Urban Perspectives on UAVs Infrastructure Development

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***Abstract* — The drone industry has the potential to catalyze a positive transformation within the transportation sector. Numerous technological advancements and regulatory milestones have been achieved, resulting in significant progress in Air Traffic Management (ATM) solutions. The SESAR project, coupled with the collective efforts of various stakeholders, has positioned the market for readiness. However, to fully unlock this significant potential and actualize the vision of the Digital European Sky, strategic challenges must be addressed. One of these challenges pertains to the scarcity of ground infrastructure. The paper highlights the need for comprehensive ground infrastructure planning and proposes a spatial analysis to strategically identify the optimal airspace to place aerial pathways for drones in urban and rural scenarios. The outcomes of the proposed spatial analysis inform the placement of critical infrastructures, including vertiports and charging stations. Taking inspiration from urban planning principles, the proposed research wants to contribute to the development of a "Ground and Aerial Traffic Master Plan", highlighting pertinent constraints to be considered for the analysis. The paper offers an in-depth background analysis, presenting the state of the art subdivided into key research areas. First preliminary findings are presented, and future research directions are outlined.**

Keywords: U-space, Advanced Air Mobility, Infrastructure Planning, Corridors, Vertiports, Spatial Analysis, Urban Planning, Drone Traffic, UAVs, Ground Infrastructures, Spatial Constraints, Airspace Management

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are a technology employed within various domains, including professional applications such as surveillance and mapping, as well as recreational pursuits. An emerging sector is the transportation industry, where the use of drones is becoming an increasingly prominent topic of discussion (as seen with Amazon [1]). The innovation occurring within the UAV industry carries immense potential, not only for transforming the industries in which they are applied but also for generating far-reaching social impacts, both in professional settings and daily life.

Technological [2] and regulatory [3] advancements have contributed to the progress of Air Traffic Management (ATM) solutions and to significant strides in the rapid proliferation of drones expanding their potential across various industries.

The Single European Sky ATM Research (SESAR) program has contributed to the progression of the European drone market, assuming a pivotal role amidst the ongoing succession of technological upheavals characterizing the UAVs [4].

Despite these advancements, the community agreed that there is a need for acceleration to achieve the goal of fully implementing the Digital European Sky [5]. The lack of ground infrastructures is undoubtedly a key factor in its effective implementation.

The aim of this paper is to propose a method - along with a theoretical discussion and some first results - to show how to find the best placement of the aforementioned infrastructures. Taking the urban planning discipline as a guide, a pivotal consideration in this domain is the strategic delineation of optimal aerial pathways that drones can traverse. Just as terrestrial city planning involves careful road mapping and zoning, our focus resides in crafting a coherent framework for the optimal use of airspace. In essence, our research endeavors to help developing what could be termed a "Ground and Aerial Traffic Master Plan". Basically, we propose to conduct a comprehensive spatial analysis to identify the "sky roads" for drones to navigate both in urban and rural environments, ensuring safe and efficient drone operations while accounting for factors such as terrain topography, societal acceptability, meteorological conditions, drone energy consumption, main bird migration routes and areas, and current regulations. By analyzing these factors, we intend to establish the most efficient and safe airspace to place the corridors for drones travelling, and, subsequently, to use this information for finding the most convenient placement of the ground infrastructures (i.e., vertiports, charging stations).

This article is structured as follows. In Section II, we delve into the background along three key guidelines: a master plan for drone infrastructures, corridors, and vertiports. Each of these aspects is presented along with an overview of the related state of the art. Section III provides an in-depth exploration of the core idea in its most comprehensive form, akin to a long-term research vision. Section IV includes a use case description and a discussion on the constraints for the analysis, highlighting the contributions they can provide. Section V contains initial findings that serve to elucidate the methodology and the expected results. Section VI provides an overview of the future developments in our ongoing research.

II. Background

In the Advanced Air Mobility (AAM) National Plan, ENAC, the National Civil Aviation Authority in Italy, claims that AAM is poised to have a significant impact on the urban mobility sector for goods and people, as well as its supply chain. However, relying solely on "traditional technological models" is not sufficient. It is necessary to "go beyond the technological sphere and extend to the infrastructural, regulatory and economic ones". For doing this, ENAC emphasizes the importance to gather commitment from territorial authorities to integrate the new mobility services into existing and future urban plans [6]. An urban plan or *master plan*, indeed, is a comprehensive framework that provides guidance for land use, infrastructure construction, mobility management and environmental sustainability of a specific urban area. These strategies are then used to organize the planning process into spatial and temporal dimensions, facilitating a structured and informed approach to urban growth [7]. The proposal of a "Ground and Aerial Master Plan", defining the best zones for placing both corridors and vertiports, goes in this same direction.

Closely aligned with our vision, the taxonomy delineated by [8] and deeply developed in [9] entails establishing a commercial traffic infrastructure that, upon reaching urban centers, disseminates into the "last mile" [2] through the most efficient transportation modes (whether ground-based or aerial via drones).

The imperative for comprehensive planning is demonstrated by various projects, including the initiative in Bavaria [10] and Switzerland [11]. Here, prior to identifying suitable vertiport locations, a meticulous selection process was undertaken involving collaborative deliberations among multiple regulatory bodies that have a planning authority [10].

In this section, we firstly examine the literature that moves towards the definition of a territorial plan in this aviation sector. Afterwards, since our focus is on corridor and vertiport positioning within the proposed plan, we will then concentrate on the review of the state of the art related to these key elements.

