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ORIGINAL ARTICLE

Fostering UAM implementation: from bibliometric analysis to insightful knowledge on the demand

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Abstract
In the current era, a new class of lightweight, silent, and all-electric aircraft that can take off and land vertically is about to transform mobility in major urban centers. Safer and quieter than helicopters, and operating in some cases without a pilot, they can supplement land mobility. Indeed, urban air mobility (UAM) has recently been a hot topic for debate and scientific research. However, it requires new types of service and technology and a novel business model. For a successful implementation, this paper provides the most insightful knowledge and actors, focusing on demand assessment through current research advancements in the area of urban air mobility. For that purpose, bibliometric analysis has been conducted, using a four-step methodology based on the search of the most frequently used keywords. The research work investigated the needs of the main stakeholders and illustrated how UAM can mitigate the pressure put on decision-makers regarding the mobility demand. The results show recent trends in scientific publications and citations, most cited articles, countries, and organizations that are more involved in this research subject, keyword co-co-occurrence analysis to identify and analyze current research areas and their associated barriers and challenges, using the VOSviewer software and WoS analytic feature.

Keywords Urbanization · Urban mobility · Multi-dimensional urban mobility · Urban air mobility · eVTOL · Bibliometric analysis

1 Introduction

In recent years we have been witnessing, the rapid growth of urbanization is posing a major challenge to the world. An alarming increase in population growth, transport, economic, social, and environmental problems are becoming more acute across the globe in "Mega Cities" (UN 2020). Industries were welcomed to these cities since they knew the cities could hold their workforce and provide a healthy environment for both the workers and the enterprises. Then, with these advancements, came the increasing human demands, e.g., food, health, housing, education, security, climate change, and urban mobility, etc. The economic attractiveness of cities has thus generated, through the ages, a rapid increase in the urban population, leading policymakers to rethink mobility to cope with the density of traffic, infrastructure renewal, sustainable development, and safety of the passengers.

The regular commute of an increasing number of people will become more difficult as urbanization continues to increase demand and traffic volume. In this context, convergence tends to shift toward the use of digital platforms offering a variety of services, on-demand, more adapted to the immediate needs of users. Through intelligent mobility, the renewal of urban mobility has indeed brought out alternatives to usual travel, giving way to soft mobility, the reasoned use of personal vehicles, multi-modality, and international mobility. In addition to digital convergence, tariff convergence also appears to be a key factor in a successful

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implementation (Jittrapirom et al. 2017). However, the expansion of terrestrial networks to comply with the new needs and constraints is beginning to show its limits and suggests the conquest of the air to diversify the mobility offer, as is already done in some large cities that have introduced an air transport mode (helicopters, small carriers, drones, etc.), for the transport of both humans and goods.

Urban mobility stakeholders are now adopting a new paradigm urban air mobility (UAM), a third-dimensional urban mobility mode that will complement or integrate with two-dimensional urban mobility modes to address the above-mentioned concerns. The contribution of this work provides a useful insight to urban mobility stakeholders, i.e., scientific community, solution providers, public authorities as well as users in their decision-making process. This bibliometric analysis will highlight the important research areas, barriers, and challenges available in the scientific literature and give some guidelines for future research and successful implementation.

The rest of the paper is structured as follows: Sect. 2 devoted to the literature review summarizes the overall context of this research work that motivates to solve the general concerns related to urban mobility, and proposes definitions, examples of solutions, and concepts behind UAM operations; Sect. 3 provides a four-stage methodology adopted for the proposed bibliometric analysis, while Sect. 4 shows the main research results and detailed analysis of several UAM research areas, the associated barriers, and challenges for UAM implementation. Finally, the last section concludes the findings and suggests some perspectives of the present research work.

2 Literature review

In this section, we summarize the general context and motivation of the research work and briefly present a solution we propose to address common urban mobility concerns, along with useful definitions, concepts, and examples from the literature.

2.1 Context and motivation

A report regarding urbanization has shown that a growing percentage of the population is concentrated in urban settlements and that cities have predicted to expand their share of the world population from 52% in 2010 to 66% by 2050 (Audenhove et al. 2018). In addition, a United Nations (UN) report presented that megacities were a solution to the ever-growing needs of the population developed, with hopes of economies of scale, both for the governments and the businesses in various domains such as construction, manufacturing, supply chain, etc. (UN-Habitat 2020). Studies on urban mobility predict a growing demand, especially in terms of passengers and goods in future: according to Audenhove et al. (2018) in the year 2010, a trillion passenger-km mobility demand is 25.8% that will be 48.4% in the year 2050, almost double in the percentage of current demand, and urban goods mobility demand is 9.5% in the year 2010 and will be 28.5% in the year 2050, and it is almost triple in the percentage of current demand. Such rapid growth of urban mobility demand introduces a range of urban mobility concerns, such as traffic congestion, infrastructure, passenger safety, and environmental pollution.

Urbanization creates a lot of traffic-related problems and congestion has proved to be a significant concern. A recent study on road traffic congestion measures toward a sustainable and robust transportation system and results showed that traffic congestion costs the USA about 2.9 billion gallons of fuel and more than 121 billion dollars each year (Qiao et al. 2021). Commutes will then become more challenging if the number of vehicles continues to rise while the road system and parking areas remain unchanged. However, the problem of congestion cannot be eradicated by merely initiating infrastructure projects, such as bridges, roads, railway networks, etc. Technology has evolved as a tool to solve human problems and making lives easier, and it is greatly helpful in reducing congestion by better utilizing existing transport infrastructure.

A report on important challenges in transportation indicated that infrastructure is one of the main concerns in the urban mobility sector and that most other issues are dependent on first fixing this critical issue. There is a chain of railway networks, roads, footpaths, airports, and other infrastructure projects which facilitate transportation needs to be planned according to the projected needs of each community.

Energy consumption has colossally enhanced due to urban transportation. Consequently, pollution has increased. Coupled with vexing noise, pollution has rendered the life of urban people miserable as it is gravely injurious to their health (Ortego et al. 2017). In Europe for instance, pollution kills 600,000 people and the government expends more than 1600 billion dollars every year, while negative impacts on the environment such as emission of CO_2 and pollutants and noise nuisance are caused by urban mobility.

