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THE USE OF DRONES IN URBAN CONSTRUCTION: TECHNOLOGICAL APPLICATIONS, OPERATIONAL BENEFITS, AND IMPLEMENTATION CHALLENGES

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ABSTRACT:

The rapid expansion of urban areas generates an urgent need to adopt innovative technologies capable of optimizing engineering processes and addressing current demands for sustainability, safety, and accuracy. In this context, unmanned aerial vehicles (UAVs – drones) emerge as promising technological solutions in the field of urban construction, owing to their versatility, accessibility, and ability to provide high-resolution data within a short timeframe. This study analyzes the role of drones in various stages of urban construction projects in Romania, with a focus on applications such as digital mapping, photogrammetry, 3D modeling, progress monitoring, and technical inspections of infrastructure. The adopted methodology includes a combination of documentary analysis and qualitative interviews with experts, which underpin a conceptual model for UAV–GIS–BIM integration. The paper also proposes a four-dimensional matrix correlating technological applicability with levels of complexity, operational risks, and associated costs, providing an analytical framework useful for the strategic evaluation of UAV implementation in urban environments. The results indicate increased efficiency in data collection and processing compared to traditional methods, as well as significant potential for optimizing construction project management. Concurrently, current challenges are highlighted, including legislative, logistical, and professional training issues. The conclusions support the necessity for developing a standardized operational framework and suggest future directions for research and innovation in the domain of smart construction.

1. INTRODUCTION

Accelerated urbanization, characterized by infrastructure expansion, increased population density, and a multiplication of urban redevelopment projects, exerts significant pressure on industries involved in the design, execution, and maintenance of the built environment (Elghaish et al., 2020; Muhmad Kamarulzaman et al., 2023). In this context, the urban construction sector faces an urgent need to streamline operations, reduce costs and execution times, while simultaneously addressing demands related to sustainability and construction quality. Conventional solutions for site management, work monitoring, and topographic surveying often prove inefficient in the face of the increasing complexity of urban projects (Herrmann, 2016; Szóstak & Nowobilski, 2022; Vangu et al., 2025).

Over the past two decades, technological advancements in civil aviation, automation, and spatial data processing have led to the widespread development and adoption of unmanned aerial vehicles (UAVs), commonly known as drones.

Initially used predominantly in military and surveillance applications, drones have rapidly penetrated the civilian sector, including fields such as precision agriculture, mapping, industrial inspections, and more recently, urban construction (Călina et al., 2018; Li & Liu, 2018; Zhou & Gheisari, 2018).

In this domain, drones offer several competitive advantages: the ability to collect accurate data within a short timeframe, access to hazardous or otherwise inaccessible areas, and seamless integration of aerial imagery and measurements into complex digital workflows such as Building Information Modeling (BIM) and Geographic Information Systems (GIS). Their applications range from high-resolution aerial topography to progress monitoring, structural safety inspections, and on-site resource management (Irizarry & Costa, 2016; Jeelani & Gheisari, 2021; Vangu, 2022).

Nevertheless, despite their significant potential, the integration of drones into dense urban environments presents a series of challenges. These include restrictive aviation regulations, privacy and data security concerns, technological limitations related to flights in confined or electromagnetically disturbed spaces, as well as the necessity for qualified personnel for operation and data interpretation. Moreover, the standardization of processes and data formats to ensure compatibility with existing digital systems (BIM/GIS) remains a challenge in many countries, including Romania (Adouane et al., 2019; Basir et al., 2020; Vangu, 2022).

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Recent research in the specialized literature has highlighted the benefits of drone utilization in urban construction, while also emphasizing the lack of applied studies in specific geographic contexts to evaluate the real applicability, operational efficiency, and sustainability of implementing these technologies (Albeaino & Gheisari, 2021; Namian et al., 2021, Zhong et al., 2025). The aim of this article is to investigate the use of drones in urban construction in Romania through an integrated analysis of advantages, limitations, and development prospects. The article seeks to contribute to the consolidation of the theoretical and practical framework regarding the role of drones as advanced digital tools in transforming urban engineering processes, offering a synthesis of the specialized literature as well as a detailed analysis of the framework for drone applications in construction (economic, legislative, techical, and social).

2. MATERIALS AND METHODS

For the purpose of this research, a qualitative approach was adopted, carried out in multiple stages, aiming to rigorously analyze the potential use of drones in the field of urban construction. In the initial phase, a series of relevant secondary data were collected and analyzed from the following sources: scientific articles published in specialized journals, national and European legislative regulations concerning the use of drones, as well as official positions expressed by competent state institutions (civil aviation authorities, construction regulatory bodies, environmental and urban planning agencies).

To complement this information and gain a better understanding of the current technological and operational context, interviews and informal consultations were conducted with construction industry specialists, authorized drone operators, as well as academic staff involved in research and innovation in civil engineering and aeronautical technologies.

Based on these initial data, it was concluded that drones can be successfully utilized in the urban construction sector, possessing significant potential to improve operational efficiency, occupational safety, and the quality of site monitoring (Lee et al., 2020, Vangu et al., 2025). Building upon this premise, the research was structured around three main directions: identifying the primary technological applications of drones in construction, highlighting the operational benefits resulting from their use, and analyzing the challenges associated with large-scale implementation, from both technological and juridical-administrative perspectives. The logical framework of the research process is presented in Figure 1.