A. *Ground and Aerial Traffic Master Plan for UAVs*

<u>An example of urban plan in traditional aviation</u>

An example of urban plan can be found in the Italian national airport planning documents [12], and it is related to the impact of the traditional aviation infrastructures on the landscape. Protective zones are delineated, and, for each of them, the following type of construction parameters are defined: maximum building heights, permissible construction materials (to minimize light reflection and visual obstruction for pilots), population density considerations (lower density corresponds to reduced risk), allowable activities (to mitigate potential impact risks, for instance, the severity of damage would be higher if an aircraft were to collide with a gas station than with a field), and designated distances to mitigate noise perception.

However, compared to traditional aviation, for the unmanned aviation there will be a significantly larger array of factors to consider, spanning a broader geographical scope for each type of both tangible and intangible infrastructures.

<u>An example of spatial plan in unmanned aviation</u>

Bauranov and Rakas [13] have proposed several hypotheses for urban corridors planning, such as how intersections will be checked, the efficiency of different structures, the possibility of different types of corridors depending on drone characteristics, priority and tasks, overlapping of multiple types of drones, flying between buildings, and the potential location of nodes. In this case, general risk factors are indicated: safety, obstacles avoidance, collision avoidance, weather (mostly wind), social acceptability (noise, visual pollution, privacy), flight restrictions (dynamic and static). It focuses mainly on the urban environment and therefore gives particular importance to social acceptability, especially in the case of flying between buildings, where the privacy of people must be considered.

<u>Multi-criteria analysis plan</u>

Additionally, some academic papers ([14], [15], [16], [17], [18]) use a multi-criteria analysis to identify the least risky of route for drones. However, only a limited number of these studies endeavors to connect various concepts into a cohesive decision-making process. Moreover, none of them applies the multi-criteria analysis also to the integration with the other infrastructure elements, except to corridors. Following are some examples.

Kim and Bae [14] expose the results of an Unmanned Traffic Management (UTM) prototype developed in Korea working on a map that evaluates the ground risk as proposed by the DACUS project [15]. They summarize the "Ground risk model" in five other subcategories: (i) *event model* (due to system errors or collisions); (ii) *impact model* (location and size of affected area); (iii) *exposure model* (presence at a given time and location: mean population density, population behavior patterns, population density map, car traffic, etc.); (iv) *incident stress model* (building, car, or tree protection factors); (v) *harm model* (probability of fatal events). A map has been drawn up for each of the sub-models. The result is a series of pixels on which the ground risk is calculated according to an equation that considers the overlay of all the models listed before. As required by "Specific Operations Risk Assessment" (SORA) [18], they have developed criteria examining the direction and possible arrival position in case of a fall. One of the main points of interest of this work is the airspace capacity estimation to allocate drones using an equation to minimize the probability of collision. Interestingly, they adapted the model to account for possible external phenomena such as wind to calculate the footprint on the ground in the event of a fall.

In [16], for the construction of the risk map, drawn up for the urban scenario, the following factors were considered: population density, obstacles, protected areas, restricted or not restricted areas.

In [17], the corridors are planned based on existing infrastructures, where the best route according to proposed algorithm is computed considering the minimum risk and coverage of 5G antennas, calculating the best reception angle.

B. *Corridors*

Urban and extra-urban corridors

Throughout the academic production, the use of corridors for drone traffic is divided mainly into two categories: urban and extra-urban. In literature extra-urban corridors are static, while urban ones are typically designed to be dynamic and activated based on the flight needs [19], this because the knowledge of where the drones travel allows to place the infrastructures more effectively and efficiently, in particular on a large territorial scale.

Corridors in SESAR plans

An in-depth analysis of the short, medium, and long-term plans developed by SESAR was conducted by Bolić and Ravenhill to explore existing works related to corridors and their potential connections [4]. This examination sought to identify any relevant initiatives already undertaken or that could be linked to the corridor and vertiport concepts. Within these plans, a notable distinction is evident between the advancements made in civil aviation objectives, which have progressed significantly, and those pertaining to U-space.

The most interesting objectives and most connected to the theme of corridors are those identified within the European ATM Master Plan [20]. It highlights 4D flight planning as a key approach to achieving “trajectory-based” navigation. The Master Plan encompasses several objectives, among them: the creation of U-space, virtualization of decision-making processes for dynamic routing and optimization, and 4D navigation for point-to-point flight without conflicts. To realize these goals, the pivotal role of Artificial Intelligence (AI) development is emphasized, enabling easier and more efficient air traffic management [21].

Through funding, the SESAR program has contributed to the birth of some projects that have carried forward the concept of corridor implementation from various points of view, even if in most cases they are still at the theoretical state. Currently, the most advanced classification has been developed by the CORUS-XUAM project [3]. Following the traditional aviation approach, it has subdivided the drone flight space into different categories based on the area flown over, the operator certifications, the drone weight, and the onboard technologies. U-space will assist operators during all the flight phases and, when required, airspace structures are defined, temporarily or permanently, to allow drone operations.

Need of corridors for U-space implementation

This research path originates from the idea that drones cannot be flown indiscriminately, corridors must be established in specific areas to facilitate the development of infrastructures for commercial flights. While the optimization of drone paths for automatic flights has been theoretically established, its practical implementation is still in its infancy due to geographical constraints and the need to construct physical, digital, and non-material infrastructures to support drone traffic [22]. Indeed, drone flight requirements are different from traditional aviation aircrafts, so infrastructure locations will have to be pinpointed to facilitate the placement on the territory of specific technologies for drone needs [23]. When considering cities, the U-Space setup will be more complex than in rural areas (many more factors must be contemplated) [14], and the limitations for flying must consider a much greater variety of factors [13].

