (Thipphavong et al., 2018) sheds light on other operational concepts by considering the broader range of missions, aircraft types, airspace, and hazards as important aspects that need to be taken into account and balanced. The paper presents a high-level description of concepts at two different stages of operational maturity, which is aimed to establish the starting point for a new UAM framework. The first concept assumes low-density operations with a low frequency similar to Visual Flight Rules (VFR) flights, along with a small set of fixed routes between a few take-off and landing areas. The latter is envisioned for higher-density operations with high frequency in a small network of vertiports feeding a common hub location and managed by UAM operator and third-party services. Being well aligned to what UBER Elevate proposed, Airbus Blueprint (Balakrishnan et al., 2018) provides a detailed road-map for the safe integration of autonomous aircraft. It underlines the importance of four different pillars that will underpin the operational concept, namely stakeholder roles, air traffic configuration, regulations, and system architecture.

Fig. 1. Progress estimation for areas and elements relevant for UAM.

The review of the previously mentioned documents could be leveraged to determine the main implementation and operational challenges in the UAM domain, as depicted in Fig. 1. The present paper analyses some key items to better understand the current status of UAM and to potentially anticipate its future development and implementation. The list of the selected items that will be further assessed in this paper is split into five areas of interests, namely technology, infrastructure, services, societal consideration and policies (see Fig. 1) by relying on the main concepts and ideas found in the relevant sources discussed above. The list is non-exhaustive on purpose as the scope of the paper is far from providing a comprehensive overview of all elements but rather gives a thorough assessment of the most critical areas and items already acknowledged in the relevant literature. A rough estimation of the progress of different elements within each of the five areas is provided in the time-frame spanning from 2020 to 2050. It has to be emphasised that the timeline projections are not rigid in time, but rather present an initial approximation based on the information found in the academic publications and industrial reports, but also on the authors' own educated assumptions and interpretation.

As observed, some of the technologies, services or other items analysed in this paper have already fulfilled high maturity criteria, but they need further development in order to meet the specific aeronautical requirements on safety, security, robustness levels or certification. In any case, one can easily identify huge differences in the progress among the elements on the list. Understanding these differences and the relationships between elements is paramount for assessing the current UAM status and its future evolution. From the perspective of the widely adopted Technology Readiness Level (TRL) framework (Olechowski et al., 2015), one can observe a clear distinction between given technologies with respect to their aeronautical and non-aeronautical implementation varying from TRL3 or TRL4 to TRL7 to TRL8 respectively. In addition to the TRL framework, the NASA UAM Coordination and Assessment Team

(UCAT) recently developed a framework called UAM Maturity Level (UML). This scale is designed to reflect the evolution of a UAM transportation system, from the current state of the art to a highly developed, future state (Goodrich and Theodore, 2021). The UML scale consists of six levels being differentiated by a combination of three primary attributes: traffic density, operational complexity, and reliance on automation. Therefore, UML scale is focused on the maturity assessment of a UAM system as a whole, rather than on the assessment of its individual system elements. With the exception of UML1, the UML2 to UML6 levels represent operationally deployed capabilities and from the perspective of the TRL scale, have a TRL9. Bearing in mind that UML1 precedes a commercial operating capability it is the only maturity level with a corresponding TRL less than 9. In this regard, UML1 or UML2 could be applied to almost all technologies considered in Fig. 1. On the other hand, despite the fact that 5G and automation-related technologies may have sufficiently enough potentials to reach UML3 or UML4 due to the technology enabling swarm flight of drones, they still need to be considered in the broader context underpinned by the UML framework.

- **Technology:** The technology stands as the most important pillar that underpins the UAM concept. In particular, substantial technological progress, especially regarding propulsion systems and battery storage (Kuhn et al., 2011; Rezende et al.), have resulted in a large number of flying vehicle designs and prototypes for personal air transport. In addition to advances in the propulsion systems, the evolution of autonomous capabilities of the vehicles will also take place as a mid- to long-term concept capitalising on a strong commonality with the constituent technologies developed for automobiles. The paper will discuss the foreseen progress of the propulsion systems, as well as potential advances in the vehicle design that are likely to occur in the near to mid future. Section 2 provides details about the selected technologies while Section 8 discusses the most recent industrial innovations.
- **Infrastructure:** The establishment of operational infrastructure is an essential prerequisite for successful UAM development. The primary physical infrastructures for UAM operations are vertistops and vertiports that have a relatively small footprint and thus lower capital expenditure compared to ground-based transportation. To capture the transportation benefits of UAM and enable high levels of autonomy, the technical requirements and infrastructure for communication, navigation and surveillance (CNS) must be also researched and developed. In addition to locating and constructing vertiports and vertistops, the seamless UAM operations will also require network design containing a route structure for VTOLs from any origin location to any destination location to facilitate integration with the existing ATM. Section 3 describes different available Concept of Operations that relates operational and technical requirements for successful UAM. Section 4 provides insight into ground infrastructure, mainly focusing on the location, design and size of vertiports.
- **Services:** The UAM is expected to provide a plethora of opportunities in the context of new urban mobility concepts. High luxury UAM service has been already offered in the form of helicopter-based passenger service in a large number of cities. The introduction of VTOLs may replace the helicopters and potentially open up the possibility for the connections that were not viable in the past due to various barriers (e.g. cost, vehicle range, obstacles, terrain, etc.). Specifically, the UAM is foreseen to provide affordable on-demand aerial mobility (ODM) for everyone in the broader context of the expansion of the sharing economy in the mobility sector. Finally, the incorporation of other inter-modal transportation with aerial ODM could be seen as an ultimate phase within the emerging concept of Mobility as a Service (MaaS) that combines different transportation options to offer a seamless travel. The detailed discussion on the user-oriented UAM services will be given in Section 4.2 to shed some light on the role of UAM in the context of the sharing mobility. In addition, an overview of the potential business models that can be deployed to foster the development of different types of UAM services will be covered in Section 7.
- **Societal consideration:** The public acceptance appears to be a crucial factor in widespread adoption of VTOL and UAM. The emergence of drone technology and its growing use has already triggered a number of concerns that can be applicable to VTOL operations. Among first, safety has traditionally been a factor of primary concern that has to be ensured continuously. In addition to safety issues raised by the application of novel technology, UAM will also create some additional externalities, such as noise and visual disruption due to the expected activities in the lower level airspace. The operation of VTOLs may affect the privacy that becomes more relevant when VTOL is in the phase of descending or climbing in the vicinity of private property. Most of these aspects will be thoroughly discussed in Section 5.
- **Regulation:** As observed from Fig. 1, the regulation definition is a transversal activity that needs to be performed in a continuous and progressive manner in order to ensure safe UAM operations. The compliance with the regulations imposed by aviation authorities, namely - US Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA), will be mandatory for all market actors. With this regard, the certification process of the new VTOL vehicles will be of crucial importance for a prompt UAM introduction, since the certification of the new aircraft concepts has historically been a very slow process. As seen in Fig. 1, EASA has recently made a substantial progress in the certification of small VTOL vehicles, and a similar process for larger vehicles is anticipated to occur in the near future. This topic will be explored in-depth in Section 6.

As in any transport system, the level of service offered to the customers in the UAM will greatly depend on the progress of other system components. Fig. 2 provides a diagrammatic representation of the relationship between the service, as a core element of the system, and other relevant items. Technology covers a myriad of elements connecting new vehicle designs and propulsion systems with new power sources and alternative fuel. One should also bear in mind that the progress of autonomous vehicles will require further advancements in the area of communication technologies and in particular, the 5G network deployment. Provision of infrastructure is tightly related to the vertiports and ground infrastructure that needs to be further developed in order to accommodate new vehicle designs, which in turn, will have a high impact on the type of service provided to the passengers. However, the UAM system is broader than just physical infrastructure and vehicles. It also includes a variety of policies and institutional

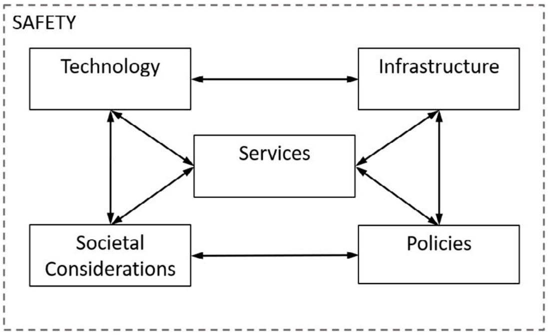

Fig. 2. Inter-relationship of UAM-related items.

settings that underpin the coordination of UAM services. As a new paradigm, successful UAM introduction will need to ensure public acceptance and user adoption which presents a main hurdle identified in the relevant literature. Finally, all mentioned components need to support the service to the passengers, as a core idea surrounding the UAM, while safety is considered as some of the most important operational characteristics of contemporary civil aviation.

The paper contains 9 sections, each of them describing a relevant aspect affecting the implementation of UAM. Technological aspects are described in Section 2, the operational ones in Section 3, the urban mobility framework in Section 4, the societal aspects, including modal choice and acceptance, in Section 5, the legal and regulatory aspects in Section 6, the business models in Section 7 and the industrial framework in Section 8. The final section, Section 9, exposes the main challenges and conclusions.

2. Enabling technologies

The list of technologies directly or indirectly related to the development and implementation of UAM is a long one. Some of them are already present in the aeronautical and Unmanned Aircraft Systems (UAS) fields, but in any case, they need to be adapted and matured to fulfil UAM requirements. Some previous reviews on UAM already listed the items to be considered. As already mentioned, UBER company, in its Elevate document (Holden and Goel, 2016) state that batteries, vehicle design and performance, and air traffic control are the key high-level technologies to assess. It also mentions other items that we can relate to the previous ones, namely noise and emissions, efficiency, reliability and safety. AIRBUS, in its document "Blueprint for the sky" (Balakrishnan et al., 2018), states that automation, communications and Air Traffic Control (ATC) are key elements to progress on the implementation of UAM. BOEING, in its Future of Mobility White Paper (BOEING, 2018) also identifies ATC, communications, autonomous vehicles and vehicle performances as key topics. DLR, the German Aerospace Centre, has focused on the U-Space and air traffic control issue (DLR, 2017).