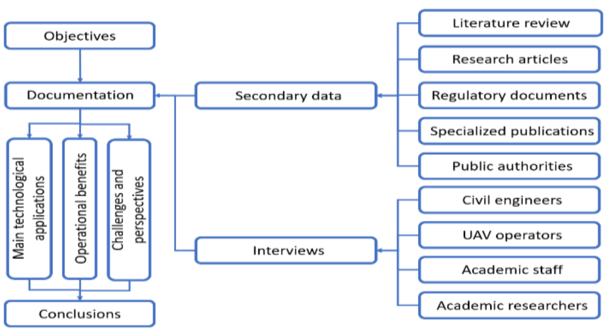

Figure 1. Applied methodology

The use of unmanned aerial vehicles (UAVs) in the urban construction sector entails a complex integration of hardware and software technologies, legal regulations, environmental constraints, and operational procedures, all adapted to the specific context of the built environment (Călina et al., 2018; Wang et al., 2020). The theoretical methodology for implementing drones in this field must be built upon an interdisciplinary understanding that combines principles from civil engineering, photogrammetry, geographic information science, and civil aviation. The design and implementation of an operational program dedicated to drone utilization in construction requires careful planning of several essential elements, as well as the adequate allocation of necessary resources. This technological transition involves not only the acquisition of specialized equipment but also the adaptation of current processes and working methodologies (Călina et al., 2018).

Regarding resources, the efficient use of drones primarily requires outfitting with specific equipment, including professional-grade drones, high-precision sensors (LiDAR, multispectral cameras, thermal imaging, etc.), and accessories compatible with construction applications. Alongside these, the implementation of advanced software solutions for processing, analyzing, and exploiting data obtained from photogrammetric flights is necessary—such as 3D processing software, GIS, Building Information Modeling (BIM), and data integration platforms within workflow systems (Colomina & Molina, 2014; Grecea et al., 2016; Song et al., 2009). Another essential element is human resources. The successful implementation of such a program depends on the involvement of qualified personnel: authorized UAV operators, engineers specialized in geospatial data processing, and construction experts capable of integrating the obtained data with traditional design and execution methods (Albeaino & Gheisari, 2021; Romanian Civil Aeronautical Authority, 2022). From a cost perspective, several categories must be considered. On one hand, initial costs include the acquisition of equipment and software licenses, as well as expenses related to the initial training of involved personnel. On the other hand, recurring costs during the operational period include equipment insurance, subscriptions for software updates and maintenance, and continuous investments in personnel professional development. Additionally, unforeseen or occasional costs may arise due to technical interventions, equipment replacements, or damages. Furthermore, as UAV usage expands within operations, additional costs related to acquiring supplementary sensors, upgrading the drone fleet, or integrating emerging technologies may occur. Figure 2 presents the main cost categories, along with their evolution over time. The cost distribution may vary depending primarily on the technological solutions adopted; however, initial costs will always be significantly higher compared to operational and occasional costs.

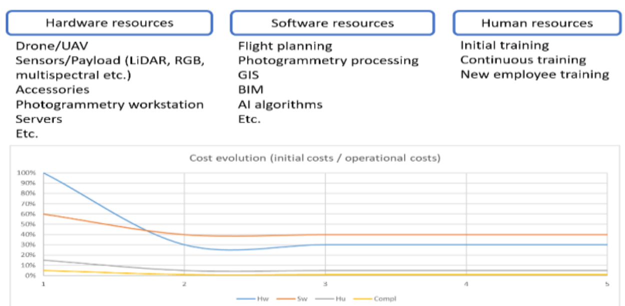

Figure 2. Types of costs and estimation of their evolution over time

Last but not least, the adoption of UAV technologies in construction entails a process of adapting current working practices. This involves revising and updating traditional methodologies, integrating drone-generated data flows into decision-making and operational processes, and, in some cases, redefining roles within design, supervision, and execution teams. Consequently, the successful implementation of such a program requires a strategic, multidisciplinary, and flexible approach capable of addressing both the technical and organizational demands of an ever-evolving construction environment (Elghaish et al., 2020; Herrmann, 2016).

In the urban environment, drone applications are diverse and include the generation of digital terrain and surface models for planning purposes, monitoring construction progress through successive phases, inspecting structurally difficult-to-access elements, quality control, and volumetric assessment of materials (Szóstak & Nowobilski, 2022; Vangu et al., 2025). These operations first require selecting an appropriate type of drone: typically, multirotor platforms are preferred for their maneuverability and precision, as opposed to fixed-wing drones, which are more suitable for covering large areas in open environments. The most commonly used models are equipped with high-resolution optical sensors (RGB), GNSS positioning systems with centimeter-level accuracy (RTK or PPK), and, in some cases, LiDAR or thermal sensors for advanced inspection applications (Cho & Lee, 2023; Vangu, 2022).

Methodologically, urban drone operations require careful flight planning, taking into account building density, obstacle height, the presence of power lines, airspace restrictions, and risks associated with UAV control loss. Missions are usually pre-programmed using autonomous flight software that allows automatic route generation and optimization of flight parameters such as altitude, speed, and image overlap (Călina et al., 2018; Vangu, 2022). In urban contexts, flight altitude is typically low, ranging between 30 and 80 meters, to avoid collisions with vertical obstacles and to achieve high spatial resolution. Flight speed is adjusted to maintain data stability and image clarity.
A fundamental prerequisite for implementation is compliance with applicable legal regulations. In Romania, the Romanian Civil Aviation Authority (AACR) regulates civil drone use, and urban flights are subject to strict restrictions, particularly concerning maximum altitude (generally 120 meters), flights near critical infrastructure, as well as equipment registration and authorization. UAV operators must hold competency certificates, and flight missions require notifications and sometimes approvals from local authorities or the Romanian Police. Additionally, adherence to personal data protection regulations (GDPR) is essential, since flights over populated areas may capture images implicating citizens' right to privacy (Romanian Civil Aeronautical Authority, 2022; Vangu, 2022).

Environmental conditions represent another critical factor in drone utilization. Strong winds, precipitation, extreme temperatures, or the presence of intense electromagnetic fields (generated by urban infrastructure such as relay stations or high-voltage cables) can affect sensor operation, flight stability, and positioning accuracy. Consequently, flight planning must include a preliminary analysis of weather conditions and operational risks (Bahabry et al., 2019).

Regarding data processing, the standard methodology involves using photogrammetric software that enables the generation of orthophotos, 3D models, and point clouds. These digital products can subsequently be integrated into Building Information Modeling (BIM) systems for construction lifecycle management or Geographic Information Systems (GIS) for spatial analyses. The accuracy of the acquired data is typically validated by comparison with ground control points established on-site using traditional surveying equipment (Adouane, 2019; Colomina & Molina, 2014; Song et al., 2009).