Corridors design and airspace management

The design of airspace separation will heavily influence the structure of drone corridors [13]. The minimum separation between drones, which depends on onboard technology, together with other essential factors must be considered when planning. However, currently a standardized framework for the design of these corridors does not exist. Efforts are being made to compile and integrate the conceptual designs from each SESAR project in the Concept of Operations for EuRopean UTM Systems (CORUS) [3]. Indeed, each project born under the SESAR supervision focuses on a particular sector of corridor development, some on their location, some on their structural conceptualization, still others on their traffic capacity, etc. One of the simplest explanations is given within the USEPE project, where the corridors are imagined as “tubes on which drones travel in only one direction” [24]. They are differentiated into categories of speed and travel necessity. USEPE project imagines placing them on low-risk areas within the city such as rivers, railway lines, etc. It should also be noted that within the same project the concept of “Density-Based Airspace Management” was developed, where the space is divided into many 3D cells representing various levels of use. It predicts that corridors and 3D cells will be mainly used within cities and will open or close in sequence dynamically, depending on external conditions and needs.

Some examples of possible navigation scenarios are discussed in BUBBLES [25] according to the airspace categorizations elaborated in the CORUS-XUAM project and considering different types of drones and vehicles of varying sizes. In this work, they envision a corridor structure shaped like a rectangular box divided into four sections. However, only two of these sections would be used for drone traffic: the upper right and the lower left corners (Figure 1). The other two are used either to change lanes, or for deconflictualization purpose. Moreover, some virtual openings were hypothesized for leaving the corridor to reach areas that are not covered by the main one (Figure 1).

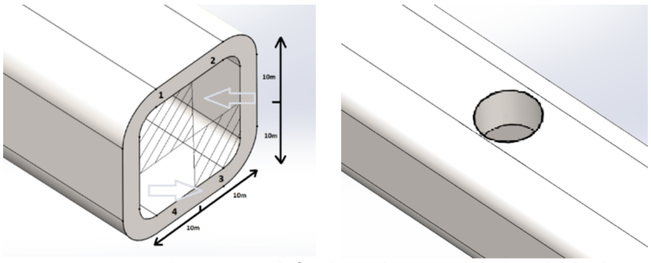

Figure 1. Corridor sections (left side) and openings (right side) [25].

Vila Carbó and Iocchi [26] worked on a concept with two types of structures to accompany the volumes: corridors and boxes. The aim is to present the basis for developing a model that calculates the level of conflict. They work on calculating the possible frequency of conflicts that may occur within a corridor.

The DACUS project analyzes traffic management based on airspace capacity. It is particularly interesting for the parameters to be considered in flight planning starting from a simulation within a road graph [27].

C. *Vertiports*

Taxonomies for UAV shelters

Significant portions of the academic literature encountered in this domain are focused on the spatial classification and allocation of vertiports in relation to the target demographic and their possible integration into the broader spectrum of public and private transportation networks. A noteworthy perspective, elucidated by Lineberger et al. [8], delineates a tripartite taxonomy for UAV shelters. First, “Vertihubs”, characterized by their expansive dimensions, encompassing multiple landing and parking facilities, and strategically positioned on the peripheries of cities or in external locales to function as pivotal hubs. Second, “Vertiports”, embodying a more limited number of landing and parking provisions, typically situated atop existing structures. Lastly, “Vertistations”, which tend to offer a singular landing locus, similarly elevated above urban edifices.

However, this categorization is not universally recognized, in [28] the authors carried out an analysis on the most used keywords in the field of Urban Air Mobility (UAM) ground infrastructure and found out that the term “vertiport” is now being predominantly used in general when speaking about Vertical Takeoff and Landing (VTOL) UAM operations.

Vertiport Placement Analysis

The topic of vertiport placement, with the primary focus on economic and interconnection aspects, is addressed in [10] and [11]. In particular, they carried out a simulation to find the best placement considering the potential demand and, hence, the economic sustainability. Both studies found out that the vertiport planning should consider their quick accessibility and their connection to the broader network. The findings in [11] indicate that speed and access time are critical factors. Moreover, the pricing would only be competitive for individuals with medium to high incomes.

The positioning of the vertiports can also be influenced by its design and structure, which are determined in accordance with the regulations of each national flight agencies, such as [29] in the United States and [9] in Europe. In particular, in [9] the European Union Aviation Safety Agency (EASA). delves into the integration of vertiports within urban landscapes, providing essential parameters for their creation encompassing both physical structures, signage, and technological aspects. The context is centered on vertiports for manned aircraft VTOL-capable, rather than unmanned ones.

Vertiport infrastructures and social acceptability

In [22], the authors discuss the necessity of having adequate infrastructures to foster the development of a robust drone market, while also raising awareness about potential challenges to social acceptability (such as noise and property owners being unwilling to permit overflight). One of the challenges is to anticipate the high volume of flights of future, necessitating an increasing reliance on onboard vehicle technologies. The vertiports will have to accommodate such traffic. EASA proposed a so-called Obstacle Free Volume (OFV) as a protection volume above take-off/landing pads to create a safe environment for UAM operations, especially in congested and obstacle-rich environments [28]. The potential of opening the vertiport market to private individuals is also intriguing. This could lead to individuals making their facilities available and offering drone services, aiming to generate income [11].

III. Main Idea

The main objective of this research is to assist the scientific community in expediting the implementation of a common Digital Sky for the European territory, proposing a method that leverages urban planning principles and the potential of spatial analysis to find the optimal placement of tangible and intangible infrastructures related to U-space management, such as corridors and the resulting ground infrastructures.

