A Collaborative GIS for Planning of Urban Drone Launch and Landing Site Locations

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Abstract

The recent emergence of urban air mobility (UAM) is transforming urban landscape, with studies predicting its increasing role in the coming decades. This emergence of UAM calls for developing decision-support tools for planning of launch and landing sites (LLS) in constrained and complex urban environments. Such decision-support tools must be useful and usable in the context where planning processes related to this emerging technology are also emerging themselves. In practice, this means carefully designing the functionality of the tool itself according to the current and future user needs, as well as clarifying the roles and responsibilities of different actors in the planning process. This research presents the development of a geospatial decision-support tool for identifying the potential urban UAM LLS for drones with a diameter of up to 3 meters. In addition, this study presents the preliminary evaluation of this decision-support tool with a set of potential users, including urban planners from the cities of Helsinki (Finland), Stockholm (Sweden) and Hamburg (Germany).

1. Introduction

1.1 The emergence of Urban Air Mobility

Recent years have seen an emergence of diverse Urban Air Mobility (UAM) technologies. While UAM encompasses both drones and piloted electrical Vertical Take-off and Landing aircraft, this work focuses on uncrewed systems, commonly referred to as drones (Grote et al., 2021). This recent technological development of drones has partly been due to the convergence of several technical factors (Cohen et al., 2021). 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 communication, which has enabled improvements in collision avoidance and navigation tasks while flying. The convergence of these UAM technologies together with other digital technologies (e.g., sensing, communication, pricing) being deployed, enables drones to operate in (semi-)autonomous manner, in the conditions referred to as Beyond Visual Line of Sight. 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).

1.2 The needs for decision-support in urban air mobility

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). An LLS is defined as the area and infrastructure capable of providing support for the landing and take-off of a drone for urban operations. 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 multiple demands for urban land use, such as different emerging urban mobility technologies or different residential or organisational needs.
- There are multiple goals that land use and its change have 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.

Besides those constraints listed above, the need for decision-support in planning the LLS locations in urban areas relates to two important decision aspects (Mladenović et al., 2024). The first aspect is the plethora of anticipated (un)desired impacts and the non-linear nature of drones as an emerging technology. Here, decision making faces a double-bind problem called the Collingridge dilemma (Mladenović et al., 2022). 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.

The second decision aspect pertains to governance, as long-term interactions of different actors guided by a somewhat stabilised system of rules (Olin & Mladenović, 2024, 2025). As already recognized in the drone operations certification processes (Öz et al., 2022), emerging technologies often face the so-called "problem of many hands" (Mladenović, 2024). Similar kinds of complex multi-actor settings emerge also due to increasing activity in limited spaces of abundant stakeholders, another example being spatial planning (Bonnevie et al., 2023; Eräranta & Mladenović, 2021). 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 (Te Brömmelstroet et al., 2022). Beyond the many hands problem, and similar to other emerging urban mobility technologies (Mladenović & Haavisto, 2021; Stilgoe & Mladenović, 2022), decisions related to drones face a so-called institutional void, defined as missing rules, processes and actors. A clear example of this void is the fact that low altitude urban space sometimes is not owned or governed by cities themselves who have to provide the land for LLS. Moreover, 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.

1.3 Research aim

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. In order to enable that capacity development, there is a need for developing responsible and accountable decision-support tools (DST) that would aid with planning LLS locations in urban areas. This study aims to fill this gap by presenting a development of such a tool, complemented by the expert evaluation from a set of potential users, including urban planners from the cities of Helsinki (Finland), Stockholm (Sweden) and Hamburg (Germany). The scope focuses on drones that have diameter smaller than 3 meters, and are only intended for freight transport, thus leaving outside of the scope the location problem for larger hubs and use cases of passenger transport.

2. Literature Review

A number of previous studies have investigated the operational planning challenges of UAM (e.g., Kim, 2020; Long et al., 2023). 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. In contrast to operational planning, a wide range of LLS infrastructure is available and used based on the operational requirements (Mavraj et al., 2022; Schweiger & Preis, 2022). The LLS spatial 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. For the purpose of this research, the focus is on LLS areas approximately 10 times 10 meters in size, as an area to be accounted for in the location decision supported by a DST. Previous research that has focused on LLS location choice problem has used GIS and multi-criteria decision-making techniques (Ayhan et al., 2019; Fadhil et al., 2019; Kim et al., 2022; So et al., 2023). These tools have shown the potential of DSTs for prioritization and selection of LLS in urban and peri-urban environments. However, some of these tools requires a plethora of data, including such difficult to obtain data as demand. In contrast, some tools are not explicitly taking into account the need to have trade-offs among decision criteria. Thus, there is still a gap in having a responsible and accountable DST for LLS location choice problem, which would take into account the advanced decision-support techniques but also allow its use in practical contexts.