From a risk perspective, two major categories can be distinguished: technical risks related to equipment failures, signal loss, or collisions; and legal or ethical risks arising from non-compliance with legislative frameworks or unauthorized use of obtained data. Mitigating these risks requires implementing safety protocols, periodic equipment maintenance, operator training, and the adoption of clear data management policies (Jeelani & Gheisari, 2021; Namian et al., 2021, Zhong et al., 2025).

Therefore, the methodology for drone utilization in urban construction entails not only selecting high-performance equipment but also developing a rigorous operational strategy encompassing technical, legal, environmental, and ethical aspects. In the absence of such an integrated methodological framework, the application of drones in urban environments remains limited despite the proven potential of these technologies in modern engineering practice.

2.1 Conceptual Model: UAV–GIS–BIM Integration Workflow in Urban Construction

The use of drones in urban construction can be systematized into a conceptual model for integrating UAV technology into engineering processes, spanning from aerial data acquisition to their utilization within complex digital systems (Adouane et al., 2019; Badea et al., 2015; Xhafa & Kosovrasti, 2015). The proposed model can be theoretically represented by a workflow consisting of five successive stages, as illustrated in Figure 3:

- *Spatial data acquisition through UAV flights* – involves planning and executing aerial missions to generate overlapping aerial images or LiDAR data;
- *Photogrammetric processing and three-dimensional reconstruction* – entails using specialized software to obtain orthophotos, 3D models, point clouds, Digital Surface Models (DSM), and Digital Terrain Models (DTM);
- *Integration into Geographic Information Systems (GIS)* – enables spatial analysis, correlation with other geospatial databases, and visualization within complex urban contexts;
- *Import and correlation with Building Information Modeling (BIM) models* – is achieved by converting UAV data into formats compatible with platforms such as Revit, ArchiCAD, or Navisworks, allowing intelligent modeling of constructed elements;
- *Application for decision-making* – the obtained results are employed in decision-making processes related to project management, quality control, cost forecasting, and urban infrastructure maintenance.

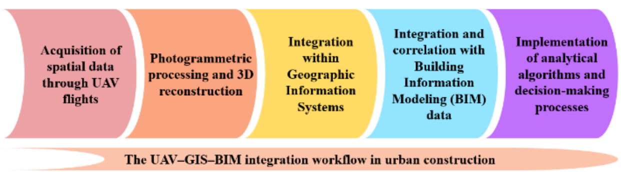

Figure 3. The UAV-GIS-BIM integration workflow

This model emphasizes *interoperability between platforms* and *the bidirectional flow of data*, whereby field information is digitized and subsequently reintegrated into design and construction systems (Basir et al., 2020).

2.2 Conceptual Model: Applicability–Complexity–Risk Matrix in the Urban Environment

To better understand the adaptability and feasibility of drone usage in urban construction, we propose a multidimensional conceptual model based on a three-dimensional matrix that correlates three essential variables: *functional applicability, technological complexity*, and *operational risks*. This model can serve as a valuable tool during the planning and strategic decision-making phase, facilitating comparative analysis of various UAV (Unmanned Aerial Vehicle) implementation scenarios in the urban context (Elghaish et al., 2020; Muhmad Kamarulzaman et al., 2023).

Functional Applicability: This dimension reflects the range of activities and operations in which drones can be integrated with added value in the construction sector. The main identified functional uses include: topographic surveying and generation of 3D terrain models, structural inspection of buildings or infrastructure, progress monitoring, volumetric control, and visual documentation.

Technological Complexity: This dimension refers to the level of sophistication of the technologies involved in UAV missions, which directly impacts both costs and the skills required for operation and post-processing. Technological complexity is determined by several factors, including: the type and performance of sensors used (RGB sensors, multispectral, thermal or LiDAR cameras, etc.); integration and compatibility with digital systems (such as GIS, BIM, or other construction management software solutions); the degree of automation; and the demands of post-processing.

Operational Risks: The assessment of operational risks is essential for any UAV mission in an urban environment, where infrastructure density and the presence of people pose additional constraints compared to rural or industrial settings. Key risk factors include: high urban density, electromagnetic interference, unstable weather conditions, legal limitations, and issues related to privacy and data protection.

Matrix Utilization: This three-dimensional matrix can be employed as *a preliminary decision-making tool for evaluating any UAV mission* within an urban context. By positioning a specific application within a conceptual space defined by the three axes (applicability – complexity – risk), it becomes possible to estimate the degree of feasibility, the required resources, and the level of preparedness needed.
Moreover, the matrix can serve as a foundation for developing assisted planning algorithms for UAV missions, providing decision support for operators and project managers. It can also be integrated into a multi-criteria analysis framework to compare different technological options based on the specific characteristics of each urban project (e.g., type of work, location, existing constraints, etc.).

Model Extension: Integrating the Cost Dimension for Cost–Benefit Analysis
To provide a more comprehensive and well-grounded evaluation of drone utilization in urban construction, the proposed conceptual model can be extended by adding a fourth dimension—*the costs associated with UAV technology implementation and operation*. Thus, the initial applicability–complexity–risk matrix is transformed into a four-dimensional model *capable of supporting cost–benefit analyses*, which are essential in the decision-making process.

By integrating these variables into a four-dimensional analysis, each UAV use-case scenario can be evaluated not only in terms of technical feasibility and operational risks, but also *from an economic and strategic perspective*. This type of evaluation enables the identification of applications with the highest cost–benefit ratio, the optimization of investments, and the prioritization of implementation phases according to the available budget and the project's specific objectives.

Furthermore, this approach allows for differentiation between *applications with high applicability but significant costs and moderate risks* (such as LiDAR scanning for critical infrastructure), *and those with low costs and broad applicability but limited operational impact* (such as routine visual documentation).

As illustrated in Figure 4, the extended model becomes *a strategic planning and management tool for technological innovation* in urban construction, supporting informed decisions regarding UAV adoption in accordance with the resources, requirements, and constraints specific to each project.