Often, the more congested the traffic in urban areas is, the more accidents, injuries and deaths are probable. According to Kiba-Janiak and Witkowski, many accidents take place due to an increase in traffic (Kiba-Janiak and Witkowski 2019). Some countries have experimented with rules like allowing only a specific segment of cars (e.g., cars with odd or even registration numbers) on roads on certain days. Nevertheless, there is also a decreased sense of safety among the commuters to follow these rules.

Thus, above-mentioned concerns put a different kinds of pressures on public authorities while making policies as illustrated in Fig. 1. End-users, for example, wish to travel for education, job, and leisure. Therefore, they want on-demand transportation, quick and innovative commute options, and personalized services. Mobility providers include public and private transportation operators, as well as technology providers, who invested their money in providing solutions expect a return on investment (ROI). They are also asked to rethink their business model to meet the requirements of the demand increase. To fulfill these needs, several pressures can occur, such as land utilization (scarcity), infrastructure renewal and maintenance, and new construction (roads, bridges, railway stations, and airports). Thus, as a supervisory and regulatory body, the public authorities must determine which partnerships and regulations to implement, as well as which services to provide and in what manner. Urban mobility causes negative impacts on the environment such as emission of CO_2 and pollutants and noise nuisance. As a result, public authorities are more focused on reducing these pressures, especially in the context of sustainable development.

The expansion of terrestrial networks to meet the new needs and concerns mentioned above is beginning to show its limits. The authors of this study then advocate the conquest of the air to diversify the mobility offer and define new business models for the mobility of the future, which requires understanding how UAM operates, what are the main challenges to address, and the barriers to cope with, to ease the burden on ground-based transportation networks. Few large cities have already initiated air transport mode (helicopters, air taxis, drones, etc.), for the transport of both humans and goods, but on a relatively small scale. As urban mobility stakeholders progressively embrace the new paradigm (UAM), a third-dimensional urban mobility mode that will complement or integrate with the existing two-dimensional urban mobility, decision aid is required to lessen pressures put on public authorities. In the following section, we explain the paradigm shift from 2 to 3D mobility, along with the presentation of the main associated concepts.

2.2 Definitions and concepts related to UAM operation

In this section, we will first identify and highlight the most often used definitions of UAM available in the literature, then describe the main concepts behind a UAM operation.

According to Thipphavong and co-authors, “Urban Air Mobility (UAM) is an emerging concept of air transportation using quiet and efficient manned and unmanned vehicles to conduct on-demand, scheduled operations, e.g., emergency medical evacuations, rescue operations, humanitarian missions, newsgathering, ground traffic flow assessment, weather monitoring, package delivery, and passenger transport”, whereas Airbus goes beyond the conceptual view and precise that UAM a kind of vehicle: “an aerial vehicle concept for passenger transportation offer a more reliable and more environmentally desirable alternative to reduce congestion on transport networks” (Poulton 2017). As an outcome of these definitions, focusing on the urban mobility concerns presented previously, we consider UAM as the third dimension of mobility, which is a highly efficient solution for the traffic issues of cities in which two-dimensional capacity cannot cope with the exponentially increasing number of vehicles and subsequent accident frequency and pollution therein.

Traditional UAM operation is depicted in Fig. 2, which can be used to characterize the process of a multimodal UAM service. The associated platform enables on-road auto rides for the first phase of the journey, namely drive from the pickup site to a vertiport/vertistop (the field intended for the take-off of helicopters and short take-off planes). Passengers

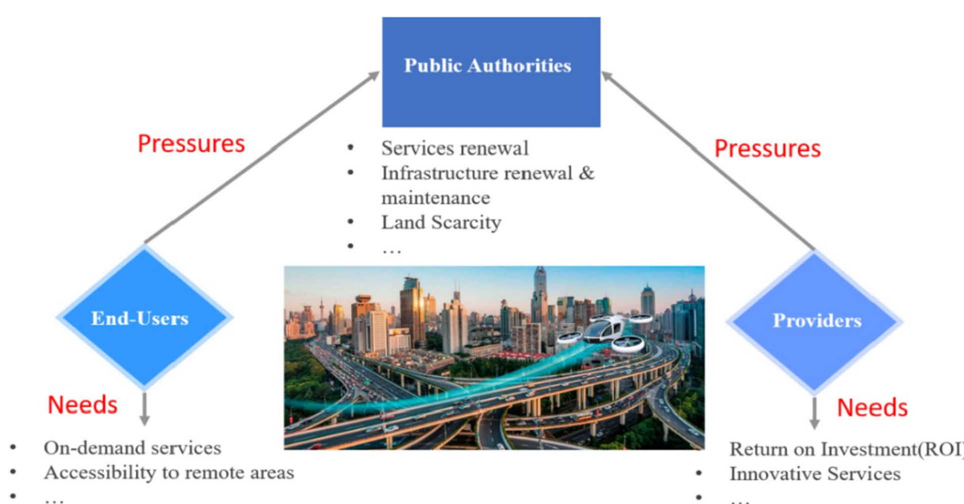

Fig. 1 Needs of urban mobility stakeholders that put pressures on public authorities

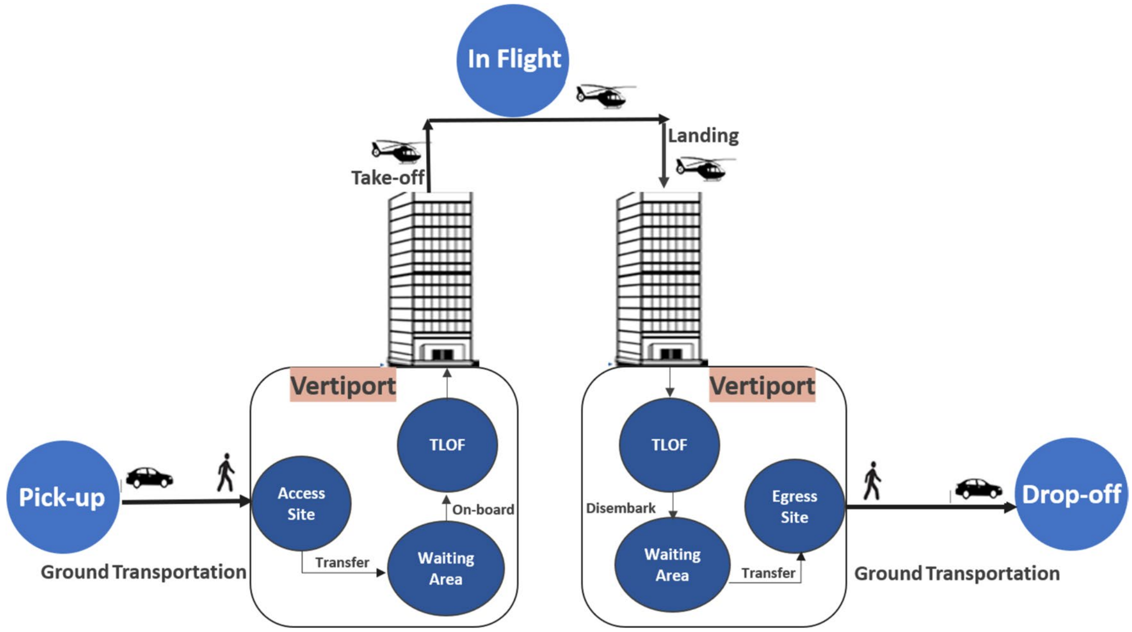

Fig. 2 Concept of UAM operations adopted from Wu and Zhang (2021)

