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SMART GREEN MOBILITY
CITYAM

Development of a geospatial decision-support tool for Urban Air Mobility landing and launch site location planning

Analysis, Framework and Technical Setup

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Summary

This report, a part of the CITYAM project funded by the Interreg Baltic Sea Region, focuses on the background analysis and development for a decision-support tool (DST), to be used in planning suitable locations for landing and launch site (LLS) of Urban Air Mobility technologies, namely drones with a diameter not larger than 3 metres. This and similar types of aerial vehicles are expected to appear in the mobility systems of European municipalities over the coming years, and thus require responsible deployment. The report is primarily targeted to civil servants and municipal officials, especially those in municipal and regional organisations currently responsible for land use and public deployment of drone technology.

The importance of developing a DST for LLS selection is emphasised by the constraints of urban land use, drone technology, anticipated impacts, and the current void in rules and roles for drone-related decision-making within municipalities. On the one hand, assumptions for DST development are based on elaborated drone flight dynamics in the urban environment, such as LLS access, design, and interaction with flight corridors. On the other hand, assumptions for DST development are based on the need to define the scope of the LLS planning process, assuming distributed responsibility among drone operators, the municipality and civil aviation authority.

Based on the aforementioned assumptions, a set of functional requirements for DST have been defined, including multi-criteria analysis as the suggested decision-support framework. As such, the requirements and framework are supposed to be useful in CITYAM case municipalities, while also being transferable to other contexts, with possible modifications for specific constraints. Moreover, a set of potential decision criteria for LLS location choice is identified, paving the way for a systematic and transparent approach to decision-making. The development also includes defining key planning process phases, as well as suggestions for roles and responsibilities within a LLS planning process.

The DST prototype is implemented in a geospatial environment, formulating multi-criteria analysis within the open-source Quantum Geographic Information (QGIS) System as weighted overlay analysis. In addition, the development includes formulation of back-end data management and front-end user interface.

The report concludes with suggestions for further research and development, both in the realm of decision-support tools but also in the realm of governance of Urban Air Mobility technology in general.

Contents

Abbreviations

BVLOS - Beyond visual line of sight

CAA - Civil aviation authority

DST - Decision support tool

EASA - European Union aviation safety agency

GIS - Geographic information systems

GUI - Graphical user interface

LLS - Landing and launch site

MCA - Multi criteria analysis

UAM - Urban air mobility

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1. Introduction

1.1 The emergence of Urban Air Mobility and the LLS location problem

The recent years have seen an emergence of diverse Urban Air Mobility (UAM) technologies, generally referred to as drones (Kramar et al., 2021; Grote et al., 2021). This emergence is as part of the wider urban mobility system transformation for sustainability, aiming for such goals and impacts as increasing safety, equitable accessibility, reducing pollution, energy consumption and costs (Banister, 2008; Geels et al., 2017; Mladenović et al., 2020; Mladenović et al., 2021; Ryghaug et al., 2023). Technological development of drones in recent years has partly been due to the convergence of several technical factors (Cohen et al., 2021; Floreano & Wood, 2015). For example, advances in battery technology coupled with light-weight materials have increased the energy density and flight endurance of battery-electric drones, making it possible for them to cover longer distances and carry heavier payloads. In addition, there has been development of various avionics devices responsible for sensing, computing and telecommunication, which has enabled improvements in collision avoidance and navigation tasks while flying. The convergence of these UAM technologies together with other urban technologies (e.g., sensing, communication, pricing) being deployed as of the time of the writing of this report, enables drones to operate in (semi-)autonomous manner, in the conditions referred to as Beyond Visual Line of Sight (BVLOS).

Simultaneously with the technical development and the development of a European regulatory framework, the number of applications and use cases for drones in the urban and peri-urban environment has been increasing (Ayamga et al., 2021; Merkert & Bushell, 2020; Pöysäri, 2023; Tojal et al., 2022). For example, these use cases include infrastructure inspection (Shafiee et al., 2021), special purpose logistics (Grote et al., 2023) and enabling telecommunication (Wang et al., 2017). As such, tasks that drones have been responsible for deal with two basic aspects of accessibility (Figure below), one being digital connectivity (i.e., bottom right node in the figure) through sensing and communication (i.e., “eye-in-the-sky”), and the other being physical mobility (i.e., bottom left node in the figure), by picking-carrying-dropping load (i.e., “hand-in-the-sky”). Applications so far have been mostly focused on non-safety critical timing, while there are also applications to domains with safety-critical timing, such as healthcare sector related deliveries (Carrillo-Larco et al., 2018; Chowdhury et al., 2021). Leaving the aspect of human mobility with UAM technology outside the scope of this report, the cases here focus on drones whose largest diameter should be under 3 metres.

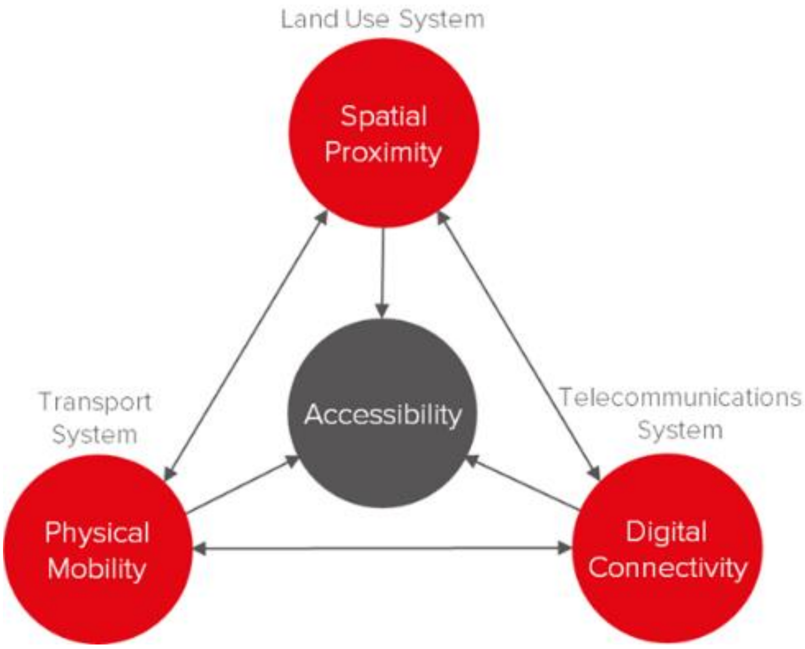


Figure 1: The concept of triple-access relevant for urban environments (Triple Access Planning)

Drones, being an emerging technology, have five general attributes: radical novelty, fast growth, coherence, prominent impact, and uncertainty and ambiguity (Rotolo et al., 2015). Given the important past lesson that technological trajectory (i.e., a path of development and diffusion that specific technology has over time) over time is usually non-linear, it is safe to assume that both the design of drones (e.g., rotors, number and position of rotors, wings, tethering, control algorithms, etc.) as well as concepts and terminology around drones will continue to change (Mladenović & Haavisto, 2021). As such, this report will use the generic term “drone” for all the possible versions of the current and future UAM technologies. Besides this aspect of anticipation, it is also safe to assume that as diverse actors start to use drones for diverse use cases, the number of drones, flights, and flight hours is expected to increase in urban areas (Garrow et al., 2021). Finally, with the changes in the broader society around the technology, non-linearity of technological trajectories can be represented with a multitude of S-curves of technology diffusion, as in the following figure.

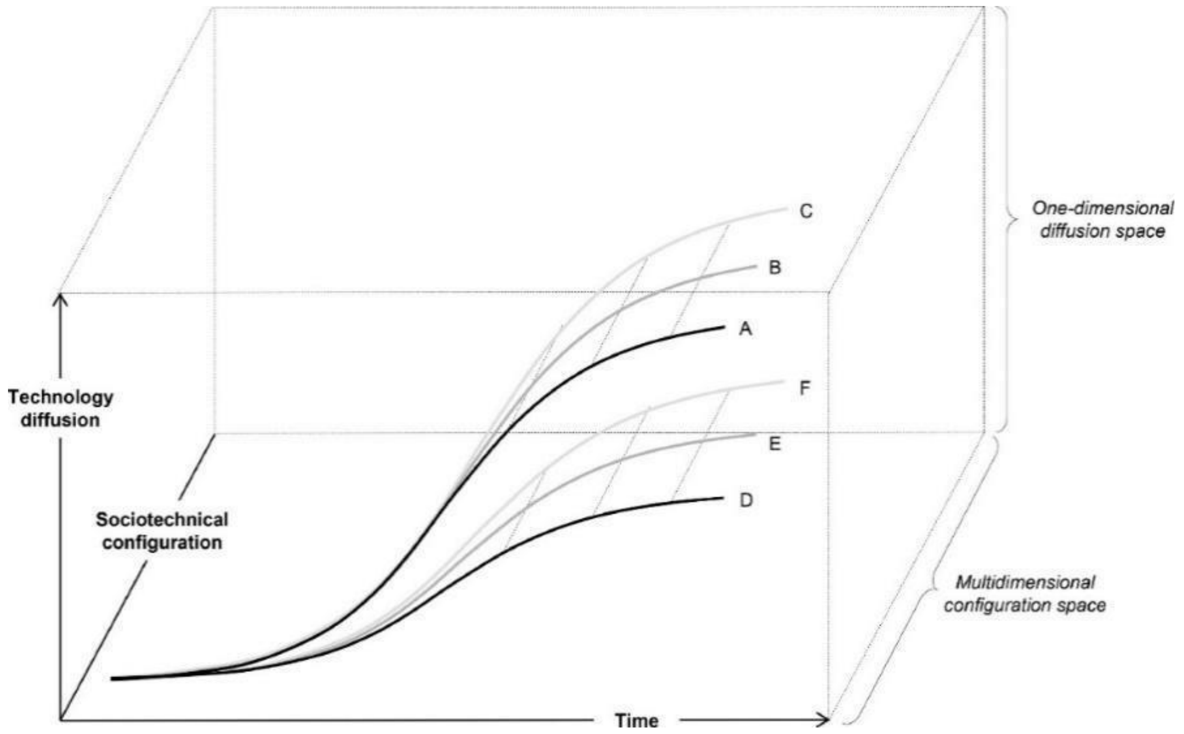


Figure 2: Six potential development trajectories (A-F) for an emerging technology, resulting in different socio-technical configurations and/or different levels of diffusion (Andersson et al., 2020)

At the core of drone's technological trajectory in the urban context, there is a location choice problem for drone landing and launch sites (LLS), more specifically in urban areas. However, we also know that emergence of urban mobility technologies is intertwined with broader constraints of urban space allocation (Mladenović & Stead, 2021). Thus, LLS location choice problem is a multi-faceted issue that involves determining the optimum locations for different drone use cases within an urban area, including the following constraints:

- Urban land is a scarce and limited resource.
- Urban land is owned by different stakeholders in different contexts, including public and private actors.
- Urban land often already has assigned use and is used by residents and organisations.
- Urban land use changes have planning dynamics that are on a scale of decades, which is quite a different dynamic from technological trajectory change, which are often relatively shorter in time.
- Urban land use has potential for dynamic use only in specific locations, such as seasonal changes in using streetspace for snow storage, or daily changes in curb use and allowed parking duration.
- There are multiplied demands for urban land use, such as different emerging urban mobility technologies or then different residential or organisational needs.

- There are multiple goals that land use and its change has to contribute to, which are part of a wider urban system transformation, beyond the mobility system transition, such as improving quality of life, social cohesion or resilience to climate change.

1.2 The need for a decision-support - impacts and governance

The need for decision-support in planning the LLS locations in urban areas relates to two important decision aspects - anticipated impacts and governance. On the one hand, responsible and accountable decision-support is needed given a plethora of anticipated impacts and the non-linear nature of drones as emerging technology (Genus & Stirling, 2018; Mladenović, 2019). Here, decision making faces a double-bind problem called the Collingridge dilemma. On the one hand, in the early stages of a drone's technological trajectory it is hard to predict impacts. On the other hand, once the technology matures, it becomes more difficult to change that same technology. This “Catch-22” situation is depicted in the following figure, where the technological flexibility as a capability to change technological trajectory in its early stage is relatively high. At that early stage, anticipation of impacts can and should be improved (i.e., depicted with a change from blue to green line). Here, it is important to remember the precautionary principle, used to help decision-making when there is scientific uncertainty against the possible impacts of a particular action, product, or service. According to the EU Court of Justice the precautionary principle is defined as a general principle of community law requiring the competent authorities to take appropriate measures to prevent specific potential risks to public health, safety and the environment, by giving precedence to the requirements related to the protection of those interests over economic interests.

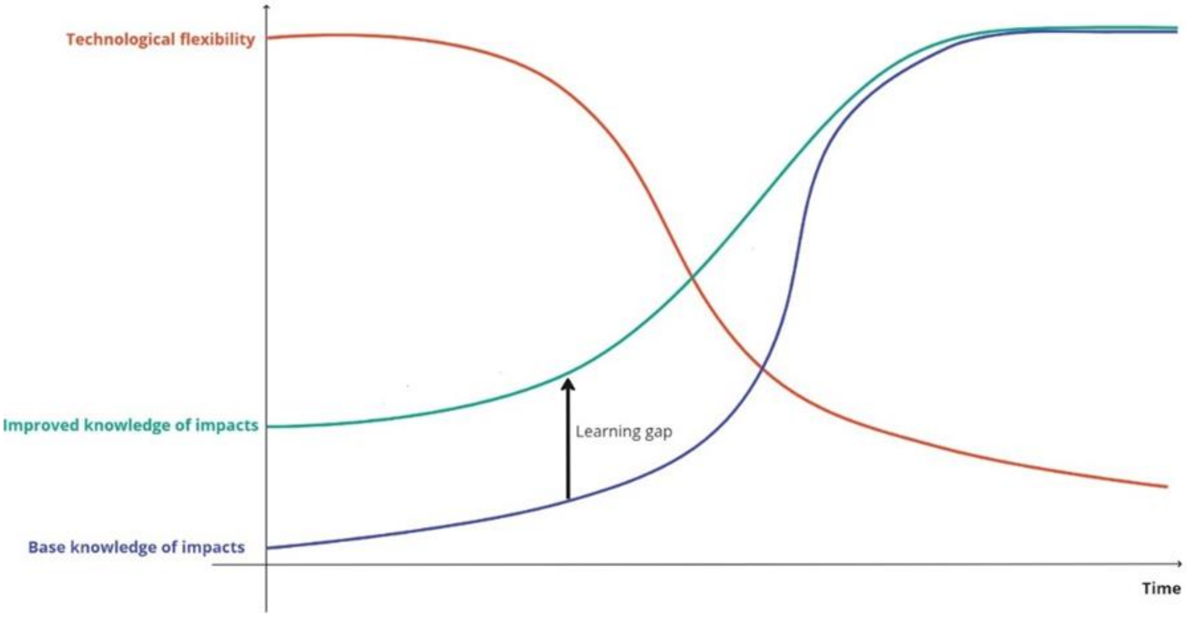


Figure 3: Revised depiction of Collingridge dilemma to account for improved anticipation (Mladenović et al., 2022)

Given the Collingridge dilemma above, it is important to understand the types of anticipated impacts from drone technology, and pay special attention to the undesired impacts. When talking about anticipated undesired impacts from UAM, the main first order impact in terms of urban safety is the question of air and ground risk. Air risk is how likely the drone is to collide with other airspace users (Fricke et al., 2021), while ground risk is the likelihood of causing any fatalities, injuries or property damage on the ground (Primatesta et al., 2020), given that a drone can fall anywhere within a certain radius from the route, usually with uniform probability distribution. These risks go back to the high kinetic energy that a drone as an object in motion has, which can lead to bone fractures and lacerations from rotor blades, among others (Duma et al., 2021; Gorucu & Ampatzidis, 2021; Pozzi et al., 2022). Moreover, both of those risk types relate to a number of potential conflicts between/among drones and the urban environment at large, which does not just include static obstacles such as buildings (Churchwell et al., 2018; Tiusanen et al., 2022), but also dynamic ones, such as birds (Lyons et al., 2018). Besides the share of conflicts among objects in the air, safety risk of drones also depends on technical failure of different drone components (e.g., sensor, communication, rotor, parachute) as well as criminal intent and cyberattacks. Further details are presented in the following Table 1, depicting both safety issues as preventing direct harm as well as security as preventing intentional misuse or criminal intent.

Table 1: Classification of safety & security in UAM (Long et al., 2023).

Classification	Safety & Security
● Personal safety	● Passenger: Passenger interference (disruptions, hijacking, sabotage, etc.) ● People on the ground
● Environmental safety	● Weather risk - Wind gusts (especially in high-density urban areas) ● Avian/Bird strike risk
● Operational safety	● Risk of insiders: Air and ground crew human factors (loss of situational awareness, task saturation, etc.)
● Physical security	● Sabotage: Critical system failure (degraded or loss of command and control, GPS; engine failure; etc.) - Terrorism
● Cybersecurity of all the enabling IT systems	● Ticketing/Booking - Air traffic management, communications, navigation, surveillance - Autonomous aircraft systems

Besides direct impacts limited to safety only, we can anticipate a range of other potentially undesired impacts affecting the overall welfare in a society (Kraus et al., 2020; Wang et al., 2023; Al Haddad et al., 2020; Straubinger et al., 2021). Closely related to safety are broader security concerns, such as those related to general public privacy. (Yaacoub et al., 2020; Shafique et al., 2021). In addition, there is also noise from drones, related to their high pitch stemming from rotor speed which can be a few thousand revolutions per minute. Besides the rotor speed, there is also influence from proximity to the ground given the point source of emission, which as an outcome might be approaching noise of 100 dB for commercial delivery drones (Paine, 2019; Torija & Clark, 2021). Besides the sound intensity, the sound type might be substantially more annoying to people than road traffic or aircraft noise due to special acoustic characteristics such as pure tones and high-frequency broadband noise (Schäffer, 2021). However, the actual noise pollution impacts will vary both on the properties of the environment (e.g., buildings, weather), operations (e.g., flight frequency), and subjective resident experiences (e.g., existing tolerance for noise by emergency vehicles). Similarly, besides collisions with birds, drone noise might have other impacts on wildlife, such as changes to behaviour we are already seeing for wildlife in the urban environment (Slabbekoorn & den Boer-Visser, 2006). Further secondary impacts might also include changes in the perception of public space, relating to those aspects such as perceived safety, urban aesthetics or place attachment (Thomas & Granberg, 2023). Changes in perception in public space can in turn lead to other impacts, such as those related to changes in daily activity space of residents, and associated changes in overall well-being, energy consumption and other emissions.

On the other hand, in contrast to anticipating impacts, the need for decision-support relates to the question of responsible governance (Bonnefon et al., 2020). Here, we define governance as the long-term interactions of different actors guided by a somewhat stabilised system of rules (Rhodes, 2007; Verma et al., 2023). As already recognized in the drone operations certification processes (Öz et al., 2022), emerging technologies often face the so-called “problem of many hands” (Van de Poel, 2015). Many hands problem refers to a setting where a decision task is commonly shared by more than one person, or among a group. Involvement of multiple hands make the task difficult to proceed, both in terms of accountability as well as responsibility. Such a problem of many hands is already quite common in decisions about location problems in cities, since planning processes in general have to include a range of stakeholders, including city planners, politicians, private stakeholders, specific community groups, and the general public. Beyond the many hands problem, and similar to other emerging urban mobility technologies, decisions related to drones face a so-called institutional void, defined as missing rules, processes and actors (Mladenović et al., 2022). A clear example of this void is the fact that low altitude urban space is sometimes not owned or governed by cities themselves who have to provide the land for LLS.

Overall, current municipal civil servants do not have much experience with drones as emerging technology or their anticipated impacts. In addition, processes and responsibilities across different actors are missing. Since municipalities are a key stakeholder responsible for land use planning and broader societal impacts in their area, there is a clear need to develop institutional capacity to make decisions about drones in the urban area. More specifically, one of these decision domains is the land allocation for LLS sites. Thus, the decision-making need is formulated as the need for a decision support tool (DST) that would aid with planning LLS location. Such a tool has to be useful and usable (Pelzer, 2017) in supporting urban planning activities for deciding on LSS location. The DST presented in this report aims to mitigate these risks and minimise the undesired impacts of drones in the urban environment, while also helping to develop supportive policies and overall governance approach.

1.3 Report aim and scope, methods used, and report outline

The aim of this report is to elaborate on the underlying factors, develop a decision-support framework and process, as well as present the technical setup for a decision-support tool (DST) to be used in planning LLS locations within municipal purview. The report is part of the CITYAM project (Interreg Green Mobility), and its primary audience are civil servants in municipalities and regional authorities, while secondary audiences are civil aviation authority representatives, UAM operators, and other key stakeholders currently or to-be responsible for LLS location choice. The focus of CITYAM is on different UAM drones except the electric vertical take-off and landing (eVTOL) aircrafts that are supposed to carry substantial load or passengers. The scope of this report is in synergy with other CITYAM reports, such as 1.1 on European regulations (Kista Science City), 1.2 on social acceptance, 1.3 on use cases, and 1.5 on readiness levels.

The background analysis and development of DST are done using a combination of different complementary methods. Analysis is done using rich picture diagramming (Lewis, 1992; Bell et al., 2019), as a visual communication technique used to capture and represent complex situations, issues, or systems in a holistic and inclusive manner. Typically employed in systems thinking and problem-solving processes, a rich picture diagram provides a visual snapshot that incorporates diverse perspectives, stakeholders, and relevant elements within a given context. It goes beyond traditional linear representations by fostering a deeper understanding of the underlying dynamics. The rich picture diagramming is complemented with desktop research of the academic and grey literature as well as individual and group stakeholder interviews (Flick, 2022). As such, this analytical approach encourages dialogue with stakeholders, helping to uncover hidden insights, identify potential solutions, and develop a more comprehensive understanding of the complexities involved with drone LSS location. On the other hand, the diversity of interviewees combined with systematic negation and abstraction is needed to avoid several well-known biases in technology foresight, such as framing, desirability, overconfidence, or anchoring bias (Bonaccorsi et al., 2020; Mladenović et al., 2020).

Besides the individual interviews (list of interviewees available in Appendix I), the development process included several workshops (Appendix II). The first collaborative workshop, held February 2023, was conducted to collect possible criteria for LLS location choice as well as suitable and unsuitable locations for LLS. In addition, the workshop also focused on identifying relevant stakeholders for LLS location planning in the specific municipality, namely Helsinki, Stockholm, Hamburg, Tartu, Riga, and Gdansk. The workshop was divided into two parts, starting with the individual questionnaire for each participant followed by a structured group discussion.

The second workshop was conducted in Tartu in June, 2023. The workshop was divided into two parts. The first part focused on collecting additional criteria for LLS location choice, followed by a discussion session on the planning process of LLS location choice. During the first part of the workshop, participants identified additional criteria into four criteria groups named, user pull-to, user push-away, system pull-to and system push-away. Moreover, participants also provided comments on structuring criteria into four groups. During the second part of the workshop, participants were divided into two groups. Participants of the first group focused on the development of the DST. The participants of the second group included the practitioners from Stockholm, Riga, Tallinn and Gdansk were interviewed about the planning process for the LLS location choice process. During the interview, the participants discussed the planning processes, challenges, good practices in respective cities, and expectations from the DST.

The third workshop was conducted in Stockholm in August, 2023. The workshop presented the developments made in developing LLS location choice process, after which, participants provided information about established planning processes in partner countries, phases in planning processes and contracting of public spaces. Additionally, the workshop also focused on presenting the progress made in developing the GIS DST and collecting feedback related to the development of the tool. Participants from Helsinki, Hamburg, Stockholm, Gdansk, Riga and Tallinn participated in the workshop.

Final workshop of 2023 was conducted in Hamburg in December, 2023. The workshop shared the progress made in developing the decision framework, report and GIS DST. After the update, the focus of the workshop was to confirm the direction of development of the planning process and GIS DST, as well as provide feedback on the supporting report. Project partners from Helsinki, Hamburg, Stockholm, Gdansk, Riga and Tartu participated in this workshop.

Simultaneously with the analysis, development of DST has focused on Geographic Information System (GIS), as the optimal environment for the decision-support needs. The development has proceeded iteratively through clarifying functional and technical requirements, use process, and user interface. Initially, the tool is developed and tested in Helsinki, Stockholm and Hamburg, with the further rollout to Tartu, Gdansk and Riga, as well as other municipalities in the Baltic Sea Region and beyond

After the introduction section, this report includes the assumptions related to spatial scale and location choice for drone interactions in section 2. The report defines functional requirements for DST in section 3, including specific requirements for in-meeting multi-stakeholder sessions. The decision support framework, employing Multi Criteria Analysis, is detailed in section 4, and the planning process, roles, and responsibilities are discussed in section 5. Section 6 delves into the development of the DST in a GIS-based environment. In section 7, the report concludes with general recommendations for drone LLS planning, suggestions for tool development and validation in 2024, and considerations for future DST development beyond the report's scope.

2. Assumptions behind the spatial scale and location choice for drone’s interaction with ground level

2.1 Fundamentals of drone flight in urban environments

Simply put, drones fly because sped-up air has more kinetic energy and therefore lower static pressure (Hoffmann et al., 2007; Gorji-Bandpy & Aly, 2021; Semkin et al., 2020; Götten et al., 2021). The following figure depicts basic forces acting on a drone during flight. The rotors on a drone spin at high speeds, creating an upward force called lift. This lift is generated by the rotors pushing air downward, in accordance with Newton's third law of motion (i.e., for every action, there is an equal and opposite reaction). The faster the rotors spin, the more lift is generated. In addition to lift, the spinning rotors also generate thrust, which is used to move the drone in different horizontal directions. By varying the speed and angle of the rotors, the drone can be manoeuvred in any direction. Countering the lift and thrust, the air itself as a fluid with its own dynamics leads to drag, and the weight of the drone itself, which depends on the components of the drone. An essential trade-off in drone design is between stability and speed.