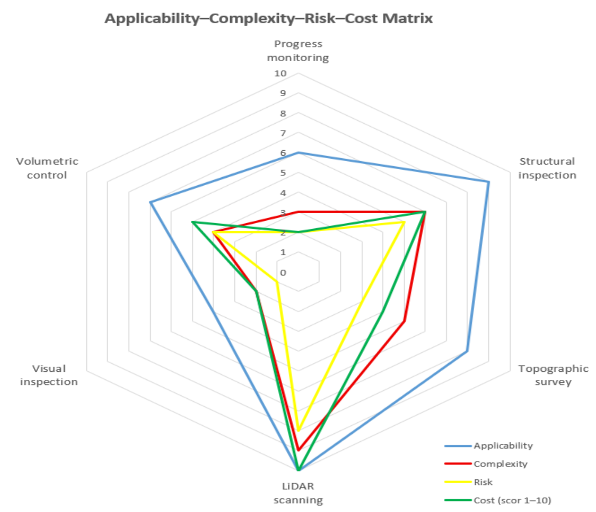

Figure 4. The applicability-complexity-risk-cost matrix

Table 5 provides an example of numerical coefficients assigned based on the type of activity to be performed, the level of applicability and technological complexity, as well as the associated risks and costs.

Activity	Applic ability	Compl exity	Risk	Cost (scor 1–10)
Progress monitoring	6	3	2	2
Structural inspection	9	6	5	6
Topographic survey	8	5	3	4
LiDAR scanning	10	9	8	10
Visual inspection	4	2	1	2
Volumetric control	7	4	4	5

Table 5. Data input for the applicability-complexity-risk-cost matrix

The coefficient values presented in Table 5 were estimated under the following working assumptions:

- Operational environment: the municipality of Craiova, Dolj County — a regulatory context that is generally permissive regarding UAV deployment, yet subject to flight restrictions due to the presence of a nearby airport;
- A specialized company equipped with professional-grade geodetic instrumentation;
- Personnel with proven expertise in classical engineering surveying methods, yet with limited operational experience in UAV-based data acquisition, particularly within urban settings.

It is important to note that there is no universally applicable set of standard coefficients, as each specialized company operates with distinct resources (equipment, personnel, time availability, etc.), and the activities may be conducted in operational contexts that vary significantly. Therefore, each provider of specialized geodetic services must perform a thorough assessment of the task-specific requirements, the environmental and operational conditions, as well as the available technical and human resources, in order to determine appropriate coefficient values tailored to these particular conditions.

3. DISCUSSION

3.1 Efficiency and Accuracy of Data Collection in Urban Environments

In the field of urban construction, the rapid and accurate collection of data is a critical factor for project success, and UAV technology represents a transformative advancement in this regard. Drones enable the acquisition of large volumes of geospatial data in a significantly shorter time compared to traditional methods, such as manual topographic surveys or measurements using stationary instruments. The level of precision achieved can reach below 2–3 centimeters, allowing not only for highly detailed mapping but also for the detection of small-scale construction elements and any associated structural anomalies.

The use of UAVs for photogrammetric data acquisition in urban environments offers numerous advantages; however, the accuracy of the information obtained is significantly influenced by a range of technical and operational factors. Firstly, the precision of the raw data collected is directly dependent on the technical performance of both the UAV platform and the onboard sensor, particularly the stability of the aerial platform, the quality of the imaging system (including resolution, sensor size, and optical distortions), and the efficiency of the navigation and positioning systems (such as GNSS, IMU, etc.). A second category of factors with a considerable impact on data accuracy relates to the operational environment. Flights conducted in densely built-up urban areas are often challenged by vertical obstacles (e.g., buildings, poles, vegetation), which may restrict the field of view of the sensors or generate reflections and shadows, thereby compromising image quality. In addition, meteorological conditions — such as wind, variable lighting, rain, or fog — can adversely affect flight stability and image clarity. Strict adherence to established flight and data acquisition protocols (including constant flight altitude, appropriate image overlap, consistent flight speed, and optimal sensor orientation) is essential to minimize measurement errors. Another critical aspect is the photogrammetric processing stage, which involves three-dimensional reconstruction and the extraction of quantitative data. Errors may arise during this phase due to factors such as improper camera calibration, suboptimal image alignment algorithms, poorly distributed or insufficient ground control points, or artifacts caused by reflections or textureless surfaces.

To achieve high-accuracy results, an integrated approach is required — one that combines the use of high-performance equipment with the rigorous application of measurement and processing methodologies tailored to the specific characteristics of the urban environment. Such an approach is essential for reducing, or even eliminating, errors that may occur during data acquisition and processing, whether systematic, random, human-induced, or procedural in nature.

In urban environments, the use of UAVs offers clear advantages, primarily due to their ability to fly over areas that are inaccessible or hazardous, such as active construction sites, rooftops, tall façades, or confined spaces between buildings. This capability significantly reduces risks to human personnel and minimizes disruptions to urban operations. For instance, façade inspections or monitoring of high-altitude construction activities—traditionally performed using scaffolding or cranes—can now be conducted quickly and at lower cost, without the need for large on-site teams.

Moreover, the repeatability and frequency of UAV-based measurements enable continuous, real-time monitoring, which helps prevent significant deviations from the original project plans. UAVs thus facilitate the production of regular, up-to-date reports with visual support and dynamic 3D models, enabling timely adjustments in construction processes and minimizing material and time losses. This time efficiency translates into substantial project-level cost savings and contributes to improved overall construction quality.

3.2 Integration of UAV Technologies with Digital Systems: GIS and BIM

One of the most transformative contributions of UAVs to urban construction lies in their ability to provide essential data for digital platforms such as Geographic Information Systems (GIS) and Building Information Modeling (BIM), making these systems dynamic and capable of reflecting the physical status of construction sites in real time or near real time. GIS enables the management of spatial information through georeferenced databases, offering a holistic perspective on the site, surrounding environmental conditions, and adjacent infrastructure. UAVs can be employed to continuously supply updated data, which is crucial for integrated urban planning and for assessing the impact on the built environment.

