Institutional and spatial constraints on locating VoloPorts in Greek metropolitan areas

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Abstract

Recent technological developments in aviation, such as vertical take-off and landing and electric engines, are bringing the development of integrated urban air transport systems closer and are generally helping to promote the concept of Urban Air Mobility (UAM). UAM makes it possible to provide integrated air transport services for people and goods in urban areas, reducing travel time initially and leading to cost reductions in the future. The development of UAM will allow urban airspace to be used for short and medium range operations, potentially connecting larger urban areas or neighbouring cities. However, the operation of UAM requires, on the one hand, the development of appropriate urban infrastructure to provide full and vertical support for aircraft, such as vertical landing and take-off areas, specially designed intermediate areas for embarkation and disembarkation of passengers and cargo, as well as areas with operational technical bases for loading, parking and maintenance of aircraft. All this is the concept of the VertiPorts/Voloports/Vertistops. However, the development of a VertiPorts/Voloports/ Vertistops in the dense and complex modern urban environment can be challenging, as on the one hand specific rules for aviation safety have to be followed, and on the other hand their integration into the urban environment requires compliance with the rules of urban planning, land use and protection of private property.

This paper presents the challenges that researchers have to face in order to integrate Voloports into an already formed and dense urban environment, such as that of the city Athens, the metropolitan centre and capital of Greece, in respect to various constitutional, institutional and spatial restrictions.

1. Introduction

Urban Air Mobility (UAM) is an emerging and fast-growing field encompassing urban transport and urban aviation that could further develop the schemes of Mobility-as-a-Service (MaaS) in urban areas, bringing together the existing concepts on transportation facilitation to the great potentials of mass and public urban aviation.

The advancements on autonomous flying vehicles development (Igbinobaro, 2022; Lascara et al., 2019; Straubinger et al., 2020) and of vertical take-off and landing (eVTOL) technologies (eVTOL) (Courtin et al., 2018; Johnson and Silva, 2018; Kleinbekman et al., 2018; Schweiger and Preis, 2022; Straubinger et al., 2020) render UAM a key factor in improving urban mobility conditions for the transport of people and goods as these vehicles will be able to cover long distances in urban environments in less time, compared to traditional modes of transport and in particular compared to road transport and ensure sustainability in urban mobility (Kasliwal et al., 2019; Schaumeier and Luftfahrt eV, 2023).

Key infrastructure facilities for the seamless operation of UAM are those of Vertiports and Voloports (Li et al., 2023; Schweiger and Preis, 2022; Slomski and Harman, 2021; Straubinger et al., 2021). Vertiports will be terminals for the embarkation and disembarkation of passengers and goods, parking of vehicles, but also areas where flying vehicles will remain when not in use and be maintained and their development should include:

- vehicle charging points,
- areas with special facilities for vehicle maintenance
- passenger. Cargo waiting/unloading areas,

At the same time VoloPorts will be specially designed hubs for the landing and take-off of aircraft (driver-less or not-eVTOL), where passengers will be able to board and disembark from aircraft. In vertiport are included single launch pad facilities, Vertistops.

What diversifies Voloports to Vertiports is that Voloports concern metropolitan cities, which are densely populated urban areas.

The challenge for VoloPorts is to integrate them into the overall urban and transport planning of urban areas, so that they become part of an integrated transport system. VoloPorts should be linked to metro stations, railway stations and bus terminals. The dense urban fabric poses challenges for the location of such facilities, which require free urban space as well as compliance with the legislation on property and the protection of property rights, which derive from constitutional mandates and property law.

In a UAM environment, the categories of facilities/infrastructures where (e)VTOL aircraft land and take off will be divided into the following categories:

1) Vertiports

Vertiports will be fairly large facilities covering urban and peri-urban areas, and could evolve to 'Vertihubs'. They will be the core of the UAM network, providing maintenance and repair infrastructure for the flying vehicles and having a centralised control system for their operation.