Kellermann et al. (2020) provide an extensive review of publications about UAS (Drones), focusing on freight and passengers transport. Courtin et al. (2018) provide a summary of the enabling technologies, mentioning Short Take-off and Landing (STOL) capabilities, distributed electric propulsion, electric motors, flight controls, blown lift (aerodynamics of the wing), and batteries. Among the items the authors analysed, there is a reference to the technical barriers. The most relevant group is related to technical aspects, and more precisely about the autonomous flight, airspace integration, electrical batteries and communications. The study analysed 111 relevant publications, mainly from academic authors. It complements the industry point of view expressed in the above-mentioned (Holden and Goel, 2016; Balakrishnan et al., 2018; BOEING, 2018).

Taking into consideration the above references, a shortlist of technologies have been selected, which will be described in the current section. They have been considered to be high-level technologies that are directly related to the future daily operations of the UAM vehicles. The reference to UAS, understanding them as Remote Piloted Air Systems (RPAS) or drones, will always be present in this description. Early adoption of the technologies described here will enable the UAS operations, and will help to mature them till the required safety, robustness and acceptance levels for passenger transport operations. The list is as follows:

- Vehicle configuration
- Propulsion system
- Batteries and hydrogen power source
- Autonomous vehicles
- Communications and navigation
- UTM and ATM

2.1. Vehicle configuration and VTOL vehicle

In addition to a list of companies and their prototypes, Vascik (2017) also provides the relevant information on the historical background of ODM air transport. It started in the 1960s and 1970s with relevant research (see also the report by MIT and NASA

MIT, 1970), and in 1953 with the first commercial air transportation company. It used helicopters in Los Angeles, San Francisco, New York and Chicago (USA). Gupta et al. (2013) attempt to provide an outlook of the different types of vehicles that could potentially operate in the UAM environment together with their potential categorisation. Ren et al. (2017) provide more relevant information; since the authors focus on civil UAS and their categorisation with regards to the operation at low-altitude airspace and UTM.

Vertical Take-off and Landing vehicles are the most relevant ones when describing the implementation of UAM services (Holden and Goel, 2016; BOEING, 2018; Balakrishnan et al., 2018). The helicopter can be considered the precursor of such vehicles, which will show different configurations, but having the VTOL capability as the point in common. Caprì et al. (2009) describe an analysis of a network of Take-off and Landing Area (TOLA) for the use of emergency helicopters. The research interest is the fact that they assess the design requirements for TOLA and vertiports when considering VTOL vehicles. STOL vehicles are also considered as an option, so it is interesting to check out (Courtin et al., 2018), who propose a trade-off analysis to identify the balance between runway length and vehicle performances. The description of the aerodynamics effects due to the distributed propulsion is relevant for the STOL capabilities. It is something to consider when designing not only STOL but also VTOL vehicles. Pradeep and Wei (2019) and Kleinbekman et al. (2018) propose the analysis of VTOL vehicles regarding the arrival concept of operations. Both papers deal with energy efficiency when considering several arrival strategies for a multi-rotor VTOL vehicle. The combination of modelling, aircraft capacities and arrival concepts of operations for VTOL vehicles is interesting from the point of view of creating links between all these items. Related to the Concept of Operations (ConOps), the optimisation of air operations is relevant for the safe operation of VTOL or STOL vehicles in urban areas (like Pradeep and Wei, 2018 analyse in the case of VTOL vehicles).

Polaczyk et al. (2019) provide an interesting summary of current technologies and developments on Electrical Vertical Take-off and Landing (eVTOL) vehicles. It lists the published performance figures of the vehicles while describing future challenges. The performance, as the characteristics, lists are not complete since a lot of the mentioned vehicles are under development. Electrical vehicles are well represented, showing different propulsion systems. Brelje and Martins (2019) focus on design issues. The paper provides an in-depth review of electrical batteries and propulsion, and their effects on vehicle design. The scope of the paper includes several types of vehicles, which is relevant for future UAM since the vehicle configuration is still under discussion. Ren et al. (2017) discuss the categorisation of UAS. The proposed categorisation also considers the mission purpose as a key parameter. The description scope is broad enough to be helpful when increasing the size of the vehicle, as it could happen when moving from current UAS to future passenger vehicles. Gupta et al. (2013) focus on UAS military-oriented applications and vehicles. Although from the point of view of the civil UAS, the description could not be so helpful since the broad spectrum of sizes in the military UAS is not reproduced (still) into the civil vehicles. Nevertheless, it should be considered when passenger vehicles will enter operation. Some of the systems described in this paper, like fault monitoring, are just recently available in civil vehicles but should be matured when moving into passenger transport.

2.2. Propulsion system

Propulsion technology is the enabler to get safer and reliable VTOL vehicles, with a strong and direct link to electric vehicles design. Shamiyeh et al. (2017) review personal air vehicle concepts. The paper describes the new propulsion systems, paying careful attention to the ones enabling VTOL and Personal Air Transport Systems (PATS) vehicles. Shamiyeh et al. (2018) expand the design concepts presented in a previous paper mentioned above and related to the relationship between distributed electric propulsion with the new design of VTOL vehicles. Kim et al. (2018) present the electric propulsion concept, describing the benefits and the effects on vehicle design, both for conventional and VTOL ones. The research presented in this papers describes the improvement on the efficiency of the distributed electric propulsion, together with the flexibility of installation of its related systems and sub-systems. Propulsion technologies for UAM are maturing, and the existing experience within the sector is helping to reach a high maturity level. Hendricks et al. (2019) propose a propulsion analysis tool aimed for design purposes of propulsion systems adapted to the UAM vehicles, and more particularly to VTOL vehicles. The paper analyses the propulsion system from a multi-disciplinary perspective. Focusing on a specific tilt-rotor vehicle (proposed by the National Aeronautics and Space Administration (NASA)) the authors analyse the propeller design, the electrical set up and connection of several motors and cooling system, and the thermodynamic analysis of a gas turbine feeding the thermal management system. It is also interesting to consider the analysis by Courtin et al. (2018) in regards the electric STOL vehicles, which identifies the performance of the vehicles in regards the take-off and landing capabilities.

A clear trend, not only on UAM, but in mobility, is that it will be electric or it will not be (Dijk et al., 2013; Wheeler et al., 2013). Electric propulsion requires efficient batteries. Other energy sources, as alternative fuels, are not so well positioned. Research on Hydrogen as an aviation fuel could switch the perspective (Khandelwal et al., 2013). In any case, due to noise and emissions, added to the societal impact, an electrical power source is the one attracting the attention. Fredericks et al. (2018) describe the relationship between air vehicle performance and electric batteries specifications. Although the technology is progressing, the paper describes a long way with further work to be developed. As described above, Brelje and Martins (2019) identify the relationship between electrical batteries and electrical propulsion systems. Alternative fuels are nowadays a trending research topic in the aviation field. Yilmaz and Atmanli (2017) describe the type of alternative fuels while Braun-Unkhoff and Riedel (2015) analyse the feed-stock available, including biomass, to produce alternative fuels. UAM designs are not considering these kinds of fuels since it is expected that electrical battery technology will be mature enough to enter into service with the first vehicles. Noise and emissions are the main drawbacks of these kinds of fuels, so they are not really considered when assessing the energy sources. Besides, for larger vehicles, alternative fuels could be the early adopted solution till electric batteries or hydrogen are not available.

2.3. Autonomous vehicles

Ground autonomous vehicles are at full-demonstration level or even available on the market. Research about autonomous cars is a huge and well-developed field. The effects of introducing autonomous cars on overall mobility are discussed by Pavone (2015), who describes the importance and implications of unmanned and autonomous vehicles, while the general relevance of autonomous mobility is presented and assessed. Greenblatt and Shaheen (2015), as well, show the benefits of both the autonomous vehicles and ODM, its economic impact, and the environmental impact of their combination (i.e., ODM using autonomous vehicles). Bimbraw (2015) provides a complete analysis of the state-of-the-art, as well as future trends for autonomous cars. Fagnant and Kockelman (2015) describe some of the implementation barriers such technology could face. Although focusing on ground transportation, the same barriers can be extrapolated to flying vehicles. One of the critical technologies related to autonomous flying vehicles are the control algorithms, enabling not only autonomous flights but also autonomous guidance for formation flights or detect and avoid manoeuvring. Grocholsky et al. (2000) describe the development of new decentralised control algorithms, which could help manage a large number of devices and/or vehicles. Balachandran et al. (2017) describe the research on algorithms enabling Beyond Visual Line of Sight (BVLOS) flight. Concepts like geo-fencing, obstacle avoidance, or avoiding collisions with other traffic are studied for the purpose of UAS. It is a first step towards expanding these concepts to UAM for passenger transport. Chiaramonti et al. (2006) explain formation dynamics and control, focusing on three different types of formation: leader-wingman, virtual leader and behavioural approaches. Considering crowded urban air-space strategies similar or inspired by formation flight could increase safety and reduce airspace congestion. Another relevant technology is related to Sense and Avoid or Detect and Avoid. It is strongly related to safety, which is also the main concern. A useful review of the technology is provided by Prats et al. (2012) and reference therein.

2.4. Communications and navigation

UAS implementation will impose the substantial issues to be considered for UAM passenger transport. The research effort performed to enable flight formation with drones Radmanesh and Kumar (2016), Wang et al. (2007), Justh and Krishnaprasad (2002) has demonstrated how important communications systems are. The need for coordination and sharing data of multiple types, combined with a large number of airspace users, requires huge broadband. It is well accepted that 5G is one of the solutions. Research covers a broad range of topics; from the adaptation of 5G signal for aeronautical use (Ma and Zhang, 2016), to the security on using 5G networks for aeronautical communications (Li et al., 2019b). It is interesting to highlight a particular circumstance when dealing with 5G and UAS, which could be extended to UAM vehicles. Researchers are proposing that UAS and UAM vehicles will not be only the airspace users but also will act as communication relays (Hosseini et al., 2019; Gopal and BenAmmar, 2018; Frew and Brown, 2008). Using the same vehicles as relays could help to diminish the shadow effects of the buildings. 5G technology is already in place, although a great number of challenges is still present at UAV communication in 5G-and-beyond wireless systems, due to the unique communication requirements and channel characteristics (Zeng et al., 2019; Li et al., 2019a).