Conversely, BIM functions as a centralized platform containing comprehensive information on the physical and functional characteristics of a building. By incorporating UAV-captured data, the BIM model acquires a realistic, "living" dimension, reflecting the execution progress at each stage. This enables construction managers to precisely identify deviations, anticipate additional costs, and optimize logistics and resource allocation.
The technical challenges of this integration stem from the need to harmonize various data formats: images and point clouds generated through photogrammetry or LiDAR must be converted into structures compatible with BIM standards. This process requires advanced software solutions, skilled personnel, and clearly defined interoperability standards, which are still under development in the construction industry.

3.3 Operating Conditions and Constraints Imposed by the Urban Environment

The urban environment presents a complex framework characterized by a high density of physical, technological, and legislative obstacles that impact UAV operations. Tall buildings create narrow flight corridors where drone maneuverability is restricted and the risk of collisions increases significantly. Suspended objects, such as power lines and telecommunication cables, pose invisible hazards capable of causing serious accidents. Therefore, flight planning requires detailed knowledge of the urban topography and the use of obstacle avoidance algorithms, a technology that is still in an advanced research phase.

Electromagnetic interference, common in urban areas due to numerous wireless networks, can disrupt GNSS signals, compromising UAV positioning accuracy and flight safety. Furthermore, specific urban weather conditions — including turbulent winds channeled between buildings and air pollution such as smog — can limit drone performance and battery endurance, imposing additional flight restrictions.

From a legislative perspective, regulations are complex and vary across jurisdictions, imposing strict limitations on flights over populated areas, sensitive institutions, and crowded public spaces. This legal framework affects the frequency and coverage area of UAV missions, necessitates special authorizations, and requires adherence to detailed protocols, which can complicate large-scale implementation of UAV operations in urban settings.

3.4 Risk Management and Security in UAV Operations

The use of drones in urban environments necessitates rigorous risk management, given the potential impact of incidents on public safety and the integrity of property. From a technical standpoint, risks include signal loss, software or hardware malfunctions, battery failures, or collisions with urban structures, which may result in crashes or accidents. To mitigate these risks, it is essential to implement redundant systems, ensure real-time monitoring, and train operators in emergency response protocols. From a legal perspective, responsibility for incidents primarily lies with the operators and pilots, and secondarily with the UAV service beneficiaries. Furthermore, the protection of personal data is of paramount importance, as drones may capture images and video recordings involving individuals or private properties. Compliance with GDPR regulations and national privacy laws is mandatory, requiring clear definitions of data purposes, retention periods, and access procedures.

Moreover, from a social standpoint, transparency and communication with urban communities where UAV flights are conducted are vital for the acceptance of the technology. Lack of information or breaches of privacy may provoke public opposition and legislative obstacles.

3.5 The Impact of Drones on Sustainability and the Circular Economy in Construction

From a sustainability perspective, drones provide effective tools for reducing resource consumption and mitigating the environmental impact of urban construction. By minimizing the need for human travel and the use of heavy equipment for measurements and inspections, UAVs contribute to lowering carbon emissions associated with construction processes.

Furthermore, drones facilitate real-time monitoring of the quality and integrity of materials used, supporting reuse and recycling practices integral to the circular economy. Through detailed scanning, the degradation of components can be tracked, enabling the planning of preventive maintenance interventions that extend the lifespan of structures and minimize waste generation.

Additionally, UAV technology aligns with smart city strategies by supporting data collection for urban sustainability analysis, optimizing resource utilization, and reducing energy consumption.

3.6 Challenges and Technological Perspectives for the Future

Future technological prospects are characterized by the increasingly advanced integration of artificial intelligence (AI) in UAV operations, enabling the full automation of processes such as flight planning, obstacle detection, and especially image analysis for identifying elements of interest.

Hybrid navigation systems that combine GNSS, computer vision, and LiDAR sensors will enhance flight autonomy and safety within complex urban environments. Concurrently, the development of interoperable software platforms that integrate UAVs, GIS, and BIM will facilitate scalable technology adoption.

Trends toward miniaturization, increased battery autonomy, and improved sensor quality will expand application domains, including security inspections, infrastructure monitoring, and emergency response interventions.

3.7 Educational and Social Implications

In the context of the widespread adoption of UAVs in construction, technical education and professional training must rapidly adapt. The integration of competencies related to drone operation, geospatial data analysis, and BIM system integration into curricula is essential for preparing engineers equipped to meet the evolving demands of the market.

On the social front, facilitating access to technology through cost reduction and the development of intuitive platforms can support the economic growth of small and medium-sized enterprises, thereby enhancing innovation and competitiveness within the construction sector.

Moreover, increased attention to ethical considerations surrounding aerial surveillance in urban environments is necessary, requiring collaboration among authorities, industry stakeholders, and communities to establish regulatory frameworks that are balanced and socially acceptable.

3.8 Cost-Benefit Analysis of Drone Utilization in Urban Construction

The implementation of UAV technology in the urban construction sector involves significant initial costs, as well as medium- and long-term benefits that have the potential to radically transform the efficiency and quality of construction processes. A rigorous cost-benefit analysis is essential to underpin managerial and investment decisions.

3.8.1 Costs Associated with Drone Utilization: Initial costs include the acquisition of equipment, which varies significantly depending on the model and the complexity of integrated sensors. Professional models, such as the DJI Matrice 300 RTK, can cost tens of thousands of euros, whereas compact and portable drones are considerably more affordable but offer reduced functionality. In addition to the hardware expenses for flight equipment, investments are required in specialized software for data processing, photogrammetric processing tools, operator training, and obtaining the necessary certifications in accordance with applicable legislation. Maintenance costs and periodic equipment upgrades are also significant, as are mandatory liability insurance policies required in many jurisdictions. Moreover, certain projects may necessitate special permits and rigorous logistical planning, involving additional human resources and time.