2) Voloports

Voloports are a subcategory of Vertiports, located in central urban areas and city centres. They must ad have adequate space for both the embarkation and disembarkation of passengers and the loading and unloading of goods. They should also have sufficient space for the simultaneous landing and take-off of more than one (e)VTOL vehicles, be equipped with a rapid charching system, and with automatic control mechanisms for security measures.

3) Vertistops

Vertistops will be connecting points between the larger Voloports. They will have one or two landing/departure positions and will only be used for the embarkation and disembarkation of passengers and the loading and unloading of goods.

The aviation industry uses specific terms for areas, urban and non-urban, intended for aviation operations, such as airports, airfields, landing and take-off areas (and glideslopes, if required), creating a grid of three-dimensional regulated areas. The high density of urban space, both in terms of land use and building density, combined with the need for more specific safety regulations for UAM, requires that when planning for the locations of the necessary facilities to taken under consideration the urban population density, POIs and central administrative and commercial areas distribution, the variation in demand density, the delivery time planning, the trip length, the short travel times, the take-off/ landing times, the Vertiports sites as UAM vehicle interchange nodes, other transport nodes and interchanges and weather conditions.

In addition and according to the FAA and EU regulations, when designing heliports, the distance between the final landing (TLOF) and take-off (FATO) points must be at least 61 m (EASA, 2022; FAA, 1999). Thus, the same should apply when planning of UAM facilities or for overall current or future urban aviation practices.

2. VoloPorts Location Constraints in Greece

In cities, urban airspace is under the regulatory competence of the State, just as urban land and sea space is. At present, urban airspace is controlled and monitored by national aviation and security authorities and by military authorities as access over military facilities and installations is strictly prohibited. At the same time, the current legal framework for drone flights establishes no-fly zones/areas in city centers, airports or natural parks, even close to urban space and cities, or defines zones where drones can be flown under certain conditions and with a flight permit, with a maximum altitude of 120 m (400 ft).

This regulatory framework results in both constitutional-institutional and spatial restrictions that any aircraft operating in urban airspace must comply with, e.g. the existing general regulations and restrictions imposed on helicopter and UAVs flights, the zones that commercial helicopters or UAV are permitted or not permitted to fly, the maximum or minimum flights hight, or take-off and landing processes.

Furthermore, urban airspace is characterised by complexity, due to the morphological landscape over which cities are developed and as the vertical development of cities is associated with the universal rights of owners to exploit their property. Legislation on the protection of properties and property rights is rigorous and strict, and regulates the vertical development within the properties' boundaries (plots or land parcels). In many countries, property rights that include development rights (buildings etc.) extend to the urban space above and/or below the property boundaries, forming the three-dimensional and strictly regulated urban space.

In particular in Greece, the legal framework for the protection of properties, as established by Greece's Constitution (especially after 1975) and Property Law (enacted in 1946), defines that property rights are extended above or under the space of a plot's or land parcel's surface area at ground level (as defined by its boundaries) and that any restriction on its normal use is subject to expropriation, thus requiring the payment of compensation (Perperidou et al., 2021a).

As the urban landscape of Greek cities is not uniformly shaped neither in the 2d nor in the 3d aspect, the urban airspace is fragmented and classified into the following three main categories (Perperidou and Kirgiafinis, 2022):

1. **Private Urban Airspace**: extends over private properties, owned by fiscal and legal entities, owners' rights, including overpassing are under strict protection as this protection is defined by the Greek Constitution, Greek Property Law and GDPR.

2. **Urban Airspace of Public Interest**: It extends over commonly used areas such as schools, churches, transport hubs, state airports, public and private legal entities, this airspace is protected from overpassing as it is under strict protection as this protection is defined by the Greek Constitution, Greek Property Law and GDPR.

