Integrating GIS and Urban Informatics for Urban Air Mobility (UAM) Infrastructure Planning

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Keywords: Urban Air Mobility, GIS-based Spatial Analysis, Urban Informatics, 3D Urban Morphology, Vertiport Spatial Allocation.

Abstract

Urban Air Mobility (UAM), enabled by electric vertical take-off and landing (eVTOL) aircraft, is an emerging transport mode considerable for multimodal urban transport systems. Integrating UAM infrastructure and vertiports spatial allocation in the urban space, requires systematic spatial analysis of urban morphology, multimodal transport accessibility, legal and regulatory constraints, and population dynamics. This paper presents a three-stage methodological framework combining Geographic Information Systems and urban informatics to identify and evaluate spatial data correlations necessary for UAM planning in dense metropolitan areas. Stage 1 addresses multi-source spatial data acquisition encompassing three-dimensional building models, cadastral records, transport network topologies, and population density surfaces. Stage 2 a GIS-based processing through three-dimensional Boolean safety filtering and multi-objective Pareto optimization of candidate vertiport sites is carried out. In Stage 3 exogenous validation is performed, with use of Monte Carlo flight trajectory simulations and stated-preference and activity – travels questionnaires surveys to ensure predictive independence from the suitability model's own inputs. Accessibility to transportation, population density and point-of-interest concentration, are important parameters as they directly determine passenger demand potential and UAM's integration to existing mobility networks. Building height and ambient noise levels are also important, as they define the three-dimensional operational envelope and the regulatory compliance boundaries that govern safe eVTOL deployment. The proposed framework contributes to the ongoing discussion on UAM spatial planning and integration to urban planning by bridging urban informatics with advanced air mobility, offering urban planners and policymakers a novel approach on UAM's integration to the overall urban and spatial planning.

1. Introduction

Rapid urbanization of urban metropolitan areas across the globe, has intensified the demand for innovative transportation solutions that combine alleviation of surface-level traffic congestion of the road network on the one hand, maintaining environmental sustainability on the other. Urban Air Mobility (UAM) is emerging as an innovative transport mode that utilises the electric vertical take-off and landing (eVTOL) aircraft solution for intra-city or intra-urban space passenger and goods transport, using low altitude aerial corridors (Thipphavong *et a*l., 2018; Garrow et al., 2021). For UAM to be operational the spatial allocation of vertiports is fundamental as those infrastructures are the ground support for UAM operations, and is a spatial problem requiring rigorous spatial analysis (Fadhil, 2018; Perperidou and Balta, 2024).

GIS combined to urban informatics can form the necessary foundation in addressing this spatial allocation optimization challenge. As urban informatics study people, places, and technology in urban environments through data-driven approaches (Foth et al., 2011; Foth, 2018) deriving large scale datasets on population flows, peoples' transport behavior, and environmental conditions that are essential inputs for UAM infrastructure planning. In parallel, the integration of urban informatics analysis within a GIS framework, where spatial data on land-uses, urban morphology and urban landscape, and institutional constraints are organized and projected, enables the multicriteria, decision-making analysis that foresees for operational safety, regulatory compliance, social equinity and financial sustainability.

In this context, the necessity for spatial data correlation is twofold. Firstly, identifying spatial-statistically significant relationships between urban informatics variables and UAM operational requirements facilitates the evidence-based vertiports spatial allocation selection. Secondly, these spatial correlations unveil the spatial dependencies and constraints that govern the feasibility of UAM integration within existing urban morphologies. Densely built and populated cities, and especially European cities like Athens with firm and rich historic background that poses further development restrictions, can become a unique set of challenges. Those challenges are a result of the compact built environments, complex legal-institutional frameworks, and layered regulatory structures that govern horizontal and vertical urban development (Perperid*ou et a*l., 2021; Perperidou and Kirgiafinis, 2022; Perperidou and Katsios, 2025).

In this paper a methodological framework that integrates GIS-based spatial analysis of urban space with urban informatics data to establish spatial correlations pertinent to UAM vertiport suitability assessment is proposed. The framework composes multi-source geospatial data - including cadastral records, transport network models, 3D building data, population density surfaces, and point-of-interest inventories - within a unified analytical environment. The paper addresses the following research gaps: (i) How can three-dimensional urban morphology, cadastral, and institutional data be systematically integrated into a GIS-based workflow to enforce volumetric safety and legal constraints that two-dimensional suitability approaches fail to address? (ii) What is the added value of treating aviation safety and regulatory compliance as Boolean preconditions, rather than weighted criteria, in multi-objective vertiport site optimization? How can external validation tools, , structurally independent from the suitability model's own inputs, be designed to provide predictive validity free from circular correlation? The paper presented herein is conceptual- methodological: develops and formalizes the analytical workflow at a level of detail sufficient for reproducible implementation, while empirical and real-world application to specific metropolitan case studies is subsequent work.