3.8.2 Direct and Indirect Benefits: Technological and operational benefits are manifold. The use of drones significantly reduces the time required for inspections and topographic mapping—from days or weeks to mere hours or even minutes. This acceleration facilitates faster decision-making and early detection of issues, thereby preventing additional costs arising from repairs or project delays. Drones enable continuous, real-time monitoring of work progress, enhancing resource management and optimizing the flow of materials and labor. By collecting precise data, they reduce the risk of human errors and contractual disputes related to measurements.

From a financial perspective, although the initial investment is substantial, savings achieved through reduced downtime, accident prevention, and optimized material consumption can rapidly offset costs. Additionally, drones can diminish the need for expensive traditional equipment, such as cranes or ground-based surveillance accessories.

In terms of safety, drones eliminate the necessity for personnel to be exposed to hazards in dangerous or hard-to-reach areas, thereby contributing to a reduction in workplace accidents and the associated costs.

3.9 Relevant Non-Financial Aspects

In addition to financial benefits, the adoption and utilization of drones positively influence a company's image by associating it with innovative technologies and sustainable practices. This enhanced reputation can facilitate the acquisition of new contracts and collaborations with partners interested in the digitalization of processes.

Furthermore, improvements in workplace safety and the reduction of environmental impact—achieved through limiting travel and the use of heavy machinery—represent essential advantages. Although these benefits are challenging to quantify, they hold increasing strategic importance.

The cost-benefit analysis demonstrates that, despite the high initial costs, the use of drones in urban construction is economically and operationally justified, providing a significant competitive advantage. To maximize these benefits, companies must select equipment appropriate to their project profiles, invest in professional training for operators, and ensure the integration of UAV data into existing digital systems. Future research focused on cost optimization and autonomy enhancement will further reinforce this trend.

Table 6 below compares traditional methods with the use of UAV technology in surveying and inspection activities within construction, highlighting the impact and benefits generated in terms of efficiency, cost, accuracy, safety, and sustainability.

Aspects	Traditional Methods	UAV Utilization	Impact / Benefit
Time for Surveying and Inspections	5-10 days	1-2 days	Reduction by 80–90%
	Average values established according to (Bhoda, 2025; FasterCapital, 2020; TrueView Drone Services, 2022; Willoughby, 2021)		
Equipment and Personnel Costs	Costs for multiple teams and traditional equipment	UAV equipment cost + operator and data processing	Significant savings in direct costs
Data Accuracy and Quality	Limited, dependent on manual measurements	Highly precise digital data, integrated with BIM/GIS	Increased accuracy and decision support
Workplace Safety	High exposure to risks and accidents	Remote operations in inaccessible areas without risk	Significant risk reduction
Environmental Impact	Transportation and heavy equipment, fuel consumption	Reduced energy and resource consumption	Low ecological impact
Operational Flexibility	Limited by terrain conditions and accessibility	High flexibility, rapid access even in restricted areas	Increased adaptability and response speed
Maintenance and Upkeep Costs	Variable costs, with physical wear and tear of equipmen	Regular costs for software, batteries, and parts	Lower long-term costs
Public Acceptance and Image	Neutral	Positive perception as innovative technology	Competitive market advantage

Table 6. Comparative Analysis of Traditional Methods versus UAV Utilization

4. CASE STUDIES

To validate the information and working methodologies, discussions were held with: representatives of specialized companies that use drones for engineering measurements in urban environments; representatives of local authorities involved in public investment projects and employing technical personnel (such as the Dolj County Council – Urban Planning Department); and representatives from the academic environment in Craiova (specifically, the Faculty of Agronomy – Department of Land Measurements, Management, and Mechanization, and the Faculty of Mechanics – Department of Applied Mechanics and Civil Engineering).

As a result of these discussions and the analysis of drone usage scenarios in the field of civil construction in Craiova, two scenarios were selected and analyzed, as detailed below.

4.1 Rehabilitation and Channeling of Râului Boulevard in Craiova

During the rehabilitation and channeling works on Râului Boulevard in the municipality of Craiova, the company PointX SRL was contracted to perform the topographic surveys necessary for documentation, monitoring, and supporting the execution process of the construction works. Due to the linear configuration of the construction site—extending over approximately 1,200 meters in length and an average width of 25 meters—as well as the high volume of road traffic in the area, a modern data collection method was selected: the use of a DJI Phantom 4 Pro V2 drone equipped with a 20 MP RGB sensor. The personnel involved had an intermediate level of experience in drone operation and photogrammetric data processing.

This approach enabled the acquisition of high-precision topographic and cartographic products, essential for tracking construction progress and ensuring comprehensive visual documentation of the site. Flights were planned and conducted at key project milestones to progressively monitor the development of infrastructure works.

The UgCS software (www.sphengineering.com/flight-planning/ugcs), developed and marketed by SPH Engineering, was employed *for flight planning and control*. The platform facilitated the definition of precise flight paths, with parameters adapted to the terrain characteristics and the technical requirements of the project. Missions were designed to cover the entire roadway corridor, achieving a ground sampling distance (GSD) of 1 cm/pixel, a flight altitude between 34 and 40 meters, a flight speed of 5 m/s, and an image overlap of 80% longitudinally and 70% laterally. The camera orientation was set to nadir in order to obtain geometrically accurate orthophotos.
Data Collection: The drone was used to perform automated flights, each resulting in the capture of approximately 800 images per mission. The aerially surveyed area per flight was around 7.3 hectares, and the total flight path length reached approximately 6 kilometers. Weather conditions were carefully monitored, and flights were conducted only during periods of good visibility and low wind, to ensure the quality of aerial captures. Each flight lasted approximately 20 minutes.

An important aspect of this method was the absence of an RTK positioning system on the drone. To compensate for this limitation and ensure accurate georeferencing of the outputs, 31 ground control points (GCPs) were precisely marked and measured in the field, evenly distributed across the area of interest. These were determined using high-precision GNSS equipment and were subsequently integrated into the photogrammetric workflow.