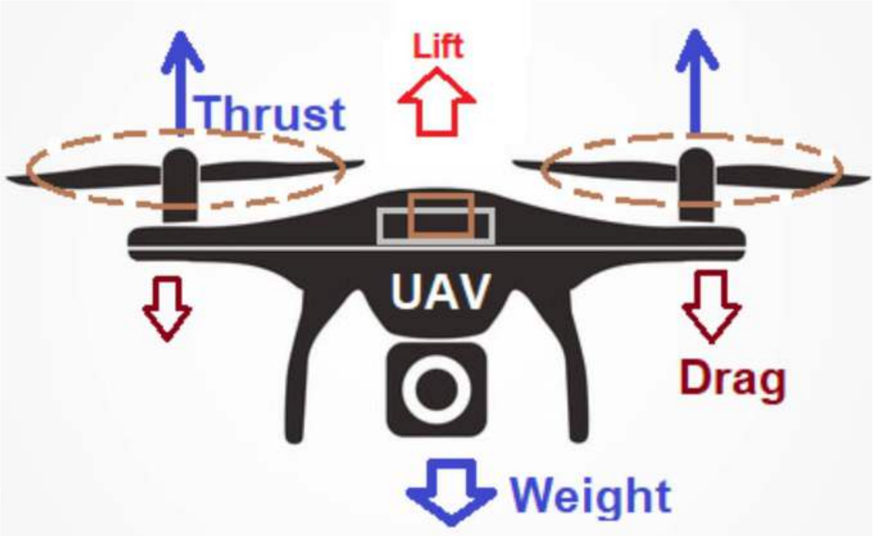


Figure 4: Basic forces acting on a drone (CFD Flow Engineering)

The key drone components are the rotors, which provide stability and control, while also enabling the drone to change its orientation and maintain stability in the air. In addition to the rotors, the key components are electronic equipment fitted in an aircraft, generally called avionics, which include for example sensors such as gyroscopes, accelerometers, magnetometer, and GNSS receiver. Together with an onboard flight controller and communication components, there is a continuous measurement of the drone's orientation and movement, and there is a continuous adjustment of rotor speed to maintain stability and execute movement intentions, such as change of travelling speed. Thus, the drone itself has a rather high level of manoeuvrability, as compared to aeroplanes or helicopters. As outlined in section 1.1, the components of drones in the future are expected to change. So far, we can already witness different configurations of rotors (e.g., four, six, eight rotors), supporting wings, failsafe parachutes, and advances in control algorithms based on machine learning.

Besides these microdynamics (i.e., approximately under 1 second temporal scale) that afford the drone high level of manoeuvrability, while flying from an origin to destination, drone's route-based macrodynamics (i.e., approximately beyond 1 second temporal scale) can be divided as:

- Take-off
- Landing
- Climb
- Descent
- Straight line flight
- Changing direction
- Hovering
- Dropping off objects
- Picking up objects

An essential part of macrodynamics of drone flight is the position of the drone in the airspace, most easily observed as height from the ground at which the drone is at each point in time. In addition, the required distances from other objects or constraints in the urban environment, which can be referred to as the horizontal corridor, can often include several tens and even hundreds of metres of horizontal clearance. i.e. ground risk buffer. Thus, a combination of these aspects results in an airspace volume, with its boundaries (Straubinger et al., 2020). For example, the lower boundary might be determined based on objects on the ground, but also noise and privacy, while the upper boundary can be defined based on conflicts with other users of the urban airspace, such as helicopters or bird migration pathways. The figure below depicts a side view of airspace volume and ground risk buffer in a conceptual manner. One can observe that drone flight volume is bounded by contingency volume from below, above and the sides.

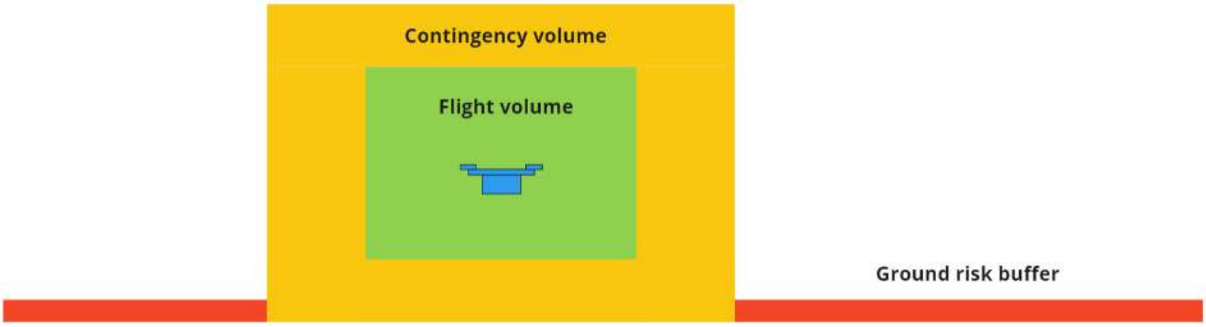


Figure 5: A conceptual side view of the airspace volume and ground risk buffers

In addition to the upper and lower boundary for airspace volume, the question of the horizontal corridor relates to areas in the municipality where permanent or temporary flight restrictions are in force. An example of such restriction zones over Helsinki can be seen from the following figure. For example, it is evident that airport proximity with its “inverted cake” airspace classes will have consequent drone restrictions. Similarly, as it can be seen from the same figure, military facilities will also have drone flight restrictions. It can be anticipated that other areas designated as no-fly zones permanently or temporarily will be introduced over time by designated authorities.

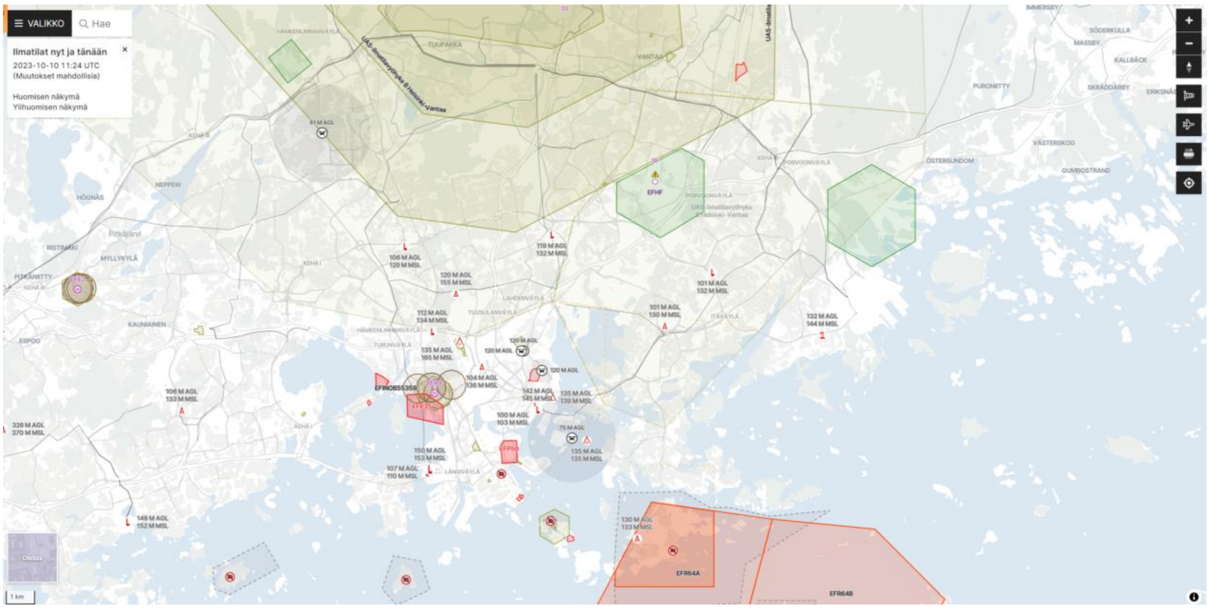


Figure 6: Various drone flight restriction zones over Helsinki (Aviamaps)

In the highly dense urban airspace (Patrinopoulou et al., 2022), airspace volume will need to be defined through virtual geofences (Hoekstra et al., 2018). Moreover, airspace volume might need to be dynamically configured in both space and time (Hind et al., 2018; Lacher et al., 2019), especially by using Flight Layers, as specific subregions where drones would have specified heading direction, maximum speed, and flight priority. Such layered configuration is a basis for altitude separation as the conflict resolution procedure in case of multiple drone demands for the same time-space. More specifically in the EU, U-space is the implementation of automated traffic management, and it consists of a set of new services (e.g., information, geo-awareness, flight authorization, conformance monitoring) relying on a high level of digitalization and automation of functions, as well as specific procedures designed to support safe, efficient, and secure access to airspace for large numbers of drones (Tojal et al., 2022). In general, the overarching interdependence between available degrees of freedom for drone flight and drone capabilities (e.g., dynamic geofences, advanced sense-and-avoid capabilities) is still a rather unresolved question (Bauranov & Rakas, 2021).

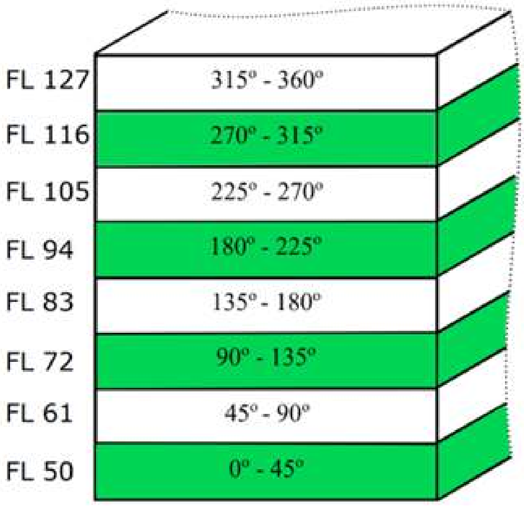


Figure 7: Schematic view of an example Flight Layers concept with an allowed heading range of 45 degrees (Tra et al., 2017)

A number of studies have investigated the operational planning challenges of UAM. These studies have focused on operational planning of UAM in terms of travel route, airspace parameters, flight distance and speed parameters, flight plan, flight route, cost efficiency, scheduling problems, landing capacities and travel time range (Qinshuang et al., 2021; Huang et al., 2022; S. H. Kim, 2020; H. Lee et al., 2022; Long et al., 2023; Rajendran & Harper, 2021; Roy et al., 2020; Xie et al., 2022).

The use of drones in urban environments, and especially in the Nordic environments, has several specific constraints (Watkins et al., 2020; Kramar et al., 2021; Kramar et al., 2022), all fundamentally related that drone is a vehicle that has to move through a dynamic fluid, i.e., air, while also needing to have contact with the ground surface for its performance (e.g., charging the battery, maintenance) and functional tasks (e.g., delivery of load). The air in itself has a changing density, usually with elevation, and thus while thinner air results in less air drag it also means that less pressure and lift is created. Thus, already this component affects the drone's ability to fly as intended. In addition to the change in density, the movement of air in the atmosphere, generally referred to as wind, brings with it further aspects for consideration in understanding constraints on drone flight. Among many components, wind has speed, direction, and rate of change in speed and direction, which can result in (micro)bursts and turbulence (ASCE, 2011; Mittal et al., 2018; Reja et al. 2022). Turbulence can further be classified into mechanical (i.e., near buildings, trees and variable terrain), convective (i.e., related to thermal and moisture aspects), frontal (i.e., related to the weather cold front position), and wave (i.e., downstream from the rotor disk). An example of mechanical turbulence between different building constellations is depicted in the following figure. Previous research has found that wind speed within the urban environment may increase by 74% and decrease by 61% from the conditions found in flat areas/open lands. Moreover, the wind direction inside the city changes based on the locality, where wind direction may change crosswise by 77°, vertically upward by 20° and vertically downward by 26° from the direction of the free-stream flow, while larger wind angles are expected due to climate change (Al Labbad et al., 2022). Besides the change in wind direction, expert interviews have suggested that 14 m/s wind gust speed is a current rule-of-thumb for maximum tolerable value by drones.

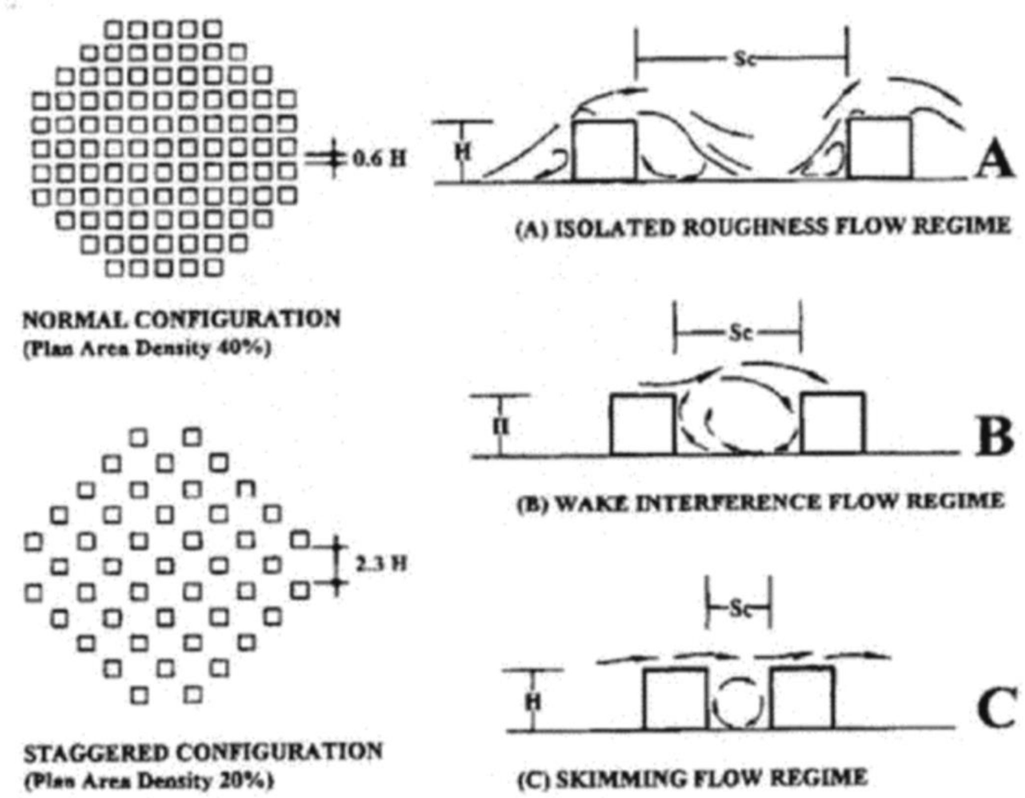


Figure 8: Depiction of urban environment aerodynamics (ASCE, 2011)

Besides wind, urban air conditions also depend on several other factors, such as temperature, precipitation, humidity, frost, icing, fog, sun glare, shadows, solar radiation, and lightning strikes (Gultepe, 2023). For example, the probability of freezing conditions increases with flight altitude. These weather aspects can affect both the changes in the aerodynamic conditions around the drone such as increasing drag or weight, as well as affecting the function of drone components, such as sensor, rotor, structural or battery capability.

Taking the above aspects into account, the taking-off and landing are highly critical phases of a drone's flight dynamics. For example, challenging aerodynamics can make it difficult to maintain control, and in combination with the objects present in the urban environment (e.g., tree) and load distribution on the drone, might require the drone to have substantial space around the LLS to adjust. Thus, the LLS area can expand in a conical shape, as depicted in the figure below, while for optimal operations, the areas should also be clear and flat.

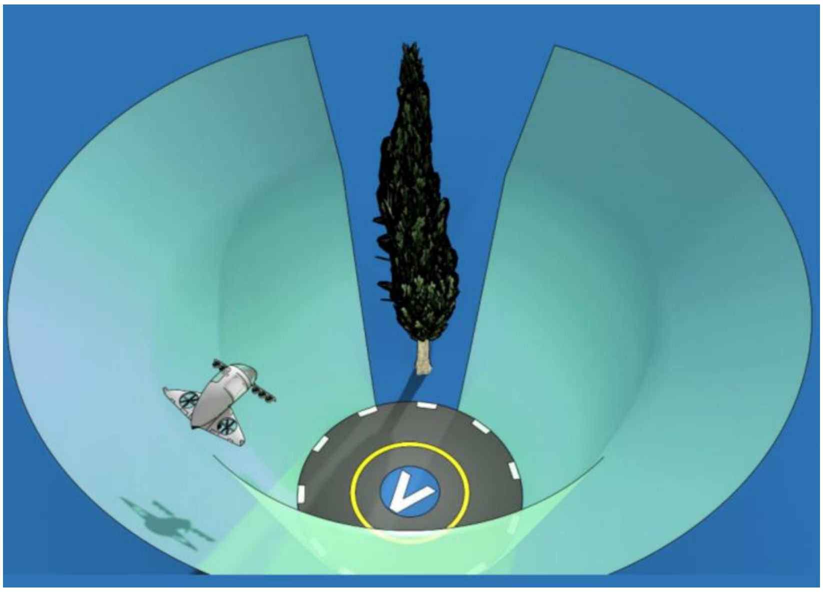


Figure 9: Vertiport obstacle-free volume with omnidirectional approach and take-off climb surface and prohibited sector — perspective view (EASA, 2022)

The following figure depicts reference volume and approach/take-off climb surface for drones in a dense urban environment, although the visualisation is for illustration purposes only as the actual suitability has not been assessed.

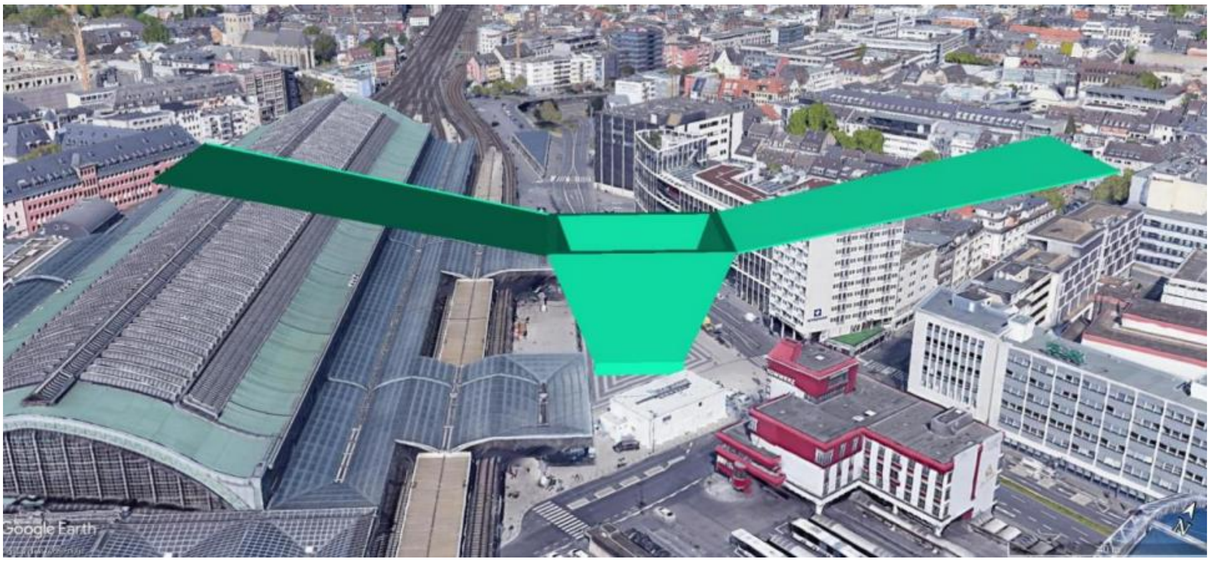


Figure 10: Reference volume and approach/take-off climb surface (EASA, 2022)

2.2 Additional assumptions related to drone flight and LLS interdependence

Continuing from the assumption that the taking-off and landing are critical phases of a drone's flight, the first set of additional assumptions relates to ownership of land/building and access to LLS. The general categorization of possibilities is depicted in the following figure with the fourfold field. On the one hand, land can either be publicly- or privately-owned, although some other options might be relevant in specific municipalities. On the other hand, LLS can be accessible only to specific expert users, e.g., emergency service or maintenance personnel, or then be open to the general public.

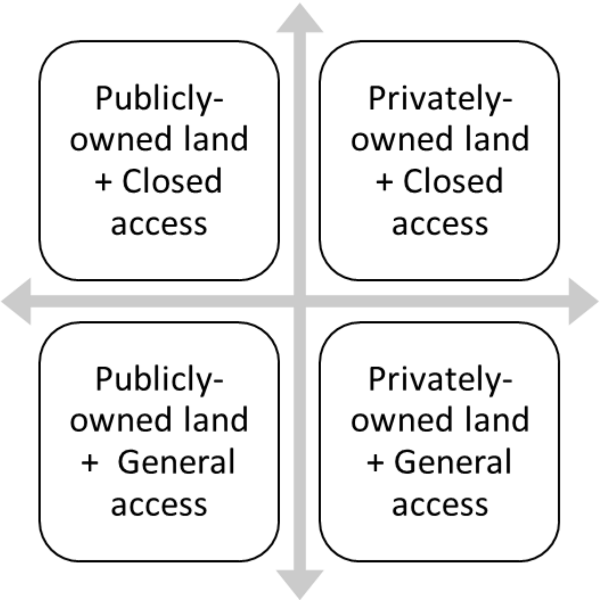


Figure 11: Possible combinations of land/building ownership and access to LLS

The second set of important assumptions relates to three types of LLS-related areas, namely Nest, Target and Exit locations, which can be categorised in the following figure. Nest is assumed to be needed for every drone use case, since it would be a place where drones can return after successful flight operations, with a need for charging, cleaning, maintenance, or storage. Broadly speaking, a Nest can be on the ground level or on the roof level. Target locations are more diverse than Nests, and correspond to different use cases of “hand-” or “eye-in-the-sky”. The essential question related to Nests and Targets that is still unclear is what is an acceptable distance between different nest and target areas for different use cases. The acceptable distance might depend on such aspects as minimum horizontal distance during take-offs and landings, the use cases, or restrictions established by CAA. Finally, given the anticipated safety risks, it is prudent to also assume that different crash situations should also be anticipated, as this is also done both in the existing ground and air mobility systems, e.g., clear zones along the highways.

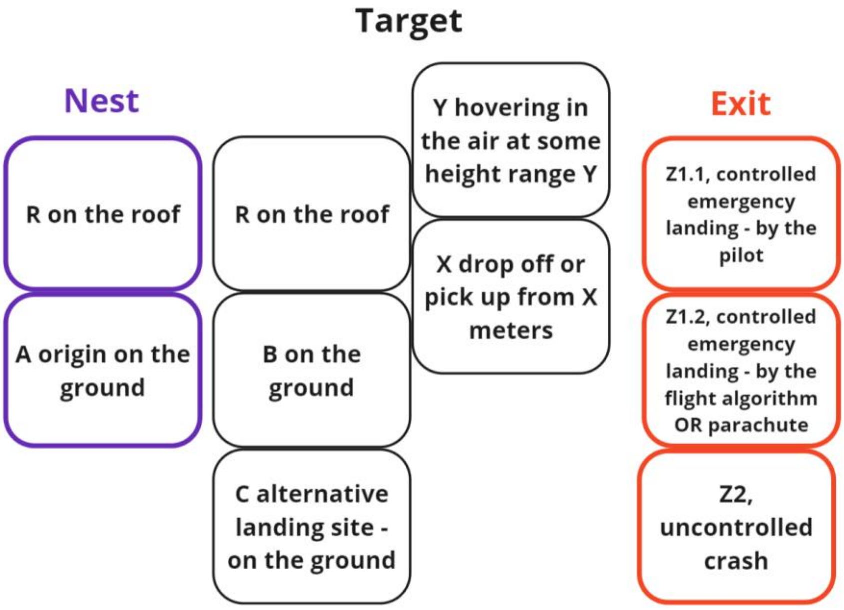


Figure 12: Classification of potential areas both on land and in the air for three different categories of flight beginning and end points

The third set of assumptions relates to the influence of airspace use on land use. Unfortunately, rules for developing drone flight paths are still in their nascent stages. Here, it is important to highlight the assumption that drones will not have to or will be able to fly in a direct line from origin (e.g., Nest A) to destination (e.g., Target B). Taking into account ground risk buffers as well as contingency Exit locations, it is safe to assume that UAM in a specific municipality or region will have to move only through designated airspace corridors. Within those corridors, specific flight trajectory will depend on other factors, such as wind, presence of birds or other drones. That flight trajectory will rely on Flight Levels and other management principles for conflict resolution (e.g., priority given to drones for emergency response over other types of drones, similar to Signal Preemption for traffic signals). As such, once the information about these corridors is available, it should be taken into account when deciding LLS locations. Conceptual depiction of these assumptions can be found from the following figure.