2.5. Air traffic management

One of the key point to progress on the implementation of UAS, first, and UAM, later, is the increase in airspace capacity. Thipphavong et al. (2018) accurately define the new scenario and how the use of airspace will change. It is well accepted that opening the sky to UAS will lead to huge demand (Thipphavong et al., 2018; Lascara et al., 2018). Existing tools and procedures in Air Traffic Management (ATM) will not be able to deal with such increase, so all aviation authorities (Federal Aviation Authority (FAA), EUROCONTROL, Civil Aviation Authority of China (CAAC), and others) are working hard on the definition of UTM and U-Space concepts. Vascik (2017) describes a careful analysis at the ATM system-level while considering other relevant aspects of the UAM implementation. On-going research also includes autonomous UAM network management and separation services, departure and arrival scheduling, continuous trajectory management for separation, seamless integration with traditional operations, the extension of UTM with Airborne trajectory management (ABTM), angular velocity management, variable separation (Bosson and Lauderdale, 2018; Cotton and Wing, 2018), but also short-term actions like how to transform helicopters routes for UAM usage (Verma et al., 2019). Two initiatives in the USA and Europe funded by NASA and EC lead the research on UAM implementation. The most advanced one is in the USA, the so-called Advanced Air Mobility (AAM) mission.[1] One of the main pillars of AAM is automation, which directly affects ATM. On the other hand, in Europe, CORUS project (Barrado et al., 2020) is relevant as well for ATM purpose since the project was dealing with the integration of autonomous devices in low-altitude airspace. Ren et al. (2017) focus on drones, and Performance Based Navigation issues (PBN), which could be of interest when dealing with a large number of UAM vehicles.

[1] https://www.nasa.gov/aam

3. Concept of operations

UAM would require gradual changes in the design and use of airspace, starting from the early implementation of drones. Not only the amount of users/vehicles but also the use of low-altitude airspace will create a significant difference with what we are used today (FAA, 2020a,b; Hill et al., 2020; Geister and Dagi, 2017). A new ConOps is required, which benefits from existing knowledge of helicopter-based urban transport (Thipphavong et al., 2018) and enables safe and robust operations. Both FAA and EUROCONTROL are working towards this aim; FAA is developing the so-called Unmanned Aircraft System Traffic Management (UTM), while EUROCONTROL is developing U-Space (FAA, 2020a; Hately et al., 2020; Barrado et al., 2020; Khairuzzaman, 2017).

Both UTM and U-Space define the Concept of Operations with regards to the type of services to be provided, as well as the implementation of these services. In 2018, the FAA released an initial Concept of Operations for Unmanned Aircraft Systems (UAS) Traffic Management (UTM) that described the operational and technical requirements for developing a supporting architecture and operating within a UTM ecosystem. This ConOps has been recently updated to support the continued maturation of UTM expanding the set of operational scenarios and describing more complex operations in denser airspace (FAA, 2020a,b). Similarly, SESAR Exploratory Research project CORUS developed U-space concept of operations for drones flying in very low-level airspace. U-space aims to gradually introduce the services over four phases, U1 to U4, in order to efficiently deal with RPAS operations. The transition from one phase to another will be driven by the increasing availability of blocks of services and enabling technologies, and the increasing level of drone automation and drone connectivity. For instance, U1 will enable U-space foundation and will be implemented in the near-term, while U4 will support the full operational capability of U-space relying on a very high level of automation, connectivity and digitalisation for the drones. The services envisioned to be introduced in the first three phases are indicated in Fig. 3. As already mentioned, U4 entails the full integration of drone flights into controlled airspace and is out of scope of this Concept of Operations. Among the services to be offered, the communication with the Air Traffic Service (ATS) is one of the important aspects that will be gradually upgraded enabling the procedural interface with ATC at the mid-term phase (i.e., U2) down to the collaborative interface enabling the communication between the Remote Pilot (or the drone itself in case of automatic flight) with ATC while a drone is in a controlled area. Since some authors agree that the initial implementation of the passenger-carrying UAM will use manned vehicles, U4 will present a step further to its implementation. Similarly to U-space, UTM also considers different types of the communications involving operator-to-operator, vehicle-to-vehicle and operator-to-Network Manager, avoiding in this way the use of ATS as one operated today.

The following references also shed some light on the communication aspects within the concept of operations. Among others, Greenfeld (2019) analyses the UAM Concept of Operations from communications point of view. The document defines some assumptions for the UAM system, which will consequently lead to different assumptions on the communication systems. The main focus of the document is on the passenger-carrying UAM considering a list of various elements including shared airspace, shared information among Remote Pilot in Command (RPIC) on one side, but also the role of different stakeholders, the definition of air corridors disabling straight and shorter patch from A to B, the use of TOLA and finally, the use of VTOL vehicles operating in the city centres on the other side. Although it focuses on small Unmanned Air Vehicle (UAV) with less than 25 kg (55 lb), Kopardekar et al. (2016) describe the UTM concept of operation as *"flexible where possible and structured where required"*, and based on use cases to define the airspace requirements while a risk-based approach would be followed where needed. Barrado et al. (2020), from the CORUS Project, are going a step further regarding airspace requirements. Although mainly focusing on the implementation of UAS for business to business services, the U-Space ConOps proposed by the CORUS project divides the whole Very Low-Level Airspace (VLL) into three new volumes; called Type X, Y and Z volumes. These three new volumes differ with respect to the service being offered and their access/entry requirements. The service offered within each of these volumes will limit the types of operations that are possible. In particular, the conflict resolution is the service with a largest difference between volumes. X volumes do not provide conflict resolution service and the remote pilot has full responsibility for ensuring safe operation. In Y volumes, only pre-flight (strategic) conflict resolution is offered, which implies that the operation plans are coordinated to avoid collision. Finally, in Z volumes, in-flight ("tactical") conflict resolution is offered in addition to strategic, meaning information about the positions and motions of other aircraft is used to guide the drones in order to avoid conflicts. NASA's AAM Concept of Operations analysed the creation of UAM corridors within controlled airspace at an early stage of the development of the UAM ConOps, but the most recent proposal (Hill et al., 2020) also mentions the definition of volume on the lower airspace, the so-called UAM Operations Environment (UOE). Outside these UOE, aircraft will follow the rules and fulfil the requirements of the specific portion of airspace.

In addition to the advanced design of airspace and new types of space volumes, the arrival and departure procedures to/from TOLA is an important aspect that needs to be defined as a part of concept of operations. Pradeep and Wei (2018) analyse arrival procedures when dealing with a mixed fleet of VTOL and winged vehicles. The authors apply optimisation methods to define the sequencing of the vehicles. Nneji et al. (2017) analyse the passenger transport scenarios while admitting that all of them are envisioned to be available in long-term future. The authors define a system-theoretic approach to analyse ODM scenarios from a technical and societal point of view relying on the available description of the previous helicopter-based transport services or personal air vehicle based on fixed-wing single pilot aircraft. Although, from a technical point of view, the described systems concepts of operations could be feasible, the authors claim that technology development and regulations will limit their successful implementation.

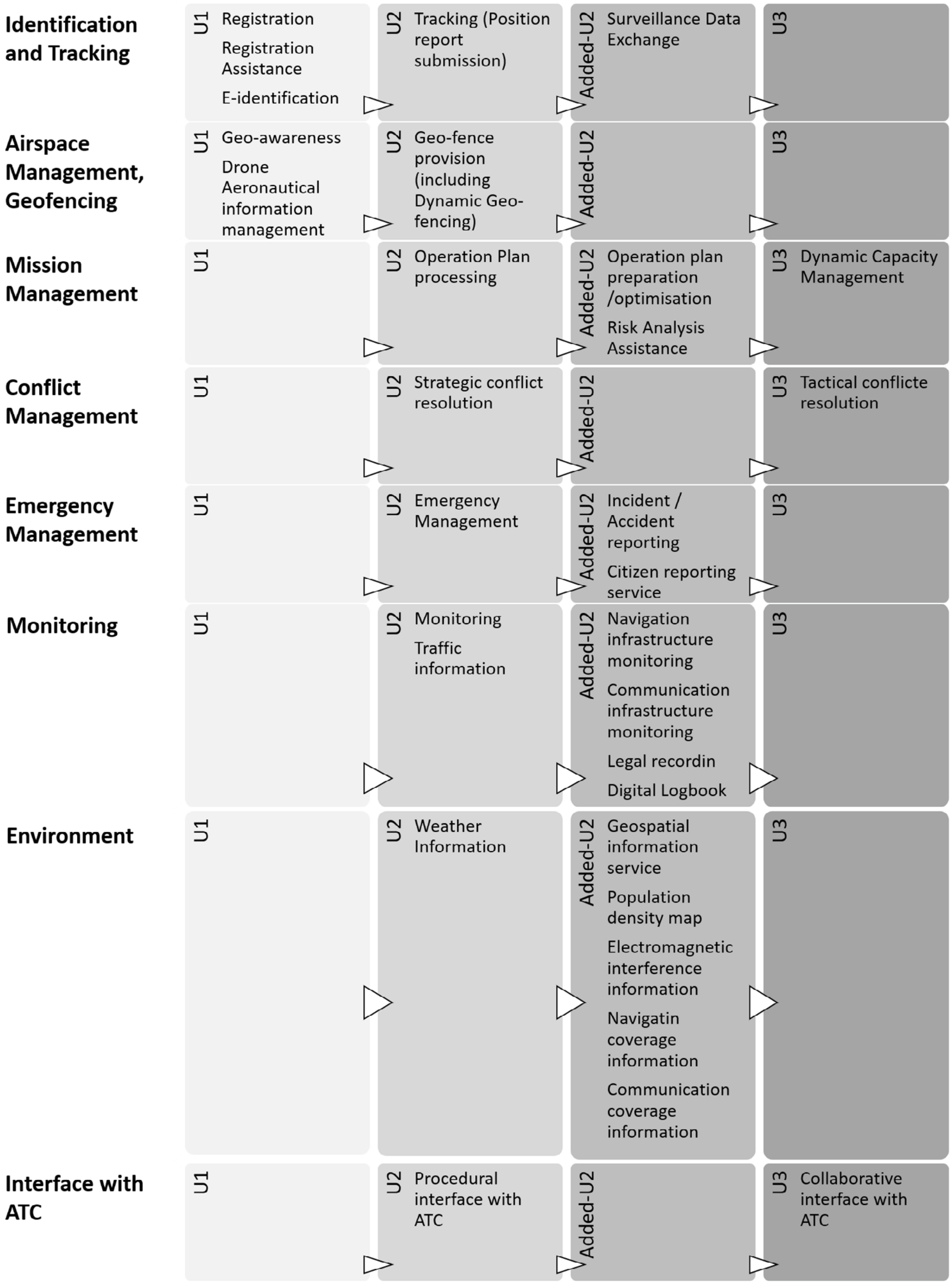

Fig. 3. U-Space services as described at CORUS Project Report D6.2.