Data Processing: The images acquired during the flights were processed using the specialized software Agisoft Metashape Professional (www.agisoft.com/features/professional-edition/). Each dataset was processed in an average time of 6 hours, following the workflow outlined below: alignment of images and identification of tie points; insertion and adjustment of ground control points; generation of the dense point cloud; creation of the digital surface model (DSM); production of the orthophoto with a resolution of 1 cm/pixel; export of 3D models and orthophotos for further use.

The outcome of these processes was the generation of high-quality photogrammetric products: orthophotos, digital terrain models, 3D surface models of the construction area, as well as detailed thematic maps.

Use of Results in the Project: The processed photogrammetric data served as the basis for developing thematic and cadastral plans, as well as 3D digital models that were subsequently used in the project for: verifying and documenting the execution stages; measuring volumes and assessing the conformity of the executed works (excavations, embankments, stratification heights); accurately determining the location of the constructed objectives; generating topographic documentation required by the beneficiary and the project oversight authorities.

The rehabilitation and channeling works spanned a duration of 14 months, during which 28 drone flights were conducted. The ground control points were determined and marked at the beginning of the project and were reused throughout the entire construction period. The flight plans were configured and saved during the initial mission and were reused for all subsequent flights, as there were no changes to the coverage area or the presence of new obstacles that would have required reconfiguration. Table 7 presents the comparative values for the main analyzed aspects, as follows:

Criteria	Drone Surveying*	Traditional Surveying**
Accuracy	1-3 cm	1 cm
Average time/mission***	7,5 h	36 h
Data Detail	Dense data across entire areas	High, but localized to surveyed points
Accessibility	Facilitated access without compromising the safety of personnel or equipment	Hazards to personnel and risk of equipment deterioration or damage
Cost	Although the required investment in equipment is significant, it can be amortized over extended periods and multiple projects. The reduced execution time also contributes to lower labor-related costs.	The measurement process requires a considerable amount of time, leading to increased personnel costs.

*Values declared by the service provider (PointX SRL)
**Estimated values provided by the service provider (PointX SRL)
***Includes the time required for field deployment, GCPs setup, and photogrammetric data processing. The GCPs were physically marked at the start of the project and reused during the entire execution period.

Table 7. Comparative analysis of traditional methods and UAV applications related to the presented case study

4.2 Monitoring the Progress of Construction Works for the Craiova Multifunctional Sports Complex

As part of the construction project for the Craiova Multifunctional Sports Complex, monitoring the progress of construction works represents a key component for efficient site management and for documenting the advancement of execution stages. In order to ensure periodic visual monitoring and to maintain an up-to-date overview of the entire worksite perimeter, the beneficiary opted for the use of a modern aerial surveillance method: the deployment of a DJI Mavic 3E drone equipped with a 20-megapixel RGB sensor. The data acquisition and processing were carried out by PointX SRL, a specialized company with the necessary material and human resources. Unlike applications that require high topographic accuracy, in this case, the photogrammetric flights were intended solely for general progress monitoring, without the need for centimetric accuracy in the final results. This allowed for more flexible planning and faster data processing.

Periodic Site Monitoring: Aerial missions were carried out every four weeks throughout the duration of the construction works. These regular flights enabled the acquisition of a series of aerial images which, once processed, formed a comprehensive visual archive of the site, clearly reflecting the dynamics and stages of execution.

Flight planning and automation were managed using the DJI GS Pro software (www.dji.com/global/ground-station-pro), which allowed for route definition, capture parameter settings, and saving of flight plans for reuse in repeated missions.

Flight Technical Details: Each flight mission was configured to fully cover the active area of the site, approximately 2.6 hectares. Flights were conducted at altitudes ranging from 35 to 40 meters above ground level, and the drone's trajectory followed a double grid pattern, meaning the drone flew the study area in two perpendicular directions. In the first flight direction, the camera was oriented vertically (nadir), while in the perpendicular direction, the camera was tilted at an angle of 40° from the vertical in order to capture building facades and other structures under construction. This approach allowed for the generation of more expressive 3D models, useful for visual analysis of the vertical progress of the works.

Flight Parameters Used: Ground Sampling Distance (GSD) of 1 cm/pixel; flight speed 7 m/s; longitudinal overlap 80%; lateral overlap 70%; flight pattern - double grid; average number of images captured per flight ~540 images; total flight distance approx. 4 km; effective flight time ~10 minutes.

Photogrammetric Processing: The data collected in the field was processed using DJI Terra software (https://enterprise.dji.com/dji-terra), which enables direct import of imagery acquired with DJI drones and rapid generation of derived products.

The average processing time was approximately 1.5 hours per flight, during which the following outputs were generated: orthophotos (with reduced accuracy but sufficient for visual evaluation), 3D models of the construction site (used for visualizations, simulations, and reporting), and sets of georeferenced images suitable for temporal comparisons.

Analyzing the two presented case studies, it is necessary to examine certain specific aspects, as outlined in Table 8:

Criteria	Case study 1	Case study 2
Accuracy	Important	Not important
Average time/mission*	7,5 h (7.3 ha, simple grid)	2,75 h (2.6 ha, double grid)
Data Detail	Details Ensuring Engineering Measurement Accuracy	Reduced Accuracy, but Sufficient to Meet Project Requirements
Accessibility	Facilitated access without compromising the safety of personnel or equipment	Difficult Access to the Construction Site, with Heavy Machinery in Operation
Flight Planning	Works conducted solely at ground level, with no aerial (tall) obstacles, allowing for the reuse of flight plans	Site dynamics and the positioning of construction equipment (cranes) required flight plan adjustments for each mission
Equipment and Infrastructure	Previous-generation, with lower investment costs but also limited performance	New-generation, with higher investment costs but significant performance advantages
Human Resources	Personnel with advanced experience in drone operation and photogrammetric processing	Personnel with advanced experience in drone operation, photogrammetric processing, and GIS systems
*Includes the time required for field deployment, GCPs setup (for case study 1), and photogrammetric data processing.		