Use cases falling within the realm of passenger and cargo transportation are the primary beneficiaries of the proposed method. Moreover, stakeholders involved in route planning as well as those interested in investing in the field of new aviation infrastructures can be interested in the finding of this research.

Regarding the ground infrastructures, from the literature analysis, there is the need of recharging stations and a classification in Vertihubs, Vertiports, Vertistations has been proposed in [8]. Numerous European projects are progressing in the development of demonstrative prototypes related also to this topic [30]. However, determining strategic placements for investments in managing sky traffic and maximizing positive effects (new services, reduction of CO_2 emissions) while minimizing negative impacts (noise, risk of falling to the ground) of such infrastructures on civil society remains a crucial question.

In Section IV, we will provide some results as initial steps in a broader research path, which will involve two types of differentiated analyses: extra-urban and urban cases.

A. *Extra-urban case*

The method involves an initial definition of the optimal airspace sectors for placing corridors for drones to navigate by calculating the minimum risk and the most convenient paths. This process will end with the identification of the best path to connect the different locations of the territory under analysis, and it can be replicated for territories ranging from provincial, regional, national, or even transnational extensions.

Step 1: Optimal Airspace-to-fly Determination

To achieve this, we firstly apply multi-criteria spatial analysis techniques (i.e., *Weighted Multi Criteria Analysis*) [31], where each spatial constraint is associated with a weight based on its attributed importance. Here are the constraints that will be taken into consideration:

- *Orography and obstacles:* refer to the natural landscape, including mountains, hills, and other physical barriers that can impact movement and route planning (i.e., altimetry, buildings, …).
- *Meteorological static information:* involves weather data such as wind patterns, precipitation, and temperature representative of the area (for instance, seasonal average).
- *Bird migration routes:* could pose obstacles and impact safety.
- *Mandatory regulations:* encompass rules and guidelines that must be followed to ensure the well-being and protection of individuals for safety and security (i.e., ground risk, military zone, …) or for preservation of natural areas. This type of data provides *flight operational data* that essentially informs about the zones where it is possible or not possible to fly according to the authorities.

The output of this first step is the determination of a cost surface where each pixel is associated to a value representing how convenient it is to fly above it. For "convenient" we mean: (i) efficient in terms of energy usage for the drone, minimizing waste; (ii) safe along the route, avoiding both fixed and mobile obstacles; (iii) acceptable in terms of social impact (noise, risks to individuals and property); and (iv) compliant with current regulations.

Therefore, at the end of this step, we have the optimal airspace to fly.

Step 2: Optimal Route Determination

Subsequently, starting from the cost surface determined in Step 1 and using specific algorithms such as the *Least Cost Path* (LCP) [33], we will iterate the calculation to determine the best route from given randomly-chosen starting and destination points within populated areas. The output of this phase is the best positioning where to place corridors for drone passage because the flight is more convenient and safer, eventually considering specific corridors dimensions [32].

Therefore, relevant authorities might decide to choose the area around these corridors as a "safety airspace" where a set of corridors can be instantiated simultaneously for different types of drones.

Step 3: Optimal Vertiport Positioning

Once this safer airspace is determined, the same procedure is adopted to identify areas where vertiport positioning is more convenient. In this case, the above multi-criteria analysis can be applied to maximize variables of interest:

- *Energy factor*: the maximum duration of a drone battery.
- *Economic factor*: which type of infrastructure is better to foresee at a particular point, considering the economic impact.
- *Corridors stability index*: given the possibility of spatial changes of the aforementioned constraints, this index will tell how likely a certain corridor can be considered static from a probabilistic point of view.

A spatial pre-processing may be needed to be sure to follow *EASA requirements* [34] specifications. In any case, the output of this step will be a set of points where positioning different types of ground infrastructure is convenient. In this case, for "convenient" we mean: (i) that minimizes cost for the infrastructure implementation; (ii) that minimizes risk of the investment; (iii) that assures a proper support to the U-space implementation; and (iv) that complies with current regulations.

B. *Urban Case*

Similar considerations can be made for the urban context with few adaptations. Therefore, in this case, the method follows the same logical steps of the extra-urban case: first determining the optimal airspace for corridors positioning, and then determining the optimal vertiports positioning.

However, for the urban case, the social acceptability issues will have a much greater influence. Moreover, considering the population density, the classes of use of the buildings flown over, the Global Navigation Satellite System (GNSS) and 4G/5G signal coverage will be of major interest for the corridor positioning. Finally, for the vertiports positioning, the roof of some buildings might be interesting targets.

C. *Demonstrator*

As will be more thoroughly justified and detailed in the "Future direction" section, the plan is to make the various steps of the method accessible through a publicly available demonstrator for illustrative purposes, to provide a better understanding of the potentialities of the proposed approach.

IV. Use case and Constraints discussion

A. Possible use case

As previously said, use cases falling within the realm of passenger and cargo transportation are the primary beneficiaries of the proposed method.

In the cargo transportation scenario, large drones travelling from distant locations to a logistics center, where the goods would be sorted, constitutes a possible use case. Once they reach the delivery point, the "last mile" is handled by smaller drones, which deliver them to the nearest possible point.

In this case, our solution would assist the authorities in charge of flight authorization in proposing flight routes for cargo transportation from one city to another so that they:

- Minimize the social impact in terms of noise and risk to individuals and properties.
- Reduce the energy consumption of the drones due to the stability of the flight level and the wind conditions.
- Reduce the risk of drone falls/accidents by minimizing obstacles along the path (buildings, birds, …).