3. Collaborative GIS for LLS Planning

3.1 Decision-Support Requirements

For developing any DST, it is important to take into account both the usefulness and usability aspects. 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 (Pelzer et al., 2014). At the level of individuals, the added value is in learning about the planning object and other stakeholders. At the group level, the added value is in improved interaction and cooperation among stakeholders through improved communication, consensus and efficiency. 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. The tool should:

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

On the usability side, 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.

At the centre of the DST development is a communicative planning approach, which depends on changing the role of a planner (Sager, 2017). The shift in the role is one away from a traditional bureaucrat/technocrat, overseeing a conventional hierarchical, controlled and administrative planning process towards one that emphasizes facilitating an open dialogue and consensus-building among stakeholders to reach mutually agreeable outcomes. In order to operationalize the communicative planning approach, our DST development is based on the concept of Collaborative GIS (CGIS; Balram & Dragicevic, 2006) and builds upon the previous implementations and evaluations by Kettunen et al. in the MSP scene (2020). Figure 1 depicts the concept where diverse stakeholders are interacting to identify and assess suitable locations for drone launches and landings in a collaborative workshop setting.

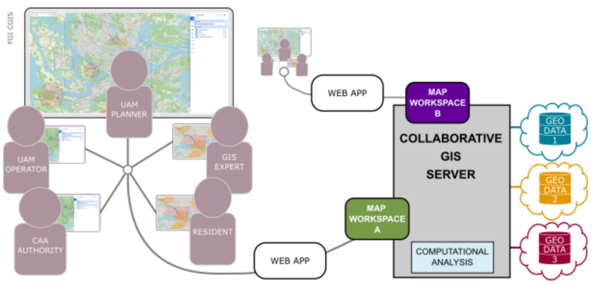

Figure 1. Interaction between the tool and the diverse stakeholders of the UAM LLS planning process as users in a collaborative GIS approach.

Besides the technical setup itself, in order to enable communicative planning, DST should be based on a multi-criteria analysis (MCA), a quantitative method suitable for enhancing discussions among key actors (Te Boveldt et al., 2021). In addition, MCA methods enable a collaborative discussion setting by being flexible and scalable in the use of spatial datasets (e.g., transport infrastructure, airspace restrictions). MCA methods are often used in transport planning (Glavic et al., 2019; Milenković et al., 2018; Mladenovic et al., 2017). In particular, a weighted overlay is a method used for implementing the MCA framework, using GIS techniques depending on several thematic GIS layers. A visual depiction of combined layers in GIS is represented in the following Figure 2. Weighted overlay models are used for having a common measurement scale of values to diverse and unlike inputs in order to create a combined analysis. Furthermore, the analysis factors may not be equally important but can have different weights. Therefore, each individual raster cell is reclassified into units of suitability, and then multiplied by a weight to assign relative importance to each.

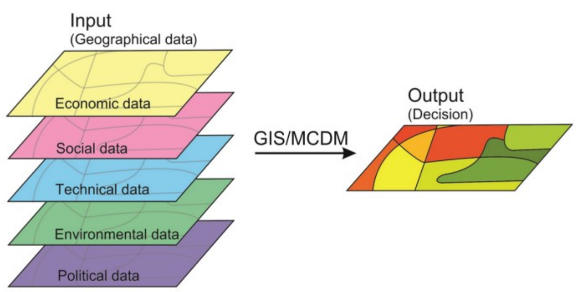

Figure 2. Spatial multi-criteria analysis based on GIS layers (Rikalovic & Cocić, 2014)

3.2 Planning Process Outline

Phasing the planning process is critical for a comprehensive and well-executed UAM LLS plan. Following are suggestions for five phases in a specific planning process. Here, we underline that UAM planner is considered to be a deliberative authority, within the modern concept of democracy. 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. Generally speaking, it is recommended not to always follow those phases in a linear order, and some iterations of the same phases might be helpful, depending on the context. For example, revisiting the location choice and involving public participation reflects a thoughtful and adaptable approach to the responsible planning process.