4. Urban mobility

For a successful UAM operation, efficient and suitable infrastructure is essential. The UAM ground infrastructure elements have to be accessible to customers and to provide satisfactory passenger and aircraft throughput. Besides, in order to provide a seamless journey, the land UAM facilities need to be connected with other mobility options and their networks. In the current context of demand-based mobility, more than ever is increasingly relevant for planners and transport operators to take into account users' needs and real-time requirements related to the transportation services. In line with this and under the influence of the sharing economy, mobility services such as on-demand mobility (ODM) and Mobility as a Service (MaaS) are going mainstream (Kamargianni and Matyas, 2017). Although these services are not new, they are disrupting the market and changing the mobility scenario. In this line, UAM is expected to follow the same trend in terms of types of services and dynamics that users will take on. One of the keys could be a close collaboration between the different stakeholders across the extended mobility ecosystem. Appropriate design of UAM system, according to the user needs and the integration with the existing transportation systems, could be a significant challenge in the urban mobility framework.

4.1. Network design

In addition to the technology and the concept of operation (Sections 2 and 3), other domains of UAM infrastructure analysis relate to the ground facilities. For efficient UAM operation, fitting its main infrastructure elements into the existing city structures is one of the biggest challenges (Rhet Flater and Leverton, 2001). The two main domains to consider here are the positioning and sizing of the take-off and landing areas (TOLA) - ground spaces of vertical take-off and landing (VTOL); and the coherence of UAM land infrastructure with existing transportation systems. When it comes to the TOLA definition, terms such as vertistop and vertiport can be found in the literature. Vertistop is used for a single VTOL platform that has minimal infrastructure. Similar to heliports, vertiports represent an airport for VTOL vehicles equipped with numerous take-off and landing pads and additional infrastructure elements (e.g. charging points for electric vehicles) (Holden and Goel, 2016; AIRBUS, 2018) Since it is directly related to UAM demand rates and travel time, the vertiport location problem is of special importance. Although there are studies dealing with vertiports placement within the study area (Antcliff et al., 2016; Vascik and Hansman, 2017a; Fadhil, 2018; Vascik and Hansman, 2019; Rajendran and Zack, 2019; Rath and Chow, 2019), none of them is based on practical experience. At this moment, the development of modern vertiports (for eVTOL aircraft) is represented only like isolated cases (Dallas Executive Airport, 2021) or as a conceptual design model (Hilbert, 2020; Dezeen, 2020). The critical matter when it comes to building new infrastructure elements for VTOL aircraft manoeuvring is space availability. Places with high attraction can face a lack of space because they are located in the middle of the urban area. Moreover, the most crucial concern is related to safety since the operation will be performed in the middle of the urban areas. In addition to new infrastructure elements, rooftops of buildings, floating barges and docks, highway cloverleaf clearings, and overtops of existing land infrastructure are considered as potential sites for vertical take-off and landing operations (Vascik, 2017). Current helipads and heliports also have the potential to be part of the future network of vertiports (Holden and Goel, 2016). Although these locations seem like logical and cheaper solutions for UAM operations, noise, and air pollution could be significant societal issue (see Section 5).

Without analysing time-consuming processes in UAM operations (e.g. passenger boarding time), the capacity of the TOLA will significantly depend on the technical characteristics and performance of the VTOL vehicles. Similarly to a standard airport, where the aircraft wake intensity determines the separation between aircraft, the down-wash of the UAM vehicle, its weight and the availability of multiple pads will determine the capacity of the TOLA. Besides that, Kim et al. (1995) state that vertiport capacity is more likely to be limited by airspace separations or gate availability than by touchdown and lift-off area occupancy times. The mentioned factors are taking relevance when the demand increase and the operation is close to the saturation point. Regarding the vertiports size and configuration, the reader can check the Federal Aviation Authority (FAA) (Peisen and Sawyer, 1994) and International Civil Aviation Organization (ICAO, 2013), ICAO (1995) reports to identify what are the current standards and criteria when designing a heliport/vertiport. However, it is not clear whether the UAM TOLA's can be adapted to the current standards, or it will require the definition of new standards. As for heliports, where the Performance Class of the helicopter is imposing some criteria, UAM landing areas will also need to consider the performance and flight capabilities of the new vehicles. In this regard, another factor that should be taken into account when designing a vertiport concerns the operations like charging electric UAM vehicles or swapping batteries, aircraft cleaning and maintenance as well as passenger boarding.

Cohen (1996) investigates vertiport archetypes regarding land use, site selection, and community acceptance issues. Cohen also provides specific insight into the areas that small and large public-use vertiports occupy. Fadhil (2018) provides a detailed analysis of minimum requirements for UAM ground infrastructure. These minimum concerns are specifically related to operational safety, charging station, noise, weather, fire hazard, communication infrastructure and parking. One of the possible vertiport conceptual designs is proposed by Choi and Hampton (2020). The authors present a strategic development framework which refers to the infrastructure integration of existing airports and future-VTOL air transport system.[2] In this way, the capacity of existing airports could be increased with minimal investment. Despite the advantages, the suggested approach could encounter many challenges and regulatory barriers. Furthermore, Germany's aerial-taxi company Lilium (Dezeen, 2020), as well as Volocopter company, exposes vertiport prototypes that could be installed on top of office buildings, car parks or shopping centres. The proposed vertiport model consists of three vital elements for UAM running: take-off and landing area, parking spots and a terminal building. As the company points out, this modular design of vertiport could be adjusted to different sites and for varying levels of demand. Finally, in the process of determining the adequate vertiport infrastructure, standardisation and certification of equipment and procedures represent a possible solution that should lead to investment cost reduction and greater efficiency.

The integration of the network of TOLA with the existing transport network is also an issue worthy of attention. Not only regarding the perspective of reaching the TOLA but also to create a multi-modal network and services (such as Mobility as a Service (MaaS)) that enhances the effectiveness of the total transportation system. Although UAM market actors emphasise that the synergy of UAM with existing modes of transport is essential, it can be concluded that current literature lacks studies that scrutinise the most efficient ways to connect. For the so-called first and last-mile problem, all available transport modes are seen as a possible solution.

[2] Similar integration have been announced by large airports in Cologne and Dusseldorf, see Lilium agrees partnership with Dusseldorf and Cologne-Bonn airports - Lilium at www.jeccomposites.com/knowledge/international-composites-news/lilium-agrees-partnership-german-airports.

Rothfeld et al. (2018) as well as Ploetner et al. (2020) conduct simulation studies in which they conclude that access/egress and process times significantly affect UAM demand rates. The impact of UAM accession time is noticeable on shorter trips. Consequently, first and last-mile duration is greatly influenced by the vertiport network density and arrangement. According to the NASA market research study (Reiche et al., 2018), one of the development scenarios of UAM envisages its scheduled use (similar to public transport) while the vertiports network could have a structure of hub and spoke model. While suburban vertiports could serve as spoke nodes, vertiport clusters in densely populated urban areas could function as hubs. In this way, each vertiport may serve a limited number of routes. In one of the most recent studies conducted by Wu and Zhang (2021), the authors developed extended single allocation hub-and-spoke network modelling to solve the integrated network design and mode choice problem. The study results are reflected in optimal vertiport locations while considering total generalised cost and mode competition.

On the other hand, Sinsay et al. (2012) used point-to-point vertiports network structure for the simulation model in order to find out the feasibility of using eVTOL aircraft to handle a significant share of a metro-regional transportation system in the San Francisco metropolitan area. As the authors accentuate, direct connection of nodes in the network should provide the maximisation of benefits to an individual passenger by providing timely service. At the same time, it could pose a challenge for ATM and UAM providers who have to solve the problem of added flights on routes and to provide vehicles capable for a long-range flight.

4.2. User-oriented UAM services

The expansion of the sharing economy in the mobility sector has led to new forms of services, which especially contribute to the more economical use of individual mobility resources. These new sharing mobility solutions make a significant contribution to the improvement of urban mobility and its sustainable development. The significant participation of new mobility sharing options means a change in the philosophy of individual mobility — from the traditional concept of vehicle ownership to the concept of On-Demand mobility. In that sense, the future development of transport envisages the transition from selling mobility services instead of vehicles and diminishing a strict separation between public and private transport, as well as between what is shared and what is owned (Spulber et al., 2016). This philosophy, originated in the automotive industry, can be replicated in the aviation sector as well. According to Vascik and Hansman (2017b), on-demand mobility for aviation presents *"an emerging concept that leverages increased connectivity through smartphones to enable the real-time matching of consumers and service providers for multi-modal, point-to-point transportation via networks of novel vertical take-off and landing (VTOL) aircraft"*.

Unlike ground-based on-demand services, ODM aviation has the potential to meet future on-demand services at higher speeds and to divert demand from passenger cars. This kind of service is of particular importance for long-distance commutes due to shortened travel time within and between city regions. Holden and Goel (2016) indicate that this innovative service has the potential to overcome urban mobility problems, especially those related to the congestion, high costs of infrastructure and decreased flexibility of the ground modes. According to Airbus (AIRBUS, 2017) it is about safer, more reliable and more environmentally friendly options than ground transportation modes. Vascik (2017) highlights that ODM air services can provide accessibility to areas of the city with a lack of connections caused by urban sprawl.