2. Literature review

2.1 UAM and ground infrastructure planning via GIS approach

The concept of UAM has evolved from theoretical proposals (Lascara *et al*., 2019; Straubinger *et al*., 2020) or limited aviation services mainly for tourists, and medical support in cities like New York, Sao Paolo, Monaco, Dubai or Sydney to large-scale operational pilot programmes in USA (FAA, 2026), Dubai (Joby Aviation, 2026), South Korea (Warwick, 2025). In Europe, Sandbox Program (Pritchard, 2025) and the OxCam AAM Corridor Project (Dimitrova, 2025), are the most advanced UAM pilot programs. As vertiports are the most critical ground-based UAM infrastructure, their spatial allocation must comply to complex spatial requirements that encompasses operational safety clearances, airspace compatibility, noise mitigation buffers, and multimodal transport connectivity (Mendonca *et al*., 2022). Fadhil (2018) developed a GIS-based multi-criteria decision analysis framework for identifying optimal ground infrastructure locations — specifically vertiport sites — for urban air mobility, while recent studies focus on spatial allocation across highways (Yoon *et al*., 2025) or more robust geospatial analysis (Lee and Cho, 2025). UAM also should be integrated to daily commuting so as to facilitate daily commuting (Daskilewicz *et al*., 2018).

The spatial allocation of vertiports within complex urban environments characterized by dense infrastructure, airspace restrictions, and heterogeneous land us, that applies multi-objective optimization framework that integrates geospatial analysis, demand modelling, and obstacle surface constraints (Lu *et al*., 2025) is a novel approach in GIS based analysis of vertiports spatial allocation.

2.2 GIS and urban informatics

The integration of GIS with urban informatics has produced transformative capabilities for the development of smart city planning, encompassing real-time mobility analytics, spatio-temporal pattern mining, and the development of digital twins (Batty, 2013; Yeh, 2024). In the context of transportation analysis and citizens patterns questionnaires surveys and their consequent geospatial and geostatistical approaches are employed so as to understand better the correlation between transportation habits and urban form and services (Perperidou, 2010). Also, data deriving from GPS traces, and land-use inventories are used to reveal how the built environment shapes daily movement and how travel behavior influences urban structure.

In addition, by combining spatial analysis techniques like network modeling and clustering with geostatistical methods that account for spatial autocorrelation and local heterogeneity, researchers and planners can examine how neighborhood characteristics such as street connectivity, transit accessibility, and the arrangement of key amenities produce distinct travel profiles, ultimately supporting evidence-based interventions that align urban policy with the actual spatial dynamics of mobility.

The concept of 15-minutes city, that was introduces within the covid pandemic (Moreno *et al*., 2021), aims to scale-down the distances that residents have to cover in order to meet their everyday needs, including the need for recreation, reshapes the concept of urban space and urban time for transportation within the framework of time-spent for 15 minutes per transport mode, thus could turn UAM into a viable and liable transportation mode within the concept of sustainable and smart cities.

2.3 Regulatory Framework of Urban Space and Spatial Restrictions

Regulatory framework on urban space includes a variety of legislation varying from the robust and firm Property Law, to urban development regulations, permissible land uses and land uses allocation and overall urban development and formation. UAM routing could be restricted by property law restrictions (Perperidou and Kirgiafinis, 2022), whereas the vertical urban development (Al-Kodmany, 2018) could pose challenges for UAM routing as straight lines just connecting spatial points, affecting at the same time the development either of ground infrastructures or intermediate docking stations. Vertical city development potential along to property law restriction, directly impact UAM operational clearances and obstacle limitation surfaces.

Thus, the integration of cadastral data, that include the limitations imposed by the property law, to urban planning prerequisites, land uses allocations and spatial requirements of UAM operations, is vital for UAM spatial analysis. All the above combined to urban informatics and especially of residents' flows and timetables is vital for the UAM ecosystem feasible design, ensuring the system's sustainability and safety.