3. **Public Urban Airspace**: Extends over public infrastructure, such as roads, streets, governmental property publicly available for use only e.g. beaches, highways, and any overpassing is allowed exempt the cases of restrictions imposed by aviation authorities, the army and the security forces.

Additionally, further constraints exist due to the urban environment and urban fabric that is not homogenous and forms a complex three-dimensional urban landscape in Greek cities and metropolitan areas, Figure 1.

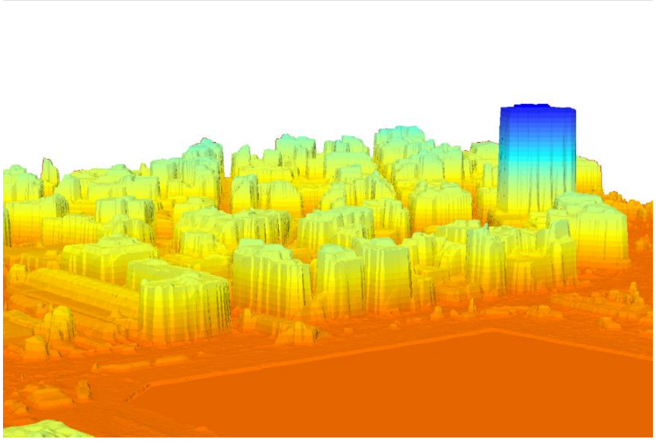

Figure 1: Urban fabric of Greece's metropolitan areas, Piraeus metro station area, close to Piraeus port, digital surface model (source: (Perperidou and Kirgiafinis, 2022).

Due to property laws and the legal framework for the protection of property rights, the development of UAM infrastructures and networks on or above private land or land of public interest is extremely difficult, as various constraints exist.

2.1 Development constraints above the ground level (on roof tops)

Greece's urban landscape in large scale urban agglomerations and cities and, in particular, its vertical development and formation is not homogenous due to varying construction periods and diversified building regulations and public law restrictions on building activities, e.g. protection of cultural heritage (Perperidou et al., 2021b). Thus, the development of Voloports in densely populated urban areas that comply, in the one hand, to flights/ safety regulations, and on the other, to properties/ property rights protection, is facing extreme difficulties.

Buildings located in the same building block, but of different hight, due to different construction period, are attached to each other, while buildings in neighbouring blocks are separated by a distance proportional to the width of the road network that is narrow, leaving no adequate space for air vehicles manoeuvres, especially during take-off and landing. In large populated Greek cities, like Athens, where due to population density and socio-economic conditions UAM development would be prioritised, the terraces of residential, office and commercial buildings are not at the same height as shown in Figure 2, thus they could not be used for the development of Voloports, or even Vertstops.

Figure 2: Unbalanced building hights on King Constantine Avenue, Athens, Greece (Source: authors editing)

Furthermore, due to the small surface area of the plots (at ground level) and the even smaller surface area of the building terraces (the surface area of the upper floors is reduced due to building regulations), the terraces do not have the sufficient surface area to meet Voloport' safety requirements. It should also be noted that on building terraces the relevant and necessary equipment for the operation of the building (e.g. solar panels, telecommunication antennas and chimneys) is installed, which further limits the available terrace area, Figure 3.

Figure 3: Small terrace surface area and unbalanced building hights Eratosthenous str, Athens Greece (Source: authors editing)

Furthermore, the over the ground development of electricity network, municipal or public lightning network and public transportation infrastructures (e.g. tram's or trolley's energy supply network) above the road network, Figure 2 and Figure 3, limit the available urban airspace that is vital for takeoff and landing maneuvers.

2.2 Development constraints on ground level unbuilt urban space

In addition to the difficulties of locating Voloports on the buildings' roof tops, there are just as many difficulties when it comes to locating them at ground level. Due to the small surface area of plots and urban land parcels, their unbuilt surface is extremely narrow, leaving insufficient space for the installation and operation of a Voloport. At the same time, the dense urban fabric makes it difficult to ensure safe vertical take-off and landing, due to narrow width of the majority of streets in Greek cities and the development of over the ground electricity network, municipal or public lightning network and public transportation infrastructures, Figure 2 and Figure 3.