So far, on-demand aviation has referred to helicopter services scheduled to transport passengers, also known as an air taxi. This service model is currently in practice for inter-city operations in some of the most populated metropolitan areas (see Section 7), between attractive locations as a shuttle service (e.g. helicopter flights between Nice and Monaco), as well as within megalopolises (e.g. flights between Rio de Janeiro and São Paulo (Aviator, 2019). Although further development of air taxi services is unpredictable, these types of air services have certainly laid the foundations for the future development of on-demand aviation.

The evolution of small and low-capacity electric aircraft that take off and land vertically, as well as advancements in the telecommunication industry, will lead to the establishment of a new type of air service in the area of on-demand mobility. Similar to ground-based on-demand models, air-based on-demand services will be required to respond to stochastic user demand. According to Dr Jörge Müller, Head of Programs and Strategy at Urban Airbus Mobility (Hader, 2020), the provision of future services can be observed through five mutually connected elements that should contribute to the efficient functioning of the entire UAM system. These building blocks are related to eVTOL aircraft and activities connected to the use of aircraft (i.e. vehicle charging, energy storage, technology development, etc.), eVTOL fleet operations, adequate Air Traffic Management (ATM) system, the integration of air and ground UAM infrastructure into the city as well as operation of the transport network from the beginning to the end of the journey. Each dimension presents a particular challenge for market actors within the UAM ecosystem, especially demanding for service providers, manufacturers and policy regulators.

Numerous ground-based on-demand business models mostly differ in vehicle ownership and driver presence. As Fadhil (2018) points out, in the case of on-demand aviation, some of these models do not seem applicable. One of the most common model, whose representatives are UBER and LYFT, is known as Transportation Network Companies (TNCs). Due to the lack of licenced pilots and eVTOL aircraft ownership, its application in the field of aviation is questionable (Vascik, 2017). For the initial stage of this new era of ODM aviation, Transportation Service Providers (TSP) seems to be a more convenient solution, in which the vehicles would be owned by a company that would also hire certified pilots. Further development of TSP will be a lot easier with the application of autonomous and pilotless aircraft. This will certainly affect the price of these services and level of safety, but it will also raise questions related to certification, regulation and ATM (Polaczyk et al., 2019). Other ODM models such as peer-to-peer aircraft sharing and renting are assumed to be very little represented since the user should be able to pilot the aircraft. On the other side, the new advances in on-demand air services do not exclude the evolution of service models such as ridesplitting and air pooling, which enables users to share the ride instead of flying alone.[3] In this way, UAM services could become more affordable to a broader range of users.

Based on predictions, UAM is not going to be able to exist alone without some form of integration with other transportation modes. Straubinger et al. (2020b) indicate that its integration with public transport is crucial. In their opinion, there are two possible development paths. On the one hand, UAM can serve as a solution to insurmountable geographical barriers (like mountains, rivers, islands, etc.) that affect the accessibility of ground transportation. On the other hand, UAM can be seen as a suitable transportation option in cases where public transport is unsuitable.

Starting from the profiles of future passengers and the mode choice factors, Straubinger et al. (2020a) present an assessment framework resulting in three different operating concepts: Urban Air Mobility as a Service (UAMaaS), Urban Air Taxi and UAM platinum. While the UAM platinum is the most likely scenario for short-term application and standing for high-income travellers, UAMaaS is a long-term solution assumed to have the lowest price of the three options and the most benefiting to future travellers. Similar predictions related to the possible development of UAM services are given by Michelmann et al. (2020). They also provided a detailed analysis of possible implications of the scenarios on key customer groups, costs, transport network and vehicle operational parameters.

MaaS concept is one of the most promising directions of future mobility transformation towards the development of user-oriented services (Simpson et al., 2019). MaaS is an emerging mobility approach that combines different transportation options (e.g. public transport, taxi, sharing mobility services, etc.) through a single digital platform. In this way, a door-to-door mobility solution that perfectly meets users' transportation needs is offered. The fundamental idea of the MaaS is in an offer of various transportation options. This is primarily related to well-developed public transport — the backbone of MaaS, which should allow a growing number of users to move around easily. Other transportation solutions, including UAM services, should be in synergy with the public transport system and not to be its competitor (Straubinger and Fu, 2019). Nesting of UAM services within MaaS concept can serve for smooth and efficient inter and intra-city movements. According to Vascik (2017) and Straubinger et al. (2020a), the synergy of MaaS concept and ODM aviation will allow certain groups of customers to use air transport services even though they could not afford it before integration. However, as Straubinger et al. (2021) pointed out, the integration is not a simple endeavour and it cannot be compared with the integration between different public transport options. Numerous challenges such as high costs, safety, and public acceptance can stand in the way of this integration. Besides that, important preconditions for integration concern both physical and operational integration, service coverage and availability, etc. (Arias-Molinares and García-Palomares, 2020; Rajendran and Srinivas, 2020). An additional threat is relevant and real-time database important for informing users and meeting its demand. Therefore, all participants in the MaaS concept must be willing to share information, which can be a challenge for air service providers. According to Shaheen and Cohen (2020), these data-sharing partnerships are important for the improvement of trip planning, operations, and fare integration.

5. Societal impacts and public acceptance

An important aspect of urban air mobility is its impact on people and the environment. Expanding and consolidating air mobility as a real alternative among all the available modes of transport in cities could face direct opposition of people. It could put much pressure on the stakeholders and politicians, who could decide to stop all the progress to fulfil the societal demand of the opposition. Safety, noise, emissions, privacy, land use and visual disruption are the most important societal and environmental concerns of UAM service, which involve communities and affect acceptance (Holden and Goel, 2016). According to the most recent and extensive EASA survey (EASA, 2021) on the societal acceptance of UAM in Europe, safety, noise, and security are among the top concerns. Safety is, unquestionably, the first and foremost aim to fulfil. Air operations in the low-altitude airspace and high-density locations make safety concerns the most important ones. Modern technologies (like autonomous aircraft), as well as ATM and communication, are going to provide greater levels of safety in urban settings.

Noise generation is a prominent limitation of UAM development, which might be particularly perceptible when the UAM reaches full-scale operation. Many UAM researchers, like Holden and Goel (2016), Antcliff et al. (2016), Vascik and Hansman (2017a), Eißfeldt (2020) or Eißfeldt et al. (2020), have emphasised the importance of noise as one of the most relevant UAM externalities while some of them also advised noise abatement recommendations and procedures.

Until now, only few studies have evaluated the environmental sustainability of VTOL aircraft, mostly comparing their external effects with passenger cars (Holden and Goel, 2016; Kasliwal et al., 2019; Lin et al., 2020). The foreseen use of new energy sources (such as electric, hydrogen and solar) for aircraft powering will probably lead to ensuring zero-emission and ultra-quiet design ambitions in urban aviation.

Other threats like the disruption of privacy, land use and visual pollution caused by aircraft movements could also address community acceptance. These concerns are going to be much more relevant with an expansion of UAM services (Reiche et al., 2018). Therefore, specific attention should be done in order to minimise these impacts.

In addition to the above-mentioned factors, social equity and the opportunity to expand UAM into mass service depend on the reasonable price of the UAM service. If the service is perceived as elitist, it can be a challenge to increase public acceptance and enable real competition with other modes of transport.

[3] Currently, companies like BLADE and UBER offer these service models.

For modal choice, three categories of factors have been consistently found to be crucial until now: socio-demographics, the built environment (e.g. density, diversity, design and the distance decay effect) and trip-related factors (e.g. trip purpose, travel time and costs, or reliability), as described in Chen et al. (2016).

However, the primary question to deal with is how people will respond to UAM technologies when they are fully mature. As in the case of autonomous vehicles, users' understanding of this new mobility level can affect transportation policies designed to influence people's behaviours proactively. That is why it will be essential to analyse how users perceive UAM, their acceptance, and their mode-use intentions.

The quality of the new transport services will be evaluated according to passengers' cognitive expectations, such as comfort, reliability, and sense of security (Johansson et al., 2006; De Oña et al., 2013). The travel experience is becoming increasingly important, with the involvement of both cognitive aspects and emotional components. That is why the modelling of travellers' behaviour regarding UAM should not only focus on objective measures and cognitive aspects but also on variables that address acceptance, attitudes and even lifestyles (Van Acker et al., 2014; Bahamonde-Birke et al., 2017).

Some authors have touched on factors that are not directly controllable, but that can influence the passenger's experience, such as social interaction or habit formation (e.g. Ingvardson et al., 2017). Individual-specific variables are also consistent in some studies, such as a concern regarding the environment or fairness (Kaplan et al., 2014). New technologies (Garikapati et al., 2016) or loyalty felt for a given transport mode (Van Lierop and El-Geneidy, 2016) are also relevant aspects to consider.

It is worth noting that research regarding mode choice considering UAM is currently ongoing. For example, Binder et al. surveyed to estimate commuters' willingness to pay for eVTOL flights in urban areas in the United States. Regarding factors affecting modal choice, a UBS analyst found that younger and more educated respondents are more willing to use pilotless aircraft (Castle et al., 2017). Fu et al. (2018) come up with similar conclusions as Castle and others, and also find that UAM seems more desirable for business trips, rather than for daily commutes. A valuable insight about factors influencing mode choice for UAM is given in the most recent study by Straubinger et al. (2020a). They have systematised the relevant factors into the following three groups: transportation service factors, individual-specific factors and attitudinal–psychological factors. Behme and Planing (2020) performed a qualitative analysis among potential users in Germany in order to determine the current perceptions regarding the implementation of air taxi. Socio-demographic, psychological and product-related factors proved to be the most influential factors for accepting the UAM services. Finally, within a broader objective to identify the potential air taxi commuter routes in 40 U.S. cities, Haan et al. (2021) employ the stated preference survey and reveal that access/egress times and aircraft operating costs are two most influential factors of air taxi demand.