Despite these advances, the reviewed literature reveals three significant gaps. First, the majority of GIS-based vertiport allocation studied rely on conventional multi-criteria decision analysis (MCDA) with expert-assigned weights, an approach that allows high scores on non-safety criteria to compensate for marginal safety performance, thereby introducing a theoretically problematic trade-off. Second, existing frameworks analysis is mainly carried out in two dimensions, treating urban morphology and landscape as a planar condition, not taking into consideration the volumetric constraints imposed by three-dimensional property rights, obstacle limitation surfaces, and vertical urban development regulations. Third, validation procedures in current studies typically evaluate suitability indices against their own constituent variables, producing circular correlations that offer no independent evidence of predictive validity. The framework proposed in this paper addresses all three gaps by introducing Boolean safety filtering prior to optimization, incorporating three-dimensional cadastral and morphological data, and designing an exogenous validation stage structurally independent from the suitability model's inputs.

3. The Methodological Framework

The proposed methodological framework is structured in three stages: (i) Multi-Source Spatial Data and Dynamic Infrastructure Acquisition, (ii) 3D Boolean Processing and Multi-Objective Optimization and (iii) Exogenous Validation and Scenario Simulation. Each stage is designed so as to adhere to modular principles, ensuring replicability within diverse metropolitan settings.

3.1 Stage1: Multi-Source Spatial Data and Dynamic Infrastructure Acquisition

The initial stage encompasses the methodical compilation and harmonization of four categories of high-fidelity, three-dimensional, and dynamic operational spatial datasets, avoiding coarse raster grids, so as to circumvent Modifiable Areal Unit Problem (MAUP) distortions. By using spatially explicit data ensures that the variability underlying urban phenomena is preserved. This enables more accurate and representative geospatial analysis across diverse metropolitan contexts. Those datasets are organised into four major 4 categories:

- **3D Urban Morphology, Cadastral Data and Institutional Constraints:** This category uses data of 3D urban morphology data deriving from Digital Surface Model (or CityGML datasets etc.), spatial (parcels and buildings footprints) and descriptive cadastral data, especially 3D development rights and 3D restriction of third parties on private properties. It incorporates accurate building footprints and 3D property boundaries cross-validated cadastral parcels boundaries to enforce strict 3D volumetric controls mandated by property and urban planning legislation.
- **Transport Networks Regional and Multimodal Data:** Transport data captures the topology of multimodal regional transit networks, including the spatial configuration of amenities and transit hubs. These data are calibrated to reflect or correlate to residents' behavioural patterns, particularly with respect to scheduling preferences and mode choice behaviour.
- **Electrical Utility and Grid Capacity Data:** This encompasses high-resolution topological load data and synthetic distribution feeder models to evaluate the localized grid's capacity. This data is imperative for meeting the direct-current peak charging demands of UAM aircraft without inducing undervoltage scenarios or necessitating substantial substation capital expenditures.
- **Dynamic Micro-Meteorological Data:** This category delineates the acquisition of historical weather records and local atmospheric data. The objective of this acquisition is to provide boundary conditions for the purpose of modeling Computational Fluid Dynamics (CFD) in the urban airspace. These boundary conditions are crucial for the operational stability of UAM aircraft.

3.2 Stage 2: 3D Boolean Processing and Multi-Objective Optimization

The Stage 1 involves methodically compiling and harmonizing four categories of high-fidelity, three-dimensional, dynamic operational spatial datasets. All Stage 1 spatial datasets are ingested into a 3D-capable spatial database/system to perform:

- **3D Boolean Safety Constraints:** Aviation safety regulations are absolute binary filters (pass – no pass). Computation of complex 3D Obstacle Limitation Surfaces (OLS), projecting precise divergence angles and departure slopes from candidate Final Approach and Takeoff (FATO) areas. Furthermore, Vertiports Land Use Compatibility guidelines dictate strict exclusionary buffer zones, where specific land uses, such as schools and other of public and common purposes areas, and residential developments, are prohibited or heavily restricted due to current downwash, outwash, and safety risks. Any violation results in immediate site disqualification.
- **Multi-Objective Optimization (MOO):** For candidate sites that satisfy all 3D Boolean safety and legal parameters, a Pareto-optimization algorithm is deployed. This approach is predicated on an explicit balancing of competing objectives without subjective weighting. The primary objective is to optimize multimodal transit accessibility. A secondary objective is to minimize the economic burden of utility grid upgrades. A third objective is to minimize the socio-environmental footprint.
- **Dynamic Acoustic Modeling:** Instead of static two-dimensional (2D) buffers, three-dimensional (3D) noise mapping tools, are employed to simulate the complex acoustic signatures of electric vertical take-off and landing (eVTOL) vehicles during hover and transition phases. These tools account for asymmetrical noise attenuation and reflection caused by surrounding urban building massing.