will then be able to switch from/to ground transportation at each vertiport's access and egress sites. Each vertiport has a boarding, disembarking, and touchdown space, as well as a landing and take-off area. As part of the multimodal service operation, passengers will first travel by ground transportation to their designated vertiport. They will be sent to waiting rooms after arriving at a vertiport, where they can wait for a short period before boarding via corresponding gates. After reaching a certain height, the aircraft will take off from a vertipad and cruise to another vertiport. Passengers must then go through a similar transfer procedure when the plane lands at the destination vertiport's vertipad before boarding ground transit to their destinations (drop-off) (Wu and Zhang 2021).

Based on the definitions and concepts provided in this section, we present in the following an overview of some examples of historical and current UAM services.

2.2.1 Definitions and concepts related to UAM operation

In this section, we explore some prior and recent examples of UAM services. Let us mention that UAM is not a new notion. The novelty of the paradigm is to bring it in the field of mass transportation, which induces many technological, social, economic, and environmental challenges that the present research work tries to structure in a simple and meaningful manner.

Indeed, examples of UAM services using helicopters date back to the 1940s. Los Angeles Airways used helicopters to transport people and mail across the Los Angeles area from 1947 to 1971, including between Disneyland and the Los Angeles International Airport (LAX). In 1968, Los Angeles Airways had two incidents due to mechanical failure, and the company was forced to shut down (Harrison, 2017, as referenced (Thipphavong et al. 2018). New York Airways also used helicopters to transport passengers between Manhattan locations and the three major airports in New York City from 1953 to 1979. This service, too, was terminated due to a series of mishaps caused by mechanical failure (Witken, 1979, as referenced in Thipphavong et al. 2018). These early UAM operations were active for over two decades before being shut down due to safety concerns; this explains the reason why we have highlighted urban mobility concerns in our definition of UAM. Besides, these historical examples demonstrate the potential importance of similar (although safer) UAM services to customers today. More importantly, however, essential rescue services can benefit in emergencies such as flood, fire, or medical emergency, etc.

Many authors acknowledged that UAM has the potential to safely and easily integrate with current urban mobility services. Several recent examples are available. For instance, Airbus revealed “EMS Airbus” for emergency medical services. The “EU-Funded AiRMOUR” project lays the path for manned and unmanned emergency medical services to fly in the air (Poulton 2017). In turn, “Air Insight Group Services” used drones for delivery and “Uber Copter” to provide Flights from Lower Manhattan to JFK. The usual cost of an 8-min one-way flight is between $200 and $225 per person, which includes private ground transportation on both ends of the journey (Uber Copter to Offer Flights from Lower Manhattan to J.F.K.—The New York Times, 2019).

In Europe, the UAM initiative is being supported by the Commission (2018) as part of the European Innovation Partnership in Smart Cities and Communities (EIP-SCC), while the US National Aeronautics and Space Administration (NASA) is developing a framework to integrate UAM airspace studies in the USA to encourage other partners and stakeholders to collaborate on their studies to increase understanding and knowledge base of the research findings (Thipphavong et al. 2018).

As UAM is a new study area with a lot of potential for expansion, it's critical to assess existing scientific research contributions in the literature to develop an efficient business model. To that end, the adopted methodology will be framed in the following section. The resulting analyses are intended to provide stakeholders with useful insights to assess UAM demand, based on current research trends and associated barriers and challenges.

3 Research methodology

In this section, a four-step methodology is adopted for an assessment of UAM current research trends, based on searching the most frequently used keywords, as suggested in Tomaszewska and Florea (2018): (i) selection of the research criteria, (ii) definition of the search period and the type of document, (iii) bibliometric analysis, and (iv) analysis of co-occurrence.

1. Selection of the research criteria. At this step, we search for scientific articles recorded in the Web of Science database (WoS), combining the most relevant keywords related to the topic, i.e., urban air mobility, air taxi, air ambulance, emergency evacuation air service, medical emergency air service, eVTOL (electric vertical take-off and landing), on-demand urban air mobility, manned air vehicle (MAV), unmanned air vehicle (UAV). These keywords were combined using the logical operator OR, along with double quotes, and * asterisk operator to get more accurate required results.
2. Definition of the search period and the type of the document. At this stage, we have chosen the range from 1975 to 2021. We found 1,012 documents in the WoS core collection database, and the resulting search showed that the first article was published in 1979 with the title "HELICOPTER AIR AMBULANCE IN A RURAL-COMMUNITY" in an "EMERGENCY MEDICAL SERVICES" Journal, written by Hill, Martin P. Then, we exported these full records and cited references into CSV file format.
3. Bibliometric analysis. At this step, using the file obtained previously as input, we used both WoS and VOSviewer analytical tools for further comprehensive analysis, i.e., count of publication year-wise, a sum of citations year-wise, the most popular subjects in articles, countries, and organizations which are more active in this research area and current research areas associated with UAM, etc.
4. Analysis of co-occurrence. At this step, using the same input file, we used the VOSviewer software. As a network visualization and exploration software tool, it allows users to construct maps based on network data. Indeed, the software assists in the creation and visualization of a map of keywords, as well as the links between them, taken from the volume of scientific publications in the input file (extracted from the WoS database). Networks of scientific publications, journals, researchers, affiliations, countries, keywords, and concepts are all examples of constructed maps. Co-authorship, co-occurrence, citations (including co-citations), and bibliographic connections can all be used to connect items.