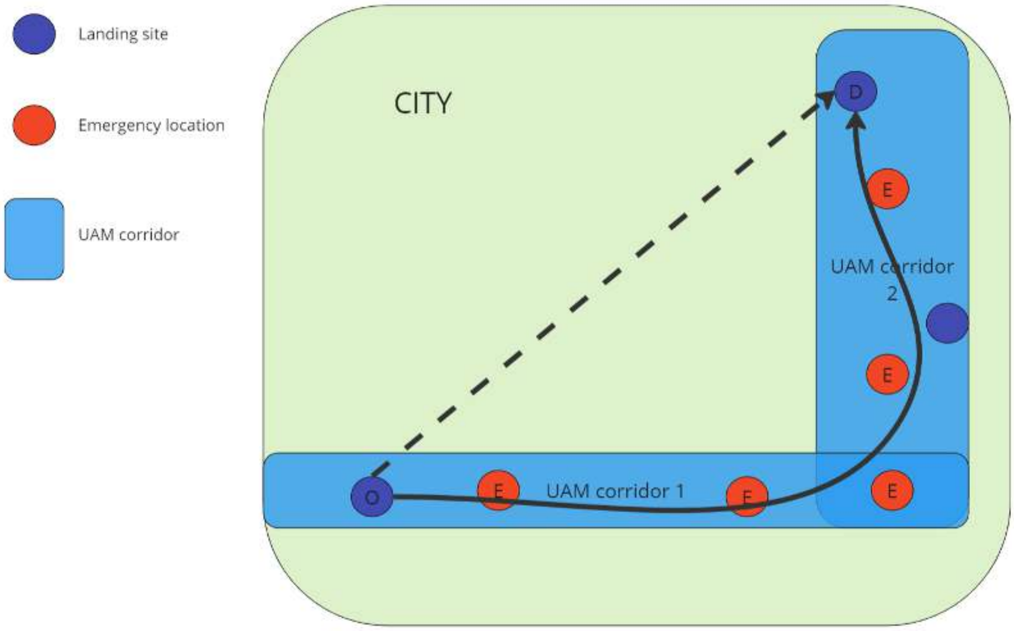
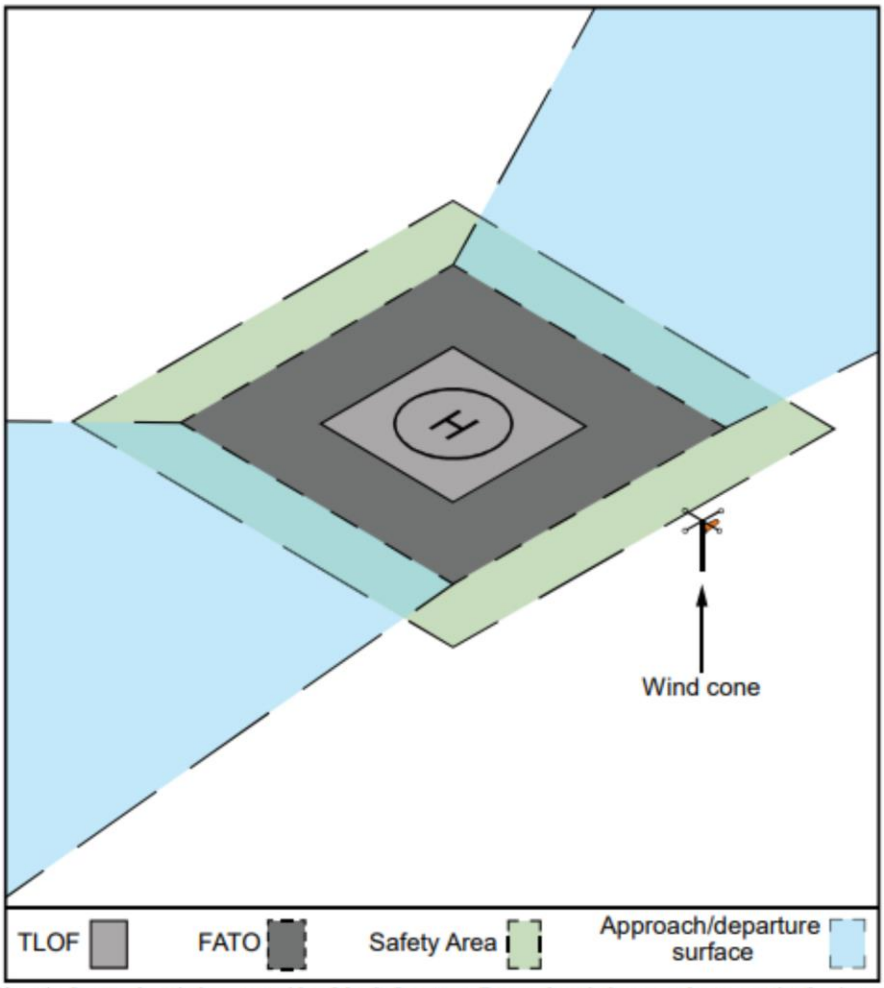


Figure 13: Conceptual depiction of the UAM corridor and LLS decisions

The last important set of assumptions relates to the design of the whole landing area, including the broader surrounding area where LLS is located. Some lessons for design of the drone LLS can be drawn from helipad design (EASA, 2014; FAA, 2023), which includes several components depicted in the following figure. Touchdown and Lift-Off Area (TLOF) is the designated area of a helipad where the helicopter's wheels, skids, or landing gear make contact with the ground during landing and takeoff. It is crucial for the TLOF to provide a stable and safe surface for the helicopter to touch down and lift off. The TLOF dimensions are defined based on the size of the helicopter that will be using the helipad. Final Approach and Takeoff Area (FATO) is the area of the helipad that includes the TLOF and extends beyond it. It is the part of the helipad where the helicopter makes its final approach during landing and initiates takeoff. The FATO needs to be clear of obstacles and provide a safe path for the helicopter during these critical phases of flight. Both TLOF and FATO are essential components of a helipad design to ensure the safe operation of helicopters. The dimensions and characteristics of these areas are determined based on various factors, including the size and type of helicopters that will be using the helipad, as well as any regulatory requirements or guidelines. Proper markings, lighting, and surface conditions are also important considerations for the TLOF and FATO to ensure safe helicopter operations, as there is often a need for people to access the site.

In addition to TLOF and FATO, helipads must be designed with clear obstacle-free zones, especially in the approach and takeoff paths – approach/departure surface marked in blue. This includes considering nearby structures, trees, and terrain that could interfere with the safe operation of helicopters. Besides these considerations, the safety area, marked in green in the figure above, is usually designated to include the availability of firefighting equipment. In addition, helipads often require security measures to control access and ensure the safety of both personnel and aircraft. This can include fencing, access gates, and surveillance systems. Finally, helipad design incorporates considerations for emergency response, including the provision of clear access for emergency vehicles.



Note 1: Locate the wind cone outside of the Safety Area. Ensure the wind cone and any security fencing or security barrier will not interfere with the approach/departure surface or transitional surface.
Note 2: See Chapter 4 for guidance on heliport markings.

Figure 14: Helipad area depiction with components (FAA, 2023)

Inferring from helipad design experiences, the following figure depicts a conceptual design of the LLS area needed for drones in urban areas. The green area depicts the area similar to TLOF in helipads. The orange area depicts a functional zone, which would be for ensuring human access to the landed or tethered drone. A clear zone is depicted in red, and is supposed to be accounted for if the LLS is located in an area with pedestrian traffic and without access control, where at least 2 metres should be left as clear from obstacles for pedestrians. Similarly, minimum distance to other specific objects in the urban streetscape might be required. The shadow zone is a surrounding area that has to be decided on a case-by-case basis, both its dimensions and design, which could also include fences for access control. The figure also depicts a tree in the form of a green circle, that can be located in the shadow zone if that has been estimated as feasible regarding landing and take-off flight dynamics. Here, a tree is just an example of an object in the shadow area, and other objects could also be considered as acceptable, such as light poles. In addition, a shadow zone needs to ensure a clear access for emergency and maintenance services, and it might also include video surveillance to deter and respond to criminal activities. Further criteria for LLS design can be drawn from EASA guidelines (EASA, 2022), and include the set of the largest dimensions, the maximum take-off mass, and avoidance of the most critical obstacle for a specific LLS area.

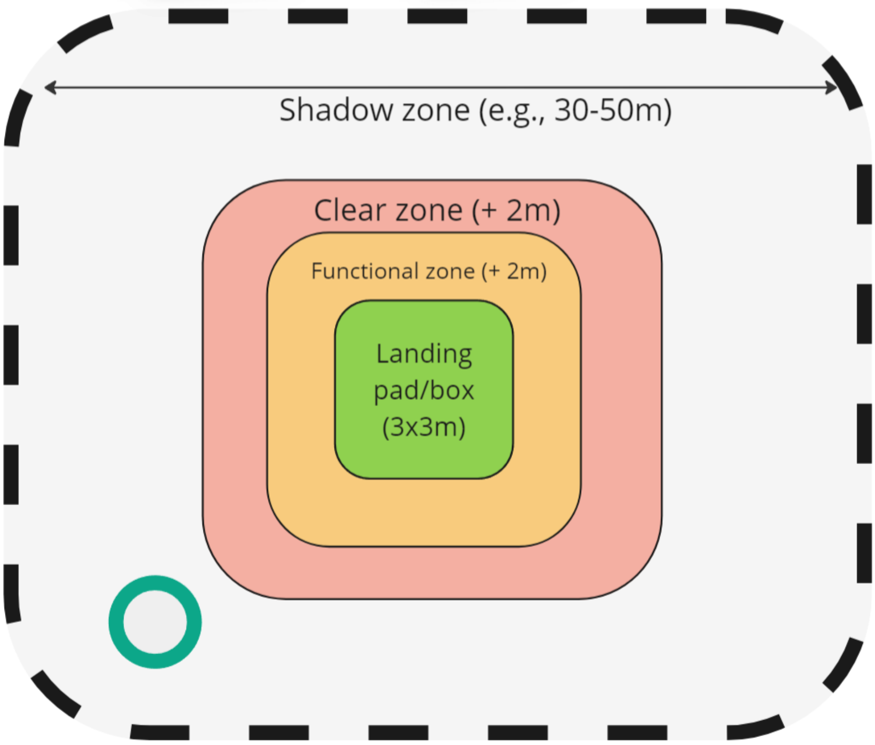


Figure 15: Conceptual design of the LLS area needed for drones in urban areas

2.3 The spatial scale of LLS

An UAM landing pad or LLS area is defined as the area capable of providing support for the landing and take-off of a drone during flight operations. Furthermore, LLS can be classified as the infrastructure components where these aircraft take off and land in urban areas. A wide range of LLS infrastructure is available and used based on the operational requirements (Mavraj et al., 2022; Schweiger & Preis, 2022). The LLS scales vary based on numerous factors such as size of drones, weight and volume of cargo attached to drones, and availability of space in urban areas. For example, not all drones need landing infrastructure, while some sites are just so called “cold” sites that do not have much supporting infrastructure. The information about LLS solutions in CITYAM report 1.3 gives further guidance and information about available companies and different solutions that cities could use. Nonetheless, based on the size of landing and launch site area, UAM landing scales can be divided into the following three categories.

The smallest landing pads are usually the size of a box. Small scale landing pads are usually used for the landing of drones without payload, usually for surveillance purposes. In some cases, small-scale landing pads may be labelled as emergency landing sites. In addition, these small-scale landing pads can be strategically located for fast access in emergency situations.

Figure 16: Small scale landing pads by DroneHub (UAV news)

Figure 17: Small scale landing pads by Snatcher (Snatcher)

Figure 18: Small scale landing pads by MaptureDrone (MaptureDrone)

Medium-scale landing pads are usually used for the landing of drones with small to medium payload. Tethered drone, cargo pole and drop point landing pads are examples of medium scale landing pads.

Figure 19: Medium scale landing pad by DHL (DHL Drone-in-a-Box System)

Figure 20: Medium scale landing pad by UPS (UPS Drone on a truck)

Figure 21: Medium scale landing pad by Valqari (Valqari)

Large scale landing hubs are used for drones with heavy payload and facilitating high volume of the flights. The scale of large landing hubs ranges close to a building unit. Landing hubs of this scale often provide recharging facilities, control and communication, logistics and warehousing facilities.

Figure 22: Large scale landing Hub in The Netherlands (Landing hub in The Netherlands)

Figure 23: Large scale landing Hub in Ireland (Landing hub in Ireland)

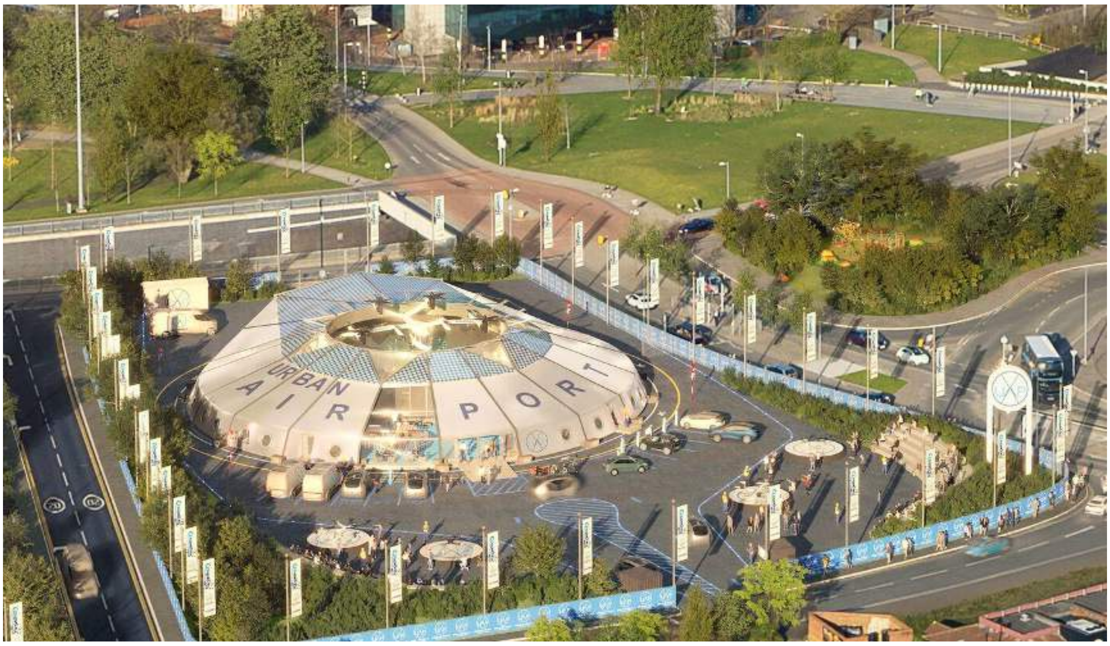


Figure 24: Large scale landing Hub by Air-One hub (Air-One hub)

Since CITYAM does not take eVTOLS into consideration, we focus the spatial scale on the first two groups of LLS scales listed above - small and medium. On those scales, the largest diameter of a drone should be under 3 metres. In combination with the above mentioned assumptions of the LLS design, an area of 10*10 metres is considered to be adequate for the location decision developed within DST.

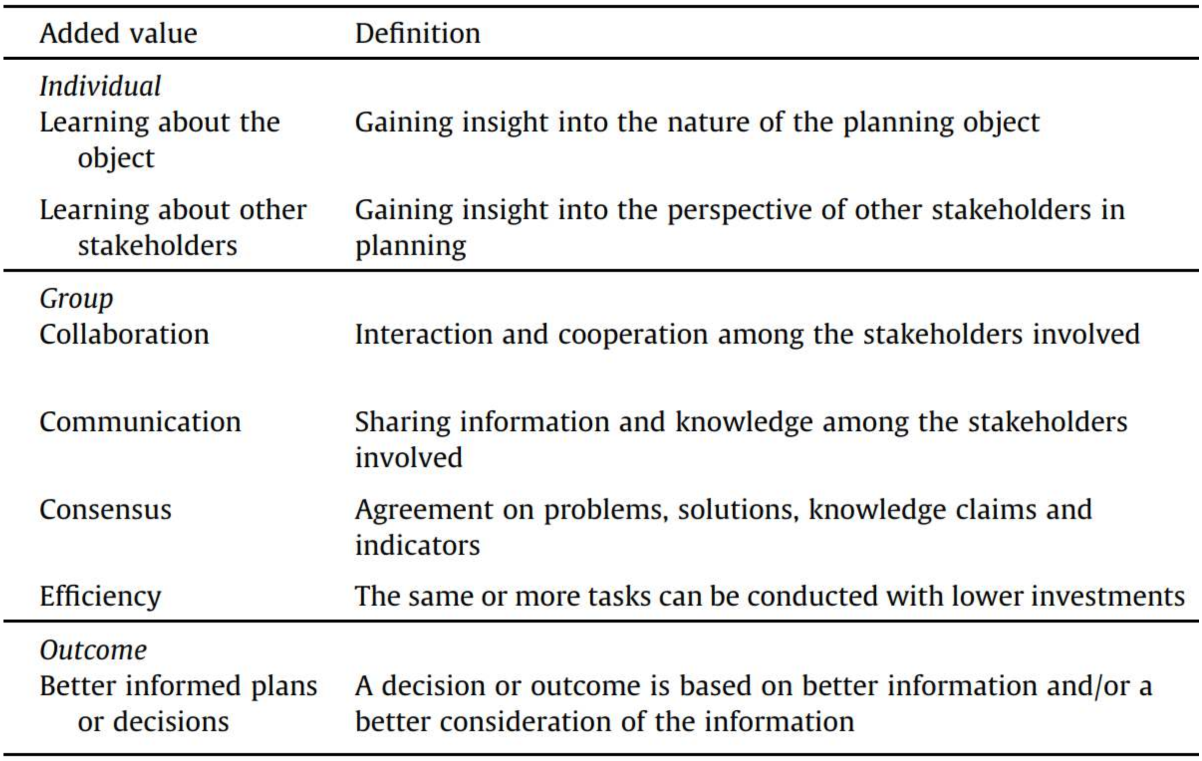
3. Definition of functional requirements for Decision Support Tool

3.1 The need for useful and usable decision support tools in a specific context

In general, DST in urban planning are tools either in the form of computer models, digital frameworks or software applications that help the practitioners in making informed decisions about various urban challenges. In general, DSTs have various uses in the planning process. DST helps the practitioners to structure the problem, analyse the data to assist in understanding the potential outcomes of the decisions. DSTs are playing a significant role in urban planning due to several reasons. DST helps the practitioners in knowledge management due to the ability to store, organise, access, and process data (Schindler et al., 2020). In addition to informing the management, DST helps in exploratory analysis, testing new ideas and facilitating collaboration. Moreover, DST improves the transparency and public engagement in the planning process, and can visualise complicated data for better communication and understanding of the problem among all stakeholders. In addition, the DST also foster transparency and helps in finding equitable and agreeable solutions among stakeholders. Finally, DST also empowers the municipalities to be more readily involved, promoting a sense of ownership and responsibility in urban planning processes (Schindler et al., 2020). Despite these advantages, practitioners must note several challenges associated with DST, listed below:

- Awareness of available tools and methods
- Expertise and technical ability to use the tool
- Appropriateness of tool for the local context
- Complexity and information requirements of the tool
- Lack of in-house resources in staff or other domains, such as resources to acquire or produce additional data
- Validation of outputs and misalignment of interpretation of results
- External influences such as political expectations and regulatory implementation
- Security of confidential data either in storage or in public access aspects of the tool

In order to balance the advantages and challenges of DST, it is important to clarify the need for usable and useful DST. The usefulness of DST is closely linked to the added value that DST has for individual or group processes as well as the outcome of a planning process. The following figure depicts different aspects of usefulness as added value in the planning process. On the usability front, the focus is on creating intuitive and accessible user interfaces for a DST. A user-friendly design ensures that planners and decision-makers can interact seamlessly with the DST, maximising their ability to harness the full potential of the tools at their disposal. For example, clear navigation, well-defined menus, and straightforward workflows contribute to a positive user experience, reducing the learning curve and increasing overall satisfaction. In addition, adequate training and support materials further enhance usability, providing users with the necessary resources to confidently navigate the DST and leverage its functionalities to meet their specific planning needs.



Added value	Definition
Individual	
Learning about the object	Gaining insight into the nature of the planning object
Learning about other stakeholders	Gaining insight into the perspective of other stakeholders in planning
Group	
Collaboration	Interaction and cooperation among the stakeholders involved
Communication	Sharing information and knowledge among the stakeholders involved
Consensus	Agreement on problems, solutions, knowledge claims and indicators
Efficiency	The same or more tasks can be conducted with lower investments
Outcome	
Better informed plans or decisions	A decision or outcome is based on better information and/or a better consideration of the information

Figure 25: An overview of usefulness in planning support systems (Pelzer et al., 2014)

An important aspect of DST usefulness is the adaptability of the tool to new contexts. DST should be adaptable for use by different planning agencies, with a reasonable transferability effort. However, it is prudent to recognize that the sociotechnical interactions connected with a local context may cause major challenges for the planning process (Goličnik & Ward Thompson, 2010; Kyttä et al., 2023; Laatikainen et al., 2018). In particular, the local context is influenced by various factors such as local geography and built environment, current public opinion, as well as wider social dynamics and global trends. The following figure depicts the interaction between the local context, data and tool. As such, it is advisable to take into account that DST needs to be flexible with potential to be transferable (Schindler et al., 2020). The challenge of transferability is partly accommodated by transparency in DST development, and explicating assumptions. In addition, it is important to underline the assumption that the UAM planning process will vary in specific local contexts and planning processes.

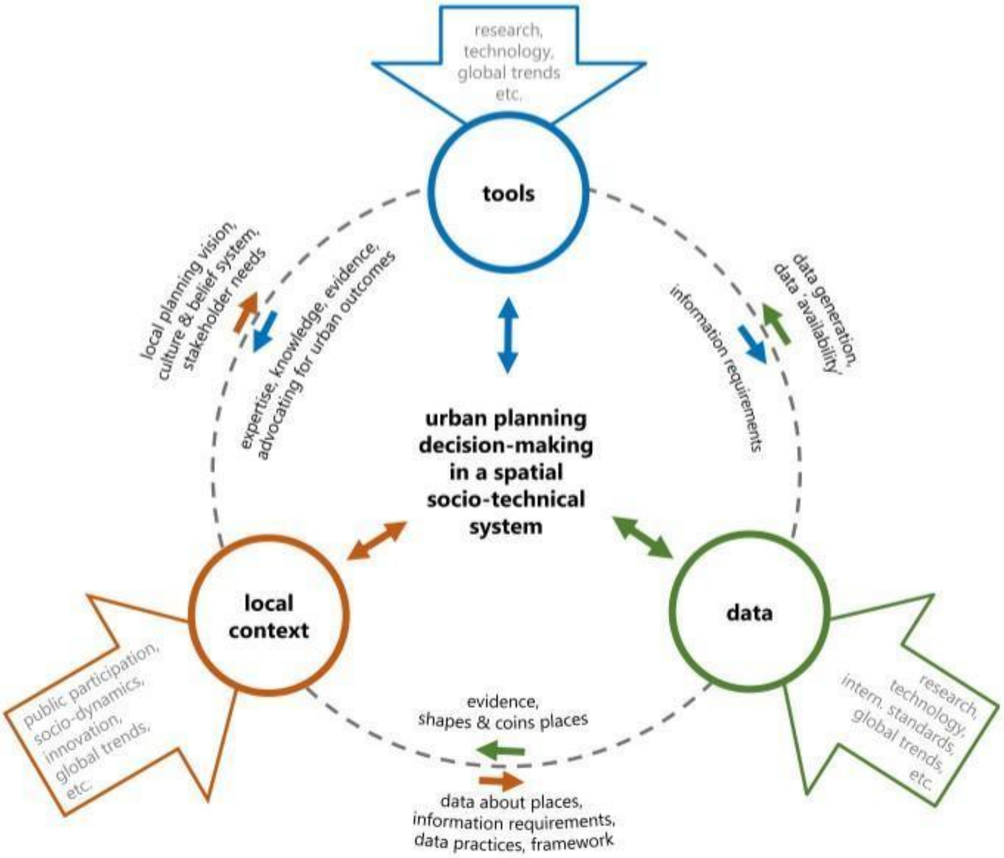


Figure 26: Interaction between tool, data, and local context in decision-making (Schindler et al., 2020b)

3.2 Types of DST in planning practice

Following is a short description of the main software tools used in planning practice, that could also be relevant for UAM planning in general.

1. Computer-aided design

This DST category includes a wide range of design software tools, capable of depicting very small design components to block level building mass, mostly using vector data. These design tools are often accompanied with various design guidelines. The trend in these DST in recent years is to upgrade them to digital twin status in order to make more comprehensive digital simulation possible and provide tools for visualisation and design by involving more stakeholders. These tools can be used for developing parametric buildings, building level massing, visualisation of design conflicts, as well as automatic calculations of areas and key ratios from the plan, including preliminary financial modelling.

2. Transport demand modelling

One set of these tools are aimed at modelling and estimating travel patterns and traffic volumes over large geographic areas, such as an entire city. Thus, the DST usually focuses on modelling travel patterns across built environments and transport infrastructure, with a lower level of detail in modelling transport system dynamics due to computational constraints. Different tool versions within this category have various options for modelling the integration with land use changes and the level of output parameters used for evaluation, primarily aggregated. These modelling tools are highly data intensive, and not adaptive to flexible development and testing of alternatives. Another set of DST that can focus more on microscopic modelling can simulate the characteristics and interactions of individual vehicles or people, but has to abstract much of the higher-level travel behaviour modelling. Thus, the level of analysis is usually limited to an intersection or street, as calibration for large urban areas is extremely difficult.

3. Impact modelling

These tools can better estimate certain impacts. For example, a tool can quantitatively model the source and propagation of noise emissions. In addition, this category includes tools that can be used for economic evaluations from planned infrastructure improvement. For example, such assessment can include return on investments for drone operators and value capture as an increase in the value of land in the immediate areas around LLS for land developers. Although these tools are useful for understanding impacts, they are often not providing an integrated impact assessment or have different spatial scales used.

4. Quantitative analysis

This category is focusing on a variety of tools that could perform a range of relatively advanced statistical and quantitative analyses. These tools are capable of developing a range of statistical models, from linear and logistic regression often used in modelling travel behaviour, to structural equation modelling that enables multi-factor analysis. However, the use of these software tools often involves a very high level of expertise in statistical methods that is not present in engineering and planning fields. In addition, this software cannot handle geospatial data.

5. GIS

Geographic Information System (GIS) is a technology mainly based on processing geospatial data and developing spatial DST. GIS integrates numerous types of information, including coordinates, maps, and satellite images to deliver a spatial context related to the problem. GIS software are applications and tools used for analysing, managing and visualising the spatial data sets. GIS software is also used for creating maps and managing other location based data. GIS tools are often used for managing city and transport system data (e.g., parking data) as they are also often integrated with web-based platforms. In addition, they can be used for analysis of raster or vector data, in order to analyse transport infrastructure (e.g., network centrality, road density, street hierarchy) or built environment infrastructure (e.g., floor surface, open space ratio). These infrastructural analyses can also include demographic data analysis, such as factors including residential or job density.

3.3 Key assumptions and scope for planning process

- The DST is developed considering the needs and capabilities of a city planner, who is responsible for the planning of urban areas. The DST and planning process has to consider the diverse nature, experiences and needs of the DST user.
- The scope of DST is confined to the location choice in urban environments, excluding the active consideration of the flight corridor paths and flight trajectory/corridors problems. Similarly, vertical zoning as a part of the operational planning is also not supported by the DST, and it is anticipated that the UAM service operators will use other tools for the operation planning, such as planning and optimization of the flight trajectory. Moreover, it remains open for now what the role of a municipality will be in the day-to-day management of its airspace. Thus, the DST is not focusing on the (real-time) traffic management tools for UAM.
- The DST and planning procedure are primarily developed for the location choice at ground street level. However, a publicly owned rooftop can be considered, allowing that it meets the requirements of the payload, as well as other safety and accessibility measures.
- The DST is developed to facilitate the selection of relatively-speaking permanent LLS which can be used in different duration (e.g., during a special event, only during part of the year). The notion of permanence for LLS translates to the allocation of a specific site at the temporal scale of a few years as opposed to the allocation for one season or a several day event.
- The landing scale is at the building/sub-block level, with the area having the largest diameter in a range of 10-30 metres. The largest LLS scale on the level of UAM hubs and similar objects is out of scope for this DST.
- According to the scope of WP 1.4, DST has been developed focusing on the long-term level of planning in urban environments. The DST does not facilitate the operational planning.