Parks, alleys and public squares are large and unbuilt urban spaces and urban land within Greek cities that could be considered suitable for Voloports infrastructure development. However, the protection of urban green and public spaces is constitutionally guaranteed under Article 24 of the Greek Constitution on "Protection of the Environment". At the same time, both the Constitution and the Civil Code institutionally guarantee and protect the right of people to live and develop in a healthy and sustainable urban environment and to enjoy environmental goods, which include green spaces.

The combination of articles in the Constitution on the right of citizens to live in a sustainable and healthy environment and articles in the Civil Code that exclude common goods such as parks, avenues and squares from the market makes it impossible to use these spaces for the development of Voloports. In addition, the principles of sustainability and the urban acquis apply, according to which it is unacceptable to reduce or eliminate green spaces and deteriorate the living conditions of residents. Consequently, any change in the purpose and use of parks, alleys and public squares is difficult, especially in the densely built and densely populated urban environment of Greek cities.

As a result, there is a lack of institutional support for location of infrastructures that would deprive residents of valuable urban green and recreational spaces.

3. Existing transport infrastructure and Voloports: the case of Athens Metropolitan Area

Athens is the capital of Greece and one of the most densely populated and densely built cities in the world. Athens Metro Area's population is over 3,700,000, while city of Athens population is little over 637,7000 inhabitants, almost 17% of metro area population (according to 2021 Greece's National Census) covering an area of 39 km2, and having population density that reaches 16,333 inhabitants per km2. Athens Metro Area and especially city of Athens host all the major administrative and financial activities of Greece, while it is the main cultural and social life center and tourists' main attraction. Athens city center, known as Athens Historic and Commercial Triangle, is under the strict protective framework of the Ministry of Culture and a series of restrictions on urban development are imposed due to cultural heritage protection legislation (Perperidou et al., 2021b).

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The Metro area is extremely dense built up and the city of Athens is the most densely populated area if Greece and one of the densely built and populated areas of Europe. Due to different development periods starting from the 1920's to the present, city of Athens is characterized by narrow streets, small plots with buildings of more than 5-7 storeys, which do not have the same height (see section 2.1), while the majority of the areas of the urban complex have similar characteristics.

Public transport in the city is provided by above-ground buses, trolleys, trams and the underground metro (line 1 is partially above ground), making the city a major transport hub. The above-ground trolley and tram networks, characterized by above-ground linear cable infrastructure, cover the city's largest and widest streets, Figure 4 and section 2.1..

Figure 4: Trolley network infrastructure in central city of Athens Road network (Source: authors editing)

At the same time, the city has the highest rate of ownership and use of private vehicles, over 1.5 per household ((Perperidou, 2010) and 2011 National Census), which are allowed to park off-street and especially on all non-primary arterial roads, further reducing the available road width for moving vehicles or creating other facilities, such as UAM service facilities, either of Voloports or of Vertistops.

Figure 5: Off-street parking in city of Athens Road network (Source: authors editing)

Thus, wide urban public spaces, and therefore the equivalent urban public airspace, are occupied by various infrastructures and other uses, such as off-street car parks, and at the same time the surface on top of buildings is not sufficient to meet the safety requirements for urban aviation, and on the ground, parks, alleys and public squares are not intended for such uses, limiting the alternatives or the suitable urban spaces for UAM infrastructures development and mainly of Voloports development.

The only urban airspace that is available and suitable for the development of Voloports (and even Vertistops) is that of major public transport hubs, such as park and ride facilities at metro or suburban railway stations, surface and underground public transport junctions, main public transport hubs connecting to national motorways, ports, airports and railway stations, and especially the airspace above the Athens Metro Network major hubs and infrastructures.