Based on the assumptions about the planning process phases as well as planning process actors, the Figure 3 summarises the suggestions in a conceptual manner. On the lower 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 upper side of the figure emphasises a procedural nature of activities over time. To underline, we assume that reflectivity and keeping track of both actors and activities over time is an essential responsibility of the UAM planner.

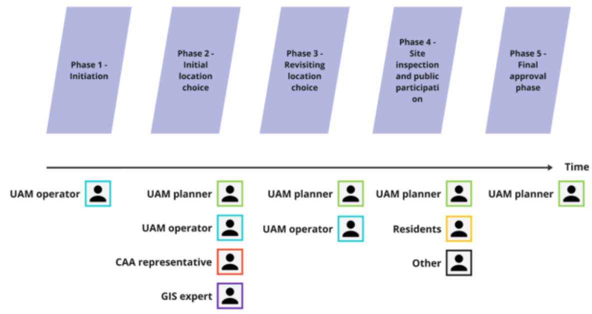

Figure 3. The conceptualization of phases and stakeholders in the LLS location planning process.

Phase 1 – Initiation: In this phase (suggested as mandatory), 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 Civil Aviation Authority (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 in this phase is crucial to align stakeholders and set the foundation for subsequent phases.

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Phase 2 - Initial location choice: During the initial location choice phase (suggested as mandatory), 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. In addition, 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 final decision, especially if it is in alignment with some other municipal plan or regulation that already has decisions about suggested location sites.

Phase 3 - Revisiting location choice: As new data emerges or circumstances evolve, this phase (suggested as optional) 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. Similarly as before, 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 planning process.

Phase 4 - Site inspection and public participation: During site inspection (suggested as optional), 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: In the final approval phase (suggested as mandatory), 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.

3.3 Stakeholders of LLS planning process

In the following, we provide an overview of the roles and responsibilities of each stakeholder involved in UAM planning and operation, as anticipated. The ultimate number of stakeholders may vary depending on the context. 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 allocated to the UAM Planner.

UAM Planner (Municipal or Regional): 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. Facilitate collaborative groupwork sessions. Could be a cross-departmental position, in contrast to existing similar roles in transport or planning departments.

UAM Operator (City-Owned or Commercial): 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 LLS areas. Ensure compliance with aviation regulations, safety standards, and community expectations. Implement marketing strategies to build trust and promote UAM services to residents and visitors.

GIS Expert in a Municipal Organization: Utilise standard GIS tools to analyse spatial data and support UAM planning. Provide mapping and spatial analysis to identify suitable locations for UAM infrastructure. Technically prepare data, workspaces, and analyses for collaborative groupwork sessions. Collaborate with planners and operators to integrate GIS data into decision-making processes.

Civil Aviation Authority Representative: 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.

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

Other Stakeholders: Land/Property Owners provide input on land use and property development related to UAM infrastructure and 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 experts provide input for environmentally responsible UAM practices and assess potential environmental impacts. Resident Associations represent the collective interests and concerns of residents, facilitating communication between residents and UAM planners/operators.

3.4 CGIS Features

The CGIS DST can be used by multiple people working together to discuss, plan, and decide the LLS locations. The features developed are thus focused on enabling such communicative planning setting, while resulting in a visual-numeric output highlighting potential landing sites within the area of interest. The example of the visual-numeric output created using the CGIS DST is depicted in the Figure 4. Overall, the key features of the CGIS are:

1. Map user interface
2. Workspace manager
3. Data manager
4. Layer manager
5. Map drawing tools
6. Weighted multi-layer analysis tool

The tool was implemented in the server environment of the Center for Scientific Computing (CSC). The CGIS platform has an extensive backend (Layman, 2025) offering user management, user access control, geospatial data management, QGIS integration via plugin, and an in-memory cache, a web-map UI (HSLayers-NG, 2025), and an analysis service.