NASA (Holmes et al., 2017; Reiche et al., 2018), Airbus (Thompson, 2018), or Georgia Institute of Technology (Binder et al.) conducted market studies and research with the aim to find potential user groups with a high propensity to accept UAM services. For example, the results of the online survey conducted by Yedavalli and Mooberry (2019) show that acceptance varies by region and city in the world. While the Mexico City inhabitants are enthusiasts about the use of UAM (with 67% of them are likely or very likely to try it), respondents from Los Angeles, Switzerland and New Zealand showed much less interest, with 46%, 32% and 27% willingness to use, respectively. Studies (Planing and Pinar, 2019; Eißfeldt et al., 2020) also show that the more informed respondents are about potential disadvantages and risks, the higher the chance of UAM services acceptance. Besides, some psychological and social barriers relating to sharing and automation will be the key to achieve user acceptance. For example, according to a survey conducted by Shaheen et al. (2018), people are more comfortable and willing to fly with passengers they knew in contrast to flying alone or with strangers. That shows a possible market for air pooling networks that could provide additional supply to scale the UAM market.

Passengers' trust and apprehension with automation and pilotless UAM will also be necessarily taken into considerations, as willingness decreased with increasing levels of automation (Shaheen et al., 2018). Winter et al. (2020) developed a prediction model to investigate the type of early adopter user who would be willing to use autonomous air taxis. Familiarity with a topic, value, fun factor, happiness, wariness of new technology and fear have been found to be important predictors of willingness to fly in pilotless air taxis. While the first four factors were positively correlated to the potential user' willingness to fly, the last two factors had negative relationships with the willingness to fly. It means that with higher values of these two factors, the user's willingness to fly would decrease. Public perception of fully automated aircraft is one of the most significant barriers (Holden and Goel, 2016). In the absence of studies dealing with UAM user acceptance, the results obtained from studies analysing other similar services (such as ground autonomous vehicles) are also used (see, for example, Al Haddad et al., 2020).

Accordingly, acceptance and attitudes research with relevance to UAM is particularly expected to be more explored with the further development of its services. It is expected that the adoption of UAM will depend on a large number of factors of different nature (i.e. socio-demographic, psychological, product and technology-related, etc.) but also the evolution of many other new or improved existing transportation services (such as shared mobility services, Mobility as a Service concept, autonomous vehicles, high-speed trains, etc.).

6. Policies

As any other disruptive technologies, UAM raises a novel concern in terms of safety and privacy. This will call for significant changes to the existing regulatory framework, spanning everything from airworthiness, operator certification to infrastructure standards. Serrao et al. (2018) provide a comprehensive overview of regulations and certification standards affecting UAM. It offers an overview on specific countries like UK, Ireland, New Zealand and Canada, in addition to focusing on the US States which released regulations on UAS and UAM implementation The Federal Aviation Authority (FAA), in the United States of America, the European

Aviation Safety Agency (EASA) in Europe, and the Civil Aviation Authority of China (CAAC) in China are the reference institutions regarding aviation safety worldwide. The three institutions are responsible for establishing regulations of different aspects within UAM in the future to provide the public confidence in new solutions. VTOL aircraft and associated ground infrastructure share some similarities to current aircraft technology and ground solutions, particularly helicopters and heliports, implying that a large portion of existing regulations and standards can be applied to vertiport infrastructure. Still, the distinctive features of the VTOL aircraft – from the means of propulsion and planned degree of autonomy – necessitate the urgent setting of guidelines or more stringent certification. Thus, in October 2018, EASA initiated a set of public consultation on its proposal for airworthiness standards for certification of VTOL aircraft stipulated in Proposed Special condition for Vertical Take-Off and Landing (VTOL) Aircraft (EASA, 2018). The aim of these actions is to facilitate the development of the regulatory framework to enable the safe operation of air taxi and electric VTOL (eVTOL) aircraft across Europe. The proposed rule for the certification applies to small-category VTOL with a passenger seating configuration of 5 or less and a maximum certified take-off mass of 2,000 kg or less, and the level of automation; considering the presence of an on-board pilot, remote pilot, or none of them. Special Conditions (2018) entails two main categories of VTOL aircraft (Enhanced Category and Category Basic), based on their capabilities after a critical malfunction in the propulsion system.

In April 2019, EASA established a separate department dedicated to electric VTOL and Special Concepts. Special conditions published in July 2019 have been revised and followed by the Means of Compliance (MoC) in an attempt to *"address the applicant's requests for clarification of EASA's interpretation of these objectives and of possibilities how to demonstrate compliance with them"* (EASA, 2020). This approach will enable the industry and a broader audience to gain an insight into EASA's interpretation and expectations from the Special Condition design objectives, which could potentially affect the design decisions. However, the regulators and standards bodies need to anticipate the types of regulations required to embrace the future development of autonomous and pilotless UAMs. As already observed in Section 1.2 (see Fig. 1), the introduction of high-level autonomous VTOL will probably follow a gradual process that assumes the presence of the pilot in the cockpit for passenger transport before any kind of autonomous flight will be introduced into service.

In addition to the expectation of being autonomous and shared vehicles, there is a crucial concern for the regulation and organisation of the airspace structure. In this light, the new regulation will need to ensure not only the operations in the low altitudes and different density of the airspace but also an interface to manned aviation, Air Traffic Management (ATM) and Air Navigation Service Providers (ANSP). A good example of the activities in place is the project CORUS, established as an exploratory research project within the context of the SESAR 2020 Wave 1 Programme. The project aimed to establish and clearly describe a concept of operations for drones in uncontrolled airspace (U-space) as well as in and around controlled or protected airspace (e.g. airfields) at the European level (Barrado et al., 2020; SESAR Joint Undertaking, 2021a). Built on the concept of operation designed in CORUS, the very large demonstration project CORUS-XUAM (2020–2022) will further assess how U-space services and solutions could support integrated urban air mobility flight operations (SESAR Joint Undertaking, 2021b). Additionally, the demonstration activities will combine flights by eVTOL with other traffic and operations in the control zones of major airports at six different locations across Europe, including different types of mission (e.g., passenger transport, logistic, delivery, emergency response and surveillance). On the one hand, the FAA jointly with NASA are leading the definition of commercial operations for UAVs. The Small Unmanned Aircraft Rule (PART 107) (FAA, 2016) defines clear operational limitations, pilot's responsibilities, and aircraft requirements. FAA is actively participating in many development projects, together with VTOL vehicle manufacturers (UAM News, 2020), while it is hardly working on the definition of the ConOps for UAM. FAA has already released two versions of its UAM ConOps by March 2020 (FAA, 2020b,a) and the one moving towards maturity level (UML4 (Hill et al., 2020)).

Similar undertakings are also taking place in China. The current regulatory framework encompasses different elements including Civil Aviation Law, the Regulation on ATM (General Rules on Flight), the Regulation on ATM of General Aviation Rules of CAAC (CCARs). In 2015 an Interim Provisions on Light and Small Unmanned Aircraft Operations (UAS Operation Provisions) was issued by CAAC. It regulates the operation of unmanned aircraft systems (UAS) with a maximum empty weight of 116 kg or less or a maximum take-off gross weight of 150 kg or less and a calibrated airspeed of no greater than 100 kilometres per hour. UAS weighing 1.5 kg or less are generally not required to follow the rule.

Overall, all the authorities still restrict the over-flight of crowded or urban areas, although it is anticipated to be changed with the further development of technology. One should also consider that the present main concern is the operation of freight UAS, and not considering passenger transport. It could happen that when dealing with passenger transport, some of the existing or future rules applicable to UAS will be more restrictive in order to fulfil high-level safety requirements.

In addition to the regulatory aspects mentioned above, there are several other regulatory points that need to be properly addressed to enable future UAM operation. For instance, Straubinger et al. (2020b) underline the importance of national authorities as key regulatory bodies that need to consider some of the relevant aspects such as flight crew licencing and training, maintenance regulations for the operation, security regulation for passengers and many others. However, it is worth emphasising the future role of local municipality authorities who will be engaged in conducting local and regional transportation planning and regulating the use of ground infrastructure and UAM operations, particularly in dense population areas. Together with national authorities and other stakeholders, local authorities will serve as mobility integrators whose aim will be to integrate both physically and digitally surface transportation with emerging mobility technologies, including urban air mobility (Shaheen et al., 2020).

Table 1
Some of the characteristics of air-taxi service available worldwide.

Company	Type of service offered	Customer interface	Average ticket price	Integration with other transport modes
Voom	–	Mobile booking platform	Equivalent to 2x the cost of a taxi service (e.g. $ 225 per ride from SFO to OAK)	–
Uber Copt	Trips between Manhattan and JFK International Airport.	Mobile booking platform (Uber app)	$ 200 and $ 225 per pax including private ground transport on both ends. (dynamically adjusted)	Road transportation through Uber taxi
Helipass	Multiple services, including shuttle and point-2-point transport	Mobile booking platform	Cost per pax, depending on the city and type of services, starting from 80 to 590 eur/pax, or more	Own fleet of Business jets
Blade	Routes in Great Los Angeles; LAX, BLADE Lounge DTLA, LA Westside, Orange County and Burbank.	Blade App	Starting at $ 195 per seat	American Airlines Cadillac service for premium-cabin guests
Melbourne CBD Transfer	Routes between key six Melbourne destinations including Melbourne Airport	–	Starting at AUS $ 390 per seat to Melbourne Airport (fixed price per route)	No integration
Helicopter Me	Routes all over NZ	No App	Not specified	No integration
Heli Securite	Routes in Southern France and Switzerland	No App	Not specified	Transport to Nice Airport, but not really integrated with other transport services

7. Business models

A number of helicopter-based taxi applications have been successfully developed in the past years worldwide, with Europe and the U.S being the prominent markets. They present predecessors to the recently emerged on-demand service mobility concept. From the Airbus Voom (AIRBUS, 2016), the first-to-market helicopter booking platform offered in the most congested metropolitan areas in the world (São Paolo, Mexico City and San Francisco) and subsequent launch of UBER Copter with its convenient three part journey connecting Lower Manhattan and Kennedy International Airport (Holden and Goel, 2016), several ODM initiatives have been emerging worldwide. Melbourne CBD Transfers (Microflite, 2020) in Australia, Hiratagakuen (2020) in Japan, Helitaxii (2020) in India, Helicopter Me (2020) in New Zealand and Securite (2020) in France are some of the air taxi helicopter services currently operating and mainly shuttling passengers between major cities and airports. Helipass (2020) is also an example to consider. It started as a touristic flight operator in Paris and now is offering multiple transport service worldwide. Its services can be booked through its application. They were in negotiations with UBER, helping to create UBER Copter service. The business model of these companies highly focuses on the end-to-end service combining ground with air transportation, already envisioned as a promising future approach and described in Grandl et al. (2018). The document defines the process of this service as follows: catching ground transport to a vertiport to cover the first mile, boarding the eVTOL flight, and, once landed, having a ride-hailing service waiting to cover the last mile. The service can be booked online and the assumed boarding and disembarking times are around three minutes each. A summary of service characteristics is provided in Table 1.