The Athens Metro Network has three lines in operation, one under construction and one under feasibility study. The three operational Athens Metro lines, the green line (developed in the 1880s), the blue line and the red line (developed and in operation after 2000), cover the Athens Metro area and connect in parallel the city of Athens and major transport hubs such as the Athens International Airport, the Port of Piraeus, the central railway stations, the central suburban railway stations, the national highways and the new residential and leisure area under development at the former Athens airport in the southern coastal suburbs of Elliniko, Alimos and Glyfada, Figure 6.

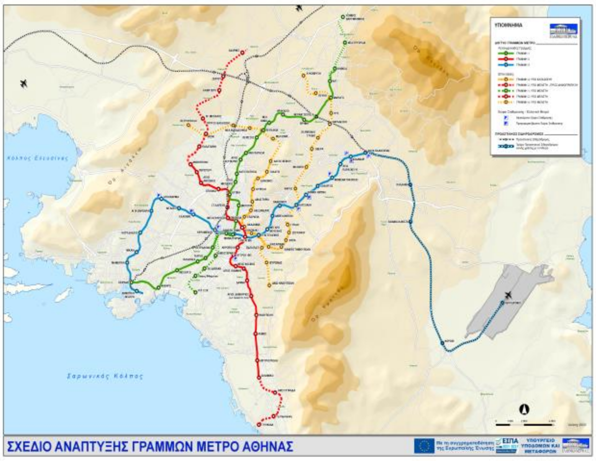


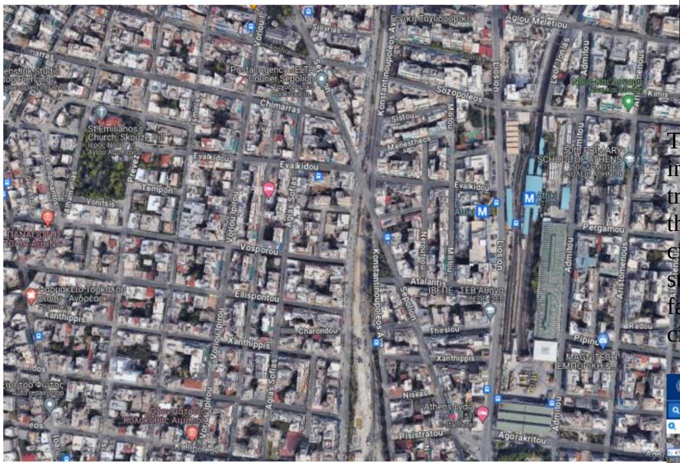
Figure 6: Athens Metro Network (Source: ("Athens Metro Lines Network Development Map," 2023))

The metro line four, the yellow line, which is under development and construction, will connect the city of Athens and its centre with neighbouring and densely populated municipalities where the university campuses and large commercial and recreational urban areas are being developed, Figure 6.

Along the network of Athens metro lines, and at regular intervals, there are extensive park and ride facilities, facilities for connecting to other public transport (which also serve as terminals for buses, trolleys, trams), and underground auxiliary metro facilities, even within the boundaries of the densely populated and built Municipality of Athens. These large-scale and transport-facilitating land uses, according to urban and integrated transport planning, can also serve as Voloport infrastructures, making the development of Voloports feasible in the near future.

Those urban surface areas are already hosting transportation services and, as these areas are legally defined, are included in the urban and spatial plan and also in the transport plans For these urban areas, no additional legal procedures are required, as they are legally defined and integrated in the urban and transport planning as areas of common interest, exclusively dedicated to hosting land uses relevant to transport and transport activities, have sufficient area to host Voloports, and are not surrounded by vertically developed obstacles and densely built-up areas that could pose a threat to vertical take-off and landing manoeuvres, Figure 7.