3.4 CITYAM DST Requirements

The aim of the DST is to support the decision making process, not to make the decision. This DST is developed primarily for the city planner and professionals responsible for acting on the behalf of the city government organisations.

General DST requirements

The current list describes general DST requirements, both for the current key uses and for long-term tool deployment. In addition to those requirements, we recognize that each planning process will contain local specifics, which needs to be recognized. In addition, the DST fundamentally relies on fostering engagement and trust, and these aspects need to be taken into account in further DST development and implementation.

1. The tool should be developed to consider the input from different stakeholders, including residents and citizens.
2. The tool should support effective communication on alternative locations and factors to take into account when planning those, both in analytical and visual format.
3. The tool should be able to process and combine diverse datasets, including soft value data and missing data through manual input, thus supporting evidence-based decision.
4. The tool should provide the memory and records of information to support the approval or disapproval of certain locations as a LLS site.
5. The tool should provide transparency to its data and the output of the process at any stage of the planning process, including ex post evaluation.
6. The tool should enable exploratory analysis and testing of new ideas in a communicative setting.
7. The tool should help with collecting data and reviewing long-term trends and urban transition targets.
8. The tool should be a cost-effective solution to set up and use.
9. The tool should provide input for the investment needs and financial planning for various stakeholders.
10. The tool should provide different functionality for different users, i.e., admin, main user, view user.

DST requirements for in-meeting multi-stakeholder session

Following are five key requirements for functionalities needed during a multi-stakeholder planning meeting.

1. Import: The DST should enable adding LLS area-point to the map by defining the dimensions for the specific case, either by drawing or by import.
2. Export: The DST should enable exporting of data generated during a planning meeting, such as in the form of maps, tables, or lists of geolocations.
3. Show values visually: The DST should provide an effective information visualisation on a map for all the stakeholders in a planning meeting. A good example for the visualisation can be a coloured scheme to depict location suitability. The areas in green colour can represent high propensity to use the area for the LLS. Whereas, yellow/orange colour can show the areas requiring further information and attention for the decision-making. Red areas can show the restricted areas or the areas already known to have low propensity to be used for the LLS.
4. Show values analytically: The DST should enable the user to activate a pop-up to inform about the changes in analytical values.
5. Change parameters: The DST should support the iterative discussion among different stakeholders. The ability of the tool to iterate the decision-making process with additional/reductive input in a meeting can be helpful for effective communicative and decision-making. For example the tool should allow changes in factors and locations considered in the discussion (e.g., adjust weights of a certain data layer, or switch-on/switch-off the desired data layers). In addition, the tool should allow the addition of a new layer and process it during the planning meeting.

4. Decision support framework

4.1 Multi Criteria Analysis

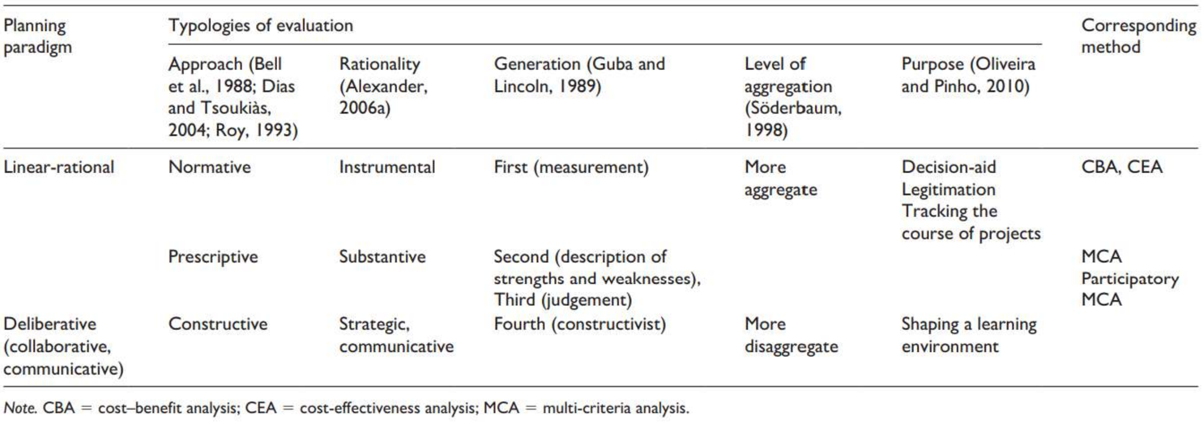
The decision support framework for DST has to be designed to help explore weakly structured or unstructured problems, characterised by input from many actors with different objectives, many alternatives, and high uncertainty including diverse impacts and their distribution. The decision support framework is developed upon multi-criteria decision-making technique, which has been previously used for the selection and prioritisation of the LLS (So et al., 2023). Multi-criteria decision support framework or multi-criteria analysis (MCA) has been recognized in general as a useful decision support framework for solving challenges of complex and uncertain nature, where the problem is semi-structured and requires both expert knowledge (Mladenović & Abbas, 2013) and integration with different data sources (Balta & Öztürk, 2021; Dakic et al., 2018). Therefore, numerous studies on urban planning have used it to structure and comparative evaluation the knowledge fields. The central idea of MCA is decision matrix, depicted in the following figure, consists of the following key components:

- **Alternatives:** The different options or choices that are being considered in the decision-making process. These could be different courses of action, solutions, products, or strategies. In the case of this project, alternatives are landing locations.
- **Criteria:** The factors or attributes that are used to evaluate and compare the alternatives. Criteria are the basis for making a decision and can include various dimensions such as cost, quality, feasibility, performance, and other relevant considerations for the decision domain - such as UAM location choice.
- **Weights:** The relative importance or priority of each criterion in the decision-making process. Assigning weights allows decision-makers to emphasise certain criteria over others based on their significance. Weights are usually expressed as percentages or numerical values.
- **Scores:** Scores are assigned to each alternative for each criterion to reflect how well each alternative meets the specified criteria. Scores are typically on a normalised numerical scale (e.g., 100%, 1-10, etc.) and are used to quantify the performance or suitability of each alternative with respect to each criterion.

		LLS 1		LLS 2		LLS 3		LLS 4	
CRITERIA	WEIGHT	RATING	TOTAL	RATING	TOTAL	RATING	TOTAL	RATING	TOTAL
LAND USE TYPE	15%	1	3.75%	2	7.50%	3	11.25%	4	15.00%
CULTURAL HERITAGE	14%	3	10.50%	1	3.50%	2	7.00%	4	14.00%
WIND	13%	3	9.75%	4	13.00%	2	6.50%	1	3.25%
NOISE	12%	2	6.00%	1	3.00%	4	12.00%	3	9.00%
OTHER POLLUITION	10%	1	2.50%	3	7.50%	2	5.00%	4	10.00%
GPS/GSM SIGNAL	8%	1	2.00%	4	8.00%	3	6.00%	2	4.00%
WILDLIFE	8%	2	4.00%	1	2.00%	3	6.00%	4	8.00%
ELEVATION DIFF.	8%	3	6.00%	4	8.00%	1	2.00%	2	4.00%
CHARGING INFRA	7%	1	1.75%	3	5.25%	2	3.50%	4	7.00%
MAINTENANCE	5%	1	1.25%	2	2.50%	4	5.00%	3	3.75%
	max		TOTAL Alt 1		TOTAL Alt 2		TOTAL Alt 3		TOTAL Alt 4
	100%		47.50%		60.25%		64.25%		78.00%

Figure 27: An example of MCA decision matrix with four LLS alternatives

Multi-criteria decision support framework helps the decision makers to assess the criteria, especially in a situation where there are multiple stakeholders with different objectives. The Figure 7 shows various methods for the evaluation in the planning paradigm. Moreover, it presents the relevancy of multi criteria analysis framework in deliberative planning processes.



Planning paradigm	Typologies of evaluation					Corresponding method
	Approach (Bell et al., 1988; Dias and Tsoukiàs, 2004; Roy, 1993)	Rationality (Alexander, 2006a)	Generation (Guba and Lincoln, 1989)	Level of aggregation (Söderbaum, 1998)	Purpose (Oliveira and Pinho, 2010)	
Linear-rational	Normative	Instrumental	First (measurement)	More aggregate	Decision-aid Legitimation Tracking the course of projects	CBA, CEA
	Prescriptive	Substantive	Second (description of strengths and weaknesses), Third (judgement)			MCA Participatory MCA
Deliberative (collaborative, communicative)	Constructive	Strategic, communicative	Fourth (constructivist)	More disaggregate	Shaping a learning environment	

Note. CBA = cost–benefit analysis; CEA = cost-effectiveness analysis; MCA = multi-criteria analysis.

Figure 28: Typologies of evaluation given the planning paradigm (Geert et al., 2021)

Multi-criteria decision support framework has the following characteristics:

- Multi-criteria decision support framework is an easy-to-use tool that equips practitioners to assess various policy options. MCA is also a flexible framework that can be tailored for various contexts, different stakeholders and their priorities and different criteria.
- MCA provides a mechanism to evaluate a range of criteria or the groups of criteria. This range helps to include both numerical and non-numerical criteria in the decision making process. Moreover, this group comparison provides a policy maker to revise or prioritise their decision based on group (e.g., environmental, social, etc.,).
- Multi-criteria decision support framework also provides a platform for transparent and justifiable process to ensure the trust of stakeholders and ensure the consensus on the decision made. By considering the relevant criteria, the framework can help to ensure that decisions are based on objective.
- MCA can help decision-makers to assess the potential risks and uncertainties associated with different options. By explicitly considering the potential outcomes and trade-offs associated with different criteria, MCA can help decision-makers to identify and manage risks more effectively.

There are several methods within the broader category of MCA, including Simple Additive Weighting (SAW) (e.g., Abbas et al., 2013), Analytic Hierarchy Process (AHP) (e.g., Mladenovic et al., 2017), and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (e.g., Milenković et al., 2018; Glavić et al., 2019), each with its specific focus and application. Besides some differences in how scores are calculated with these different methods, the key aspect and a crucial step in MCA is assigning weights. There are several ways to complete the criteria weighting, and the choice of approach depends on the preferences of decision-makers and the specific characteristics of the decision problem. Three common approaches are:

1. Direct weighing through ranking

Decision-makers rank the criteria in order of importance, from the most important to the least important, and this is often done with AHP. The ranks are then converted into weights, with the top-ranked criterion assigned the highest weight and so on, which can be done in relative values based on the number of criteria. This method is simple and intuitive, being most suitable when decision-makers can easily provide an ordinal ranking of criteria based on their perceived importance.

2. Pairwise comparison of criteria

AHP is a method that involves pairwise comparisons of criteria to derive their relative importance. Decision-makers compare each criterion to every other criterion and assign relative importance values. Each criterion has to be thus relatively evaluated as less or more important than each other criterion. These comparisons result in a matrix of pairwise comparison values, capturing the perceived importance of one criterion relative to another. Once the matrix is completed, it can be evaluated for consistency, defined by the transitiveness between the entries in the matrix (e.g., if A > B and B > C, then A > C). Thus, a consistent matrix is the one that performs better than a random matrix. The approach is suitable when decision-makers are comfortable expressing their preferences in pairwise comparisons, while it provides a structured way to derive weights by capturing the relative importance of criteria.

3. Expert panel

A group of experts is convened, and through rounds of discussion and feedback, a consensus is reached on the weights of criteria. The consensus is based on the Delphi method that involves iterative rounds of feedback to reach a group consensus. The combination of expert panels and the Delphi method are useful when decision-making involves multiple stakeholders with diverse perspectives. Iterations of discussion can also include explicit weighing by different evaluators with averaging and distribution visualisation, such as in Multi-Actor MCA (Macharis et al., 2012).

4.2 Potential set of decision criteria for selecting drone LLS

The following figure depicts a conceptualization that decision criteria for drone LLS should be selected based on both the perspective of the residents as well as the overall urban mobility system. In addition, decision criteria can be also classified as “pull to”, meaning that they are providing reasons for having a LLS in a specific urban location, as well as “push away”, meaning that they are providing reasons for not having a LLS in a specific urban location. The same data source can be used for criteria in multiple of these fields.

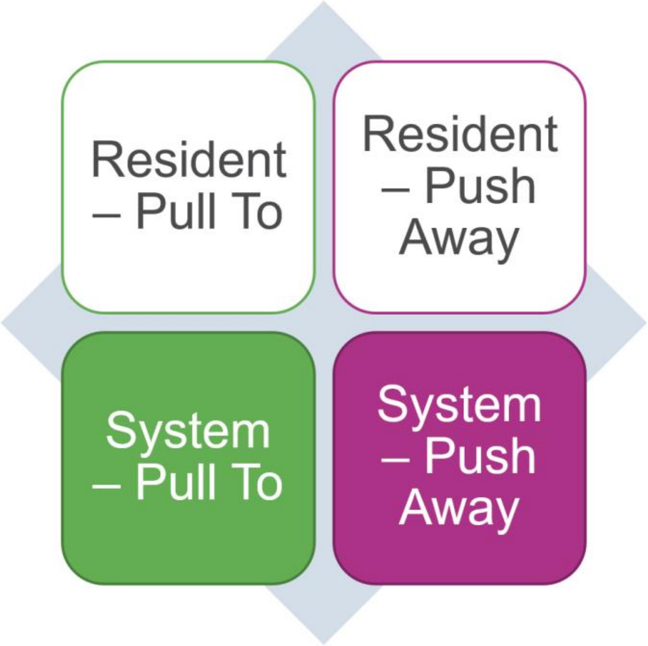


Figure 29: Four-field set of decision criteria

Based on the following literature (Brunelli et al., 2023; Long et al., 2023; Rothfeld & Moeckel, 2018; Kim & Yoon, 2021; Lee et al., 2023; Al Labbad et al., 2022; Kreimeier et al., 2018; Robinson et al., 2018; Vascik et al., 2018; Shin et al., 2022; Cohen, 1996; Vascik & John Hansman, 2017; Willey & Salmon, 2021; Robinson et al., 2018; Murça, 2021; Tojal et al., 2022; So et al., 2023) and the interviews with stakeholders, below are two criteria sets for “pull to” and “push away”, not sorted in order of importance.

Potential “pull to” criteria from resident and system perspective:

- land use type
- land/building ownership
- point of cultural or touristic interest
- major transport and logistics node
- building height
- median household income
- median gross rent
- office rent price
- job/population density
- office rent price
- proximity to public transport
- existing parking surface
- elevation difference per LLS area
- existing infra suitable for LLS
- roof shape

- charging infrastructure proximity
- maintenance requirements
- GPS/GSM signal quality
- travel accessibility to the location
- lighting conditions

Potential “push away” criteria from the resident and the system perspective:

- existing urban noise level
- designated quiet areas
- kindergarten or primary school
- playgrounds or sports areas
- cultural heritage or religious objects
- visual pollution and aesthetics
- wind speed
- prevailing wind direction
- probability of air turbulence
- probability of freezing conditions
- bird nesting or migration area
- area for other protected wildlife
- wind turbines
- electricity power lines
- emergency service station
- airport zone
- helipad zone
- flight corridors
- urban or regional railroad line
- urban motorway
- minimum distance between two landing locations

Each of these criteria would be introduced in the particular decision situation based on previous experiences, drone use case, and political priorities in the city. Moreover, the criteria set for the location choice needs to be updated over time, for example by considering changing safety regulations or concerns of the general public in terms of individuals’ acceptance and broader societal acceptability (Al Haddad et al., 2020; Keller et al., 2021; So et al., 2023; Tan et al., 2021; Wang et al., 2023).

Based on the first workshop mentioned above, one of the topics that should be elaborated as part of the municipality's strategy is the type of places where there should be always and partially forbidden access for emergency landing or for fly-over routes. Such groups include potentially critical infrastructure, such as airports, power plants, embassies, prisons, military areas and buildings of high political value, among others. Similarly, some of the green-blue areas could be of strategic importance, such as both quiet parks and busy parks, public playgrounds, nature and wildlife areas including protected natural areas, especially areas with nesting birds and vulnerable wildlife. With regard to the built environment, strategy could allow for specific assessment in the case of build-up areas, on-water areas, open areas and areas with low acceptance of urban air mobility services were highlighted as no go sites. A few external factors were also highlighted as important criteria for the selection of LLS. Those factors include areas with high winds, low quality of GSM and GNSS signals, intermodal areas, and areas with obstacles and accessibility to charging infrastructure.

All decisions need to have well-elaborated criteria, taking into account anticipated impacts, which can be used for inter/intra-organisational learning between the planning cases (Mladenović, 2022). General public participation processes and expert assessment can provide further criteria related to topics of safety, regulation, infrastructure, vicinity to critical infrastructure, service design, user case, operational consideration, and wider social impacts. Besides that, a strategic approach to UAM in a municipality would also require further clarification of internal and external decision processes related to such aspects as land ownership and use, environmental impact assessment, and street construction and maintenance.

5. Planning process, roles and responsibilities

5.1 Stakeholders and communicative UAM planning

Several groups of stakeholders were pointed out as needed to be involved in planning and selection of LLS, as in general UAM-related decisions are distributed across governance levels (Raghunatha et al., 2023). Based on the expert interviews, the major group of stakeholders begins with drone operators and civil aviation authorities, continuing with various departments within a municipality, other private stakeholders and the general public. The EU Drone Strategy 2.0 (EU Strategy, 2021) underscores the critical role of citizen participation, pointing out that ''Local communities, cities, regions have a deciding role for ensuring the alignment of Innovative Aerial Services with the needs and preferences of their citizens. They have a key role in deciding to what extent drone operations can be conducted in their territories. For example, they are in a good position to assess which critical infrastructure should be protected, whether operations should be allowed in day or night-time, what should the measures in place be in terms of noise and visual abatements.'' (p.12). In addition, the EU Drone Strategy 2.0 has also pointed out that ''The role of municipalities is also pivotal in terms of regional planning in urban and rural areas and creation of dedicated infrastructure to accommodate vertiports or take-off and LLS. Local administrations should be involved and be able to convey a message of certainty and transparency to society about what, how, when and where Innovative Air Mobility will be deployed. Citizens' participation in regulatory sandboxes, living labs and demonstrations should be encouraged to include local/regional aspects in the final decision regarding Innovative Air Mobility deployment'' (p.13). Finally, in connection to the EU precautionary principle, the importance of citizen participation is even more important at the emerging stage, when there is a need to anticipate impacts. As such, planning LLS also provides an opportunity for improving or in some places rethinking participatory processes, which are often not implemented with high quality in traditional transport planning (Mladenović et al., 2021).

Based on the need to effectively accommodate a large number of stakeholders in the planning process, it is important here to highlight the need for a specific approach to UAM planning - communicative planning with a DST (Pelzer et al., 2015). Essentially, the communicative planning approach centrally depends on changing the role of a planner (Sager, 2017). The shift in the role is one from a traditional bureaucrat/technocrat, being in charge of a conventional hierarchical, controlled and bureaucratic planning process (Fainstein, 2000). Instead, the communicative planner has responsibilities in developing the planning process with a base of communicative dialogue and collaboration that covers a range of relevant actors in dialogue (Arnstein, 1969; Healey, 1997; Gunder et al., 2017). Here, the objective of urban planners is to inform and listen to various actors, play a role in negotiation and building consensus among various aims, views and judgements, while reflecting the results of the consensus to the plans. The following table summarises the differences between the traditional and communicative planning suggested to be applied in the UAM planning process.

Table 2: Differences between the Instrumental and Communicative Rationality (Willson, 2001).

Issue	Instrumental Rationality	Communicative Rationality
• Role of the planner	• Expert/analyst. Often a specialist (e.g., modeling, community affairs, finance, etc.). • Official role is objective, but usually plays a political role.	• Communicative expert with technical knowledge and skill. • Plays multiple roles--process design, activist mediation, education and technical roles. • Self discloses roles.
• Purpose of planning	• Problem solving and optimization, with a rational decision-maker as the client. • Finding the best solution for a fixed and known set of ends.	• Reaching an understanding that facilitates action. • Increasing capacity for reasoned deliberation and democratic decision-making.
• Planning process	• A sequence of linear steps (with feedback). • Assumes that facts and values can be addressed separately. • Action follows knowledge.	• Recursive process: fact, value and discovery are interlinked. • Emphasises learning and consensus building. • Is invented/modified as part of the planning activity. • Action and knowledge are simultaneous.
• Communication	• Planners' communication is assumed to provide accurate representations of facts and values; has standard meaning outside of action.	• Communicative processes produce meaning and linguistic "action". • Planners seek to improve the validity with which claims are made, e.g., truthfulness, legitimacy and sincerity.
• Problem framing	• Problems can be defined and bounded in a single frame; problems can be broken into pieces and recombined; problems can be defined in the absence of solutions; problems can be "solved".	• Multiple problem definitions and frames are acknowledged; problems are broadly bounded. • Planning actively engages multiple problem frames, seeks creative redefinition.
• Analysis/ Modeling	• Reductionism, reliance on data and models as forms of inquiry. • Knowledge is empirically established.	• Quick-response models used along other forms of knowing. • Modeling claims are part of discourse.

Communicative planning is a multifaceted process that is guided and influenced by a range of principles and rules that reflect the collective vision of the stakeholders (Hajar et al., 2018). These principles include the factors that help in settling the quality of the collaborative process such as transparency, inclusivity, participation, dialogue and collaboration. Moreover, other objective-oriented principles such as equity and justice, flexibility and adaptiveness, shared vision, empowerment and conflict resolution helps to create an outcome that is better and more effective and reflective to the objectives (Gunton & Day, 2003). Thus, it will be very important in each UAM planning process to clarify its principles. In addition, clear rules of the game play a crucial role in enabling the collaborative decision-making process. These rules often involve various stakeholders from the organisations of governments and city planning organisations, including rules for the planning process to ensure that the process is fair. Figure 13 shows the theoretical framework of the communicative planning approach, as well as the iterative process of various stakeholders and their roles in communicative planning for a successful collaborative planning.

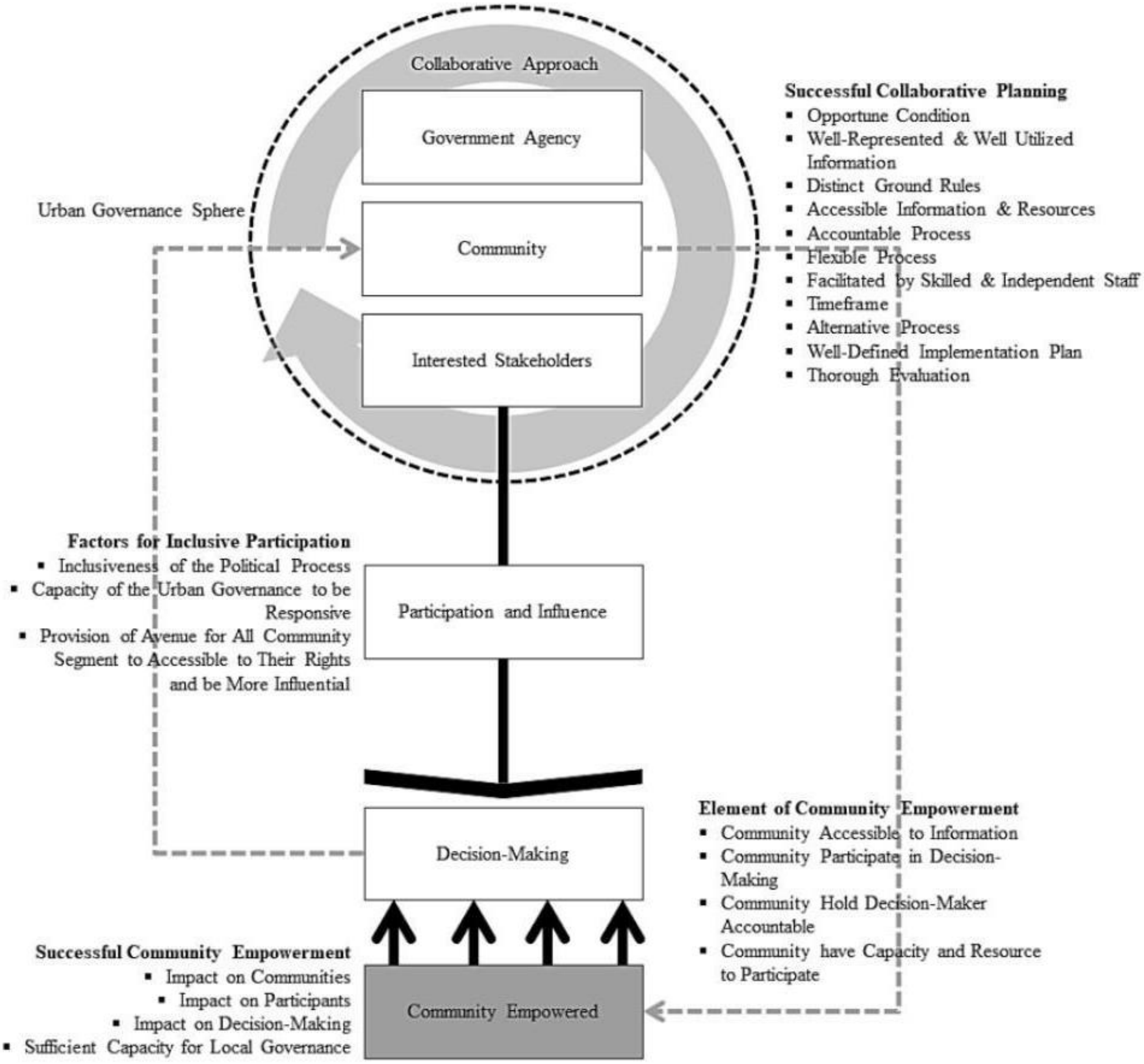


Figure 30: Theoretical Framework of Collaborative Planning (Hajar et al., 2018)

5.2 Planning process phases

Phasing the planning process is critical for a comprehensive and well-executed UAM project. It is recommended not to always follow those phases in a linear order, and some iterations of the same phases might be also helpful, depending on the context. For example, revisiting the location choice and involving public participation reflects a thoughtful and adaptable approach to the responsible development process. Following are suggestions for five phases in a specific planning process. The responsible UAM planner is in charge of deciding the ultimate number of steps in the plan, including shared responsibility for regulatory bodies and key municipal and CAA stakeholders.

