# Insights on state of the art and perspectives of XR for human machine interfaces in advanced air mobility and urban air mobility

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**Abstract.** With technological innovation and advancements, especially in autonomy, battery and digitization, the future of air transport and mobility is transiting towards a broader spectrum of Advanced Air Mobility (AAM) and Urban Air Mobility (UAM). UAM envisions safer, faster, and more sustainable air mobility for smarter cities and urban environments including passenger transport and goods delivery. Nevertheless, this concept is still considered extremely breakthrough and several technological and operational aspects are mostly undefined. In this context, a comprehensive approach to AAM/UAM may be to adapt cutting-edge technologies in developing sustainable framework and Human-Machine Interfaces (HMIs) in order to realize the challenges, benefits, and conditions of such transport system in advance for future safer, more reliable and globally approved operations. One of the technologies that can contribute to accelerate advancements through human centred simulating UAM processes and operations is XR (eXtended Reality). This paper presents the early steps of a multidisciplinary study performed under the framework of PNRR (Piano Nazionale di Ripresa e Resilienza) and MOST (Centro Nazionale Mobilità Sostenibile) project in analyzing the perspectives of XR based HMIs for UAM paradigm and potential AAM/UAM use case scenarios that can be simulated with XR in view of attaining efficient and effective future solutions. Furthermore, the work introduces the state-of-the-art overview on XR facilitated UAM applications and considers prospective potential use cases that can be developed through PNRR research study in demonstrating XR as an enabling technology in promising areas of the UAM framework.

## Introduction

Air mobility, also referred to as AAM or UAM, has emerged as a transformative concept in the realm of transportation, offering new possibilities for efficient and sustainable movement of people and goods. According to the studies performed in the framework of the Italian AAM Strategic Plan, the global AAM market is expected to grow at a 20-25% rate from 2021 to 2030, reaching an estimated value of around USD 38-55 billion per year [1]. A significant interest is paid to its implementation in the context of urban environments where UAM represents a promising vision for the future of transportation of goods and passengers, aiming at providing efficient and sustainable aerial transportation solutions within urban areas [1][2]. According to Tojal et al., UAM is a mobility concept for urban areas that makes use of any kind of mainly Unmanned Aerial Systems (UASs) to perform any type of mission that is operated in the Very Low Level (VLL) airspace aiming at improving the welfare of individuals and organizations [3]. Thanks to technological advancements in UAM in conjunction with advanced materials, aircraft architecture, enhanced battery capacity, digitalisation of air traffic management etc., the commercial exploitations of such mobility system is expected to become a reality in Europe within 3 to 5 years [4]. However, the actual implementation of UAM comes with numerous challenges. The safe integration of UAM vehicles into urban airspace, the development of infrastructures such as vertiports and changing stations, regulatory frameworks, public acceptance, and efficient operations are among key considerations (as highlighted in Fig.1)[5][6]. These challenges necessitate a multidisciplinary approach that involves collaboration between industry stakeholders, policymakers, urban planners, aviation authorities, and technology innovators [7]. Therefore, attention has been increasing towards contemplating innovative technologies in simulating and developing advanced human-machine interfaces (HMIs) through human and user-centred approaches for future UAM scenarios and foreseeing the challenges in order to find efficient and effective solutions and support regulatory processes.

Immersive media comprising Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are amongst the currently fastest growing and promising tools for such innovative HMIs. These, also commonly referred to with the umbrella term XR, enable the users to experience immersive and interactive environments, and have been proven to enhance design validations, reduce training costs, enhance user engagement, improve communication and collaboration with seamless data access etc.[8], [9],[10],[11]. Through a comprehensive analysis of existing literature, case studies, and industry developments, the present work aims to provide insights into the current state of UAM scenarios and explores the potential role of XR-based HMIs and simulations. By understanding the complexity of UAM, we can better appreciate the significant impact it may have on urban transportation and facilitate its successful integration into our cities.

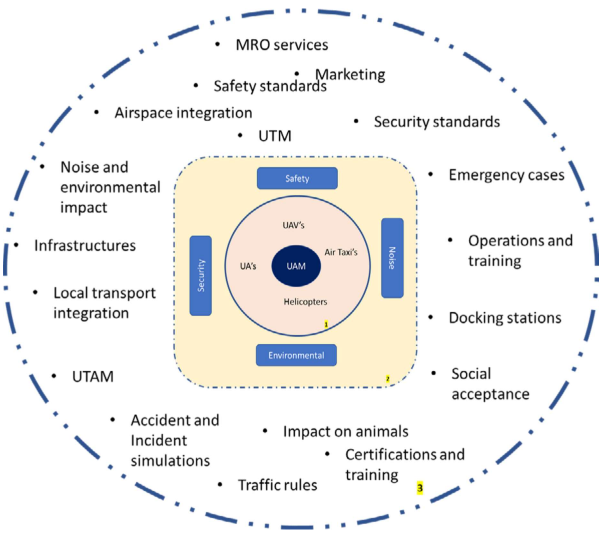


*Fig. 1. Overview of XR simulation themes for UAM: (1) Types of UAM (2) Top concerns highlighted by EASA (3) Potential UAM themes for XR applications.*