(a)



(b)

Figure 7: a) Doukisis Plakentias Metro Hub and public transport Terminal, Chalandri Municipality & b) Attiki Metro Hub, Municipality of Athens (Source: Google maps)

3.1 Connecting the new urban area of Hellinico to central Athens via UAM

The urban environment of the Athens Metropolitan Area for developing the UAM infrastructure, and in particular the Voloports, is, as mentioned above, rather peculiar and complex. This is because there is a continuous development not only in the center of Athens, but also in the suburban areas, whereas there is a debate on the increased buildings' height.

On the occasion of the flagship urban development in the Ellinikon area, Figure 8, where, in addition to residential development, one of the largest urban parks in Europe, "The Ellinikon Experience Park", is being created and developed, as well as other activities such as commerce, entertainment, etc., which are already attracting not only residents but also tourists, the scenarios for connecting area to the center of Athens via are of particular interest.

Figure 8: The under development Hellinico Area (Source: Hellenic Cadastre)

The Zappeion area, Figure 9, is one of the largest open spaces in the centre of Athens Municipality, which already hosts transport facilities and in particular parking facilities, is close to the Syntagma square and Metro Station and close to the historic city center and the Acropolis, and has been selected as a case study to develop scenarios for the development of Voloports to facilitate the connection of the Hellinico development to the city center.

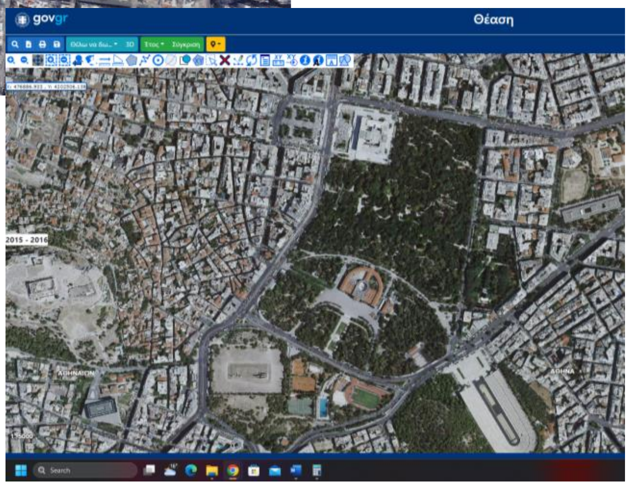


Figure 9: The Zappeion area (the Athens historic center and the Acropolis are on the left, the Syntagma sqr and the Syntagma Metro Station are on top) (Source: Hellenic Cadastre)

The connection between Elliniko and Zappeion is now by two routes: the northern route, which runs parallel to Mount Hymettus via Vouliagmeni avenue, and the southern and coastal route via Poseidonos and Syngrou avenues. The average trip time, by car, on these routes is 30 minutes and can take

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over an hour in heavy traffic. All three avenues have 4 lanes in each direction and their airspace has no particular obstacles, so UAM routes can be developed, the shortest being that of Vouliagmeni Avenue due to shortest route length, Figure 9.

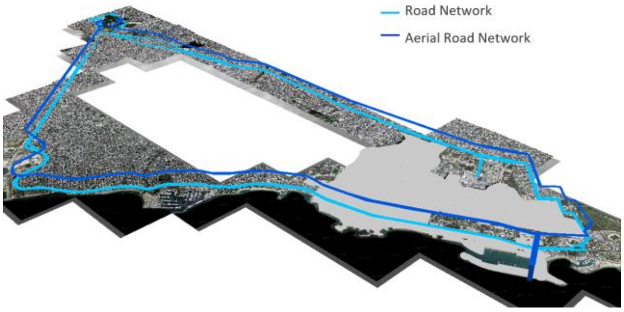

Figure 10: Connection between Elliniko Area & Zappeion Area, via road and UAM (Source: authors editing)

Along the Vouliagmenis Avenue and next to the Hellinico Area the Hellinico Metro Station is located, the Hellinico metro Station, thus a Voloport can be created there, Figure 11. On the other hand, and due to the importance of Syntagma Square, a Vertiport can be created at Zappeion, to ensure that flying cars can performs vertical take-offs and landings while respecting environmental and noise constraints and avoiding the existing obstacles of the existing urban fabric, without this facility taking up valuable urban space, Figure 12.