3.3 Stage 3: Exogenous Validation and Scenario Simulation

The final stage of the process involves the validation of the theoretical suitability outputs against independent, exogenous variables. This ensures that no index is evaluated against its own constituent inputs, thereby avoiding circular correlation.

The proposed methodological framework is depicted in Figure 1.

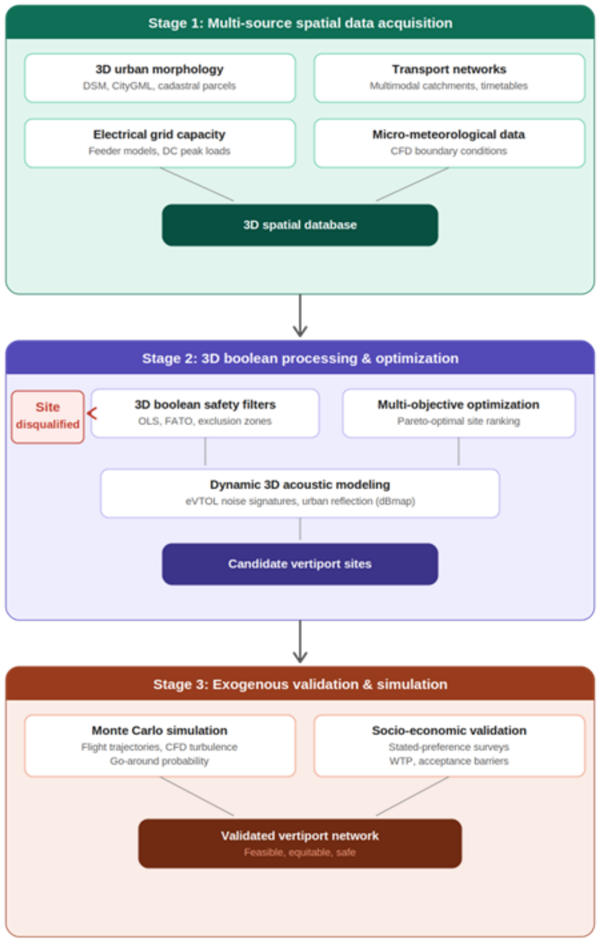

Figure 1. Three-stage methodological framework for integrating GIS, urban informatics, and UAM spatial data.

- **Monte Carlo Flight Trajectory Simulation:** The viability of highly ranked vertiport sites is validated by running thousands of simulated flight trajectories into the candidate FATOs. These simulations integrate the three-dimensional urban morphology with microscale wind disturbance and computational fluid dynamics (CFD) turbulence modeling to assess actual aircraft performance, controllability limits, and the probability of go-arounds under varying meteorological conditions.

- **Stated-Preference and Socio-Economic Validation:** The socio-economic viability and social equity of the vertiport network are substantiated through localized stated-preference surveys. This analysis identifies the heterogeneous traits of potential UAM users, measuring crucial public acceptance barriers such as acrophobia, noise sensitivity, and exact willingness-to-pay metrics, ensuring that the modeled infrastructure aligns with real-world human behavioural economics.

4. Discussion

The proposed three-stage methodology deviates fundamentally from prevailing vertiport siting approaches, which have predominantly relied on two-dimensional GIS-based suitability indices with subjective expert-assigned weights. It should be noted that this paper deliberately presents a conceptual-methodological framework rather than a case-study-driven empirical analysis. This choice is motivated by two considerations. First, UAM is still at a pre-operational stage in most metropolitan areas, and the high-resolution input datasets required by the framework, particularly three-dimensional cadastral records with volumetric property rights and georeferenced electrical grid capacity models, are not yet publicly available in harmonised form for any single city. Second, before committing computational resources to a large-scale empirical implementation, it is essential to formalise the analytical workflow, specify the inter-stage data flows, and articulate the validation logic at a level of detail sufficient for reproducible application. The framework is therefore designed as a transferable methodological template: once the requisite datasets become available for a given metropolitan area, each stage can be instantiated with case-specific parameters without altering the overall analytical architecture.