Phase 1 - Initiation (suggested as mandatory)

In this phase, an UAM service operator defines the project's strategic goals, establishes the project team, and conducts an initial assessment of resources and potential challenges. At that moment, an UAM service operator submits a request for location to both CAA representative and UAM planner. In that request, the UAM service operator explains in a written and visual form drone use case, including type of drone, type of LLS, type of transported objects if applicable, access rules to LLS, max load, flight time, LLS dimensions, and other associated requirements that affect the design and dimensions of LLS. In addition, the UAM service operator should also include in the request a list of anticipated impacts and risks, mitigation measures, and other specifications, such as preferred city area or types of locations. Clear communication of the project's purpose and objectives is crucial to align stakeholders and set the foundation for subsequent phases.

Phase 2 - Initial location choice (suggested as mandatory)

During the initial location choice phase, the UAM Planner arranges a meeting for evaluating the potential sites based on factors such as airspace regulations, existing transportation infrastructure, and other criteria defined by a municipal strategy. The DST is used in this meeting. Stakeholder engagement may begin at this point to gather input from local authorities, communities, and other relevant entities, fostering collaboration in the decision-making process. In some cases, the initial location choice can result in a decision, especially if it is in alignment with some other municipal plan or regulation that has made decisions about suggested location sites.

Phase 3 - Revisiting location choice (suggested as optional)

As new data emerges or circumstances evolve, this phase allows for a dynamic reassessment of initial location choices. It provides an opportunity to adapt to changing conditions, incorporating updated information on factors like urban development plans, environmental considerations, and technological advancements to ensure the selected locations align optimally with the project's long-term vision and a municipal strategy. Stakeholder engagement may continue at this stage, including a variety of participation methods, such as community forums, surveys, and information sessions to address concerns, build transparency, and integrate valuable local perspectives into the decision-making process.

Phase 4 - Site inspection and public participation (suggested as optional)

During site inspection, the project team conducts thorough assessments of shortlisted locations, examining factors such as infrastructure readiness, environmental impact, and safety considerations. Simultaneously, active public participation can be also combined with these activities, as an important method for collaboratively understanding challenges and solutions.

Phase 5 - Final approval (suggested as mandatory)

In the final approval phase, the project team consolidates findings from previous stages into a comprehensive proposal for regulatory bodies and key municipal and CAA stakeholders. This phase involves navigating through regulatory processes, addressing any outstanding concerns, and obtaining the necessary approvals to move forward. Successful completion of this phase marks the green light for the subsequent implementation of the UAM service in the selected location.

5.3 Planning process roles and responsibilities

The following is an overview of the roles and responsibilities of each stakeholder involved in Urban Air Mobility (UAM) planning and operation, as anticipated. The ultimate number of stakeholders may vary depending on the municipality. Each stakeholder plays a crucial role in the successful planning, implementation, and operation of UAM, contributing to the overall safety, effectiveness, and acceptance of this emerging transportation mode. The assessment of need for further stakeholders must be done as often as possible, and based on the responsibility principles. However, we underline here that UAM planner is considered to be a deliberative authority, within the modern concept of democracy (Mäntysalo et al., 2023).

1. UAM Planner (Municipal or Regional)

Responsibilities: Develop and implement strategic plans for integrating UAM into the municipal or regional transportation infrastructure. Assess and choose suitable locations for UAM infrastructure, considering urban development, zoning regulations, and community impact. Collaborate with various stakeholders to ensure alignment with broader urban planning goals. Could be a cross-departmental position, in contrast to existing similar roles in transport or planning departments.

2. UAM Operator (City-Owned or Commercial)

Responsibilities: Manage the day-to-day operations of the UAM service, including scheduling, maintenance, and safety protocols. Collaborate with the UAM Planner to select optimal locations for vertiports or takeoff/landing zones. Ensure compliance with aviation regulations, safety standards, and community expectations. Implement marketing strategies to promote UAM services to residents and visitors.

3. GIS Expert in a Municipal Organization

Responsibilities: Utilise Geographic Information System (GIS) tools to analyse spatial data and support UAM planning. Provide mapping and spatial analysis to identify suitable locations for UAM infrastructure. Collaborate with planners and operators to integrate GIS data into decision-making processes, ensuring efficient and safe UAM operations.

4. Civil Aviation Authority Representative

Responsibilities: Enforce aviation regulations and standards related to UAM operations. Work with UAM planners and operators to ensure compliance with safety, airspace management, and licensing requirements. Provide regulatory guidance to facilitate the integration of UAM into existing aviation frameworks.

5. Residents

Responsibilities: Actively participate in public engagement sessions to express concerns, preferences, and feedback related to UAM implementation. Stay informed about the project's progress and potential impacts on the community. Engage in discussions to ensure that UAM planning considers residents' perspectives and addresses their needs.

6. Other Stakeholders

Land Owner/Property Owner: Provide input on land use and property development related to UAM infrastructure. Collaborate with planners to negotiate land use agreements.

Police/Emergency Services: Collaborate on emergency response planning and procedures related to UAM incidents.

Air Navigation Service Provider: Coordinate airspace management and navigation services to ensure the safe integration of UAM within existing air traffic.

Environmental Organisation: Advocate for environmentally responsible UAM practices and assess potential environmental impacts.

Resident Association: Represent the collective interests and concerns of residents, facilitating communication between residents and UAM planners/operators.

Based on the assumptions about the planning process phases as well as planning process actors, the following figure below summarises the suggestions in a conceptual manner. On the left-hand side of the figure, one can see a list of actors described above. The list of these actors should be deliberated about at the beginning of the process, while allowing chance for changes during the process. The right-hand side of the figure emphasises a procedural nature of activities over time, with examples of phases that are suggested as obligatory (in purple), and those phases which can be added to a specific planning process (in blue). Reflectivity and keeping track of both actors and activities over time is an essential responsibility of the UAM planner.

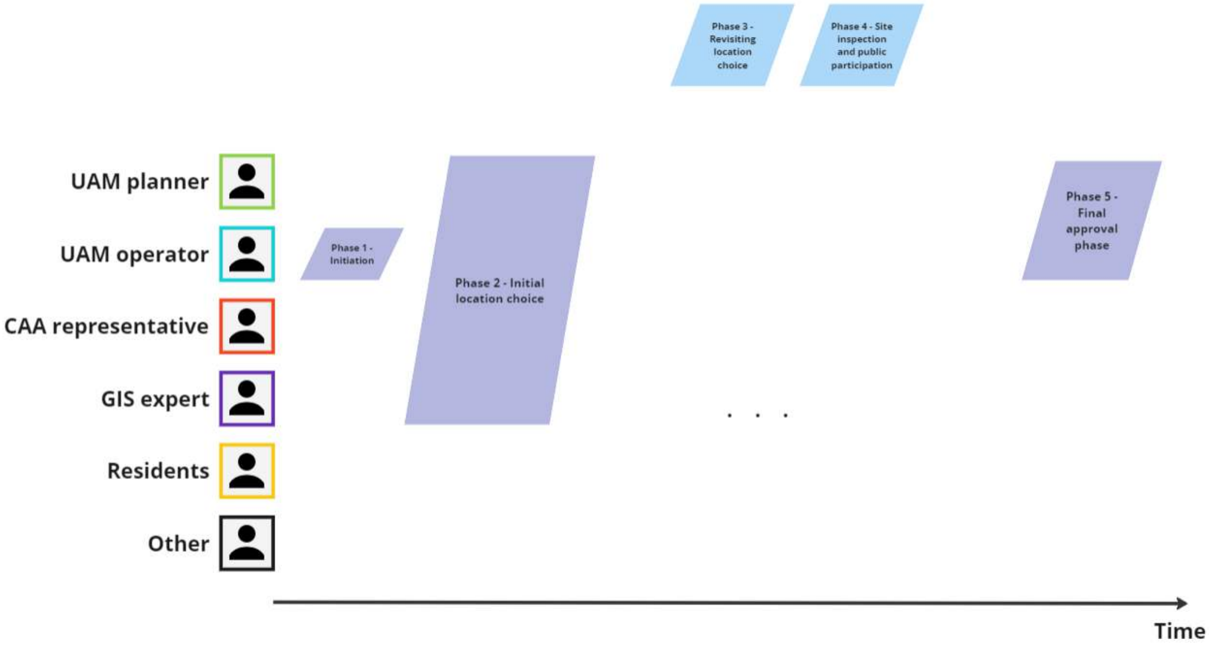


Figure 31: A conceptual depiction of LLS planning process, including roles and phases

5.4 Sub-process of MCA implementation and its role in the process

In general, it is suggested that MCA framework and DST are used in above-mentioned phases two, three and five, whenever there is a need to deliberate about the location choice and make a final decision that should be recorded. The steps involved in a typical multi-criteria analysis process may vary depending on the specific context and the complexity of the decision problem. In addition, it is suggested to use MCA as a way to enhance discussions among stakeholders or experts (Te Boveldt et al., 2021). However, here is a general outline of the steps involved in a multi-criteria analysis:

1. Define the decision problem and possible alternatives

Clearly articulate the decision problem or objective that needs to be addressed. Identify the alternatives or options available for consideration.

2. Identify criteria

Identify and define the relevant criteria that will be used to evaluate the alternatives.

3. Define weights for criteria

Assign weights to the criteria to indicate their relative importance or significance.

4. Evaluate each alternative for each criterion

Gather data for each alternative with respect to each criterion. Evaluate how well each alternative performs on each criterion.

5. Normalise and aggregate the score for each alternative

Normalise the data to bring it to a common scale (e.g., 1-10), especially if the criteria are measured in different units or have different ranges. Use the weights assigned to the criteria to calculate a weighted score for each alternative, as well as aggregate the scores obtained for each alternative across all criteria to obtain an overall score for each alternative.

6. Sensitivity analysis

Conduct sensitivity analysis to assess the impact of changes in criteria weights or alternative scores on the final rankings.

7. Document the analysis

Rank the alternatives based on their overall scores. Make a decision or identify a shortlist of preferred alternatives. Examine trade-offs between alternatives, especially if there are conflicting objectives or criteria. Document the entire MCA process, including the criteria, weights, data sources, calculations, and final results.

The sub-process of MCA implementation in the knowledge management process is defined so that there is at least one planner as the main moderator, as in the following figure. In addition to the moderator planner and area experts, process management has to take into account tasks related to the DST itself. Namely, process management has to be based on the understanding that DST also plays an important role in the decision-making process. Each one of the actors, namely, planner, area experts, and DST, is represented in horizontal layers of the process diagram.

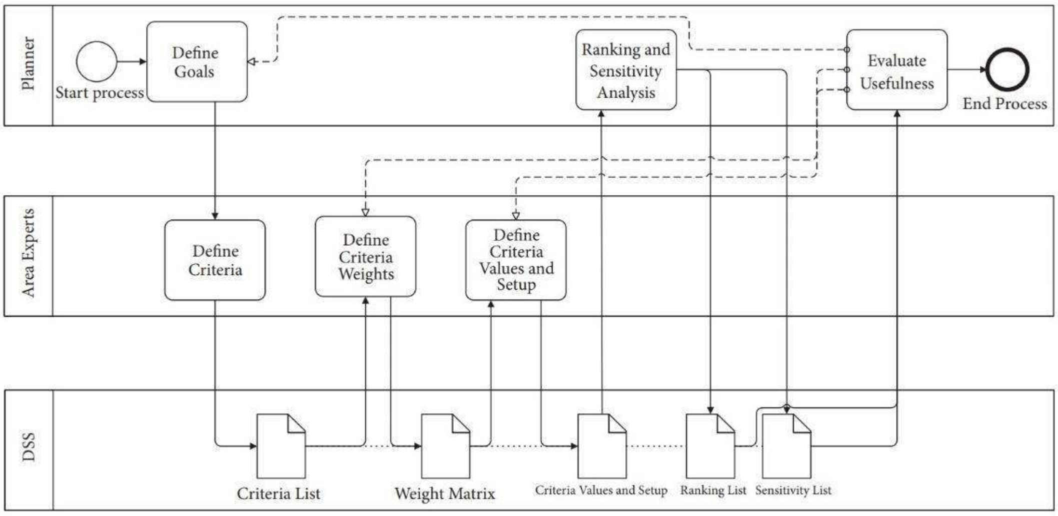


Figure 32: Knowledge management roles, activities, and process outputs (Glavić et al., 2019)

6. DST implementation as Geographic Information System

6.1 Overview of Geographic Information Systems (GIS)

A number of analysis methods are available to the decision-maker in exploring a location choice solution, such as various optimisation models (Glavić et al., 2018; Van Eck & De Jong, 1999). However, an increase in use of spatial DST in urban planning has been seen in recent times (Y. Wang & Zou, 2010). Spatial DST can provide a set of solution spaces visually on which decision makers can focus their discussions and make collective choices (Yeh & Chow, 1996). GIS has been used for solving location choice problems, quantifying multiple factors such as supply and demand (Rybarczyk & Wu, 2010). GIS-based location analysis has been used for various private location choice decision problems such as location of shopping facilities, (Scott & He, 2012). In the public domain, it also has been widely used for supporting public planning decisions such as use of the open space planning (Yeh & Chow, 1996). In city planning, accessibility models are usually applied to ensure equity and system-wide efficiency objectives (Rybarczyk & Wu, 2010; Suárez-Vega et al., 2012). GIS has been used to perform multiple criteria analysis for bicycle paths planning, estimate bicycle demand, conduct least cost path analysis, and assess transportation risk (Atkinson et al., 2005; Nash et al., 2005; Ritsema Van Eck & De Jong, 1999; Rybarczyk & Wu, 2010; Snyder et al., 2008).

In the case of UAM, GIS has been used for the location choice problem of LLS for UAM services (Arellano, 2020; Ayhan et al., 2019; M. S. Kim et al., 2022; Rothfeld & Moeckel, 2018). The following two figures depict examples of GIS-based DST for UAM location purposes, one having far too great spatial resolution (i.e., larger than an urban block size) for spatial location of LLS, while the other only depicts layers (i.e., criteria) which do not add up to a visual representation of more or less suitable LLS locations. Thus, there is a clear need for CITYAM DST with different GIS implementations.

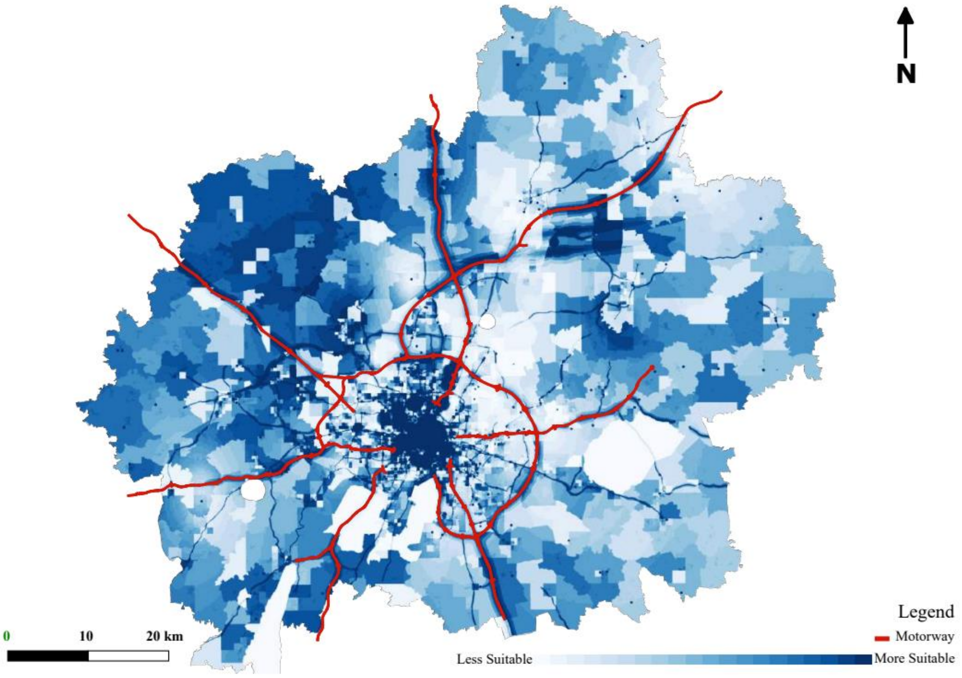
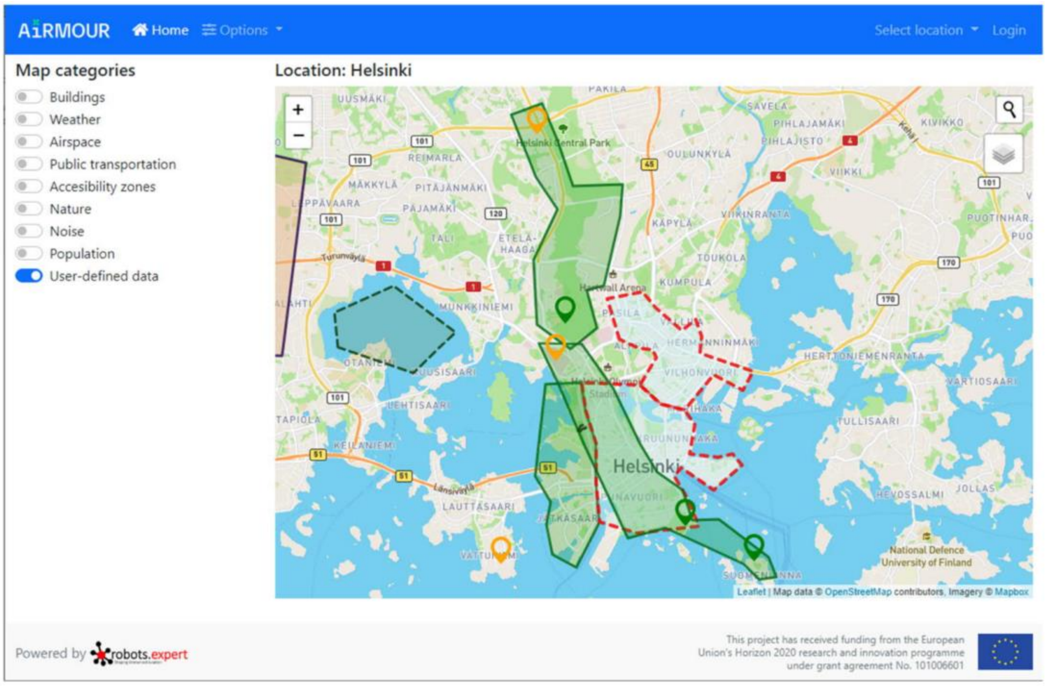


Figure 33: GIS-based visualisation of areas suitable for landing sites in Munich (Fadhil, 2018)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101006601

Figure 34: GIS Tool developed for AiRMOUR project (AIRMOUR)

6.2 Weighted overlay analysis

Weighted overlay is a method used for implementing the MCA framework. A Weighted suitability model or Weighted overlay analysis is developed using GIS techniques depending on several thematic GIS layers (Omran, 2008). A visual depiction of combined layers in GIS is represented in the following figure. Weighted overlay models are used for using a common measurement scale of values to diverse and unlike inputs in order to create a combined analysis. Furthermore, the factors of the analysis may not be equally important in the framework. Therefore, each individual raster cell is reclassified into units of suitability, and then multiplied by a weight to assign relative importance to each.

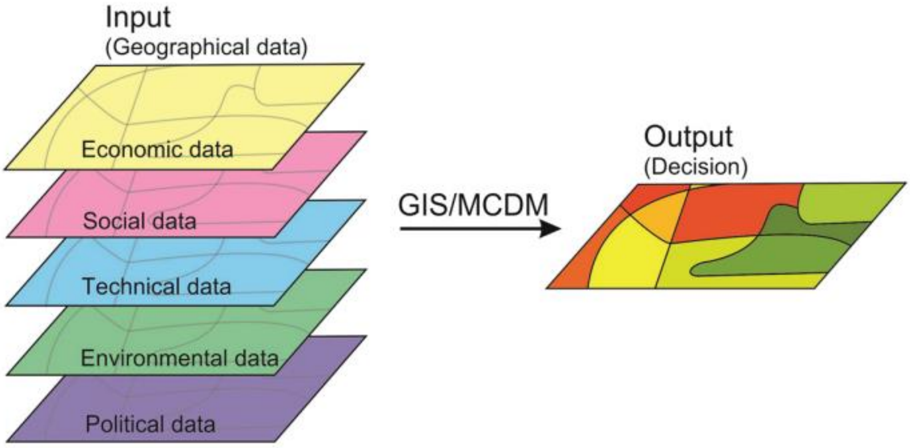


Figure 35: Spatial multi-criteria analysis based on GIS layers (Rikalovic & Cocić, I. 2014)

There are various tools to conduct weighted overlay analysis. For example, ArcGIS uses the following process to perform the analysis.

- Each raster layer is assigned a weight in the analysis.
- Value of a raster in a given layer is specified using a common scale or normalised values are used.
- Raster layers are overlaid, multiplying each raster cell's suitability value by its layer weight.
- Values are summed to derive a suitability value.
- These values are written to new cells in an output layer.
- The symbology in the output layer is based on these values.

The simplified workflow described above can be applied to the LLS DST. However, as the workflow gets more advanced it integrates additional and more complex steps. These steps stand from the nature of the DST being directed to be used in UAM solutions, and LLS mapping in particular. For example, drones in almost all cases (excl. unusual scenarios) are going to land on soil or land instead of water. This in turn necessitates the removal of data from areas located above water.

By assigning a weight to each raster in the overlay process, the process allows to control the influence of different criteria in the suitability model. Multiplying each layer's weight by each cell's suitability value produces a weighted suitability value. Weighted suitability values are summed for each overlaying cell and then assigned to an output layer.

In the figure below, the Weighted Overlay analysis is illustrated numerically. Two input rasters are reclassified to a common scale of 1 to 3 and assigned percentage influence. Cell values are multiplied by their respective percentage influence and summed to create the output raster. For instance, the upper-left cell values are derived by multiplying inputs (2 * 0.75) = 1.5 and (3 * 0.25) = 0.75, resulting in a sum of 2.25. As the Weighted Overlay output is an integer raster, the final value is rounded to 2.

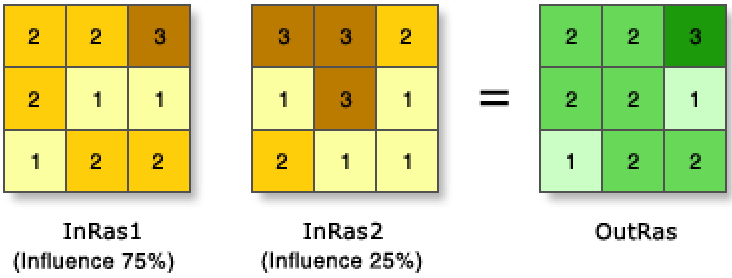


Figure 36: Example of weighted overlay analysis (ArcGIS Pro tool)

6.3 Front-end user interface

The CITYAM project aims to develop a user-friendly user interface for the DST. Mock-up of the user interface is depicted in the following figure. The front end UI of the GIS DST should have the following functionalities.

- The various user profiles should be allowed through user login options.
- The UI should provide an option for the save as map -GIS layer in jpeg or pdf format.
- The UI should provide an option to import the GIS data layer.
- After the addition of a GIS data layer, there should be an option to re-visualise the map.
- There should be an option to add a potential LLS point.
- There should be an option to change the weight of a GIS data layer.
- There should be an option to turn-on and turn-off a GIS data layer.
- There should be an option to zoom-in and zoom-out the GIS map.

- The UI should have a legend of the map showing the suitability and unsuitability scale of numerical values and North direction symbol for the map.