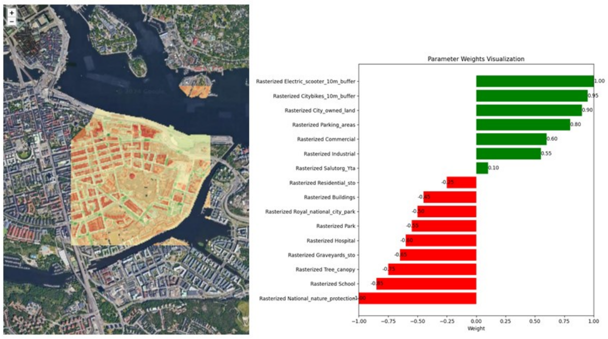

Figure 4. A Traffic Light Map for Drone Landing Sites in Stockholm.

4. Expert Tool Evaluation

The evaluation of the tool was conducted in a workshop setting, where the tool was introduced and tested, followed by a questionnaire for workshop participants. First, the evaluation considered the usability of the tool in terms of such aspects as data management or user interface. Second, the evaluation focused on the usefulness of such a tool in a wider communicative planning process. Usefulness and usability have been evaluated using the five-point Likert scale. Lastly, the expert evaluation provided suggestions for improvements in response to open-ended questions. The urban planners from Helsinki, Hamburg and Stockholm participated in the workshop to test the CGIS tool. These cities have been selected as those with recent or ongoing UAM experiments, where LLS location decisions already had to be done without any DST use.

4.1 Usefulness feedback

Overall, the tool has received positively skewed feedback regarding usefulness (Table 1). On the one hand, the tool has been deemed effective in helping users understand the planning process and in having an important role to facilitate the discussion and reach consensus. On the other hand, the tool has also been deemed effective in offering real solutions, with moderate agreement on the achievement of a shared vision and moderate credibility of the results.

Question/Aspect	1	2	3	4	5
Did CGIS tool help you understand the planning process?		40%		60%	
Did CGIS tool help to facilitate a discussion?			40%	20%	40%
Did CGIS tool help you make a more informed decision?			20%	80%	
Did the result offer a real solution to the problem?		40%	40%	20%	
We achieved a shared vision about possible solutions			80%	20%	
The result was credible / believable		20%	40%	20%	20%
The CGIS tool helped us to reach consensus		20%	40%	40%	

Table 1. Usefulness feedback

4.2 Usability feedback

In general, the tool has received positively skewed feedback regarding usability (Table 2), which is also evident from the answers to the final question about tool usability. On the one hand, the respondents were highly satisfied with the data management features (e.g., uploading or connecting data) and with the tool's ability to evaluate an area in a city. Moreover, the feedback provided also indicated that there is an overall positive perception of the ability to draw features on the map – a feature that is sometimes needed as ad hoc part of the stakeholder discussion meetings. On the other hand, the biggest split in perception between lower and higher usability was regarding the web map workspace.

Feature/Aspect	1	2	3	4	5
Collaborative web map workspace use		40%		40%	20%
Data management by upload or connection			20%	60%	20%
Map-based area analysis			20%	40%	40%
Drawing features on a map			30%	40%	40%
Overall usability for planning drone LLS			40%	60%	

Table 2. Usability feedback

4.3 Suggestions for Improvements

Suggestions for improvements were in terms of streamlining workflow for layer management, technical reliability, and integrated help and guidance features. First, the process of switching from the data manager to the layer manager when adding new layers could be streamlined. Users should have the option to add multiple layers to the map and manually switch to the layer manager when ready. Second, the tool's functionality needs to be refined, as technical issues were encountered during use, such as errors in analysis runs and difficulties with data uploading. These challenges highlight the need for improved system reliability. Moreover, the tool did not have all the key data layers included in the test sessions. Third, the feedback was that basic integrated help or guidelines should be included in the application to explain how weighting affects the analysis. For example, the relative impact of changing a layer's weight from 0.4 to 0.6 should be clarified to aid decision-making. In addition, a demonstration video could enhance usability and onboarding of UAM planners.

5. Conclusion

Overall, results highlight that the DST effectively supports decision-making, enhances understanding the spatial situation in the planning, and facilitates discussion. In addition to the direct findings related to this case, this research opens up several pathways for further research. On the one hand, the development of CGIS tool should be done in synergy with further development of an ecosystem of tools to support various decisions pertaining to UAM in urban environments, such as those used for defining urban air flight corridors. On the other hand, further research on actor responsibilities and planning processes is needed (Pönkänen et al., 2025), especially in relation to policy changes and new governance models. Such efforts would need a greater collaboration with social science concepts and methods (Ryghaug et al., 2023).

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