Furthermore, stakeholders involved in route planning, as well as those interested in investing in the field of new aviation infrastructures, can use the finding of this research to determine the optimal locations for building new ground structures.

B. Constraint Discussion

The larger the number of constraints, the more effective the analysis will be. So, here we provide a discussion on the spatial constraints that can be exploited.

As for *altimetry*, in our initial analysis, we are considering this data in its raw form. However, advanced processing can undoubtedly enhance flight performance output. It has been demonstrated that altering the multi-rotor drone altitude leads to increased energy consumption, making it preferable to delay altitude changes when they are minimal [35]. Furthermore, being situated atop a mountain could render the system more susceptible to atmospheric phenomena. Our future goal is to correlate changes in slope and altitude with precise energy consumption metrics.

With respect to the *buildings*, information regarding their height, typology and density is crucial. Especially in urban scenarios, matching this data with the most recent urban plan would significantly enhance traffic characterization. It would enable the avoidance of the most congested areas during specific time slots (i.e., when students are entering or leaving school), while identifying the least congested ones.

Moreover, matching this data with *census population*, can help analyze the social acceptability factor. Areas with higher population density are less likely to be significantly affected by the frequent passage of drones. Mobile phone cell data, to gauge the concentration of people in specific locations and at particular times, could prove valuable for future projects aiming at creating a dynamic layer to help avoid these areas during their busiest periods.

Protected natural areas might be incorporated in flight operational data provided by national authorities, specifying where it is permissible or not to fly. In the Italian case [36], not all of them are included in the ATM-09 calculations. In our initial analysis, we included the protected natural areas from the national geoportal, as specified in the "First Results" section. However, in future iterations, we intend to expand our dataset to include additional details such as *Important Bird and Biodiversity Areas* (IBA), and *bird migration routes*, which are highly relevant for drone flights.

Regarding *flight operational data*, the national authority should always be the point of reference to stay informed and compliant with any updates.

Another important factor is the integration of *meteorological data*. This data can be categorized into static and dynamic types. Static meteorological data encompasses long-term forecasts, providing insights into anticipated weather patterns over an extended period using historical data. Conversely, dynamic meteorological data pertains to real-time or upcoming meteorological events that may deviate from the initial prediction. Understanding these forecasts is crucial for strategic flight route planning and allows for anticipating and proactively mitigating potential disruptions caused by adverse weather conditions. The inclusion of dynamic data facilitates real-time adaptability during flights, enabling drones to adjust their routes or flight levels to navigate changing weather conditions.

Finally, other type of data can be of interest in ensuring safety and airspace monitoring, particularly concerning *Communications, Navigation, and Surveillance* (CNS) systems. However, this will be the outcome of a specific future research.

V. First results

In this section, we describe the process to generate the first results and we provide a description of a possible use case application. The intent is to unveil the potential of the analysis and the typology of results that could be extracted.

A. Area for Analysis

Italy is divided into multiple regions, each of which is responsible for managing its own geospatial data. The choice of the study area fell on Emilia-Romagna region because it is the one with the largest amount of freely available data both on current research and for future developments. Notably, it offers a substantial database of historical weather information.

B. Data for Optimal Airspace Calculation

For the calculation of the optimal airspace for flying, we used: flight operational data, altimetry, buildings, census population data, protected natural areas. Here are the details for each of this information.

The *flight operational data* were sourced from D-flight [36], the Italian national portal responsible for providing access to this information for both amateur and professional drone pilots. To acquire the necessary data, we submitted a specific request outlining the bounding box limits of our study area.

The *altimetry* data were obtained at a resolution of 10 meters (resolution used for all layers) from the Tinitaly website [37], and these data underwent processing by the National Institute of Geophysics and Volcanology (INGV). It's worth noting that the data available on the Tinitaly site are provided in smaller quadrants compared to the overall extent of the Emilia-Romagna region. Consequently, we downloaded the data and clipped them to align with the borders of Emilia-Romagna.

Regarding *population density*, data pertaining to the population is accessible through the National Institute of Statistics (ISTAT) website, with updates occurring every 10 years [38]. As of now, the 2021 data is in the process of publication, albeit in provisional format. Therefore, for the current analysis, we opted to utilize the 2011 dataset. It's important to note that the final project will incorporate the 2023 data. Using this data, we can perform calculations at the sectional level, such as evaluating population density. Subsequently, using a linear interpolation, the data was transformed, into a raster format to facilitate further analysis and visualization and the comparison with the other layers.

B*uildings* data, as well as various other characterizations of the Italian territory, have been accessed through the Military Geographic Institute (IGM) website under the designation of the National Synthesis DataBase (DBSN) [39]. Similarly, building data was processed to calculate edifices density using a linear interpolation to obtain a raster.

Finally, as regards the *protected natural areas*, we gathered this information from the Emilia-Romagna regional geoportal [40].

C. *Data Preparation and Multicriteria Analysis*

After rasterizing, all the data was subjected to normalization and summation, with varying weights assigned to the different layers. For instance, areas subject to flight restrictions will be assigned different weights.

In spatial analysis, the process of aggregating criteria using weights, typically through summation, is often referred to as Weighted Multi-Criteria Analysis (WMCA) [31]. WMCA is a common technique used to evaluate and rank alternative spatial locations based on multiple criteria, where each criterion is assigned a weight to indicate its relative importance in the decision-making process. The utilized weights are shown in Table I.