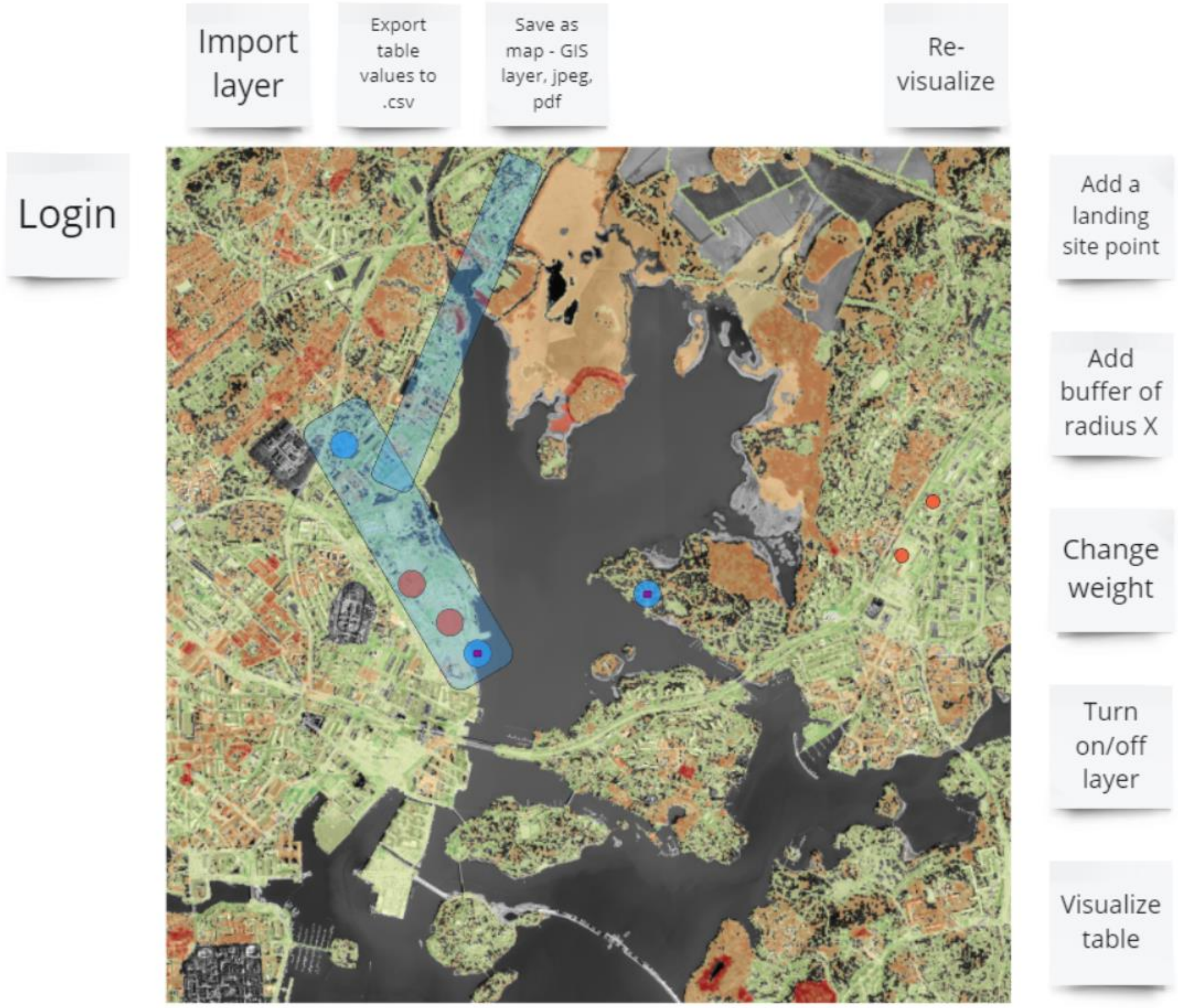


Figure 37: Mock-up of user interface planned for CITYAM DST

6.4. Desktop and browser solutions for implementing DST

There are various GIS tools and software with various features and capabilities. Three distinct options for desktop and browser solutions in the development of the DST were identified. These options included geospatial desktop software, plugins for these software and a web-based graphical user interface options. Some of the commonly used desktop software are following:

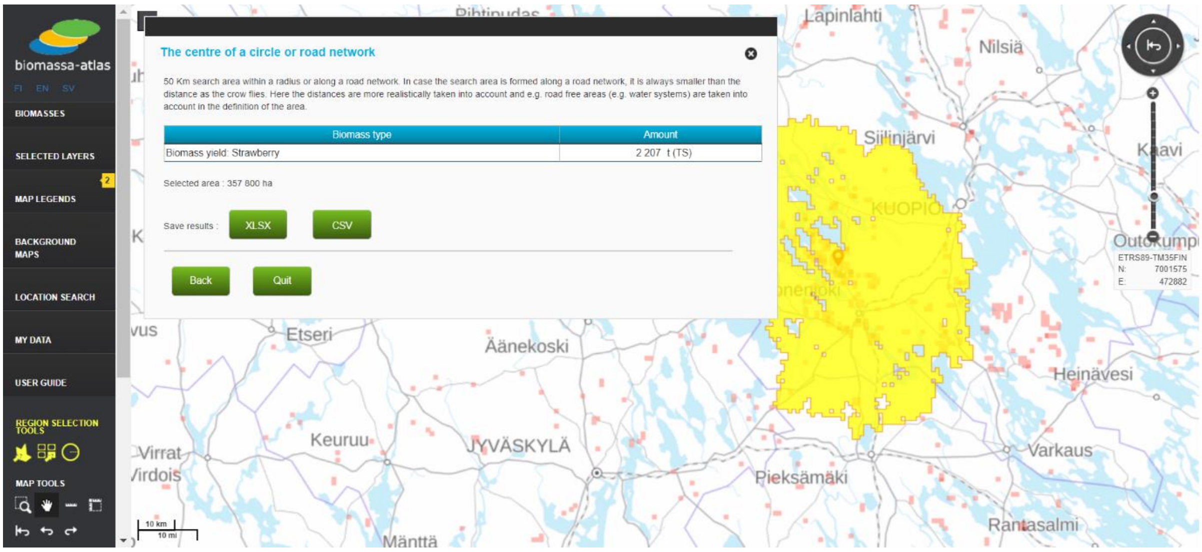
- ArcGIS: ArcGIS is a widely used GIS tool for spatial analysis among the professionals. ArcGIS allows users to create, analyse and visualise with a range of applications both in desktop as well as online version and server-based solutions. The competences of

ArcGIS cover the basic mapping to advance geodatabase management and real-time data integration.

- Quantum GIS (QGIS): Similar to ArcGIS, QGIS also provides a wide range of mapping and spatial analysis. In comparison to ArcGIS, QGIS is an open-source software. In terms of functionality, QGIS can process numerous data formats and has a large library of plugins to enhance the functionality of the software. Similar to ArcGIS, QGIS has also been a common choice of planners, researchers, and other professionals due to the versatility.

A number of different geospatial programming libraries and frameworks to develop a web interface for the DST were investigated. This investigation remains a work in progress. Significant insights have been achieved, pinpointing libraries that are more resource-intensive and those less aligned with requirements. In the evaluations, three alternatives were considered as most promising: Oskari framework, Python libraries, and the uMap framework.

Oskari framework (an example implementation in the following figure) was considered as a promising option since it is used in many use-cases, although mostly in Finland. It is developed by NLS and one benefit of it would have been the in-house experience of colleagues regarding the tool development inside the framework. The Oskari framework enables the possibility to make own analyses and make the app have a distinct visual theme. However, after researching the tool it was found out to be one of the resource-intensive and complex solutions to start with. After gathering further experiences, there was a negative feedback concerning the challenges and difficulties associated with developing and modifying the framework.



The centre of a circle or road network

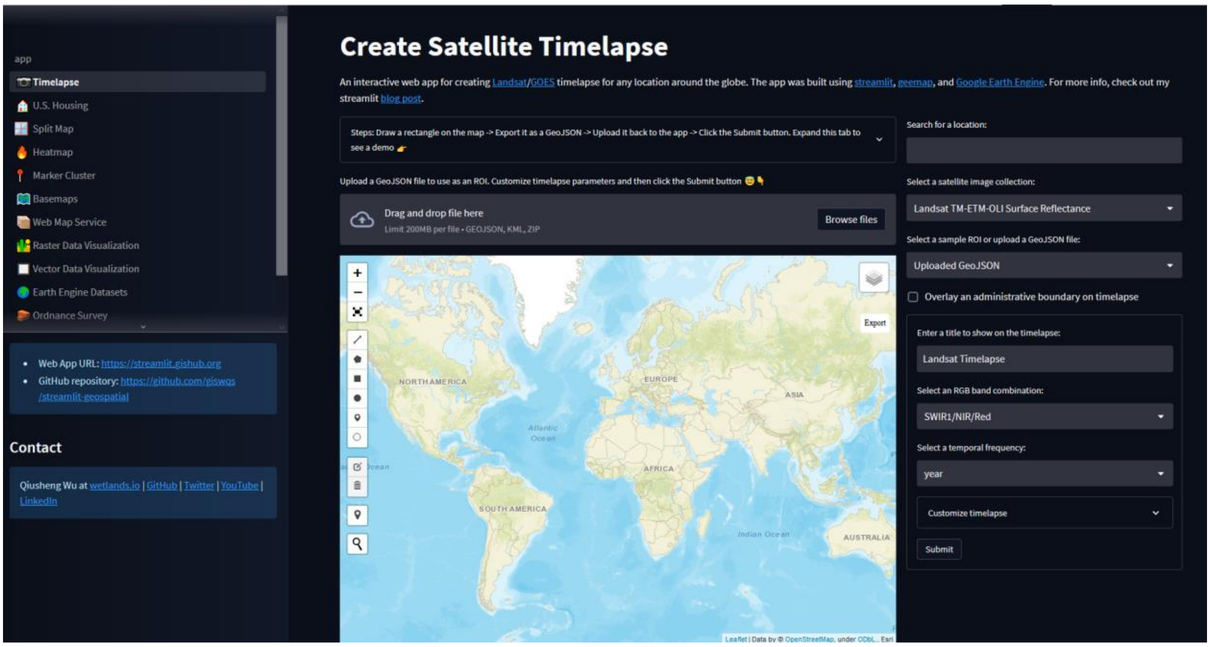
50 Km search area within a radius or along a road network. In case the search area is formed along a road network, it is always smaller than the distance as the crow flies. Here the distances are more realistically taken into account and e.g. road free areas (e.g. water systems) are taken into account in the definition of the area.

Biomass type	Amount
Biomass yield: Strawberry	2 207 t (TS)

Selected area : 357 800 ha

Figure 38: Biomass Atlas on Oskari platform (Oskari Biomass Atlas)

The next approach shifted focus towards utilising libraries rather than relying on pre-built frameworks. This shift involves certain trade-offs. While it offers a broader range of development options and allows for a more customised approach, it also potentially increases the workload and introduces challenges related to library dependencies. In contrast to Oskari, which leans heavily on JavaScript (frontend) and Java (backend), the later solutions explored were centred around Python, where the distinction between frontend and backend was not as clearly defined. One such option was Streamlit (an example implementation in the following figure), notable for its ease of development and ability to integrate with the Leafmap python package. Although Leafmap is built upon numerous open-source geospatial DST and packages such as folium, ipyleaflet, ipywidgets, WhiteboxTools and whiteboxgui, Streamlit had challenges to integrate custom actions with e.g. ipyleaflet and ipywidgets (Wu, 2021).



- Web App URL: https://streamlit.gishub.org
- GitHub repository: https://github.com/giswqs/streamlit-geospatial

Contact

Qiusheng Wu at wetlands.io | GitHub | Twitter | YouTube | LinkedIn

Create Satellite Timelapse

An interactive web app for creating Landsat/GOES timelapse for any location around the globe. The app was built using streamlit, geemap, and Google Earth Engine. For more info, check out my streamlit blog post.

Steps: Draw a rectangle on the map -> Export it as a GeoJSON -> Upload it back to the app -> Click the Submit button. Expand this tab to see a demo 👉

Upload a GeoJSON file to use as an ROI. Customize timelapse parameters and then click the Submit button 😇👇

Drag and drop file here
Limit 200MB per file • GEOJSON, KML, ZIP

Search for a location:

Select a satellite image collection: Landsat TM-ETM-OLI Surface Reflectance

Select a sample ROI or upload a GeoJSON file: Uploaded GeoJSON

☐ Overlay an administrative boundary on timelapse

Enter a title to show on the timelapse: Landsat Timelapse

Select an RGB band combination: SWIR1/NIR/Red

Select a temporal frequency: year

Figure 39: Example of Streamlit application (Streamlit for Geospatial Applications)

Example of one such action was to create a simple UI components for users to choose the study area grid size and then add it to the map. This could not be done with Streamlit but the problem was tackled by combining Jupyter notebooks and Voila, the latter of which turns notebooks into standalone web apps.

The combination of ipyleaflet and ipywidgets presents robust solutions where users can interact with the map and other elements simultaneously. Leafmap combining these elements remains a viable option under consideration for its specific functionalities and benefits. For example, WhiteBoxTools adds the element of building the GIS workflows described in 6.2 & 6.5. All in all, Leafmap is very well documented and developed. It was firstly developed as part of Geemap python package that enables geospatial analysis and visualisation with Google Earth Engine (GEE). This means that Leafmap can be integrated with cloud computing platforms, which GEE is a great example of while providing a vast catalogue of satellite imagery and geospatial datasets.

The third evaluated web-based solution was the uMap framework. This framework provides a platform for creating interactive maps, offering essential GIS features. It enables the addition of overlays, and the creation of points, lines, and polygons. It also supports the import and export of data, offers customization options for map styling, and facilitates collaborative map-making through user accounts. Users can employ overlays and draw points, lines, and polygons as well as import and export data, customise styling, and collaborate on map creation with user accounts. An example of its application is the Baltic Explorer, a collaborative web GIS tool designed for maritime spatial planning that has been developed at NLS. This tool is optimised for a touchscreen-friendly, multi-user interface adaptable to various screen sizes. In addition to its core functions, Baltic Explorer includes enhanced capabilities for performing cross-overlay calculations.

Regarding data storage, PostGIS plays a crucial role in the GIS tool, offering versatile features. It provides robust spatial data storage capabilities for various data types, including points, lines, polygons, and multi-geometries across both 2D and 3D dimensions. With its efficient spatial indexing, users can perform searches based on geographic location. The tool offers a diverse range of spatial functions that empower dynamic data filtering and analysis. Additionally, it offers geometry manipulation tools for tasks like simplification, transformation, and generalisation. PostGIS excels in supporting both the storage and manipulation of raster data, encompassing elevation and weather data, while also offering geocoding and reverse geocoding functionalities. A fundamental feature is its seamless integration with third-party tools such as QGIS, GeoServer, MapServer, ArcGIS, and Tableau, enhancing the overall flexibility and interoperability of geospatial workflows.

In conclusion, it is important to note that the more complex technical architecture of the planned DST still needs further testing and evaluation. The overall plan for the backend analysis workflow is rather clear. As noted, the DST is more than just a straightforward user interface, as it also is going to include a complex backend that brings together automated workflows, databases, and servers. All these components need to be carefully worked out and adjusted to ensure the DST functions effectively and can be used online by multiple users simultaneously. Based on our analysis, the uMAP framework seems the best suited to the final implementation of the GIS DST. However, in the first prototype, the focus was on developing the methodology and understanding how different layers and weightings impact outcomes. Consequently, the first prototype was implemented in the local environment using automated workflows, primarily through QGIS.

6.5 First prototype of the LLS decision-support tool

The first prototype of the LLS DST, ready for further testing with planners and continuous development, was developed in the desktop GIS environment using QGIS. The designed GIS workflow LLS planning has five major phases:

1. Planning Objectives: Define the objectives for LLS planning, outlining the application, specific goals, and criteria.
2. GIS Data Collection and Pre-processing: Gather geospatial data relevant to the LLS planning task from open Apis and geoportals as well as user datasets and perform necessary pre-processing steps to process the dataset into correct format and to ensure data quality. Also design weighting for different data layers.
3. Data Processing: Carry out weighted overlay analysis to identify best suited locations for LLS.
4. Analysis and Production: Evaluate results of multi-criteria analysis and identify the best locations for LLS.
5. Dissemination: Communicate the results and findings effectively, making the information accessible to relevant stakeholders.

Different stakeholders are involved in various planning phases as outlined in Section 5.3. From each of the phases, it is possible to return to any of the previous phases, and iterate until acceptable outcomes are achieved. For example, Phase 5 is crucial for multi-actor co-development, allowing input from stakeholder groups outside city planning, regulatory bodies, and operator organisations. The entire process is illustrated in Figure below.

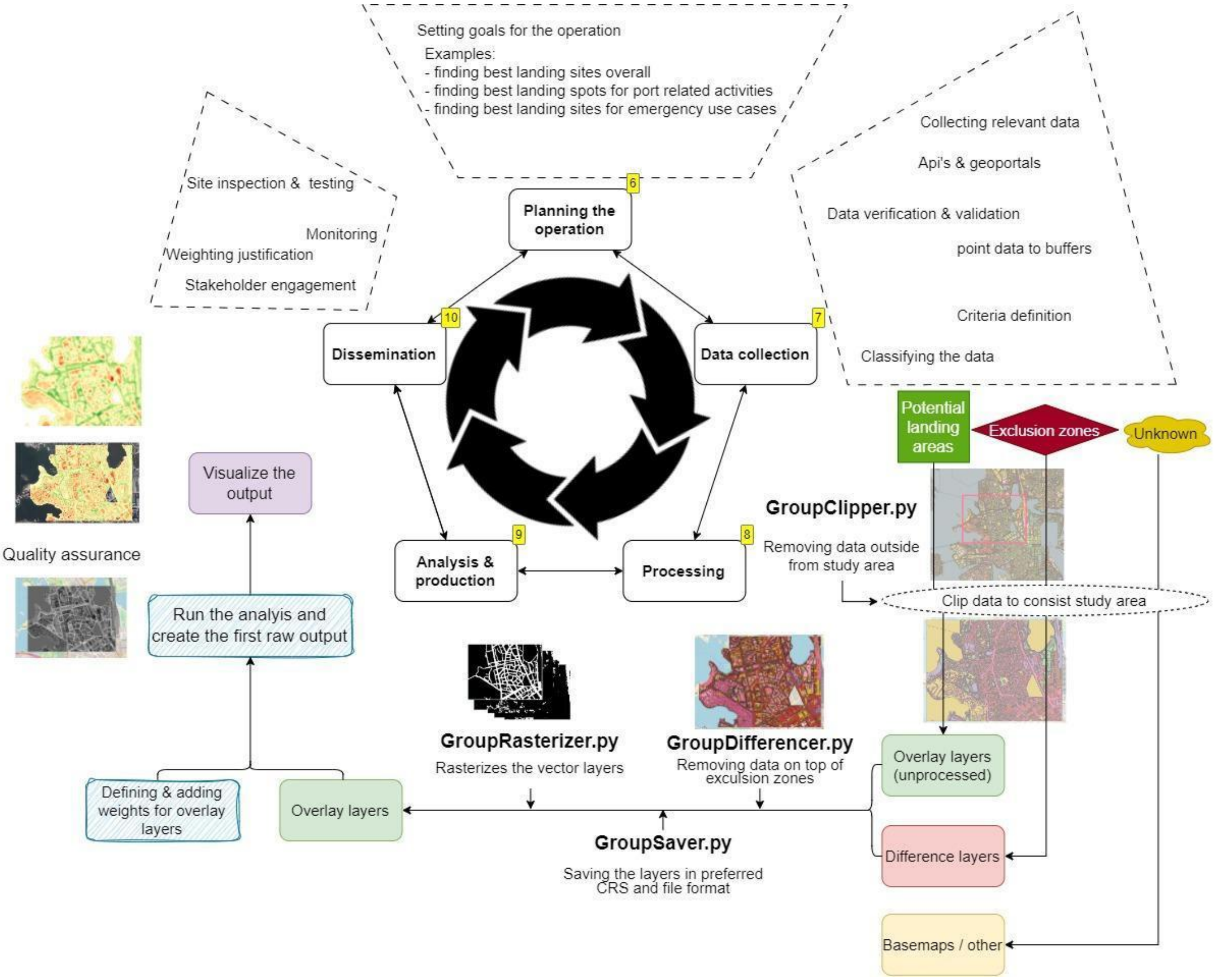


Figure 40: Flow chart of GIS based LLS planning

To showcase the prototype, a raster grid with a 10 x 10 m cell size is generated over the area of interest. Multiple map layers are considered in planning. Firstly, areas that are not suitable for

LLS were excluded from the analysis, such as flight restriction areas and water areas. Potential areas were then included in the weighted overlay analysis. As mentioned in section 4.2, decision criteria can be classified as “pull to”, meaning that they are providing reasons for having a LLS in a specific urban location, as well as “push away”, meaning that they are providing reasons for not having a LLS in a specific urban location. For example, car parking lots, city bike parking places, bare ground, and low vegetation areas are considered attractive, pull-to factors for LLS. On the other hand, nature reserve areas, kindergartens, graveyards, and areas with trees were considered poorly suited, push-away factors for LLS. Exemplary weighting for different GIS layers and the resulting “traffic light” map, representing the suitability of different areas for LLS based on weighted overlay analysis, are presented in the figures below. The former figure shows pull-in layers in green, and push-away layers in red. The latter figure shows the view on the map, with green areas being more optimal for LLS, while red areas are not suitable for LLS location.

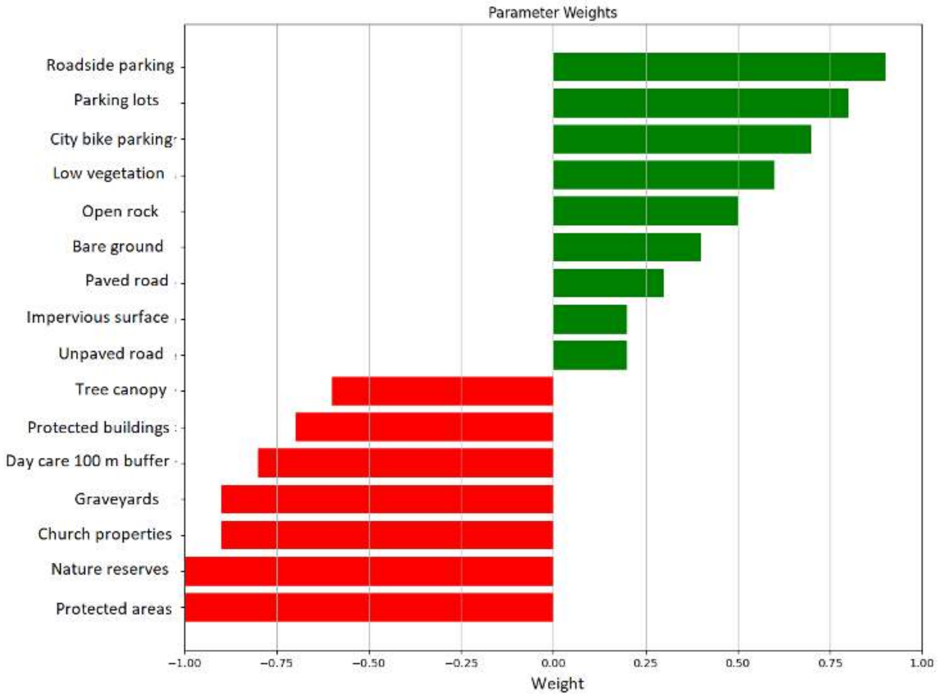


Figure 41: Example of weighting of different layers used in LLS planning

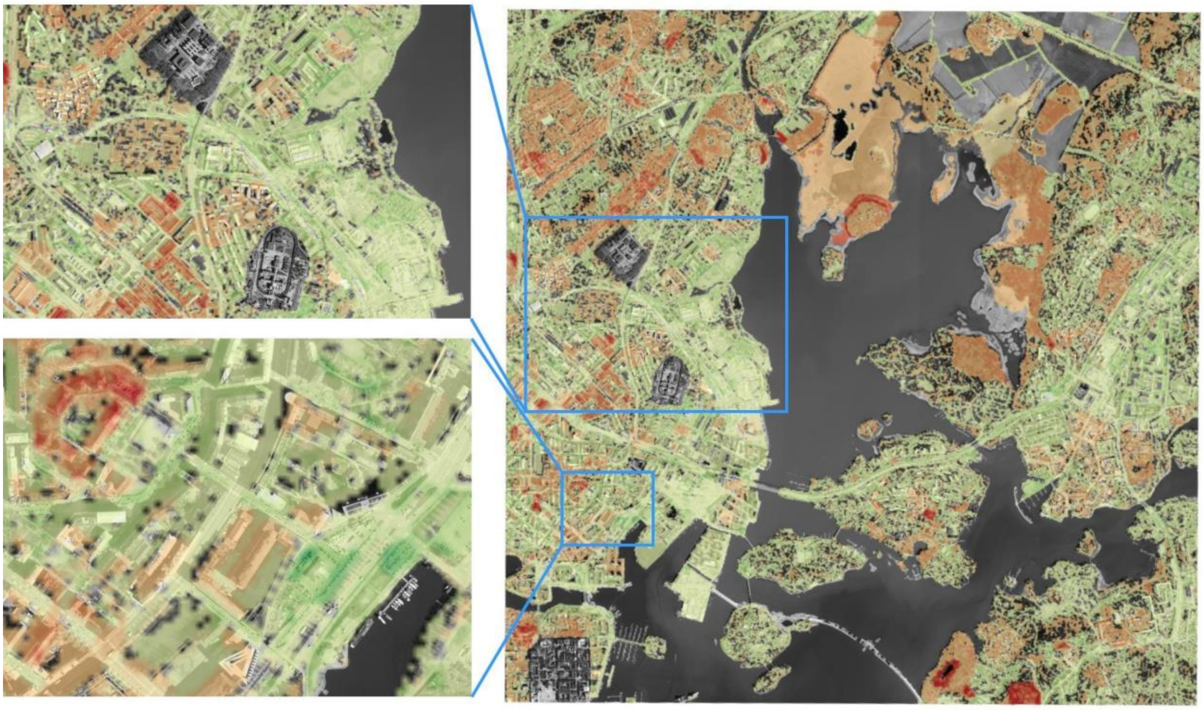


Figure 42: An example of a “traffic light” map for LLS in the City of Helsinki calculated using weighted overlay analysis

7. Conclusions

7.1 Summary of outcomes and recommendations

Given that drones are an emerging technology with expected non-linear changes over time, both drone design and terminology will continue to change over time. Although diverse, use cases for drones in urban environments can be classified as “eye-in-the-sky” or “hand-in-the-sky”, with or without safety critical timing for flight time. Moreover, it is expected that the number of drones, flights and flight hours will continue to increase for some time in the future. Reminding about the Collingridge dilemma mentioned above, city officials and urban planners need to use the current window of opportunity to shape the trajectory of drone technology and deployment. Location choice for LLS is in focus of the CITYAM project and this report, as one of the central challenges for the technological trajectory of drones in urban areas.

Overall, the LLS location problem in itself is a multifaceted problem, pertaining to limited land availability, multiple simultaneous demands for that land, and limitations to dynamic land use. In addition, the need for decision-support in planning LLS locations also stems from a plethora of anticipated undesired impacts in combination with unclear governance as changing roles, responsibilities and processes, underpinning the general lack of experience with drones in the public sector. With that in mind, the report clarifies some essential assumptions, specifically about the physics of drone flight in urban environments, which besides constraints stemming from fluid dynamics of air also face constraints by urban environment at large, which includes built environment, residents, and wildlife. Thus, taking-off and landing are highly critical phases of a drone's flight dynamics. Taking into account other key assumptions about access to LLS, integration with city-wide flight corridors, detailed design of LLS to accommodate different use areas, as well as an assumption that drones in focus of CITYAM are not going to have a diameter larger than 3 metres with similar size landing technology, the spatial scale for LLS assumed for tool development is 10 x 10 metres.