The integration of three-dimensional volumetric data deriving from cadastral and urban planning datasets, addresses a critical gap in the literature, where urban morphology is typically treated as a planar phenomenon, whereas limitations imposed by property law and urban planning are often neglected. This simplification poses significant challenges, particularly in the context of vertiports'' spatial allocation. The vertical dimension plays a crucial role in determining obstacle clearance, approach and departure slope geometry, and the volumetric envelope necessary for safe aircraft manoeuvring. At the same time the respect of institutional constraints, e.g. property law or even personal data safeguard, is core stone especially for the adoption of UAM by residents and the public in general.

The framework's adoption of Digital Surface Models, and 3D cadastral records enables the computation of Obstacle Limitation Surfaces with geometric fidelity that is unattainable through two-dimensional representations. Furthermore, the treatment of aviation safety and legal compliance as non-negotiable Boolean filters—applied prior to any optimization—eliminates the theoretically problematic possibility that high scores on non-safety dimensions could offset safety deficiencies, a risk inherent in conventional multi-criteria approaches.

The replacement of static two-dimensional noise buffers with three-dimensional dynamic acoustic modeling constitutes a substantial advancement. In densely populated urban areas, the configuration of building massing gives rise to intricate acoustic reflection and shielding patterns, resulting in significant deviations in the noise footprints' geometry from a circular model. The framework's employment of eVTOL-specific acoustic signatures during hover and transition phases serves to refine the socio-environmental objective, thereby enabling the Pareto optimization to distinguish between sites on grounds invisible to cruder assessment methods. Additionally, the incorporation of electrical grid capacity as an explicit optimization objective addresses an infrastructure constraint that has received insufficient attention. Specifically, peak direct-current charging demands can impose localized stresses on distribution networks that are not captured by aggregate capacity metrics.

The exogenous validation stage addresses a pervasive methodological vulnerability in spatial suitability assessments: the circular evaluation of an index against its own constituent variables. When a suitability score is validated using criteria that were previously instrumental in its computation, the resulting correlation is, at the very least, identical or tautological in nature. This correlation offers no independent evidence of predictive validity. The present framework mitigates this risk by validating outputs exclusively against structurally independent, exogenous variables.

The Monte Carlo flight trajectory simulation functions as a physically grounded validation mechanism. By generating simulated approaches into candidate FATOs under varying meteorological conditions, it tests whether theoretically suitable sites are operationally viable in terms of aircraft controllability, go-around probability, and tolerance to microscale wind disturbances. The integration of Computational Fluid Dynamics turbulence modelling with three-dimensional urban morphology data provides a validation criterion that is fundamentally different from the geometric and accessibility metrics used in traditional processes.

The residents survey component introduces a human behavioural dimension that was previously absent from the physical and spatial analysis of UAM. The survey can include metrics as, activity – transport patterns, acrophobia, sensitivity to noise, willingness-to-pay extra amount among the general population and thus to identify UAM potential users that could lead to better analysis and formulation of UAM services in terms of trajectories and vertiports spatial allocation. This comprehensive evaluation aims to ascertain the congruence between the locations identified by the spatial model and those where actual demand for UAM services is anticipated to materialize. This validation is particularly critical given the under-development state of the UAM market, where revealed-preference data from operational services remain largely unavailable and stated-preference methods constitute the primary instrument for gauging prospective user behaviour and social acceptance.

The use of high-resolution spatial data helps to resolve the Modifiable Areal Unit Problem (MAUP). The Modifiable Areal Unit Problem (MAUP) occurs when analytical outcomes are shaped by the particular spatial boundaries used to aggregate data, rather than by the actual geographic patterns they aim to represent. Especially in the cases of vertiports spatial allocation, the implications are considerable. When a raster cell averages building heights across a large area, it may conceal a tall building, leading to a failure to meet obstacle clearance standards at a given candidate site. The proposed framework addresses this by operating at the scale of individual parcels and building footprints, thereby minimizing aggregation-related errors and preserving the spatial detail needed to properly evaluate site-level constraints.