Flight operational data and *protected natural areas* correspond to no-fly or restricted zones, so the weights are higher to make them not convenient to fly over.

Census population data and *buildings* density were assigned an intermediate weight. In these areas, indeed, flying is possible, but the social acceptability factor (noise and visual impact) must be estimated. It is noteworthy that, in [16], the buildings presence is, instead, considered a protection factor since they focused on the ground risk calculation.

Finally, the *altimetry* was assigned the lowest weight since it is possible to fly, but the altimetry elevation impacts on the multirotor battery duration.

TABLE I. WMCA UTILIZED WEIGHTS

Constraint	Weight
Flight operational data	0.308
Protected natural areas	0.308
Census population data	0.154
Buildings	0.154
Altimetry	0.077

The result of this first step is the cost surface represented in Figure 2. The areas tending towards blue are where it is more convenient (hence less costly) to fly.

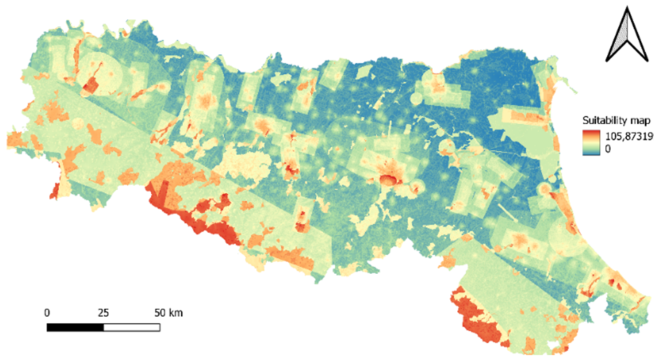

Figure 2. Multicriteria analysis result: cost surface.

We plan to enhance this step by unequivocally designate flight-restricted areas as completely off-limits. This refinement not only would ensure accuracy but also expedite calculations by excluding areas where the ban is already established and known.

D. *Optimal Vertiports Positioning*

Once we obtained the cost surface, to simplify the analysis we worked on the potential vertiport locations identifications. Referring to EASA technical specifications [9] and considering that this was an extra-urban analysis, we focused on placing vertiports outside urban centers, specifically targeting areas exceeding 1000 m^2. In cases where multiple points were closely situated, a 2 km buffer was applied to select just one. As stated in [9], large roofs with few obstacles around in sparsely populated areas were considered favorable candidates.

To perform these calculations, we utilized a weighted clustering process followed by an iterative distance calculation from the centroids of the resulting clusters.

It's worth noting that in certain municipalities, industrial buildings of the required size were not available. Nevertheless, industrial areas were often a viable choice. The output of this phase is depicted by black dots in Figure 3.

Optimal Corridor Positioning

After having individuated vertiport positions, a Least Cost Path analysis was conducted to determine the optimal paths between these nodes (vertiports), thus effectively establishing a network of corridors (see Figure 3).

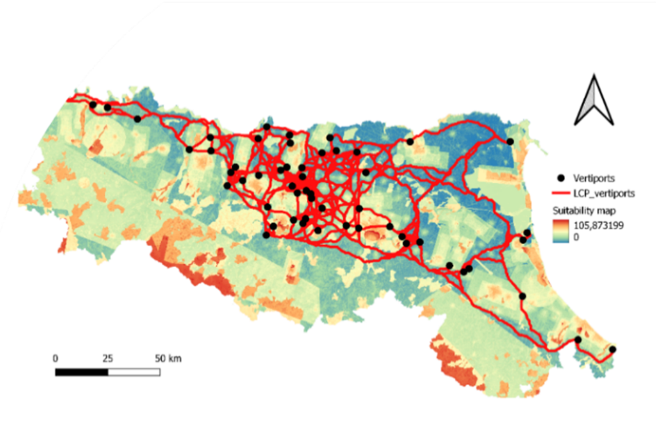

Figure 3. Vertiport and corridor locations through WMCA/LCP analysis.

VI. Conclusions & Future works

Beyond enhancing the efficiency of drone operations, our analysis has a broader impact on urban and rural planning. By establishing optimal aerial corridors, we not only pave the way for seamless drone transportation, but also provide a framework for the strategic development of supporting infrastructure, including vertiports and charging stations. Ultimately, our study contributes to sustainable and effective drone integration into existing infrastructural networks. The outcomes of our spatial analysis provide critical information to build a strategic roadmap for future endeavors, particularly concerning the installation of essential infrastructures. Ground infrastructures and planning tools are primary drivers for drone solutions in real-world scenarios. Therefore, by investing in the necessary infrastructures, the implementation of drone solutions will experience a significant acceleration in various applications. Urban planning principles, as well as spatial analysis tools, are envisioned as central elements for the development of U-space infrastructure to fully unlock the potential of drone industry, thus leading to transformative changes and substantial societal benefits.

Our research plan for the next future is to further deepen the analysis for the *extra-urban case* with several refinements. In particular, we are planning to take into consideration:

- meteorological data, IBA areas and volatile migratory routes, 5G coverage, noise pollution, and urban land use for the "Optimal Airspace where to fly" step;
- corridor dimensions when calculating the corridor positioning.

All these considerations will be brought into the *urban case* scenario. We have already started a research path plan in collaboration with another European university where we will focus on the spatial constraints that have a significant impact on safety for urban scenarios. In addition to this, we plan to:

- improve safety by incorporating a risk-prediction model, calculating the area in which a drone could fall taking into account its speed and wind conditions and considering the building presence as a protection factor, as in [16];
- integrate vertiport positioning analysis with public and private transportation, considering a strategic placement of vertiports in proximity to bus stops or easily accessible large parking areas to enhance overall transportation connectivity.