After clarifying the assumptions about drone and LLS technology, scope for the LLS planning process is defined, followed by general functional requirements for DST, including multi-stakeholder in-meeting requirements. The decision support framework is suggested to be based on multi-criteria analysis, whose key components are alternative LLS locations, while those are selected based on decision criteria, weights of those criteria, and evaluation score for each alternative. MCA has been selected due to its capability to help structure the problem while enabling communication across different stakeholders. Besides the framework, a list of potential criteria to use in LLS location choice has been provided, including a general approach to consider some criteria as those pro having LLS in a certain location (i.e., “pull-in”), and those against (i.e., “push-away”), while strongly encouraging documenting the process of how criteria, their weights and scores are defined.

Determination of the type of places where there should be always and partially forbidden access for emergency landing or for fly-over routes should become part of a municipality's strategy. With regard to the built environment, outcomes of a specific assessment of certain built-up areas, on-water areas, open areas or areas with low acceptance of urban air mobility services should be reflected in the strategy too. General public participation processes and expert assessment can provide further criteria related to topics of safety, regulation, infrastructure, vicinity to critical infrastructure, service design, use case, operational consideration, and wider social impacts. Besides that, a strategic approach to UAM in a municipality would also require further clarification of internal and external decision processes related to such aspects as land ownership and use, environmental impact assessment, and street construction and maintenance.

Since the MCA framework by itself is not enough for developing DST, the report also included analysis and recommendations for organising the planning process into phases, including defining roles and responsibilities for different stakeholders. Here, we underline that municipalities should appoint a UAM planner, who receives requests from UAM operators, and addresses them alone or in collaboration with other actors within the municipality. In that process, the focus is on moving away from traditional technocratic towards more communicative planning which is more suitable in the domains with multiple stakeholders and substantial uncertainties. Simultaneously, the advantages of MCA are also better leveraged given the suggestion for more iterative planning approach that also includes DST as communication enabler for UAM planner, who is taking a role of the communication moderator during multi-stakeholder in-meeting sessions.

Four different alternatives were studied as potential technical solutions for the LLS DST: desktop GIS platform (QGIS), Oskari webmap framework, Python libraries, and uMap framework. The first LLS DST prototype was implemented using QGIS and evaluated in the Helsinki area. A number of open GIS layers were collected from geospatial portals and processed into a suitable format. Subsequently, they were assigned with appropriate weights. A weighted overlay analysis was used to find the most potential areas for LLS. The results were visualised using the “traffic light” colour scheme. The initial prototype will serve as the foundation for co-creation with various stakeholders in the implementation of the actual LLS DST in Activity 2.1. In Activity 2.1, QGIS software is used in collaboration with cities for planning. The uMAP framework was chosen as the foundation for the DST, as it has been proven useful in similar multi-stakeholder planning tasks in earlier studies by the Finnish Geospatial Research Institute.

Further development in 2024 during CITYAM Activity 2.1 should include iterative development of DST, including workflow, UI, and web-based implementation. In addition, a user manual for DST will be developed, as a complement to this report. That manual will also include guidance on updating data, for example, internally by using the GIS task force within the municipality or in relation to ongoing Digital Twin initiatives. To continue development and validate the usefulness of the solution, the DST will be piloted during Activity 2.1 of CITYAM, planned to take place in Helsinki, Hamburg and Stockholm in 2024. The experiences gathered from piloting DST will be used to develop guidance on using the multi-criteria method, including such aspects as which criteria to focus on given the use case, how to assign weights, how to record the planning process, etc. Piloting the DST will also include an analysis of impacts of different weightings used in multi-criteria analysis, as well as evaluating possibilities for automating part of the planning process. Validation will be based on hands-on workshops and post-workshop questionnaires.

7.2 Recommendations for further development beyond the scope of this report

There are three main areas suggested for further development beyond the scope of this report. One of those areas is further development of an ecosystem of tools to support various decisions pertaining to UAM in urban environments, i.e., U-space. On the one hand, there is a need for developing real-time flight information and management tools for UAM beyond municipal boundaries, based on the concept of Software Defined Airspace. Such tools can help in planning the flight operation in advance and in real-time, including various flight mission functionalities such as flight plan, approval, (semi)-automatic mission control, mission cancellation, and dynamic geofencing. Moreover, such tools can also help to identify the location and instant updates of the drone flight trajectory, and is especially important for emergency cases. Such a tool can further be integrated with the DST, especially for defining the urban air corridors. On the other hand, there is a need for developing a three-dimensional route planning tool, to be especially useful for UAM operators testing out different potential routes and LLS locations, and enabling discussion with various other stakeholders. An integration of that tool with CITYAM DST and other available tools, such as demand modelling, can help in estimating the optimal number of LLS inside urban areas. Other tools in the ecosystem, such as computer-aided design, could also be useful for relevant tasks, such as design of LLS site. In relation to these tools, there should be a continued emphasis on opening as much as data as possible and desirable (Mladenovic, 2021)

The second area for further research and development is policy innovation and governance more narrowly defined as a network of roles-responsibilities and associated processes. In particular, there is a need to clarify the process that includes both municipal authorities and CAA from the beginning. Moreover, besides the traditional municipal land use policy, there is a need to explore other potential UAM-related policies. For example, a city could limit a maximum number of take-off or landing events within a specific area and time duration. Moreover, a city could cap the number of locations eligible for LLS, and only in specific areas, which given the expectation that long-term wave for UAM deployment will have a temporal scale of decades, could help with inter-organizational learning and mitigating impacts. Such policy innovation will have to be under the umbrella of a new governance model, as depicted in the following figure. In principle, a city strategy should answer these questions related to LLS for aerial drones, as well as define the desired and undesired use cases, raising such questions as who wins and who loses (Stilgoe & Mladenović, 2022). Regarding that new governance model, there are further questions listed below, which should be clarified in the future, in general in a specific city and in particular for each LLS.

- Who can access the LLS?
- Who will own the emergency LLS?
- What permits are needed for LLS infrastructure?
- Who will construct the LLS?
- Who will maintain the LLS?
- How will the city be compensated for land used by LLS?
- How will allocation of the lot for LLS be determined (e.g., first come first served, auction, lottery, duration)?
- Who is liable in case of incidents or crashes at the LLS?

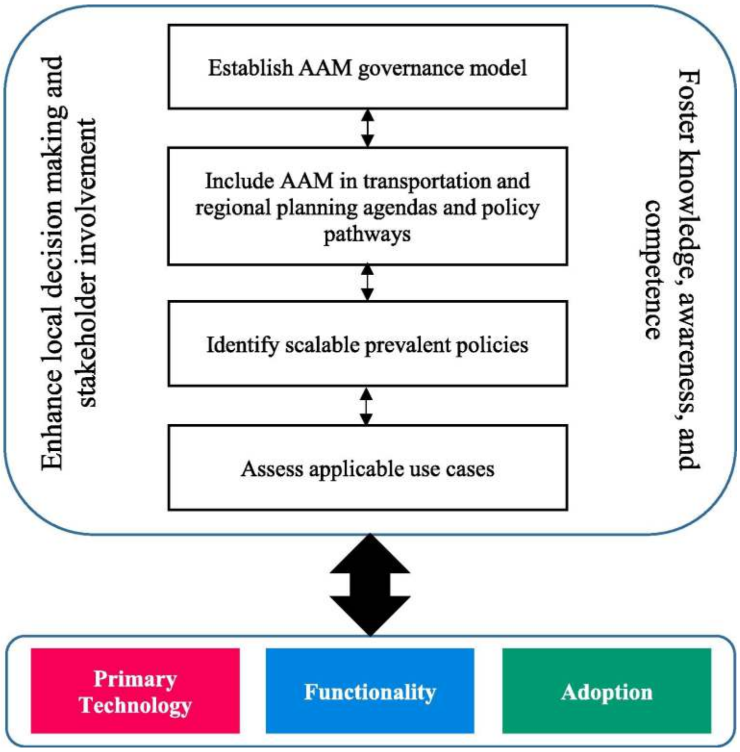


Figure 43: Policy development framework for regional UAM deployment (Raghunatha et al., 2023)

The third area for further development is the underlying mindset or paradigm within the governance culture (Olin & Mladenović, 2022). Here, it is essential to clarify the notion of adaptiveness in adaptive governance. A suitable metaphor can be found in the etymology of the word governance itself, which stems from Ancient Greek word *kubernaein*, meaning to steer, e.g., a ship. Here, on the one hand, adaptive governance would mean that decisions about an uncertain future impacts from UAM need long-term goals, just as a ship needs a compass to plot its course. On the other hand, adaptiveness is acknowledging that the ship cannot continue always on the course as initially indicated by compass, especially if the sea currents have already changed the position of the ship. As such, the long-term goals for UAM need to be defined as part of the municipal, national, and EU strategies, while also inventing mechanisms for short-term and dynamic adjustments and complements to strategic goals.

Within such paradigm change, and similarly to dilemmas with other emerging urban mobility technologies, there is a need to clarify the hierarchical position of drones in relation to other transport modes, not only in general, but for specific use cases. For example, we already know that existing emergency vehicles often get priority at intersections or their access has to be secured in all urban areas, meaning that they often have the highest position in relation to other transport modes. However, given a plethora of UAM use cases, there is a need to further elaborate this hierarchy, while thoroughly anticipating and evaluating impacts. Since LLS is not just competing for scarce urban space with transport modes, the discussion on the hierarchy will have to also include other urban land use elements. That hierarchy will not only pertain to space, but can also have a temporal aspect, as some urban elements are more or less suitable for certain parts of the year, opening up questions on the dynamic use of urban space. For example, we already know about examples where electric scooter parking is transformed into snow storage spaces during the winter. Ultimately, a development of the governance culture will have to recognize the inevitable moral underpinning of the urban transition, with both aspects of mobility justice (Mladenović, 2018; Mladenović, 2020) and just transition overall (Heffron, 2021).

References

Abbas, M. M., Mladenovic, M. N., Ganta, S., Kasaraneni, Y., & McGhee, C. C. (2013). Development and use of critical functional requirements for controller upgrade decisions. Transportation research record, 2355(1), 83-92.

AiRMOUR, Enabling sustainable air mobility in urban contexts via emergency and medical services, https://docs.google.com/document/d/1zGHs-5LH4LlOl92I-DX_CX3DO_68Io3R/edit, accessed on 10 Jan 2024.

Air-One hub Landing Solution, U.K. Flying-Taxi Hub Aims to Develop Blueprint for Aerial Roads, https://www.bloomberg.com/news/articles/2021-05-12/u-k-flying-taxi-hub-aims-to-develop-blueprint-for-aerial-roads, accessed on 21 Dec 2023.

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., & Antoniou, C. (2020). Factors affecting the adoption and use of urban air mobility. Transportation research part A: policy and practice, 132, 696-712.

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., & Antoniou, C. (2020). Factors affecting the adoption and use of urban air mobility. Transportation Research Part A: Policy and Practice, 132, 696–712. https://doi.org/10.1016/J.TRA.2019.12.020

Al Labbad, M., Wall, A., Larose, G. L., Khouli, F., & Barber, H. (2022). Experimental investigations into the effect of urban airflow characteristics on urban air mobility applications. Journal of Wind Engineering and Industrial Aerodynamics, 229, 105126. https://doi.org/10.1016/J.JWEIA.2022.105126

Andersson, J., Hellsmark, H., & Sandén, B. (2021). The outcomes of directionality: Towards a morphology of sociotechnical systems. Environmental Innovation and Societal Transitions, 40, 108-131.

ArcGIS Pro tool, Weighted Overlay (Spatial Analyst), https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/weighted-overlay.htm, accessed on 10 Jan 2024.

Arellano, S. (2020). A Data-and Demand-Based Approach at Identifying Accessible Locations for Urban Air Mobility Stations. Master's Thesis, Technical University of Munich.

Arnstein, S. R. (1969). A ladder of citizen participation. Journal of the American Institute of planners, 35(4), 216-224.

Atkinson, D. M., Deadman, P., Dudycha, D., & Traynor, S. (2005). Multi-criteria evaluation and least cost path analysis for an arctic all-weather road. Applied Geography, 25(4), 287–307. https://doi.org/10.1016/J.APGEOG.2005.08.001

Aviamaps, Helsinki restriction zones, https://flyk.com/map?drone#p=10.81/60.2155/25.0125, accessed on 10 Jan 2024.

Ayamga, M., Akaba, S., & Nyaaba, A. A. (2021). Multifaceted applicability of drones: A review. Technological Forecasting and Social Change, 167, 120677.

Ayhan, B., Kwan, C., Um, Y. Bin, Budavari, B., & Larkin, J. (2019). Semi-Automated Emergency Landing Site Selection Approach for UAVs. IEEE Transactions on Aerospace and Electronic Systems, 55(4), 1892–1906. https://doi.org/10.1109/TAES.2018.2879529

Balta, M. Ö., & Öztürk, A. (2021). Examining the Dynamics of Residential Location Choice in Metropolitan Areas Using an Analytical Hierarchy Process. Journal of Urban Planning and Development, 147(4), 1–8. https://doi.org/10.1061/(asce)up.1943-5444.0000753

Banister, D. (2008). The sustainable mobility paradigm. Transport policy, 15(2), 73-80.

Bauranov, A., & Rakas, J. (2021). Designing airspace for urban air mobility: A review of concepts and approaches. Progress in Aerospace Sciences, 125, 100726.

Bell, S., Berg, T., & Morse, S. (2019). Towards an understanding of rich picture interpretation. Systemic Practice and Action Research, 32, 601-614.

Bonaccorsi, A., Apreda, R., & Fantoni, G. (2020). Expert biases in technology foresight. Why they are a problem and how to mitigate them. Technological Forecasting and Social Change,151, 119855.

Bonnefon, J. F., Černy, D., Danaher, J., Devillier, N., Johansson, V., Kovacikova, T., ... & Zawieska, K. (2020). Ethics of connected and automated vehicles: Recommendations on road safety, privacy, fairness, explainability and responsibility.

Brunelli, M., Ditta, C. C., & Postorino, M. N. (2023). New infrastructures for Urban Air Mobility systems: A systematic review on vertiport location and capacity. Journal of Air Transport Management, 112. https://doi.org/10.1016/j.jairtraman.2023.102460

Carrillo-Larco, R. M., Moscoso-Porras, M., Taype-Rondan, A., Ruiz-Alejos, A., & Bernabe-Ortiz, A. (2018). The use of unmanned aerial vehicles for health purposes: a systematic review of experimental studies. Global health, epidemiology and genomics, 3, e13.

CFD Flow Engineering, Working Principle and Components of Drone, https://cfdflowengineering.com/working-principle-and-components-of-drone/, accessed on 10 Jan 2024.

Chowdhury, S., Shahvari, O., Marufuzzaman, M., Li, X., & Bian, L. (2021). Drone routing and optimization for post-disaster inspection. Computers & Industrial Engineering, 159, 107495.

Churchwell, J. S., Zhang, K. S., & Saleh, J. H. (2018). Epidemiology of helicopter accidents: Trends, rates, and covariates. Reliability Engineering & System Safety, 180, 373-384.

Cohen, A. P., Shaheen, S. A., & Farrar, E. M. (2021). Urban air mobility: History, ecosystem, market potential, and challenges. IEEE Transactions on Intelligent Transportation Systems, 22(9), 6074-6087.

Cohen, M. M. (1996). The Vertiport as an Urban Design Problem.

Dakic, I., Mladenovic, M., Stevanovic, A., & Zlatkovic, M. (2018). Upgrade evaluation of traffic signal assets: high-resolution performance measurement framework. Promet-Traffic&Transportation, 30(3), 323-332.

DBX-G7 Drone-in-a-Box System, Drone-in-a-Box Solutions, https://www.unmannedsystemstechnology.com/expo/drone-in-a-box/, accessed on 21 Dec 2023.

DHL Drone-in-a-Box System, DHL express launches its first regular fully-automated and intelligent urban drone delivery service, https://www.dhl.com/global-en/home/press/press-archive/2019/dhl-express-launches-its-first-regular-fully-automated-and-intelligent-urban-drone-delivery-service.html, accessed on 21 Dec 2023.

Duma, L. A., Begonia, M. T., Miller, B., & Duma, S. M. (2021). Proposed injury threshold for drone blade lacerations. Annals of biomedical engineering, 49, 1125-1127.

EASA. (2022), Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category, https://www.easa.europa.eu/en/document-library/general-publications/prototype-technical-design-specifications-vertiports.

EASA. (2014), Easy Access Rules for Aerodromes (Regulation (EU) No 139/2014), https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-aerodromes-regulation-eu-no-1392014.

EU Strategy, A Drone strategy 2.0 for Europe to foster sustainable and smart mobility, https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13046-A-Drone-strategy-20-for-Europe-to-foster-sustainable-and-smart-mobility_en, accessed on 10 Jan 2024.

European Commission. (2022). A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe. Brussels.

European Metropolitan Transport Authorities (EMTA), EMTA Barometer, 2020, https://www.emta.com/spip.php?article1380, online; accessed 9 May 2021.

F. Hirschhorn, A. Paulsson, C. H. Sørensen, W. Veeneman, Public transport regimes and mobility as a service: Governance approaches in Amsterdam, Birmingham, and Helsinki, Transportation Research Part A: Policy and Practice (2019).

Fadhil, D. N. (2018). A GIS-based analysis for selecting ground infrastructure locations for urban air mobility. Master’s Thesis, Technical University of Munich.

Fainstein, S. S. (2000). New directions in planning theory. Urban Affairs Review, 35(4), 451–478.

FAA. (2023), Heliport Design, Federal Aviation Administration, https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5390_2D_Heliports.pdf.

Flick, U. (2022). The SAGE handbook of qualitative Research Design. Sage.

Floreano, D., & Wood, R. J. (2015). Science, technology and the future of small autonomous drones. nature, 521(7553), 460-466.

Fricke, H., Förster, S., Brühl, R., Austen, W. J., & Thiel, C. (2021). Mid-air collisions with drones. In ATM Seminar.

Garrow, L. A., German, B. J., & Leonard, C. E. (2021). Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research. Transportation Research Part C: Emerging Technologies, 132. https://doi.org/10.1016/j.trc.2021.103377

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. Science, 357(6357), 1242-1244.

Geert te Boveldt , Imre Keseru and Cathy Macharis (2021). How can multi-criteria analysis support deliberative spatial planning? A critical review of methods and participatory frameworks, https://journals.sagepub.com/doi/pdf/10.1177/13563890211020334.

Genus, A., & Stirling, A. (2018). Collingridge and the dilemma of control: Towards responsible and accountable innovation. Research policy, 47(1), 61-69.

Glavić, D., Milenković, M., Nikolić, M., & Mladenović, M. N. (2018). Determining the number and location of winter road maintenance depots–a case study of the district road network in Serbia. Transportation planning and technology, 41(2), 138-153.

Glavić, D., Mladenović, M. N., & Milenković, M. (2019). Decision support framework for cycling investment prioritization. Journal of Advanced Transportation, 2019, 1-15.

Glavić, D., Mladenović, M. N., & Milenković, M. (2019). Decision Support Framework for Cycling Investment Prioritization. Journal of Advanced Transportation, 2019. https://doi.org/10.1155/2019/7871426

Goličnik, B., & Ward Thompson, C. (2010). Emerging relationships between design and use of urban park spaces. Landscape and Urban Planning, 94(1), 38–53. https://doi.org/10.1016/J.LANDURBPLAN.2009.07.016

Gorji-Bandpy, M., & Aly, A. M. (Eds.). (2021). *Aerodynamics*. IntechOpen.

Gorucu, S., & Ampatzidis, Y. (2021). Drone Injuries and Safety Recommendations. UF/IFAS Department of Agricultural and Biological Engineering, 2021(3).

Götten, F., Finger, D. F., Havermann, M., Braun, C., Marino, M., & Bil, C. (2021). Full configuration drag estimation of short-to-medium range fixed-wing UAVs and its impact on initial sizing optimization. CEAS Aeronautical Journal, 12(3), 589-603.

Grote, M., Oakey, A., Pilko, A., Smith, A., & Cherrett, T. (2023). The Scope for Integration into Multi-modal Urban Logistics Services. The Routledge Handbook of Urban Logistics, 72.

Grote, M., Pilko, A., Scanlan, J., Cherrett, T., Dickinson, J., Smith, A., ... & Marsden, G. (2021). Pathways to unsegregated sharing of airspace: views of the uncrewed aerial vehicle (UAV) industry. Drones, 5(4), 150.

Gultepe, I. (2023). A Review on Weather Impact on Aviation Operations: Visibility, Wind, Precipitation, Icing. Journal of Airline Operations and Aviation Management, 2(1), 1-44.

Gunder, M., Madanipour, A., & Watson, V. (Eds.). (2017). The Routledge handbook of planning theory. Routledge.

Habermas, J. (1984). The theory of communicative action: Jurgen Habermas; trans. By thomas McCarthy. Heinemann.

Hajar, S., Misnan, B., Zanudin1, K., Ngah2, I., Siti, &, & Misnan3, H. (2018). A Conceptual Paper: Collaborative Planning for Community Empowerment in Urban Planning. www.nzaar.com

Healey, P. (1997). Collaborative planning: Shaping places in fragmented societies. Macmillan Press Ltd.

Heffron, R. J., (2021). What is the “just transition”?. Achieving a just transition to a low-carbon economy, 9-19. Palgrave Macmillan, Cham.

Helsinki Regional Transport Authority, Liikkumistottumukset Helsinginseudulla 2018, https://hslfi.azureedge.net/globalassets/hsl/tutkimukset/liikkumistutkimus/

Helsinki, 2022, Getting around Helsinki, https://www.myhelsinki.fi/fi/info/liikkuminen-helsingiss%C3%A4#Kavellen, online; accessed 15 Mar 2022.

Hind, H., El Omri, A., Abghour, N., Moussaid, K., & Rida, M. (2018). Dynamic airspace configuration: Review and open research issues. In 2018 4th International Conference on Logistics Operations Management (GOL) (pp. 1-7). IEEE.

Hoekstra, J. M., Ellerbroek, J., Sunil, E., & Maas, J. (2018). Geovectoring: reducing traffic complexity to increase the capacity of uav airspace. In International conference for research in air transportation, Barcelona, Spain.

Hoffmann, G., Huang, H., Waslander, S., & Tomlin, C. (2007). Quadrotor helicopter flight dynamics and control: Theory and experiment. In AIAA guidance, navigation and control conference and exhibit (p. 6461).

Huang, C., Petrunin, I., & Tsourdos, A. (2022). Strategic Conflict Management for Performance-based Urban Air Mobility Operations with Multi-agent Reinforcement Learning. 2022

International Conference on Unmanned Aircraft Systems, ICUAS 2022, 442–451. https://doi.org/10.1109/ICUAS54217.2022.9836139

Interreg Green Mobility, CITYAM - preparing cities for sustainable urban air mobility, https://interreg-baltic.eu/project/cityam-interreg-baltic-sea-region-green-mobility/, accessed on 10 Jan 2024.

Keller, M., Hulínská, Š., & Kraus, J. (2021). Integration of UAM into cities–the public view. Transportation Research Procedia, 59, 137-143.

Kim, M. S., Hong, W. H., Lee, Y. H., & Baek, S. C. (2022). Selection of Take-Off and Landing Sites for Firefighter Drones in Urban Areas Using a GIS-Based Multi-Criteria Model. Drones, 6(12). https://doi.org/10.3390/drones6120412

Kim, N., & Yoon, Y. (2021). Regionalization for urban air mobility application with analyses of 3D urban space and geodemography in San Francisco and New York. Procedia Computer Science, 184, 388–395. https://doi.org/10.1016/j.procs.2021.03.049

Kim, S. H. (2020). Receding Horizon Scheduling of On-Demand Urban Air Mobility with Heterogeneous Fleet. IEEE Transactions on Aerospace and Electronic Systems, 56(4), 2751–2761. https://doi.org/10.1109/TAES.2019.2953417

Kista Science City, CITYAM - Regulations and integration of Urban Air Mobility in city planning, https://interreg-baltic.eu/wp-content/uploads/2023/12/D1.1-Regulations-and-integration-of-UAM-in-city-planning-CITYAM-final.pdf, accessed on 10 Jan 2024.

Kramar, V., Hinkula, H., Erkkilä, J., Kolli, T., Rauhala, A., & Röning, J. (2021). Overview of the Nordic Challenges for Unmanned Aircraft Systems. In 2021 30th Conference of Open Innovations Association FRUCT (pp. 86-98). IEEE.

Kramar, V., Nikolakopoulos, G., Röning, J., & Tomasello, F. (2021). Urban Air Mobility Overview—The European Landscape. In 2021 30th Conference of Open Innovations Association FRUCT (pp. 99-106). IEEE.

Kramar, V., Röning, J., Erkkilä, J., Hinkula, H., Kolli, T., & Rauhala, A. (2022). Unmanned aircraft systems and the nordic challenges. In New Developments and Environmental Applications of Drones: Proceedings of FinDrones 2020 (pp. 1-30). Springer International Publishing.

Kraus, J., Kleczatský, A., & Hulínská, Š. (2020). Social, technological, and systemic issues of spreading the use of drones. Transportation Research Procedia, 51, 3-10.

Kreimeier, M., Strathoff, P., Gottschalk, D., & Stumpf, E. (2018). Economic assessment of air mobility on-demand concepts. Journal of Air Transportation, 26(1), 23–36. https://doi.org/10.2514/1.D0058

Kyttä, M., Randrup, T., Sunding, A., Rossi, S., Harsia, E., Palomäki, J., & Kajosaari, A. (2023). Prioritizing participatory planning solutions: Developing place-based priority categories based on public participation GIS data. Landscape and Urban Planning, 239(August). https://doi.org/10.1016/j.landurbplan.2023.104868

Laatikainen, T. E., Hasanzadeh, K., & Kyttä, M. (2018). Capturing exposure in environmental health research: Challenges and opportunities of different activity space models. International Journal of Health Geographics, 17(1), 1–14. https://doi.org/10.1186/s12942-018-0149-5

Lacher, A., Degarmo, M., Maroney, D., Niles, R., Vempati, L., & Lascara, B. (2019). Urban Air Mobility Airspace Integration Concepts Operational Concepts and Exploration Appoaches.

Landing hub in Ireland, Ireland to open first first passenger and cargo vertiport in 2022, https://www.dronewatch.eu/ireland-to-open-first-first-passenger-and-cargo-vertiport-in-2022/, accessed on 21 Dec 2023.