After applying this methodology, we obtained several useful and interesting insights, which are discussed and analyzed in detail in the following section.

4 Results and discussion

In this section, we present the key results of the study and a detailed analysis of several UAM research areas, the associated barriers, and challenges for UAM implementation. We will first start with the main tendencies presented in the next sub-section.

4.1 Main tendencies of the UAM research activities

It is worth mentioning that the majority of authors consider UAM as a new and untested concept. Figure 3 clearly shows that the trends of scientific publication are increased exponentially in recent years. When the number of papers published in each successive year is analyzed, a modest rise in interest can be seen after 2001, and a substantial increase after 2015. Since 2015, the number of articles in the WoS database on the studied topic has surpassed 50 practically every year and has exceeded 100 in the last three years. It is noteworthy to note that in the first five months of 2021, there have already been over 50 publications.

As a result, Fig. 4 illustrates the sum of citations also increased as the number of publications increased over time. Only in 2020 will it have about 1200 citation indexes, indicating a strong research collaborative culture in this field. It is interesting to note that there have already been over

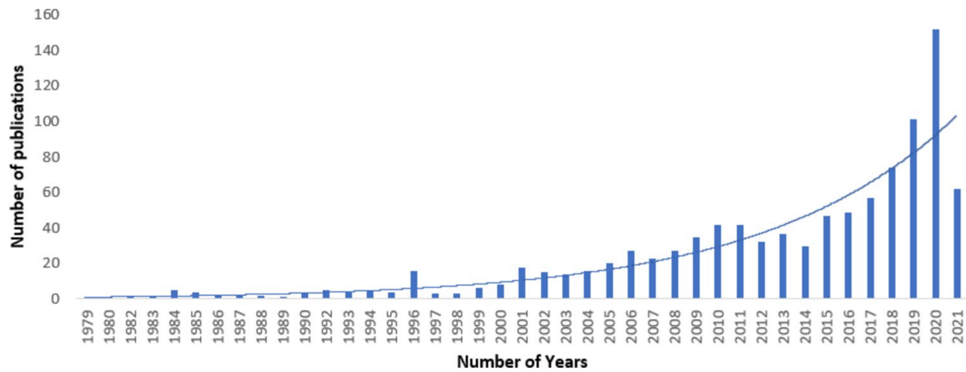

Fig. 3 Publications year-wise

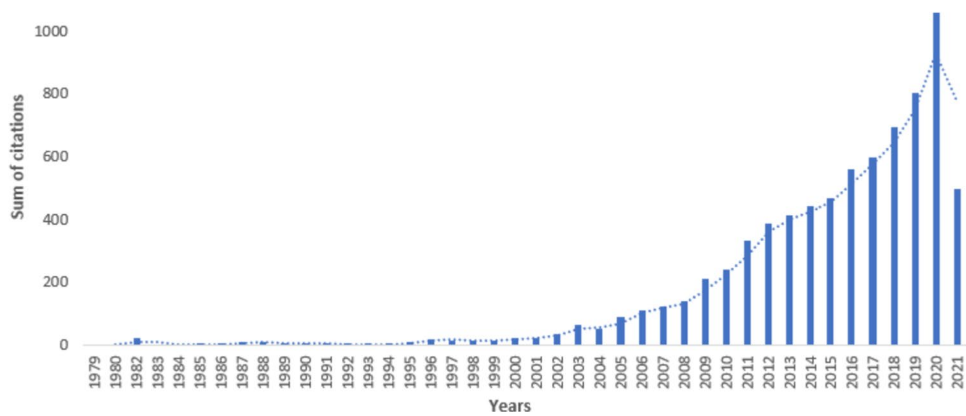

Fig. 4 Sum of times cited by year

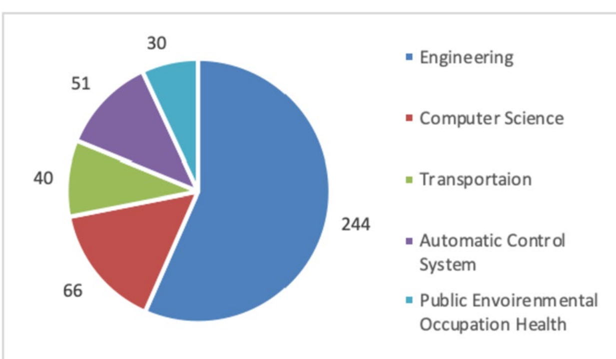

Fig. 5 The top 5 fields of research

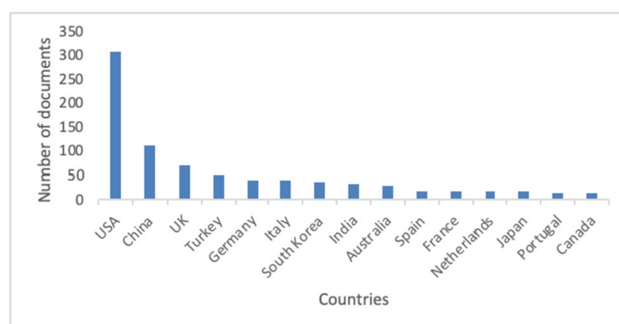

Fig. 6 Top 15 countries and regions

400 citations in the first five months of 2021. Although the total number of publications in the studied topic is relatively small compared to other areas of research, it is clear from the above trends that the subject is gaining in importance, offering real opportunities to leverage the potential of investment.

Figure 5 shows the five most common study fields of publications, which shows that this is an interdisciplinary research topic. "Engineering" is the most predominant field, with more than 200 articles, followed by "Computer Science" and "Automation control systems" (over 50). Surprisingly, "Transportation" is not the predominant field of research; this shows that UAM development is not just a matter of mobility offers or services, and requires addressing multidisciplinary challenges and barriers (as stated above).

Figure 6 illustrates the top 15 countries and organizations that are actively engaged in research activities in the field of UAM. The graph shows that the USA is currently ahead of the rest of the world. However, including China, the United Kingdom, Turkey, Germany, and other European and Asian countries, are cognizant of the relevance and importance of this research subject and are following the lead of the United States.

Figures 7, 8 show the list of the top 10 institutions which are enthusiastically participating and investing funding to promote scientific research in UAM: most of the organizations actively involved in this field are situated in the USA (e.g., NASA and Johns Hopkins University).

In Table 1, we present the top 5 cited papers about their respective domains and highlight the main issue that has been addressed.