The business model of the available helicopter companies encompasses the integration of on-demand service with traditional transport mode (i.e. taxis) in an attempt to deliver seamless, reliable and personalised (i.e. fit-for-purpose) mobility. In this way, on-demand helicopter service will provide a plausible alternative for relatively price-inelastic business travellers who seek a convenient substitute for congested road transportation and in turn, are willing to pay more for such kind of service. Vascik (2017) already identifies ODM transportation services as a viable business model that can be translated in the aviation community from several successful ground-based ODM business models persisting today. For instance, UBER introduced the share mobility concept which provides passengers with the possibility to share the flight and thereby save on the ride cost (Holden and Goel, 2016). In terms of the customer interface, customers usually use the application on their smart phones to book the trip specifying the pick-up location, number of seats and preferred itinerary.

Although the value of air taxi helicopter service is undoubtedly acknowledged, the sustainability of this business model is still a subject of concern. The major drawback stems from the fact that the aggregate time-saving for the end-to-end journey might not match the customer expectations (Shah, 2020), which may divert him/her to other modes of transportation. On the other hand, Moore and Goodrich (2013) investigate the operational characteristics and cost structure of different air-taxi start-ups that operated across the U.S. in the late 2000s using available aircraft technology (i.e. single engine piston aircraft, twin turbofan aircraft, etc.). The authors identify that low load factor, low utilisation rate, high fuel/energy costs and high total operating costs of these aircraft types stand as major barriers to sustainable growth. They also underline that these issues can be potentially overcome by the deployment of electric propulsion as a disruptive technological enabler (Fredericks et al., 2018). In light of recent development in the area of fully eVTOL vehicles, air taxi service could offer a faster and reliable transportation mode in the future. It will fundamentally alter the constraints and objective functions that bound the current aircraft design and concept of operations (Moore and Goodrich, 2013; Rajendran and Srinivas, 2020; Polaczyk et al., 2019; Pradeep and Wei, 2019).

Nevertheless, how the UAM business will develop in the future is still high uncertain depending on the large number of interrelated factors Hansman and Vascik (2016), Vascik (2017), Al Haddad et al. (2020) and Straubinger et al. (2020b). As discussed, the UAM ecosystem consists of a large number of public and private actors who need to establish different forms of cooperation agreements to capture values. The future UAM development will pave the way for a variety of business models, confronting a wide array of policy, financial, and marketing challenges. Among others, Nneji et al. (2017) as well as Hansman and Vascik (2016) emphasise the relationship between service operators and the vehicle owners as the two most prominent market actors who can establish different levels of ownership structure. In addition to service operators, Straubinger et al. (2020b) identify the other market actors and provide some insight into potential collaboration and vertical integration between them. The development of the business models with the UAM concept significantly depends on the understanding of the future pathways and possible scenarios which assumes different levels of market size, availability to the public and integration in the current transportation systems. Moreover, Stocker and Shaheen (2018) emphasise the relationship between the automation level of the vehicles and the potential business models. Reiche et al. (2018) identify the three most challenging "use cases" for future urban air mobility around which business models will develop: last-mile delivery, air metro and air-taxi. Similarly, Baur et al. (2018) distill three main use cases for UAM service: air taxis, airport shuttles and intercity flights — each characterised by specific technological and operational requirements. For instance, Michelmann et al. (2020) considered a variety of environmental factors influencing the development of UAM to define the future scenario framework. Similarly, Baur et al. (2018) distilled three main use cases for UAM service: air taxis, airport shuttles and intercity flights — each characterised by specific technological and operational requirements. Among others, Michelmann et al. (2020) consider a variety of environmental factors influencing the development of UAM to define the future scenario framework. Finally, Cohen and Shaheen (2021) integrate the findings from different sources and proposed three UAM market segments prevailing in the near future among which passenger mobility segments can be realised through five different service models including personal aircraft, air pooling, air-taxi, semi-scheduled and scheduled service.

Leveraged by the study of Michelmann et al. (2020) and taking into account the studies of Cohen and Shaheen (2021) and Reiche et al. (2018), the authors analyse in detail three different scenarios for future UAM concept development yielding totally different business models in terms of targeted customer segments and cost structure.

In order to describe the emerging business models underpinning each of the three scenarios proposed, the methodology developed by Boons and Lüdeke-Freund (2013) will be applied. The methodology also found its broad application in the shared mobility space (Cohen and Kietzmann, 2014). The business model framework consisting of four building blocks: a value proposition, supply chain, customer interface, and financial model (see Table 2). The framework is complemented by the information on the market segments (i.e. customer groups) targeted by each specific scenario.

In the light of the first scenario, which envisions UAM as part of MaaS, the UAM service provider's business model will be probably integrated into the broader UAMaaS business model in a specific city or region. It will restrict the UAM provider to be engage in a smaller part of the value chain comprising mainly flight operations and booking system. The UAM will complement the other means of public transport by providing convenient and low-price service to a large scale of market segments covering mass market customers as well as the premium segment for both business and leisure purposes. This business model is featured by high handling, landing and ATM costs as well as intense capital costs, whereas labour costs remain particularly low due to a high level of automation of the vehicles.

The operation within the second scenario is very similar to the current air-taxi helicopter service mainly connecting city centres and airports. The concept also foresees the inclusion of secondary cities and smaller towns in the future air-taxi network. According to Goyal et al. (2021), these two missions could capture 0.5% of mode market share. The main competence of the UAM provider will be bounded to flight operations and service and support (i.e., technical maintenance, repair and checks). The cost structure of the given concept will still have a higher energy cost compared to UAMaaS concept as production costs of sustainable fuels that drive the air-taxi vehicles are still higher compared to electrical propulsion. In addition, the crew costs will also be higher compared to the previous concept, but still lower than today's helicopter service mainly due to the fact the vehicles, although completely autonomous, need the supervision of a "non-piloting" operator. The service offered is on-demand targeting mainly the premium market segments for both travel purposes with the aim to feed the current airline network at specific airports. Thus, various forms of partnership between air-taxi providers and network carriers may emerge in the future. Among several possibilities, air-taxi service subsidiaries created by network airlines is deemed as promising undertaking. The concept is similar to the existing trend in the airline industry called "airline-within-airline", in which network airlines create lower-cost subsidiaries to retain market dominance (Morrell, 2005; Pearson and Merkert, 2014).

Finally, the third scenario is built on the business model that is focused on a high luxurious customer-tailored air-taxi service. The scenario only includes the thin portion of the premium market covering high-income individuals for both leisure and business purposes. The air service is assumed to be operated by the vehicle manufacturer itself. This means that the operator will be engaged in a large part of the value chain comprising design, development and production of the vehicles in addition to the activities such as maintenance and flight operations. Consequently, the capital costs will constitute a large share of direct operating costs. On the other hand, due to thin market shares, the operator will not be able to reach the economy of scale for further research in vehicle

Table 2
Emerging UAM Business Models.

Segment	Value proposition	Supply chain	Customer interface	Financial model	Customer segment
Urban Air Mobility as a Service	Promotes using the public transportation and reduces emissions and traffic congestion	The integration of UAM into public transport system through high levels of inter-modality	Dedicated mobility platform (app booking system)	Probably highly subsidised with low fees for users	Demand from the premium sector as well as from the mass market, by targeting commuters, families, people with reduced mobility and also business travellers, from low to high income
Urban air-service on-demand service	Promotes using the taxi service mainly to reach airport and avoid traffic congestion	The integration of UAM air-taxi service into airlines' network	Dedicated mobility platform (app booking system)	Subsidiary of large service carrier with medium fees for users	Business and leisure travellers, as well as tourists from higher income groups the service offer rather targets a smaller premium market.
High luxury UAM service	–	No integration with public transportation	Dedicated mobility platform (app booking system)	Probably private aircraft-owned companies with high fees for users	High-income travellers that value an exclusive and fully personalised service.

design and development. This may trigger the future cooperation through public–private partnership in the area of research and development.

UAM- related technologies are currently in the focus of a variety of firms, from startups to well established aerospace companies. All these market players endeavour to derive the opportunities of this emerging market through demonstrator projects, like the one described in eVTOL (Vertical Flight Society, 2020), at different areas of research and development. According to the GreenBiz journal publication (Downing, 2019), the number of electric aircraft in development worldwide has increased by 50 per cent since 2018, with around 200 electric aviation companies currently operating with more than $1 billion of investments. Possible operational concept underpinned by the technological progress on these companies (see e.g. Hansman and Vascik (2016), Holden and Goel (2016), Kopardekar (2017), Liu et al. (2017), Nneji et al. (2017), Schuchardt et al. (2015) and Vascik (2017) will provide the opportunity for a variety of business models serving as a pillar to the successful introduction of different UAM concepts.

8. Industry

Passenger transport UAM is creating a lot of interest, not only at the research level. Companies like BOEING and AIRBUS, the two major aircraft manufacturers and integrators worldwide, are working on the field. UBER, the mobility service provider, is also working towards its implementation.

BOEING has also developed a flying prototype called PAV, for Personal Air Vehicle. It is an all-electric autonomous passenger air vehicle. The first test flight was performed in mid-January 2019 in the test site in Manassas, Virginia, USA. The prototype is a vertical take-off vehicle with wings for an efficient forward flight. The vehicle range is about 80 km, and its size is about 9 m long and 8.5 m wide. The company is also investing in the UAM start-up. To mention an example, in June 2019, BOEING invested in MATTERNET, a California-based start-up.