Table 8. Comparative analysis of the two presented case studies

Although the selected scenarios have different applications and objectives, they have been presented precisely to highlight the broad range of drone applicability within the urban civil construction sector, as well as to emphasize that the efficiency of their use depends on data accuracy requirements, personnel qualification levels, equipment performance (flight systems, processing capabilities, etc.), and the specific characteristics of the flight environment.

5. PRACTICAL RECOMMENDATIONS AND DIRECTIONS FOR FUTURE RESEARCH

Considering the potential and challenges identified in the use of drones within the urban construction sector, it is essential to formulate concrete recommendations that facilitate the optimal integration of this technology, as well as to identify priority directions for the future development of knowledge and technology.

5.1 Practical Recommendations

Firstly, to ensure the safe and efficient operation of UAVs in densely populated urban areas, it is recommended to develop standardized mission planning procedures that include a detailed risk assessment addressing physical obstacles, weather conditions, and electromagnetic interference. These procedures should be complemented by specialized training for operators, focusing on the simulation of complex urban scenarios and the management of unforeseen situations.

The implementation of integrated air traffic control systems for UAVs is imperative to coordinate multiple flights within congested urban spaces, preventing collisions and disruptions. Such systems should be interoperable with local authorities and enable real-time monitoring of operations.

From a legislative standpoint, the primary recommendation is to harmonize national regulations with European and international directives, thereby establishing a unified, clear, and predictable framework that supports the sustainable development of the UAV sector in construction. Concurrently, clear criteria regarding data protection and privacy compliance must be defined, including the deployment of anonymization and encryption technologies for sensitive information.

Regarding technological integration, investments are advised in the development and adoption of standardized software platforms that facilitate the conversion and interoperability of UAV data into formats used by BIM and GIS, thus reducing technical barriers and operational costs.

5.2 Directions for Future Research

From a research perspective, a major direction involves the development of advanced artificial intelligence and machine learning algorithms capable of fully automating UAV missions in urban environments, including flight planning, dynamic obstacle avoidance, and real-time data analysis. Research in hybrid sensor technologies (LiDAR, multispectral, thermal cameras) and data fusion will enhance the reliability and utility of the information obtained.

Another priority area is the assessment of the social and psychological impact of drone usage in urban spaces, aimed at developing communication and community engagement strategies that maximize public acceptance and minimize conflicts.

Additionally, in-depth investigation is required into the integration of UAVs within sustainable construction systems and circular economies, including case studies that quantify their impact on reducing resource consumption and emissions.
Last but not least, research focused on optimizing battery lifespan, equipment miniaturization, and increasing drone autonomy will open new horizons for their use in urban construction, including under adverse weather conditions and during extended missions.

6. CONCLUSIONS

The theoretical analysis of drone usage in urban construction confirms the high potential of this technology to profoundly transform traditional design, execution, and monitoring processes. UAVs establish themselves as essential tools for optimizing workflows, delivering clear benefits in terms of the speed and accuracy of topographic and visual data collection, with precision that, under controlled conditions, can rival or even surpass conventional methods.

In the urban environment, characterized by high infrastructure density and increased operational complexity, drones enable the addressing of specific challenges such as access to hard-to-reach or hazardous areas and continuous monitoring of construction site progress without disrupting adjacent activities. However, these advantages come with technical challenges, including navigation through narrow corridors, obstacle avoidance, and managing frequent electromagnetic interferences in cities, necessitating advanced sensor technologies and autonomous algorithms.

From a legislative and security perspective, the current framework imposes a series of strict limitations and requirements aimed at protecting public safety and the rights of individuals and entities. This context demands heightened operator responsibility, certification requirements, and compliance with personal data protection regulations, especially regarding images and information collected in densely populated public areas. Collaboration among authorities, academia, and the UAV industry is essential to develop clear and effective regulations that support widespread adoption of the technology without compromising social interests.

The integration of drone-collected data into advanced digital systems such as GIS and BIM offers a multidimensional and dynamic view of projects, facilitating informed decision-making and optimizing construction management. This synergy between UAVs and digital platforms constitutes a central pillar in the evolution toward smart cities, where construction processes are monitored and controlled in real time, reducing costs, risks, and execution time.

Moreover, the positive impact on urban sustainability is undeniable. Drones enable the reduction of resource consumption, lower pollutant emissions, and minimize waste through careful monitoring of project stages and material quality. Within the context of the circular economy, this technology supports reuse and preventive maintenance, contributing to more responsible and sustainable urban development.

Looking ahead, the development of autonomous technologies supported by artificial intelligence and machine learning algorithms will lead to extensive automation of UAV operations, enhancing safety and efficiency in complex urban environments. The creation of interoperable software ecosystems facilitating seamless integration of UAV data into BIM and GIS will be crucial for the scalability and long-term sustainability of this technology in the construction sector.

Simultaneously, the evolution of this technology requires rapid adaptation of educational systems and professional training so that engineers, architects, and project managers acquire the competencies necessary for the optimal and responsible use of UAVs. At the same time, social acceptance of drone usage in urban environments must be fostered through transparent dialogue, engagement with local communities, and promotion of ethical practices that respect individual rights and ensure data protection.

Therefore, drones are attributed a vital role in modernizing and streamlining the urban construction sector, yet their successful integration depends on a comprehensive approach balancing technological innovation, rigorous regulation, operational safety, and social responsibility. Only through close collaboration among stakeholders and continuous investment in research and education can UAV technology reach its full potential, contributing to the creation of safer, more efficient, and more sustainable urban environments.

As a result of the above considerations, it can be firmly stated that fully harnessing the potential of drones in urban construction requires adopting a multidisciplinary approach that combines clear regulations, advanced technologies, and social engagement. The practical recommendations proposed aim to enhance safety and operational efficiency, while the research directions emphasize the need for innovations in artificial intelligence, sensors, data integration, and understanding the social impact of this technology. Thus, through a concerted effort of the scientific community, industry, and policymakers, the use of drones in urban environments can be optimized, significantly contributing to the sustainable and intelligent development of built infrastructure.

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