Once again, transportation issues are not among the topics addressed in the most cited articles. Rather, specific domains such as unmanned air vehicles, emergency, energy conversion, UAV location optimization, and health are those that are more addressed. This demonstrates the multidisciplinary and complexity of UAM development, which requires appropriate guidance for successful implementation, as envisioned in this research work.

We then created a keyword co-occurrence map using the VOSviewer software network visualization feature to analyze the current research areas, as described in the next sub-section.

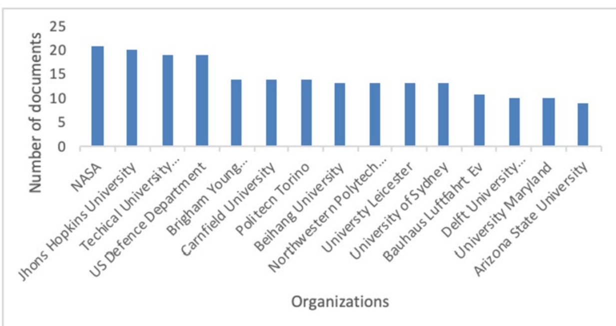

Fig. 7 Top 10 organizations

4.2 Current research areas

Figure 9 shows the keywords' relationships of the scientific publications related to the studied topic. With the text mining functionality of VOSviewer, it is possible to create co-occurrence networks of relevant terms collected from a corpus of scientific literature. The software can assist in grouping the analyzed data into clusters, allowing the main study areas in UAM to be identified; it can also group keywords into similar clusters, each with a specific color.

Figure 8 illustrates UAM research trends using the VOSviewer software overlay feature to analyses research trends over the period between 1979 and 2021. The timeline for colors is shown at the bottom left of the illustration. Before 2015, it was light blue, blue, light green, and green, and during this period, accidents, flight controls, surveillance, emissions, numerical simulation, real-time systems,

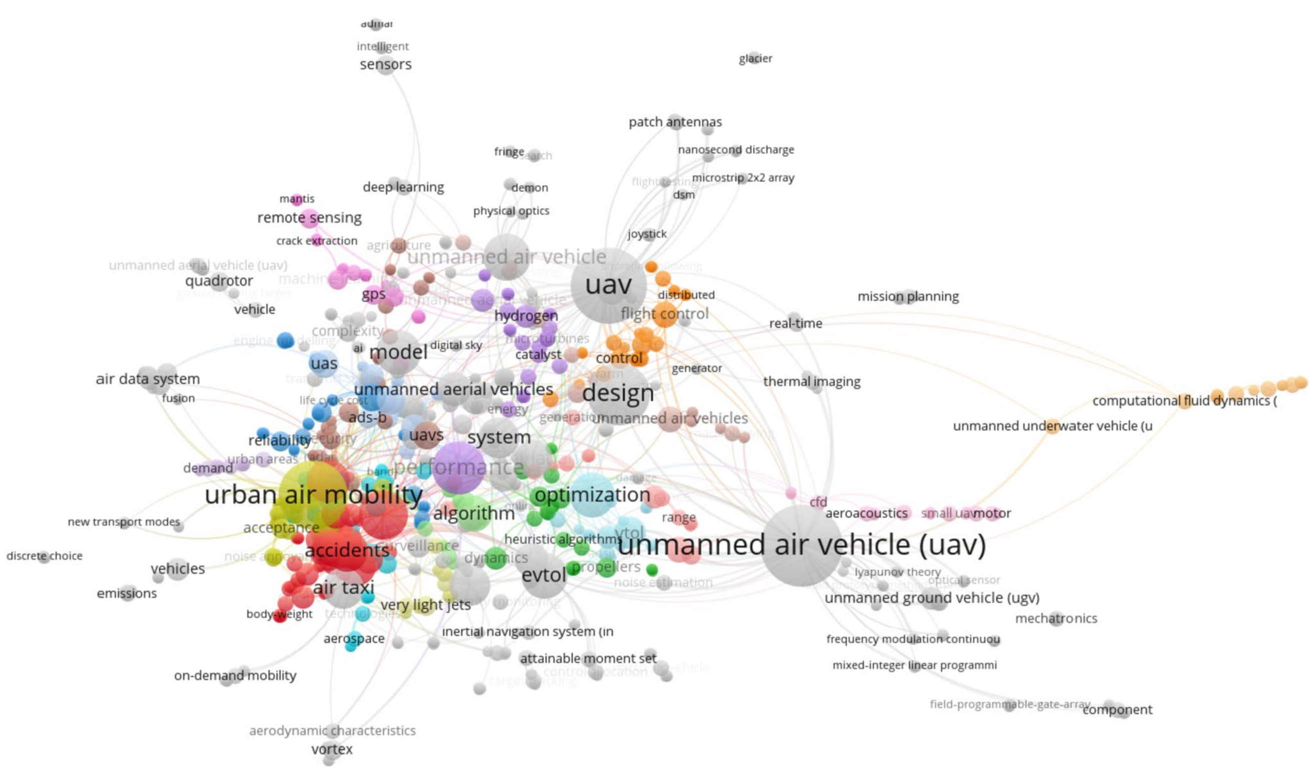

Fig. 8 Keyword co-occurrence visualization (colour figure online)

Table 1 The top 5 cited publications

Reference	Domain/Issue	Times cited
Nigam N, Bieniawski S, Kroo I, Vian J (2012), Control of Multiple UAVs for Persistent Surveillance: Algorithm and Flight Test Results https://doi.org/10.1109/TCST.2011.2167331	Surveillance/Control of Multiple UAV's	212
Maguire BJ, Hunting KL, Smith GS, Levick NR (2002),Occupational fatalities in emergency medical services: A hidden crisis https://doi.org/10.1067/mem.2002.128681	Emergency Medical service/estimate the occupational fatality rate	192
De Marqui Junior, C., Erturk, A., & Inman, D. J. (2009), An electromechanical finite element model for piezoelectric energy harvester plates https://doi.org/10.1016/j.jsv.2009.05.015	Energy harvesting/converting ambient vibration energy to usable electrical energy	182
Han, Z., Swindlehurst, A. L., & Liu, K. J. R. (2009), Optimization of MANET connectivity via smart deployment/movement of unmanned air vehicles https://doi.org/10.1109/TVT.2009.2015953	Wireless ad hoc networks/Optimization location and movement of UAV's	161
Bledsoe, B. E., Wesley, A. K., Eckstein, M., Dunn, T. M., & O'Keefe, M. F. (2006), Helicopter Scene Transport of Trauma Patients with Nonlife-Threatening Injuries: A Meta-Analysis https://doi.org/10.1097/01.ta.0000196489.19928.c0	Health/Transport trauma patients	104