For each case, we will obtain the GNSS coverage, considering realistic obstructions to satellite signals, which need to be implemented in the area and/or along the planned route.

Finally, as we already mentioned, we are working on making the steps of this analysis freely accessible through a demonstrator. The aim is to provide a better understanding of the potential of the proposed approach and to genuinely assist the community to concretely accelerate the implementation of the Digital European Sky.

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References

[1] S. Jung, Sunghun, and K. Hyunsu, "Analysis of Amazon Prime Air UAV Delivery Service," Journal of Knowledge Information Technology and Systems, vol. 12, no. 2, 2017, doi: 10.34163/jkits.2017.12.2.005.

[2] L. A. Garrow, B. J. German, and C. E. Leonard, "Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research," Transp Res Part C Emerg Technol, vol. 132, 2021, doi: 10.1016/j.trc.2021.103377.

[3] "U-space ConOps (edition 3.10)," Jul. 2022. Accessed: Nov. 24, 2022. [Online]. Available: https://corus-xuam.eu/wp-content/uploads/2022/11/CORUS-XUAM-D4.1-delivered_3.10.pdf

[4] T. Bolić and P. Ravenhill, "SESAR: The Past, Present, and Future of European Air Traffic Management Research," Engineering, vol. 7, no. 4, 2021, doi: 10.1016/j.eng.2020.08.023.

[5] "Digital European Sky," SESAR Joint Undertaking, 2020, doi: 10.2829/44355.

[6] "Piano Strategico Nazionale AAM (2021-2030) per lo sviluppo della Mobilità Aerea Avanzata in Italia," Mar. 2022. Accessed: Mar. 29, 2023. [Online]. Available: https://www.enac.gov.it/pubblicazioni/piano-strategico-nazionale-aam-2021-2030-per-lo-sviluppo-della-mobilita-aerea-avanzata-in-italia

[7] F. Cirianni, P. Panuccio, and C. Rindone, "A comparison of urban planning systems between the UK and Italy: Commercial development and city logistic plan," in WIT Transactions on the Built Environment, 2013. doi: 10.2495/UT130631.

[8] R. Lineberger, A. Hussain, M. Metcalfe, and V. Rutgers, "Infrastructure barriers to the elevated future of mobility," 2019. Accessed: Aug. 23, 2023. [Online]. Available: https://www2.deloitte.com/content/dam/insights/us/articles/5103_Infrastructure-barriers-to-elevated-FOM/DI_Infrastructure-barriers-to-elevated-FOM.pdf

[9] "Vertiports: Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN)," Cologne, Mar. 2022. Accessed: Mar. 29, 2023. [Online]. Available: https://www.easa.europa.eu/en/document-library/general-publications/prototype-technical-design-specifications-vertiports

[10] K. O. Ploetner, C. Al Haddad, C. Antoniou, F. Frank, M. Fu, S. Kabel, C. Llorca, R. Moeckel, A. T. Moreno, A. Pukhova, R. Rothfeld, M. Shamiyeh, A. Straubinger, H. Wagner, and Q. Zhang, "Long-term application potential of urban air mobility complementing public transport: an upper Bavaria example," CEAS Aeronaut J, vol. 11, no. 4, 2020, doi: 10.1007/s13272-020-00468-5

[11] M. Balac, R. L. Rothfeld, and S. Horl, "The Prospects of on-demand Urban Air Mobility in Zurich, Switzerland," in 2019 IEEE Intelligent Transportation Systems Conference, ITSC 2019, 2019. doi: 10.1109/ITSC.2019.8916972.

[12] C. Damiani and A. Allegrucci, "PRA Piano di Rischio Aeroportuale," Comune di Parma. Accessed: Oct. 05, 2023. [Online]. Available: https://www.comune.parma.it/pianificazioneterritoriale/Piano-di-Rischio-Aeroportuale-3.aspx

[13] A. Bauranov and J. Rakas, "Designing airspace for urban air mobility: A review of concepts and approaches," Progress in Aerospace Sciences, vol. 125, 2021, doi: 10.1016/j.paerosci.2021.100726.

[14] Y. Kim and J. Bae, "Risk-Based UAV Corridor Capacity Analysis above a Populated Area," Drones 2022, Vol. 6, Page 221, vol. 6, no. 9, p. 221, Aug. 2022, doi: 10.3390/DRONES6090221.

[15] "DACUS – Demand and Capacity Optimisation in U-Space." Accessed: Jan. 20, 2023. [Online]. Available: https://dacus-research.eu/

[16] S. Primatesta, A. Rizzo, and A. la Cour-Harbo, "Ground Risk Map for Unmanned Aircraft in Urban Environments," Journal of Intelligent and Robotic Systems: Theory and Applications, vol. 97, no. 3–4, 2020, doi: 10.1007/s10846-019-01015-z.

[17] A. Bhuyan, I. Guvenc, H. Dai, M. Sichitiu, S. Singh, A. Rahmati, S. Maeng, E. Ozturk, and M. Chowdhury, "Advances in Secure 5G Network for a Nationwide Drone Corridor," *IEEE Aerospace Conference*

[18] "JAR doc 06 SORA (package) | JARUS," Joint Authorities for Rulemaking on Unmanned Systems (JARUS). Accessed: Jan. 19, 2023. [Online]. Available: http://jarus-rpas.org/content/jar-doc-06-sora-package

[19] A. Fransoy, N. Escudero, I. Vidal, M. Palomar, E. Ventas, D. Gutiérrez, M. Tojal. R. Teijeiro,V. Gordo, and D. Concostrina, "D2.2 High Level ConOps," Mar. 2021. Accessed: Jan. 30, 2023. [Online]. Available: https://amuledproject.eu/deliverables/

[20] "European ATM Master Plan," Luxembourg, 2020. doi: 10.2829/695700.