Landing hub in The Netherlands, FIRST DRONE VERTIPORT IN THE NETHERLANDS PUT INTO USE, https://www.dronewatch.nl/2023/05/25/eerste-drone-vertiport-in-nederland-in-gebruik-genomen/, accessed on 21 Dec 2023.

Landing Hubs, Air-One Live: On location as world-first hub for flying taxis has lift-off, https://www.moodiedavittreport.com/air-one-live-on-location-as-world-first-hub-for-flying-taxis-has-lift-off/, accessed on 14 Nov 2023.

Lee, C., Bae, B., Lee, Y. L., & Pak, T. Y. (2023). Societal acceptance of urban air mobility based on the technology adoption framework. Technological Forecasting and Social Change, 196. https://doi.org/10.1016/j.techfore.2023.122807

Lee, H., Moolchandani, K. A., & Arneson, H. (2022). Demand Capacity Balancing at Vertiports for Initial Strategic Conflict Management of Urban Air Mobility Operations. AIAA/IEEE Digital Avionics Systems Conference - Proceedings, 2022-September. https://doi.org/10.1109/DASC55683.2022.9925753

Lewis, P. J. (1992). Rich picture building in the soft systems methodology. European Journal of Information Systems, 1, 351-360.

Long, Q., Ma, J., Jiang, F., & Webster, C. J. (2023). Demand analysis in urban air mobility: A literature review. Journal of Air Transport Management, 112. https://doi.org/10.1016/j.jairtraman.2023.102436

Lyons, M., Brandis, K., Callaghan, C., McCann, J., Mills, C., Ryall, S., & Kingsford, R. (2018). Bird interactions with drones, from individuals to large colonies. Australian Field Ornithology, 35, 51-56.

Macharis, C., Turcksin, L., & Lebeau, K. (2012). Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use. Decision Support Systems, 54(1), 610-620.

MaptureDrone, MaptureDrone in a box' prototype automated take-off and landing demonstration, https://www.suasnews.com/2018/09/mapturedrone-in-a-box-prototype-automated-take-off-and-landing-demonstration/, accessed on 14 Nov 2023.

Mavraj, G., Eltgen, J., Fraske, T., Swaid, M., Berling, J., Röntgen, O., ... & Schulz, D. (2022). A systematic review of ground-based infrastructure for the innovative urban air mobility. Transactions on Aerospace Research, 2022(4), 1-17.

Mäntysalo, R., Westin, M., & Mattila, H. (2023). Public Planner–A Deliberative Authority. Planning Theory & Practice, 24(1), 11-29.

Merkert, R., & Bushell, J. (2020). Managing the drone revolution: A systematic literature review into the current use of airborne drones and future strategic directions for their effective control. Journal of air transport management, 89, 101929.

Milenković, M., Glavić, D., & Mladenović, M. N. (2018). Decision-support framework for selecting the optimal road toll collection system. Journal of Advanced Transportation, 2018.

Mittal, H., Sharma, A., & Gairola, A. (2018). A review on the study of urban wind at the pedestrian level around buildings. Journal of Building Engineering, 18, 154-163.

Mladenović, M. N., (2018). Embracing the complexity and justice of mobilities automation. Blogged Environment.

Mladenović, M. N. (2019). How should we drive self-driving vehicles? Anticipation and collective imagination in planning mobility futures. The Governance of Smart Transportation Systems: Towards New Organizational Structures for the Development of Shared, Automated, Electric and Integrated Mobility, 103-122.

Mladenović, M. N. (2020). Mobility justice: the politics of movement in an age of extremes: by M. Sheller, Transport Reviews, 40 (1), 117-120.

Mladenovic, M. (2021). Data is not the new oil, but could be water or sunlight? From ethical to moral pathways for urban data management. In Proceedings of the 17th International Conference on Computational Urban Planning and Urban Management (CUPUM), Espoo, Finland (pp. 9-11).

Mladenović, M. (2022). Learning to plan? Knowledge framework and plan quality assessment dimensions for developing transport planning practice in South-East Europe. Journal of Road and Traffic Engineering, 68(1), 1-10.

Mladenović, M. N., & Abbas, M. M. (2013). Improved decision-support making for selecting future traffic signal controllers using expert-knowledge acquisition. In 16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013) (pp. 732-735). IEEE

Mladenović, M. N., & Haavisto, N. (2021). Interpretative flexibility and conflicts in the emergence of Mobility as a Service: Finnish public sector actor perspectives. Case Studies on Transport Policy, 9(2), 851-859.

Mladenović, M. N., & Stead, D. (2021). Emerging mobility technologies and transitions of urban space allocation in a Nordic governance context. In Urban form and accessibility (pp. 63-82). Elsevier.

Mladenović, M. N., Kyttä, M., Forss, K., & Kahila-Tani, M. (2021). 16. What could transport planning practice learn from public participation GIS method?. Transport in human scale cities, 202.

Mladenović, M. N., Leviäkangas, P., Roncoli, C., & Hänninen, S. (2020). Rethinking transport – towards clean and inclusive mobility. European Transport Research Review, 12, 1-3.

Mladenovic, M. N., Mangaroska, K., & Abbas, M. M. (2017). Decision support system for planning traffic operations assets. Journal of Infrastructure Systems, 23(3), 05017001.

Mladenović, M. N., Stead, D., Milakis, D., Pangbourne, K., & Givoni, M. (2020). Governance cultures and sociotechnical imaginaries of self-driving vehicle technology: Comparative analysis of Finland, UK and Germany. In Advances in transport policy and planning (Vol. 5, pp. 235-262). Academic Press.

Mladenović, M. N., Toivonen, T., Willberg, E., & Geurs, K. T. (Eds.). (2021). Transport in human scale cities. Edward Elgar Publishing.

Mladenović, M., Dibaj, S., & Lopatnikov, D. (2022). Evaluation of electric scooter deployment in the City of Helsinki: A perspective on sociotechnical transitions dynamics and adaptive governance. Aalto University.

Murça, M. C. R. (2021). Identification and prediction of urban airspace availability for emerging air mobility operations. Transportation Research Part C: Emerging Technologies, 131. https://doi.org/10.1016/j.trc.2021.103274

Nash, E., Cope, A., James, P., & Parker, D. (2005). Cycle network planning: Towards a holistic approach using temporal topology. In Transportation Planning and Technology (Vol. 28, Issue 4, pp. 251–271). https://doi.org/10.1080/03081060500247739

Olin, J. J., & Mladenović, M. N. (2022). Imaginaries of road transport automation in Finnish governance culture—a critical discourse analysis. Sustainability, 14(3), 1437.

Omran A.A. (2008), Integration of Remote Sensing, Geophysics and Gis to Evaluate Groundwater Potentiality – A Case Study In Sohag Region, Egypt, The 3rd International Conference on Water Resources and Arid Environments and the 1st Arab Water Forum, Riyadh, Saudi Arabia, p. 17.

Oskari Biomass Atlas, https://oskari.org/gallery/biomass_atlas, accessed on 10 Jan 2024.

Öz, E., Heikkilä, E., & Tiusanen, R. (2022). Development of an Organisational Certification Process for Specific Category Drone Operations. Drones, 6(10), 278.

Paine, G. (2019). Drones to deliver incessant buzzing noise, and packages. The Conversation, 3.

Patrinopoulou, N., Daramouskas, I., Lappas, V., Kostopoulos, V., Veytia, A. M., Badea, C. A., ... & Sedov, L. (2022). Metropolis II: Investigating the Future Shape of Air Traffic Control in Highly Dense Urban Airspace. In 2022 30th Mediterranean Conference on Control and Automation (MED) (pp. 649-655). IEEE.

Pelzer, P. (2017). Usefulness of planning support systems: A conceptual framework and an empirical illustration. Transportation research part A: Policy and practice, 104, 84-95.

Pelzer, P., Geertman, S., & van der Heijden, R. (2015). Knowledge in communicative planning practice: A different perspective for planning support systems. Environment and Planning B: Planning and Design, 42(4), 638-651.

Pelzer, P., Geertman, S., van der Heijden, R., & Rouwette, E. (2014). The added value of planning support systems: A practitioner's perspective. Computers, environment and urban systems, 48, 16-27.

Pöysäri, A. (2023). Customer value of drones. MSc thesis. Aalto University.

Pozzi, C., Paccard, B., Bermond, F., & Beillas, P. (2022). Fracture sensitivity of a human head model in surrogate drone impacts. In IRCOBI 2022 conference, International Research Council on Biomechanics of Injury (Vol. 2022, p. 2p). IRCOBI.

Primatesta, S., Rizzo, A., & la Cour-Harbo, A. (2020). Ground risk map for unmanned aircraft in urban environments. Journal of Intelligent & Robotic Systems, 97, 489-509.

Qinshuang Wei, Gustav Nilsson, and Samuel Coogan (2021), Scheduling of Urban Air Mobility Services with Limited Landing Capacity and Uncertain Travel Times, American Control Conference (ACC). (2021). IEEE.

R. Woods, J. Masthoff, A comparison of car driving, public transport and cycling experiences in three European cities, Transportation research part A: policy and practice (2017).

Raghunatha, A., Thollander, P., & Barthel, S. (2023). Addressing the emergence of drones–A policy development framework for regional drone transportation systems. Transportation Research Interdisciplinary Perspectives, 18, 100795.

Rajendran, S., & Harper, A. (2021). Simulation-based algorithm for determining best package delivery alternatives under three criteria: Time, cost and sustainability. Transportation Research Interdisciplinary Perspectives, 12. https://doi.org/10.1016/j.trip.2021.100484

Reja, R. K., Amin, R., Tasneem, Z., Ali, M. F., Islam, M. R., Saha, D. K., ... & Das, S. K. (2022). A review of the evaluation of urban wind resources: Challenges and perspectives. Energy and Buildings, 257, 111781.

Rhodes, R.A.W., 2007. Understanding Governance: Ten Years On. Organization Studies 28, 1243–1264.

Rikalovic, A. M., & Cocić, I. (2014). GIS based multi-criteria decision analysis for industrial site selection: The state of the art. Journal of Applied Engineering Science, 12(3), 197-206.

Ritsema Van Eck, J. R., & De Jong, T. (1999). Accessibility analysis and spatial competition effects in the context of GIS-supported service location planning. Computers, Environment and Urban Systems, 23(2), 75–89. https://doi.org/10.1016/S0198-9715(99)00016-2

Robinson, J. N., Sokollek, M. D., Justin, C. Y., & Mavris, D. N. (2018). Development of a methodology for parametric analysis of stol airpark geo-density. 2018 Aviation Technology, Integration, and Operations Conference. https://doi.org/10.2514/6.2018-3054

Rothfeld, R., & Moeckel, R. (2018). A GIS-based Analysis for Selecting Ground Infrastructure Locations for Urban Air Mobility. https://doi.org/10.13140/RG.2.2.36386.15040

Rotolo, D., Hicks, D., & Martin, B. R. (2015). What is an emerging technology?. Research policy, 44(10), 1827-1843.

Roy, S., Kotwicz Herniczek, M. T., Leonard, C., Jha, A., Wang, N. J., German, B. J., & Garrow, L. A. (2020). A multi-commodity network flow approach for optimal flight scheduling of an airport shuttle air taxi service. AIAA Scitech 2020 Forum, 1 PartF. https://doi.org/10.2514/6.2020-0975

Rumble Tools, Worlds First Skynest Augmented Reality System, https://www.rumbletools.com/#rbkb, , accessed on 21 Dec 2023.

Rybarczyk, G., & Wu, C. (2010). Bicycle facility planning using GIS and multi-criteria decision analysis. Applied Geography, 30(2), 282–293. https://doi.org/10.1016/J.APGEOG.2009.08.005

Ryghaug, M., Subotički, I., Smeds, E., von Wirth, T., Scherrer, A., Foulds, C., ... & Wentland, A. (2023). A Social Sciences and Humanities research agenda for transport and mobility in Europe: key themes and 100 research questions. Transport Reviews, 43(4), 755-779.

Sager, T. (2017). Communicative planning. In The Routledge handbook of planning theory (pp. 93-104). Routledge.

Schäffer, B., Pieren, R., Heutschi, K., Wunderli, J. M., & Becker, S. (2021). Drone noise emission characteristics and noise effects on humans—a systematic review. International journal of environmental research and public health, 18(11), 5940.

Schindler, M., Dionisio, R., & Kingham, S. (2020). Challenges of Spatial Decision-Support Tools in Urban Planning : Lessons from New Zealand ' s Cities. 146(2), 1–14. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000575

Schweiger, K., & Preis, L. (2022). Urban air mobility: Systematic review of scientific publications and regulations for vertiport design and operations. Drones, 6(7), 179.

Scott, D. M., & He, S. Y. (2012). Modeling constrained destination choice for shopping: a GIS-based, time-geographic approach. Journal of Transport Geography, 23, 60–71. https://doi.org/10.1016/J.JTRANGEO.2012.03.021

Semkin, V., Haarla, J., Pairon, T., Slezak, C., Rangan, S., Viikari, V., & Oestges, C. (2020). Analyzing radar cross section signatures of diverse drone models at mmWave frequencies. IEEE access, 8, 48958-48969.

Shafiee, M., Zhou, Z., Mei, L., Dinmohammadi, F., Karama, J., & Flynn, D. (2021). Unmanned aerial drones for inspection of offshore wind turbines: A mission-critical failure analysis. Robotics, 10(1), 26.

Shafique, A., Mehmood, A., & Elhadef, M. (2021). Survey of security protocols and vulnerabilities in unmanned aerial vehicles. IEEE Access, 9, 46927-46948.

Shin, H., Lee, T., & Lee, H. R. (2022). Skyport location problem for urban air mobility system. Computers and Operations Research, 138. https://doi.org/10.1016/j.cor.2021.105611

Slabbekoorn, H., & den Boer-Visser, A. (2006). Cities change the songs of birds. Current biology, 16(23), 2326-2331.

Snatcher, Double-Sided PU Leather Waterproof Hexagonal Drone Landing Pad, https://snatcher.co.za/sunnylife-ty-tjp08-for-dji-mavic-3-mini-se-air-2s-double-sided-pu-leather-waterproof-hexagonal-drone-landing-pad/, accessed on 21 Dec 2023.

Snyder, S. A., Whitmore, J. H., Schneider, I. E., & Becker, D. R. (2008). Ecological criteria, participant preferences and location models: A GIS approach toward ATV trail planning. Applied Geography, 28(4), 248–258. https://doi.org/10.1016/J.APGEOG.2008.07.001

So, J. (Jason), Chae, M., Hong, J., Youm, J., Kim, S. H., & Kim, J. (2023). Integrated Mobility Hub Location Selection for Sustainable Urban Mobility. Sustainable Cities and Society, 99, 104950. https://doi.org/10.1016/j.scs.2023.104950

Stilgoe, J., & Mladenović, M. (2022). The politics of autonomous vehicles. Humanities and Social Sciences Communications, 9(1), 1-6.

Straubinger, A., Rothfeld, R., Shamiyeh, M., Büchter, K. D., Kaiser, J., & Plötner, K. O. (2020). An overview of current research and developments in urban air mobility – Setting the scene for UAM introduction. Journal of Air Transport Management, 87, 101852. https://doi.org/10.1016/J.JAIRTRAMAN.2020.101852

Straubinger, A., Verhoef, E. T., & de Groot, H. L. F. (2021). Will urban air mobility fly? The efficiency and distributional impacts of UAM in different urban spatial structures. Transportation Research Part C: Emerging Technologies, 127. https://doi.org/10.1016/j.trc.2021.103124

Streamlit for Geospatial Applications, https://huggingface.co/spaces/giswqs/Streamlit, accessed on 10 Jan 2024.

Suárez-Vega, R., Santos-Peñate, D. R., & Dorta-González, P. (2012). Location models and GIS tools for retail site location. Applied Geography, 35(1–2), 12–22. https://doi.org/10.1016/J.APGEOG.2012.04.009

Tan, L. K. L., Lim, B. C., Park, G., Low, K. H., & Yeo, V. C. S. (2021). Public acceptance of drone applications in a highly urbanized environment. Technology in Society, 64, 101462.

Task Committee on Urban Aerodynamics of the Technical Council on Wind Engineering of ASCE. (2011). Urban Aerodynamics: Wind Engineering for Urban Planners and Designers. American Society of Civil Engineers.

Te Boveldt, G., Keseru, I., & Macharis, C. (2021). How can multi-criteria analysis support deliberative spatial planning? A critical review of methods and participatory frameworks. Evaluation, 27(4), 492-509.

Thomas, K., & Granberg, T. A. (2023). Quantifying Visual Pollution from Urban Air Mobility. Drones, 7(6), 396.

Tiusanen, R., Heikkilä, E., Välisalo, T., & Öz, E. (2022). Identification of Emerging Safety and Security Risks in Drone Operations at Work Sites. In World Congress on Engineering Asset Management (pp. 499-507). Cham: Springer International Publishing.

Tojal, M., Hesselink, H., Fransoy, A., Ventas, E., Gordo, V., & Xu, Y. (2022). Analysis of the definition of Urban Air Mobility - How its attributes impact on the development of the concept. Transportation Research Procedia, 59, 3–13. https://doi.org/10.1016/j.trpro.2021.11.091

Torija, A. J., & Clark, C. (2021). A psychoacoustic approach to building knowledge about human response to noise of unmanned aerial vehicles. International Journal of Environmental Research and Public Health, 18(2), 682.

Tra, M., Sunil, E., Ellerbroek, J., & Hoekstra, J. (2017). Modeling the intrinsic safety of unstructured and layered airspace designs. In Proceedings of the Twelfth USA/Europe Air Traffic Management Research and Development Seminar, Seattle, WA, USA (pp. 27-30).

Triple Access Planning, Discovering the 'sweet spot' of Triple Access Planning, https://www.tapforuncertainty.eu/2021/05/20/discovering-the-sweet-spot-of-triple-access-planning/, accessed on 10 Jan 2024.

UAV NEWS, Drone-in-a-Box Solutions: What's Out There? https://www.commercialuavnews.com/surveying/drone-in-a-box-solutions-what-s-out-there, accessed on 14 Nov 2023.

UPS, This UPS Truck Can Deploy an Autonomous Roof-Docked Delivery Drone, https://www.core77.com/posts/69253/This-UPS-Truck-Can-Deploy-an-Autonomous-Roof-Docked-Delivery-Drone, accessed on 21 Dec 2023.

Van de Poel, I. (2015). The problem of many hands. In Moral responsibility and the problem of many hands (pp. 62-104). Routledge.

Valqari, Company Says Its Drone Delivery Stations Will Be Essential For Last-Mile Delivery, https://insideunmannedsystems.com/company-says-its-drone-delivery-stations-will-be-essential-for-last-mile-delivery/, accessed on 21 Dec 2023.

Vascik, P. D., & John Hansman, R. (2017). Evaluation of key operational constraints affecting on demand mobility for aviation in the Los Angeles basin: Ground infrastructure, air traffic control and noise. 17th AIAA Aviation Technology, Integration, and Operations Conference, 2017. https://doi.org/10.2514/6.2017-3084

Vascik, P. D., John Hansman, R., & Dunn, N. S. (2018). Analysis of urban air mobility operational constraints. Journal of Air Transportation, 26(4), 133–146. https://doi.org/10.2514/1.D0120

Verma, A., Dunn, J., Tirachini, A., Agaton, C. B., Hsieh, I. Y. L., Mayyas, A., ... & Mladenović, M. N. (2023). Driving a sustainable road transportation transformation. One Earth, 6(1), 3-6.

Wang, J., Jiang, C., Han, Z., Ren, Y., Maunder, R. G., & Hanzo, L. (2017). Taking drones to the next level: Cooperative distributed unmanned-aerial-vehicular networks for small and mini drones. Ieee vehIcular technology magazIne, 12(3), 73-82.

Wang, L., Deng, X., Gui, J., Jiang, P., Zeng, F., & Wan, S. (2023). A review of Urban Air Mobility-enabled Intelligent Transportation Systems: Mechanisms, applications and challenges. In Journal of Systems Architecture (Vol. 141). Elsevier B.V. https://doi.org/10.1016/j.sysarc.2023.102902

Wang, N., Mutzner, N., & Blanchet, K. (2023). Societal acceptance of urban drones: A scoping literature review. Technology in Society, 102377.

Wang, Y., & Zou, Z. (2010). Spatial Decision Support System for Urban Planning : Case Study of Harbin City in China. 136(June), 147–153. https://doi.org/10.1061/(ASCE)0733-9488(2010)136

Watkins, S., Burry, J., Mohamed, A., Marino, M., Prudden, S., Fisher, A., ... & Clothier, R. (2020). Ten questions concerning the use of drones in urban environments. Building and Environment, 167, 106458.

Willey, L. C., & Salmon, J. L. (2021). A method for urban air mobility network design using hub location and subgraph isomorphism. Transportation Research Part C: Emerging Technologies, 125. https://doi.org/10.1016/j.trc.2021.102997

Willson, R. (2001). Assessing communicative rationality as a transportation planning paradigm. Transportation, 28, 1-31.

Wu, Q., (2021). Leafmap: A Python package for interactive mapping and geospatial analysis with minimal coding in a Jupyter environment.Journal of Open Source Software, 6(63), 3414. https://doi.org/10.21105/joss.03414

Xie, Y., Gardi, A., Sabatini, R., & Liang, A. (2022). Hybrid AI-based Dynamic Re-routing Method for Dense Low-Altitude Air Traffic Operations. AIAA/IEEE Digital Avionics Systems Conference - Proceedings, 2022-September. https://doi.org/10.1109/DASC55683.2022.9925777

Yaacoub, J. P., Noura, H., Salman, O., & Chehab, A. (2020). Security analysis of drones systems: Attacks, limitations, and recommendations. Internet of Things, 11, 100218.

Yeh, A. G. O., & Chow, M. H. (1996). An integrated GIS and location-allocation approach to public facilities planning—An example of open space planning. Computers, Environment and Urban Systems, 20(4–5), 339–350. https://doi.org/10.1016/S0198-9715(97)00010-0

Appendix I - List of individual interviewees

- Christina Suomi, urban planner, City of Helsinki
- Heikki Palomäki, urban planner, City of Helsinki
- Hanna Käyhkö, urban planner, City of Helsinki
- Niklas Aalto-Setälä, urban planner, City of Helsinki
- Tiia Vilén, urban planner, City of Helsinki
- Hanna Tiira, urban planner, City of Helsinki
- Marko Pääjärvi, urban planner, City of Helsinki
- Juha Niemelä, GIS specialist, City of Helsinki
- Juha Korhonen, environmental expert, City of Helsinki
- Janne Rautasuo, emergency service expert, City of Helsinki
- Johanna Löfblom, urban planner, City of Stockholm
- Kristoffer Lundgren Thånell, urban planner, City of Stockholm
- Gustav Luther, urban planner, City of Stockholm
- Mingus Wass, GIS specialist, City of Stockholm
- Anton Anander, GIS specialist, City of Stockholm
- Stefan Mundt, urban planner, City of Hamburg
- Tony Schroter, urban planner, City of Hamburg
- David Schleehahn, GIS specialist, City of Hamburg
- Jannis von Lüde, drone expert, City of Hamburg
- Juka Alender, GIS and Visualization expert, University of Helsinki
- Jukka Pappinen, drone expert, FinnHEMS
- Antioni Trani, drone expert, Virginia Tech
- Fedja Netjasov, drone expert, University of Belgrade
- Aapo Lumikoivu, drone expert, Aalto University
- Katja Paasikivi, drone expert, Aalto University
- Olli Ahtola, drone expert, The Finnish Transport and Communications Agency
- Mika Saalasti, drone expert, The Finnish Transport and Communications Agency
- Jokela Petteri, drone expert, The Finnish Transport and Communications Agency

Appendix II - List of participating organisations in workshops

Workshop 1: Helsinki

- City of Gdansk
- City of Helsinki
- City of Riga
- City of Stockholm
- City of Tartu
- Estonian aviation academy
- Forum Virium Helsinki
- Hamburg Aviation Cluster
- Hamburg Port Authority
- Kista Science City
- Riga Technical University

Workshop 2: Tartu

- City of Gdansk
- City of Riga
- City of Stockholm
- City of Tartu
- Estonian aviation academy
- Forum Virium Helsinki
- Hamburg Aviation Cluster
- Kista Science City
- Riga Technical University
- Tallinn University of Technology

Workshop 3: Stockholm

- City of Gdansk
- City of Riga
- City of Stockholm
- City of Tartu
- Forum Virium Helsinki
- Hamburg Aviation Cluster
- Hamburg Port Authority
- Kista Science City
- Riga Technical University
- Swedish Transport Agency
- Tallinn University of Technology

Workshop 4: Hamburg

- City of Gdansk
- City of Riga
- City of Stockholm
- City of Tartu
- Estonian aviation academy
- Forum Virium Helsinki
- Hamburg Aviation
- Hamburg Port Authority
- Kista Science City
- Port of Helsinki
- Riga Technical University
- Tallinn University of Technology

Appendix III - GIS data examples

Helsinki

- Environmental noise
- Forest
- Urban parks
- National conservation area
- Nature protected areas by the Government
- Nature protected areas by the private owners
- Forest classification
- High biodiversity forest
- Valuable landscape
- Population grid
- National landscape division
- Bike access parking
- Car parking
- Connection parking areas
- Traffic noise zones
- Traffic risk zones
- HSL routes
- HSL area
- Passenger boarding on public transport
- Cycle lanes
- Bicycle counts
- Park and ride
- Traffic lanes
- Park and ride
- Regional land use plan
- Registry on industrial site

Stockholm

- Building and building structures
- 3D buildings
- City map
- Base map
- District reference areas
- District boundaries
- Carpooling points
- Noise map
- Bicycle parking
- Bicycle station
- Traffic flow for pedestrian
- Annual average traffic volumes
- Cycle paths
- Land grant
- Environmental zones
- Parking data
- Cycle pump location
- Electric scooter space

Hamburg

- District division map
- Road and path network
- Resident parking areas
- Traffic situation maps
- Public transport routes
- Public transport routes
- Main roads
- 3D street cadastral map
- Traffic zones
- Nature reserve
- Bird conservation areas
- Recreation forest