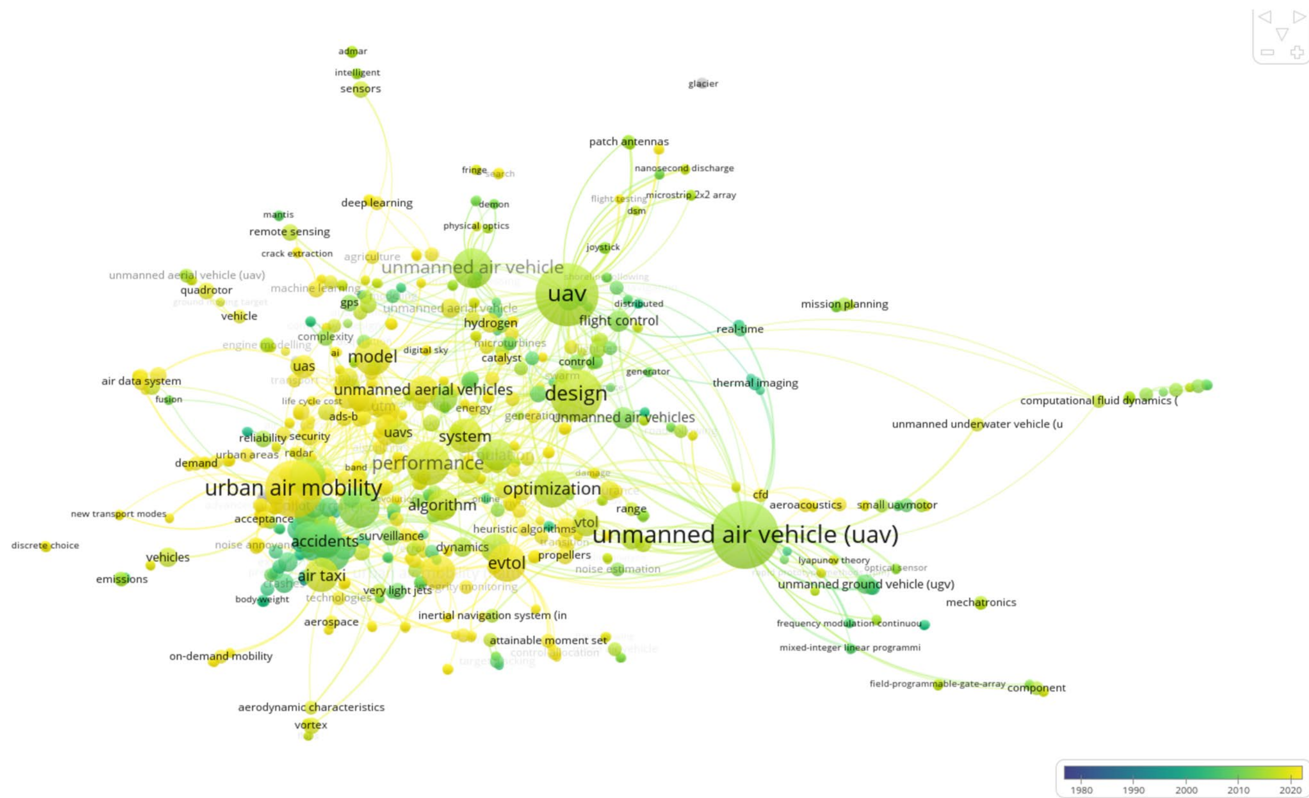

Fig. 9 Highlighted UAM research trends over time

mission planning, and intelligent sensors were all studied in detail. From 2015 to the present, this network map highlights current research areas in yellow, which includes, i.e., vehicle design and manufacture, regulations, infrastructure, operations, integration with other transportation modes, public acceptance, simulation and modeling, demand estimation, and prediction.

Through these results, we identified various active research areas which are discussed in depth in the following. Indeed, while analyzing the relationships between keywords, we identified few major research areas for successful UAM implementation such as vehicle design and manufacturing, regulations, infrastructures, operations, integration with other transport modes, public acceptance, simulation, and modeling, and demand prediction.

Vehicle design and manufacturing. A key component of a successful UAM transport system implementation appears to be the design and construction of suitable VTOL aircraft. Simultaneously, prospective suppliers and the aviation industry as a whole continue to see it as a viable and profitable option. Battery storage, electrical power transmission, and distributed propulsion systems have been utilized as performance benchmarks (Shamiyeh et al. 2018). Two fundamentally distinct VTOL configurations were examined for their features and work performance. NASA commissioned a market report to predict that air taxis and airport shuttles will be in high demand in the USA in the immediate future, with 55,000 regular trips operated by 4100 aircraft. New aircraft must be created to meet improved performance, service, and production demands to serve this market. The specifications and boundary limits for UAM aircraft design are many and, in some situations, new as compared to conventional aircraft design. UBER's Elevate whitepaper is the most wide-ranging collection of uniform standard requirements for air taxis currently available (Holden and Goel 2016). Furthermore, because public acceptance is strongly dependent on low noise emissions, the demand for them would have a direct impact on a UAM vehicle's success or failure. To guarantee public acceptance, UAM noise characteristics should blend in as much as feasible with the current urban background soundscape. This corresponds to a decibel level of 15 decibels lower than a typical light helicopter (Elevate 2018).

Regulations. Appropriate regulation, which includes defined certification criteria as well as laws controlling the UAM market itself, is one of the important research areas for a successful UAM launch. Safety and certification criteria would obstruct commercial aviation operations in urban areas. The European Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) in the USA are currently debating certification regulations. EASA is also working on airspace rules, with the first draft of a structure released in mid-2020. The proposed laws for UAVs (drones) should establish the types and modalities of airspace, while the U-Space definition should determine airspace access (SESAR 2017). U-space serves as a backbone for ordinary unmanned aerial system (UAS) and UAM operations along with connecting manned aviation, air navigation service (ANS) authorities, air traffic management (ATM), and providers. On the other hand, predicting regulatory reactions to the introduction of a new mode of transportation is complicated.