[21] F. Al-Turjman, J. P. Lemayian, S. Alturjman, and L. Mostarda, "Enhanced Deployment Strategy for the 5G Drone-BS Using Artificial Intelligence," IEEE Access, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2921729.

[22] P. D. Vascik and R. J. Hansman, "Scaling constraints for urban air mobility operations: Air traffic control, ground infrastructure, and noise," in 2018 Aviation Technology, Integration, and Operations Conference, 2018. doi: 10.2514/6.2018-3849.

[23] D. D. Nguyen, J. Rohacs, and D. Rohacs, "Autonomous flight trajectory control system for drones in smart city traffic management," ISPRS Int J Geoinf, vol. 10, no. 5, 2021, doi: 10.3390/ijgi10050338.

[24] J. Bueno, M. Baena, O. Aranda, T. Nikolaeva, V. Mollwitz, J. Rydberg, and F. Wagner, "Report on design concepts implementation Deliverable ID: D4.1," 2022. Accessed: Jan. 26, 2023. [Online]. Available: https://usepe.eu/publication/d4-1-report-on-design-concept-implementation/

[25] C. M. Calvo, "D3.1 Catalogue of generic ConOps Deliverable," Dec. 2020.

[26] J. A. Vila Carbó and L. Iocchi, "D4.1 Algorithm for analysing the collision risk Deliverable," Jan. 2021. Accessed: Jan. 30, 2023. [Online]. Available: https://bubbles-project.eu/work-packages/

[27] Á. Martínez, P. Sánchez-Escalonilla, Y. Seprey, and V. M. Gordo, "Final Project Results Report," 2022. Accessed: Jan. 26, 2023. [Online]. Available: https://dacus-research.eu/wp-content/uploads/2022/12/DACUS_D6.3_Final_Project_Results_Report_00.02.00.pdf

[28] K. Schweiger and L. Preis, "Urban Air Mobility: Systematic Review of Scientific Publications and Regulations for Vertiport Design and Operations," Drones, vol. 6, no. 7, 2022, doi: 10.3390/drones6070179.

[29] M. A. P. Meyers and R. Bassey, "Engineering Brief No. 105, Vertiport Design," Washington. Accessed: Nov. 15, 2023. [Online]. Available: https://www.faa.gov/airports/engineering/engineering_briefs/engineering_brief_105_vertiport_design

[30] V. Lappas, G. Zoumponos, V. Kostopoulos, H. Shin, A. Tsourdos, M. Tantarini, D. Shmoko, J. Munoz, N. Amoratis, A. Maragkakis, T. MacHairas, A. Trifas, "EuroDRONE, A European UTM Testbed for U-Space," in *2020 International Conference on Unmanned Aircraft Systems, ICUAS 2020*, 2020. doi: 10.1109/ICUAS48674.2020.9214020.

[31] A. Rikalovic, I. Cosic, and D. Lazarevic, "GIS based multi-criteria analysis for industrial site selection," in Procedia Engineering, 2014. doi: 10.1016/j.proeng.2014.03.090.

[32] S. Primatesta, M. Scanavino, G. Guglieri, and A. Rizzo, "A Risk-based Path Planning Strategy to Compute Optimum Risk Path for Unmanned Aircraft Systems over Populated Areas," in 2020 International Conference on Unmanned Aircraft Systems, ICUAS 2020, 2020. doi: 10.1109/ICUAS48674.2020.9213982.

[33] R. Gustas and K. Supernant, "Least cost path analysis of early maritime movement on the Pacific Northwest Coast," J Archaeol Sci, vol. 78, 2017, doi: 10.1016/j.jas.2016.11.006.

[34] "Easy Access Rules for Unmanned Aircraft Systems - Revision from September 2022 | EASA." Accessed: Mar. 13, 2023. [Online]. Available: https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-unmanned-aircraft-systems?page=4%23%5FToc18667479

[35] D. Hong, S. Lee, Y. H. Cho, D. Baek, J. Kim, and N. Chang, "Energy-Efficient Online Path Planning of Multiple Drones Using Reinforcement Learning," IEEE Trans Veh Technol, vol. 70, no. 10, 2021, doi: 10.1109/TVT.2021.3102589.

[36] "D-flight." Accessed: Oct. 05, 2023. [Online]. Available: https://www.d-flight.it/new_portal/en/servizi-d-flight/

[37] Istituto Nazionale di Geofisica e Vulcanologia - INGV, "Tinitaly." Accessed: Oct. 05, 2023. [Online]. Available: https://tinitaly.pi.ingv.it/

[38] Istituto nazionale di Statica - ISTAT, "Basi territoriali", Accessed: Oct. 05, 2023. [Online]. Available: https://www.istat.it/it/archivio/104317

[39] Istituto Geografico Militare - IGM, "DBSN - Database di sintesi nazionale", Accessed: Oct. 05, 2023. [Online]. Available: https://www.igmi.org/it/dbsn-database-di-sintesi-nazionale

[40] Geoportale della Regione Emilia-Romagna, "Parchi, foreste e Natura 2000", Accessed: Oct. 05, 2023. [Online]. Available: https://ambiente.regione.emilia-romagna.it/it/parchi-natura2000/consultazione/dati