AIRBUS and its innovation hub A^3[4] are also working on UAM. The innovation work is not limited to the development of Vahana, a VTOL aircraft with rotating wings for an efficient forward flight. The company presented the "City Airbus" prototype in March 2019. The City Airbus vehicle performed a first take-off in May 2019, a first untethered flight in January 2020, and a first full autonomous flight in July 2020 (AIRBUS, 2017, 2018, 2021). A^3 is also developing the Wayfinder project, mainly focused on the scalable and certifiable autonomy systems to enable autonomous flight. It is worst to mention VOOM (AIRBUS, 2016), a subsidiary company of AIRBUS. It was offering helicopter-based transport services in São Paolo (Brazil), Mexico City (Mexico) and Los Angeles (USA) (Lewis and Magalhaes, 2017; Subramanian, 2018). VOOM ceased its operation in March 2020 (Monnet, 2020), but one of the outcomes of offering those services was to obtain a better understanding of the commuting and mobility preferences, with views to future implementation of UAM services. A similar experience is the one provided by Helipass (Helipass, 2020), which is offering helicopter-based transport services in a large number of cities worldwide.

AIRBUS company is also working hard on the assessment of related technology and services. It provides free access to the Airbus UTM Library,[5] which contains the positioning paper (Balakrishnan et al., 2018), and other small reports related to the introduction and deployment of UAM services. An interesting example is a Community perception study (Loubière et al., 2018). What is interesting from the AIRBUS' positioning paper is the comparison it makes regarding the UTM schemes in 4 regions, namely China, Europe, Japan, and the USA.

BELL Aerospace Corporation,[6] belonging to TEXTRON Corporation, is also working on the subject. Although it is not a positioning paper, a representative of the company provided a speech in the Congress of the USA describing the position the company takes on

[4] www.airbus-sv.com
[5] www.utmblueprint.com/library
[6] www.bellflight.com

Table 3
Summary of UAM vehicle performances.

	Mean	Maximum	Minimum
Payload (kg)	225.9	816	2
Pax Capacity	3	6	1
Max Gross Weight (kg)	1169.6	5900	11.5
Number of Rotors	8	36	1
Engine Output (kW)	39.2	125	0.8
Total Output (kW)	452.7	2790	4.8
Battery Density (Wh/kg)	210.0	300	140
Battery Capacity (kWh)	69.2	320	9.6

regards UAM (Thacker, 2011). Its expertise in the design and production of helicopters makes the development of PAV a clear step forward, and the company already produced some conceptual designs.

UBER also positions itself in the field as a game-changer and its white paper Holden and Goel (2016) provides a review of the prototypes in development, including the first assessment of their capabilities.

The mentioned companies are big international ones, but other players are also present in the field. It is worth to mention VOLOCOPTER,[7] which is developing an on-demand service using the Volocopter VC200 vehicle. This vehicle is a redundant multi-copter, all-electric, and autonomous. Another good example is the company EHANG,[8] which comes from the drone industry, already produced an autonomous air vehicle with passenger transport capabilities. The vehicle, called Ehang 184, made its first flight in November 2017.

Tecnalia,[9] a research centre in Spain, presented in July 2019 a single-seat multi-copter. Thanks to their own experience in drone design and operation, its proposal is interesting because the stability of the aerotaxi is obtained through the movement of the rotors, which partially tilt when necessary. Those are a few examples that such devices are creating much interest. The list of companies and prototypes is growing fast.

A good source of information was the talk by Prof. Bülthoff, from Max Planck Institute (Bulthoff, 2017), where he described not only the research and industry involved in the development of UAM vehicles but also the research performed in the MyCopter project. Prof. Bülthoff is the former coordinator of that European project,[10] a publicly funded project through the 7th Framework program of the European Commission. The project produced a massive amount of information about the flying requirements of Personal Air Vehicle. A first report about the project can be found in Jump et al. (2011), while complete descriptions can also be found in Decker (2011), Decker et al. (2013) and Nieuwenhuizen et al. (2011).

Both Brelje and Martins (2019) and Polaczyk et al. (2019) are defining a vehicle categorisation, while providing performance and technical data. The list of vehicles includes several types, from multi-rotor, tilt-rotor to a flying car, cargo and passenger vehicles, and other categories. The paper shows an interesting but limited collection of performance data, which cannot be further updated with the available data so far. Not all the manufacturers have publicly disseminated the data for their vehicles, while others are still developing the vehicles, so the data is at the prototype level. In any case, it is interesting to summarise it here; Table 3 provides an overall summary of the available data. Although the scarce data available, it is interesting to see the differences between total output, showing that electric vehicles have still a long way to run to fulfil power requirements for large vehicles and/or heavy payloads.

The list of companies and, mainly, prototypes is large and continuously changing. A good reference to keep updated is the eVTOL web page.[11] eVTOL is a web page by the Vertical Flight Society (VFS), the former American Helicopter Society (AHS). It provides news about companies and aircraft under development. It includes two directories, the first one about companies and the second one about aircraft, some already defunct. The directory rarely includes the aircraft specifications.

Not only companies are showing their interest in UAM. Also, cities like Dubai and Singapore, São Paulo or Mexico DF, to mention a few of them, are interested. The reader can identify these cities as big metropolis that are already facing congestion and mobility problems.

9. UAM challenges and conclusions

While studies surrounding UAM dramatically grow tackling a variety of aspects from vehicle design, propulsion technology, network design, ATM, regulatory development and public acceptance, there is a persistent need to further understanding the future UAM prospects. To facilitate the in-depth analysis, the consolidation of the findings from the various disciplines of research, while overwhelmingly demanded task, was briefly summarised in Fig. 1. The study mainly deals with UAM-based passenger transport by reviewing numerous academic papers, technical reports and studies related to UAM. In addition, the paper also attempts to make a

7 www.volocopter.com
8 www.ehang.com
9 www.tecnalia.com
10 www.mycopter.eu
11 evtol.news

link with other novel ground-based mobility concepts such as e-hail/transportation network companies in order to understand the barriers for their successful integration. For the UAM concept to become fully doable in reality, a broad range of requirements are identified that have to be efficiently fulfilled. The paper analyses UAM needs with regards to technological, mobility and societal aspects, including business models and regulations as a transversal activity that needs to be developed in a continuous manner. The analysed aspects have been considered to be the most relevant items based on the extensive review.

The paper clearly states the relationship between the unmanned aerial vehicle (drone) technology and UAM development. The recent implementation of drones in last-mile deliveries will pave the way for future implementation of UAM passenger transportation as some lesson learnt from the former concept can be directly translated to the latter one. However, both concepts will have their own distinct characteristics and challenges. The common list of technologies and implementation issues is a long one: autonomous flight, airspace integration, low altitude flight over urban areas, noise, or social acceptance are some of them, while, on the other hand, integrating vehicles of different size and performance, a different type of missions, different operation and business models into low-altitude airspace, over the urban area are some of the distinctive challenges. Nevertheless, both freight drones and UAM passenger transportation require to continuously mature several technologies and concepts. The assessment of the future UAM development is very hard to perform due to the various forms of uncertainty persisting around different technologies as well as the concepts that are currently being envisioned. Focusing on our case of interest, namely passenger transport, the definition of the vehicle configuration will open the door to determine the definition of a large number of items, from the size of the TOLA to the noise footprint. In addition, the vehicle configuration may substantially influence the definition of the business models for each market actors, providing a large opportunity for market collaboration and vertical integration between different stakeholders. These multiple operational scenarios add a challenge with respect to airspace usage. Some authors introduce UAM as a breakthrough in urban mobility, presenting it as an ultimate solution to the ubiquitous problem of congestion in urban areas. However, the success of UAM to efficiently cope with this problem will highly depend on the ability of vehicles to offer enough capacity in terms of both passenger seats per journey or/and total passenger per hour. Further analysis on the trade-off between costs incurred to offer a service and number of passengers transported per time unit, in comparison to the conventional mode of public transportation (e.g., bus or train) should be done. Even considering inter-urban connections between cities or areas with a lack of existing connections by road or train, a careful analysis should be performed assessing the costs of infrastructures, operational costs, capacity and demand to clearly understand the potential benefits coming from UAM. The challenge of designing cheap vehicles with lower operational costs is, then, paramount to ensure the success of this new mean of transport.

While the operational framework for drones progresses at a rapid pace, UAM-based passenger transport is still at a very premature level. European-funded CORUS and CORUS-XUAM projects, and AAM Mission in USA are nice examples of the ongoing effort to pave the way for sharing current airspace use with drones. As broadly discussed in the paper, in order to derive its full potential in the form of ODM service or even MaaS, UAM passenger transport concept requires the further maturation of vehicle-related technologies, propulsion systems, and electrical power source, autonomous flying vehicles, noise and down-wash footprint. It also requires low operational costs and ATM strategies for the high-density occupation of the airspace, communications technologies enabling high broadband transfer of information for vehicle-based or automated ATM procedures. Air operations should also be considered because operational procedures can be largely determined by the vehicle configuration but also by its performance. The operational capabilities of the vehicle will affect not only the procedures but also the TOLA configuration, which is also affected by the supply requirements (e.g., electric charge, battery replacement, etc.), and passenger processing (boarding, disembarking and waiting). All these technologies, added to global and local legislation and regulation, will enable specific types of services, and business models. Further research on the vehicle and its integration to airspace is required. This research should not only take the experience from drones but also consider already the characteristics of larger and heavier vehicles for UAM passenger transport. Research dealing with mobility-related issues, like On-Demand mobility or Mobility as a Service applied to UAM, can easily benefit from the on-going research about ODM and MaaS for ground transportation. Infrastructures have received little attention, and it is not clear that existing infrastructures will enable the safe operation of VTOL vehicles. In any case, the topic is attracting large interest from many stakeholders, so it is likely that it will continue to grow and mature.

CRediT authorship contribution statement

Jordi Pons-Prats: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Tanja Živojinović:** Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. **Jovana Kuljanin:** Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing.

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