Infrastructure. Ground infrastructure, as well as ATM and sufficient communication infrastructure, is required for UAM (Straubinger et al. 2018). Most UAM vehicles now under development, according to the ground infrastructure layouts and designs and effective UAM operations, will need specialized UAM infrastructure. To determine the highest chance of public acceptance depends on the best use of available land to build suitable sites for UAM (Cohen 1996). Thorough regulations on how air traffic control would manage those sites, what the consequent impact will be on the vicinity, and how this will be viewed by the local, recipient community, whether the infrastructure can handle it or not (Vascik and Hansman 2017). Regarding the use of land, Rothfeld et al. (2020) conducted evaluation studies of how local people would be affected by the services and what impact there would potentially be on the city itself. The necessary ground infrastructure location selection is represented to discover the ideal sites for UAM stations, combine demand and supply-side criteria. There are several aspects to examine further, including work density, median income, current noise, population density, and ground-based transportation connectivity. The most significant aspect, according to Fadhil's respondents, is the proximity to large transportation hubs, i.e., airports or major train stations. To mention a few, UAM ground infrastructure can be installed on barges over water, roofs, on top of existing ground transportation infrastructure, and within highway intersections. Various vertiport topologies are presented such as pier topologies, linear and satellite utilizing current heliports as a study platform (Vascik and Hansman 2019). Nonetheless, the amount of space required for UAM infrastructure could be a major bottleneck for vehicle throughput. An evaluation process is prosed in Mueller et al. (2017) that includes an evolutionary discussion of potential starting points for on-demand mobility, as well as the following airspace integration principles:

- It does not necessitate the installation of extra ATC infrastructure,
- ATC is not burdened with additional tasks,
- Traditional airspace users are not hampered in their activities,
- Will fulfill all applicable safety standards and levels,
- Operational scalability will be prioritized,
- Wherever possible, flexibility will be allowed, although structure will be required.

4.2.1 Operations

UAM supports both intra-city and inter-city flying operations. For instance, short take-off and landing (STOL) services are adequate for intra-city applications, while vertical take-off and landing (VTOL) capabilities are required for inter-city services (Rothfeld et al. 2020). Aside from that, in an intra-city environment, the necessity for low-noise propulsion and autonomy is greater. The method in which they are carried out in private or public transport and whether they are on-demand or scheduled activities distinguish the various operational principles (Nneji et al. 2017). The UAM industry is made up of several sub-markets and market participants. Two of the many potential actors to consider are the service providers and the vehicle owners.

4.2.2 Integration with other transportation modes

UAM is not supposed to be a public transportation system. As a result, seamless integration with current forms of mobility, particularly public transportation (PT), is essential. However, since UAM is expected to consume significantly more energy than ground transportation (Condon and Dow 2019) the capacity limiting factor is predicted to be vertiports (Ploetner et al. 2020). When it comes to the funding structure of most transportation options, policymakers should strive for UAM structures that complement rather than compete with PT. The elimination of effective public transportation networks is likely to diminish city transportation efficiency and is incompatible with long-term sustainability goals. A similar debate is happening in the field of self-driving cars, which is likely to have substantial ramifications for other modes of transportation, particularly public transportation (Kamargianni and Matyas 2017). Transfer people from rural areas to the city's public transportation service area, may be a viable choice for effective integration. This could be particularly useful in geographically separated places with little ground connectivity, i.e., islands, mountains, and areas separated by lakes and rivers. Another option is to give service when public transit is either unavailable or inconvenient. From fully integrated ticketing to merely permitting physical transfers across modes, the degree of integration might vary.

4.2.3 Public acceptance

One of the most important considerations in debates about UAM implementation is public acceptance. The type and amount of noise produced by the vehicles, as well as the time of day and height at which they fly, are important considerations for public acceptance (Yedavalli and Mooberry 2019). Mode preference competition with private cars, public transit, and self-driving taxis in the context of UAM service is presented by Balać et al. (2017), and used multinomial logit models to show that safety, trip duration, and cost of travel were some of the most important factors influencing the public's decisions. Age, salary, household composition, and gender are among socio-demographic factors that influence mode choice as well. UAM is expected to drastically reduce travel time, especially on lengthy routes where defined time demands for boarding and deboarding are no longer important. The probit model was utilized by Eker et al. (2020) to analyze how demographic factors and prior travel habits could affect public views of the UAM's aids and downsides. Many other variables, such as gender, age, income level, educational history, and regular driving patterns, were considered to be statistically important. A framework for the selection of indicators for a multi-criteria analysis for the assessment of UAM has been provided by Haddad et al., (2020) in a case study of Upper Bavaria, in Germany. The most important factor impacting acceptability was security, followed by cost, duration, and service qualities. In addition, consumer and public acceptance are contingent on providing a transparent service and technology, as well as educating individuals on how to assure data privacy, along with safety and protection for both system non-users and users.

4.2.4 Simulation and modeling

The research on simulation and modeling is still in its early stages. Some research is underway on issues such as infrastructure specifications and organizational constraints (Rothfeld et al. 2018). UAM mode will be introduced to be integrated into transportation simulation systems, specifically MATSim (Axhausen et al. 2016), *"an open-source simulation software for building large-scale agent-based transport simulations"*. It is also interesting to see a first analysis of how the systems were performing in an agent-based simulation. MATSim's features of being easily expandable, agent-based, ideal for individualistic transportation options, and particularly essential elements that encourage the use of UAM transportation models and support for user-specific outcome assessment (Balać et al. 2017). An overview of these areas has been provided in Vascik and Hansman (2017) with a focus on the principal acceptance criteria, specific modeling approaches, perception of the potential passengers' worth of time, and possible effects of welfare and UAM implementation of those using the systems. On-demand UAM is a new means of transportation and it can be integrated into traditional transportation simulation systems (Ploetner et al. 2020) to extend these modeling capabilities by permitting the design of UAM stations and flight networks. However, for VTOL operations, the use of UAM stations in transport simulation currently needs the use of pre-defined locations. A methodology is proposed in Cohen (1996) and Rothfeld et al. (2020) to identify the best locations for vertiports or vertistops. These studies use present helicopter pads, limited fly regions, and population density in the case of Los Angeles/California.

Demand estimation and prediction. A qualitative approach to demand estimation is necessary for the scenario of new or future on-demand services like UAM. However, UAM services are equipped with sensors and enabled with

IoT; they provide a huge amount of data, i.e., journey, GPS traces, location, weather conditions, time of pickup/drop-off, number of passengers traveled, and battery efficiency, etc. (Rajendran and Shulman 2020). Processing and then analyzing these data may allow extracting insightful information for decision-makers.