Despite its methodological rigor, the proposed framework is subject to several limitations that must be taken under consideration. The accuracy and reliability of its outputs are contingent upon the availability of high-resolution, spatially explicit input datasets, particularly three-dimensional urban morphology data, three-dimensional cadastral data that include three-dimensional rights and relevant parameters of property law as well as three-dimensional urban regulations/ restrictions and georeferenced electrical grid capacity models. In many legal jurisdictions, such datasets may be incomplete, temporally inconsistent, or characterized by heterogeneous spatial coverage. This can introduce non-trivial uncertainty into the siting assessments. In contexts where building height inventories or power infrastructure records exhibit significant gaps, the framework's capacity to rigorously evaluate obstacle clearance surfaces, microclimatic wind conditions, and energy supply feasibility may be appreciably diminished. Consequently, the systematic identification and remediation of such data deficiencies constitutes a fundamental prerequisite for the robust transferability of the methodology across diverse urban environments.
From a computational perspective, the framework's reliance on stochastic Monte Carlo simulations and high-fidelity computational fluid dynamics modeling introduces notable scalability constraints. It is important to note that both techniques are computationally demanding. As the spatial extent of the study area or the number of candidate sites increases, the associated processing requirements may become prohibitive within practical operational timelines. This poses a particular challenge for large-scale metropolitan applications involving extensive candidate site inventories. Furthermore, the implementation of stated-preference and in general questionnaires survey instruments to quantify public acceptance and possible demand introduces an inherent methodological limitation. Specifically, respondents' behavior under hypothetical elicitation conditions may diverge systematically from choices observed in real-world decision-making contexts. This phenomenon is extensively documented in the discrete choice literature as hypothetical bias.
A number of ongoing research could be identified for having the potential to address the aforementioned limitations. The development of machine learning surrogate models, trained on high-fidelity simulation outputs, presents a viable pathway toward substantially reducing computational overhead while preserving acceptable predictive accuracy for CFD and Monte Carlo components. As commercial Urban Air Mobility operations transition from the conceptual to the operational phase, longitudinal empirical studies comparing ex ante stated-preference estimates with ex post revealed-preference data derived from observed user behavior will be indispensable for the calibration and external validation of demand forecasting models. Moreover, extending the analytical scope of the framework from individual site evaluation to regional-scale vertiport network optimization would constitute a significant methodological contribution. This would enable urban planners and transportation authorities to optimize not merely the placement of discrete facilities but the spatial configuration of integrated, multimodal air mobility systems at the metropolitan scale.

5. Conclusions

This paper presents a three-stage methodological framework integrating Geographic Information Systems (GIS) and urban informatics for the spatial planning of Urban Air Mobility (UAM) including the necessary ground infrastructure of vertiports. The framework advances beyond prevailing two-dimensional, expert-weighted suitability approaches by introducing three-dimensional volumetric analysis grounded in cadastral data, digital surface models, and institutional constraints derived from property law and urban planning legislation.

By treating aviation safety and legal compliance as non-negotiable Boolean preconditions rather than weighted criteria, the methodology eliminates the risk that high performance on non-safety dimensions could compensate for safety deficiencies, a shortcoming inherent in conventional multi-criteria decision analysis. Adopting multi-objective Pareto optimization balances competing objectives, such as multimodal transit accessibility, electrical grid upgrade costs, and socio-environmental impact, without subjective weightings. Three-dimensional dynamic acoustic modeling replaces static, two-dimensional noise buffers, better capturing complex reflection and shielding patterns in dense urban environments. Another contribution is the exogenous validation stage, which uses structurally independent instruments—Monte Carlo flight trajectory simulations and stated-preference surveys—to validate outputs and address circular index evaluation, providing predictive validity free from tautological correlation.

Nevertheless, the framework has limitations that should be acknowledged. Its outputs depend on the availability of high-resolution, spatially explicit input datasets, such as three-dimensional cadastral records and georeferenced electrical grid capacity models. These datasets may be incomplete or inconsistent across jurisdictions. Additionally, the computational demands of Monte Carlo simulations and computational fluid dynamics modeling introduce scalability constraints for large-scale metropolitan applications. Furthermore, the reliance on stated-preference instruments for demand estimation is subject to the well-documented phenomenon of hypothetical bias in discrete choice elicitation.

To address these limitations, future research should pursue several directions. One promising approach is to develop machine learning surrogate models trained on high-fidelity simulation outputs, which could reduce computational overhead while preserving predictive accuracy. As UAM operations transition from the conceptual to the operational phase, longitudinal studies that compare stated-preference estimates with revealed-preference data from observed user behavior are essential for calibrating demand models. Another significant contribution would be extending the framework from individual site evaluation to regional-scale vertiport network optimization, which would enable planners to optimize the spatial configuration of integrated, multimodal air mobility systems at the metropolitan scale. The proposed framework is ultimately intended to serve as a replicable, data-driven decision support tool that bridges urban informatics and advanced air mobility. This methodology will contribute to evidence-based planning of sustainable urban transport futures. Furthermore, urban planners and relevant scientists should gradually treat UAM as a feasible and sustainable transport mode for the effective implementation of the 15-minute city model, and its recognition as a reliable, safe solution for immediately transporting patients to healthcare facilities.

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