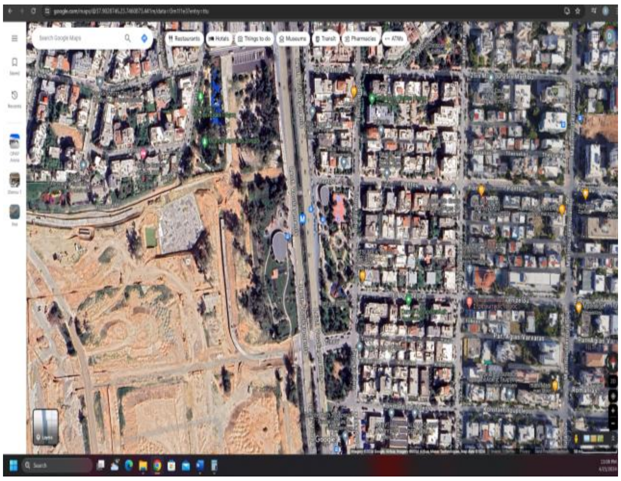

Figure 11: Hellinico Metro Station (Source: Google Maps)

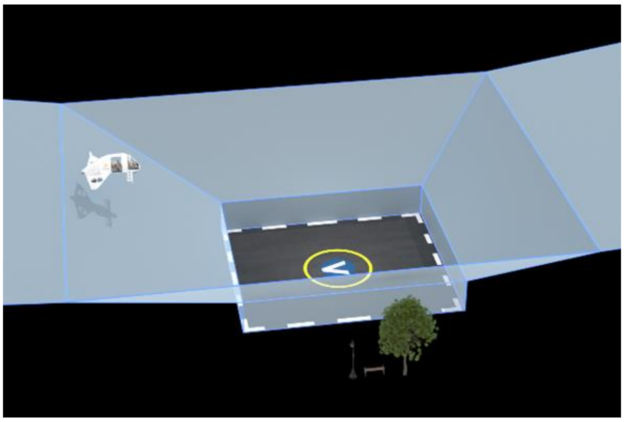

Figure 12: Vertiport example.
(Source: Vertiports in the Urban Environment, 2022)

4. Conclusions

The existing dense urban fabric and landscape of cities, and especially of Greek cities such as Athens, creates serious institutional and spatial constraints for installing UAM service infrastructures, and in particular Voloports, that are due to be developed at central areas of the urban fabric and at densely populated urban areas.

As UAM is a rapidly developing sector that can bring together not only a significant improvement in traffic conditions in urban areas (especially the central ones) and in the promotion of MaaS but also can open new ways for urban and spatial planning and cities evolution. Thus, its institutional and operational development should be compatible with the already existing urban space and urban areas land use and already formatted transport infrastructure. This approach will also not lead to social reactions due to the loss of open spaces or the restriction of on-street parking.

At the heart of the development of the UAM transport network in complex urban environments, such as Athens the capital of Greece, can be the prospect of developing Voloports on existing urban spaces and surfaces that are already used for transportation purposes, such as the Athens Metro infrastructure of park and ride, hubs, interconnection hubs to other transport mode and maintenance areas.

The possibility of locating Voloports in existing public transport facilities or on under development large scale areas, can contribute significantly to the much-needed in detailed specialization of the technical specifications on Voloports installation and construction. Furthermore, it can also facilitate the guideline that are required for UAM routes, in respect to aviation regulations and safety requirements. Furthermore, it can facilitate the integration of UAM necessary land uses, like Voloports or even Vertiports, into spatial, urban and integrated transport planning, facilitating also the overall acceptance of UAM by citizens.

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