During our analysis of these current research areas, we also identified some significant barriers and key scientific challenges that must be resolved to successfully deploy UAM, as detailed in the next sub-section.

4.3 Barriers and scientific challenges for UAM implementation

In this section, we examine the potential barriers and associated challenges for UAM adoption. According to a NASA report, these barriers are mostly related to economics, safety and security, demand, and public acceptance (NASA 2018). Detect-and-avoid capabilities, Unmanned Traffic Management (UTM), emergency procedures, data security, operator certification, flight over people, regulatory restrictions, weather mitigation are examples of safety and security barriers. Economic barriers include yearly reductions in trip costs per trip, initial infrastructure expenditures, and annual infrastructure expansion. Proven safety records, pilot training, and noise and visual interruption are all examples of public acceptability barriers. Demand-related barriers include competing modes (train, bus, bike, ride-sharing), an annual increase in the number of urban passenger trips, or air market share as a percentage of total urban passenger travels. These barriers are linked with market viability and important events or tipping moments that indicate viability (Mayakonda et al. 2020).

Several stakeholders are tasked with removing these barriers, including government planning agencies, regulators, and manufacturers, etc. Such stakeholders must know forecasted demand for UAM to properly plan for and make progress toward UAM profitability. Strong demand for UAM is projected, as indicated by the significant amount of money invested in developing vehicle technology. Along with these barriers, there are several key scientific challenges to solve to successfully adopt UAM, i.e., ride-matching, optimizing fleet procurement and pricing strategy for on-demand mobility, infrastructures, dynamic routing and integration of ground and UAM transportation scheduling, pilot and pilotless training, and scheduling, leveraging a MaaS (Mobility as a Service) and demand prediction.

4.3.1 Ride-matching

This refers to a procedure of assigning one of the vehicles to passengers on their availability. For any ride-hailing on-demand service, efficiently matching passenger demand with the availability of the vehicle is a big challenge and it is also important to reduce client wait time and empty journeys on the road or in an air taxi (Haddad et al. 2020). Another challenge of ride-matching is determined by the type of ride-hailing request, for example, on the same journey, the vehicle carries a single client from one location to another, as well as a large number of client requests that occur at the same time and have a different but close origin and destination locations.

4.3.2 Optimizing fleet procurement and pricing strategy for on-demand mobility

The pricing strategy for an on-demand service is a critical issue since it directly affects income and balance of the supply and demand (Saharan et al. 2020). The cost-cutting problem of getting the optimal fleet of vehicles for each configuration is also linked to the UAM domain. Since UAM vehicles take a long time to manufacture, forecasting demand ahead of time before launching service is a critical challenge, unlike regular on-road ODM services. The second challenge is the way of offering fare to the traveler as pricing, e.g., the base charge, duration, distance, booking, promotions, and ride-sharing discounts, and all of these influence the trip cost.

4.3.3 Infrastructure

It includes charging, maintenance, and multiple take-off and landing capabilities. It is a huge challenge to identify the best location and assess the size of these amenities, particularly vertiports (Kamargianni and Matyas 2017; Haddad et al. 2020). Thus, before choosing a suitable location, it is important to figure out how many sub-stations are necessary for each of these types, as well as the arrangement of these services. However, from customer demand, there are a variety of conflicting elements to consider while choosing a facility for effective network operations, e.g., the operational cost, public access, demographic coverage, and construction feasibility are just a few of the critical criteria related to UAM infrastructures (Farahani et al. 2010).

4.3.4 Dynamic routing and integration of ground and UAM transportation scheduling

Developing an effective dynamic routing algorithm that bridges the gap between trip cost, client waiting time, and vehicle idle time is an enormous challenge. However, many dynamic routing algorithms have been created in recent years to detect the location with the help of the GPS (Global Positioning System) (Wang et al. 2020). Another challenge is to provide cost-effective network operations; a combined scheduling approach must be used to integrate both modes of transportation.

4.3.5 Pilot and pilotless training and schedule

Due to the long training period and high human cost of UAM, determining the ideal number of pilots is a difficult task. Manpower costs are the aviation industry's second-largest expense. In training, pilots are assigned based on factors such as aircraft maintenance schedules, remaining shift time, and vehicle charge availability. As a result, research into incorporating the above-mentioned prospects for pilotless VTOL designs is a big challenge and might be pursued while considering aspects like the willingness of customers to fly in an unmanned aircraft.

4.3.6 Leveraging a MaaS (Mobility as a Service)

MaaS is a multimodal transportation service that is integrated, smooth, and supplied through a digital end-user interface in which diverse mobility providers are encouraged to collaborate and interconnect to work as an ecosystem [48]. Thus, integrating a new mode, such as UAM, into intermodal transportation may become an immense challenge for the future.

4.3.7 Demand prediction

Several challenges pertain the demand prediction. The first one is that the UAM industry lacks historical data, therefore it is difficult to predict demand analytically. The second one is based on capital requirements and operating expenses which are expected to be high in the near-term market, which may have an impact on the consumer base. The third one is that public perception of UAM is difficult to determine based on factors like safety, boarding, screening, and long-distance traveling choice, etc. (Farahani et al. 2010). Thus, using traditional public transportation data, such as taxis, buses, and trains, to build more effective artificial intelligence-based demand prediction models is a hard and intriguing future challenge.

5 Conclusions and future work

This article discussed the necessity for existing urban mobility services to be integrated with new services, such as UAM, to solve urban mobility problems that arise as a result of urbanization. The evaluations of this study lead to conclude that it is a new and innovative transportation concept. The latest research trend shows exponential growth in scientific publications which include vehicle design and manufacture, regulations, infrastructure, operations, integration with other modes of transportation, public acceptance, simulation and modeling, demand estimation, and prediction. Future challenges to be solved include ride-matching, optimizing fleet procurement and pricing strategy for on-demand mobility, infrastructure, dynamic routing and integration of ground and UAM transportation scheduling, pilot and pilotless training and scheduling, leveraging MaaS, and demand prediction. Due to access constraints, we only used the WoS database in this study. The study also showed that this is a new subject field and there is still a lot of potential active research required for the successful implantation in megacities around the world. A further step of the present work is to propose and implement a method to predict demand through various simulations, to permit identifying the relevance of investment in UAM.

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Declarations

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