## Related work on XR-based HMIs and Simulations for UAM

It is recognized that in the realm of the digital transformation of processes and the 4.0 industrial revolution, XR technologies have paved the way to advanced HMIs acting as a bridge connecting the gap between humans and machines [13]. Revenue in AR and VR market worldwide is expected to show an annual growth rate (CAGR 2023-2027) of 40.12%, resulting in a projected market volume of US$9.10bn by 2027 [14]. It is evident that XR and UAM are together rapidly growing markets. Besides this aspect it must be considered that the integration of XR-based HMIs and simulations for UAM presents numerous benefits. It facilitates the design and evaluation of user-centric interfaces that consider human factors, ergonomics, and cognitive workload in highly automated environments. Furthermore, XR-based simulations enable stakeholders to assess the feasibility and performance of UAM systems, optimize operational procedures and identify potential safety risks.

To this regard, we have performed a preliminary study on collecting a selection of the existing works in the field of XR-based UAM and categorised them into 3 different perspectives: Market, Scientific, and Industrial research (see Table 1).

*Table 1. Selection of previous works relevant for this study*

<table>
<tr><th></th><th>Reference</th><th colspan="3">Forecasts</th></tr>
<tr><td rowspan="2">Market Perspective</td><td>[1]</td><td colspan="3">Global AAM/UAM market research forecasts a growth of CAGR at 20/25% from 2021 to 2030</td></tr>
<tr><td>[14]</td><td colspan="3">AR and VR market worldwide is expected to show an annual growth rate (CAGR 2023-2027) of 40.12%</td></tr>
<tr><td colspan="2"></td><th>UAM Mission Scenarios</th><th>Description</th><th>XR technology</th></tr>
<tr><td rowspan="5">Scientific Perspective</td><td>[15]</td><td>Collaborative Decision Making</td><td>3D map rendering with planes, runways and waypoints demonstrating air traffic scenarios</td><td>AR</td></tr>
<tr><td>[16]</td><td>Simulation of Workspace</td><td>Taking off and landing a quadcopter</td><td>VR, CAVE</td></tr>
<tr><td>[17]</td><td>System integration and testing</td><td>Urban Traffic Management, UAS operations</td><td>HMI, AR CAVE</td></tr>
<tr><td>[18][19][20]</td><td>Public/ Social Acceptance</td><td>Auditory and Visual perception of drones, acceptance of Air taxis</td><td>AR, VR</td></tr>
<tr><td>[21][22]</td><td>Virtual Prototyping and Design</td><td>Urban Airport Infrastructure design, Air taxi cabin</td><td>VR, MR</td></tr>
<tr><td rowspan="3">Industry Perspective</td><td>[24][25]</td><td>Visualization of Airspace data</td><td>CLARITY: HMD for Air traffic control<br>-Drone Control with intuitive gestures</td><td>MR, VR<br><br>AR</td></tr>
<tr><td>[23][26][27]</td><td>Training and Simulation</td><td>-Real-time Tower and Apron Control Research Simulator (NARSIM)<br>-Pilot training program for eVTOL<br>-eVTOL Flight Simulator</td><td>Simulator, AR<br>AI, VR, MR<br>MR</td></tr>
<tr><td>[28][29]</td><td>Simulation</td><td>Drone Simulator</td><td>AR-to-gamepad interface</td></tr>
</table>

## Conclusion

UAM is an emerging transport system with dedicated services that integrate aerial unmanned platforms for passengers and goods transport in urban environment. As UAM progresses, there is a growing need for advanced HMIs and simulations to enhance the design, operation, and ensure safety of these complex systems. With advent growth towards automation, technologies such as XR offers innovative solutions for creating immersive environments and interactive experiences for future UAM scenarios. In this context, this paper highlights a literature study on XR-based HMIs and simulations to support UAM services. We classified the information into three perspectives of scientific, industrial and market in view of highlighting the main areas of XR-based HMIs and simulations for future UAM scenarios. It has been observed that the literature identifies the key aspects relating to the fields of virtual prototyping, design, training, simulation, human factors evaluation, airspace visualization, collaborative decision making, system integration and testing, public engagement, and education/marketing.

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