Use of UAVs and 3D Modeling in Planning

Subjects: Urban Studies

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The use of unmanned aerial vehicles (UAVs), commonly referred to as drones, is a rapidly advancing technology. UAVs have become more accessible for urban planning and historic preservation due to their lower cost of acquisition and easier entry requirements for new pilots in comparison to airborne and satellite platforms. The use of 3D modeling has been prevalent in various fields; at present, an expanding trend involves the utilization of 3D modeling technology in the preservation of historical sites. It is possible that detailed and accurate representations of existing buildings could have ethical implications for the development of 3D models. As an example, researchers have pointed limitations or even misrepresentation of buildings in the creation of digital 3D representations. Drone photogrammetry offers enhanced methods to represent existing buildings with in more detail.

Keywords: drone ; UAV ; unmanned aerial vehicle ; 3D ; three-dimensional ; digital twin

1. Overview of UAV Usage for 3D Modeling in Urban Planning

The growing body of publications suggests that UAVs have gained increasing attention among researchers, showing that UAVs have been applied to more fields as an emerging remote sensing technology [1][2][3][4]. UAV usage can be seen in publications related to transportation planning, historic preservation, land use planning, park activity monitoring, and sustainability planning [5][6]. For example, Bhatnagar et al. [7] presented a new technique for mapping wetlands using drone imagery and satellite imagery with the aim of reducing the need for costly and time-consuming field surveys. The authors captured a small number of drone images and used them to train a classifier that was then applied to satellite imagery. In another study, Donaire et al. [8] explained how drones or UAVs can take zenith images without visitors' direct participation while offering highly accurate spatial information.

Despite the diversity of UAV research in the above fields, the use of UAVs for 3D modeling in urban planning has been largely overlooked. **Table 1** provides an overview of the existing planning literature on the use of UAVs in 3D modeling, highlighting the technologies used and future opportunities for research.

Table 1. An overview of the existing planning literature on the use of UAVs in 3D modeling.

Author	Findings	Implications for Future Work	Hardware	Software
Karachaliou et al., 2019 [9]	**UAV-based photogrammetry is a cost-effective and efficient tool for mapping historic buildings and can produce results from high-quality 3D models to Building Information Models (BIM).**	**The authors suggest that using Building Information Modeling (BIM) can be beneficial in preserving historical buildings and propose that future research should concentrate on enhancing BIM-based documentation for heritage sites.**	**DJI Phantom 3 Pro**	**REVIT Autodesk, Agisoft PhotoScan**
Li, 2018 [10]	**A paper on UAV photogrammetry and its implications in urban planning. Oblique photogrammetry can significantly improve mapping accuracy and has more intersection light than vertical photogrammetry, resulting in higher 3D model accuracy.**	**The potential of oblique photogrammetry in various areas, such as spatial analysis, investigating illegal construction, assisting with planning approval, and safeguarding historical buildings, requires further exploration through research.**	**NA**	**NA**

Author	Findings	Implications for Future Work	Hardware	Software
Tariq et al., 2017 [11]	UAV photogrammetry can be used to develop realistic 3D models of archaeological sites with high accuracy to preserve digital 3D models in the management system for future reconstruction of historical sites.	The application of photogrammetry in the management of historical sites can be further explored to make it a mainstream tool for archaeological conservation.	DJI Phantom 4, Sony A5100	Photoscan
Berrett et al., 2021 [12]	Automated UAV techniques can be applied along with terrestrial photogrammetry to generate hyper-realistic 3D models that can be used for large-scale university campus planning and historic preservation and public outreach as well as potential virtual reality (VR) and augmented reality (AR) tours.	The application of advanced technologies such as LiDAR in generating 3D models can be further explored to improve accuracy and generate more realistic representations of real-world environments.	DJI Phantom 4 RTK, Inspire 2 with Zenmuse X4S, Nikon D750, Canon EOS 5D Mark III, TOPCON GR-3 GPS unit	Lightroom, ArcGIS Pro, 3D Acute
Kikuchi et al., 2022 [13]	Augmented reality combined with drones can facilitate public participation in urban design decision-making processes through implementing detailed 3D models of the city (digital twins), which can achieve both first-person and overhead views in outdoor AR with occlusion handling.	There is potential for further exploration of the use of augmented reality in urban planning and design, particularly in enhancing public participation during the decision-making process.	DJI Mavic Mini	SketchUp Make, InfraWorks, OBS Studio for AR
Erenoglu et al., 2018 [14]	UAV-assisted 3D modeling can be a time-efficient and cost-effective approach for urban planning, and can be used for mapping damages safely and efficiently after natural hazards.	Further research is needed to optimize processing parameters such as camera characteristics, image scale, quality of imagery, and hardware capacity to improve the accuracy of UAV-assisted 3D modeling.	Mikrocopter XL 8, Canon EOS-M, Satlab Sl500 GPS, Kolida KTS-442 RLC station	Agisoft Photoscan, ArcMap
Zhang et al., 2022 [15]	The use of a telexistence drone system empowered with artificial intelligence and virtual reality can achieve real-time 3D reconstruction with high-quality results.	Further exploration is required to determine the practical applications of the telexistence drone system in data analysis and decision-making. Additionally, efforts can be made to reduce the latency caused by different components of the system to improve its overall performance.	MYNT AI D1000-50/Color stereo camera, ICP Tracker	Agisoft PhotoScan
Campbell, 2018 [16]	Drone photogrammetry and VR are effective tools for historic preservation efforts, and can provide new data and experiences for decision-making. The generated VR experiences were positively received by government officials and other professionals.	Applying photogrammetry and VR can aid preservation efforts of culturally significant artifacts which developing and refining best practices for photogrammetry and VR workflow in preservation efforts.	DJI Phantom 4 Pro, Canon EOS Rebel DSLR	Autodesk (Recap Photo, 3ds Max), 3DR Site Scan, Visualive3D Mobilive, Geotag Photos, Trimble SketchUp
Alsadik et al., 2013 [17]	The proposed automated camera network method for 3D modeling of cultural heritage objects showed improved accuracy and average coverage, with a significant reduction in the number of cameras required.	The image orientation steps required for obtaining high-resolution images need improvement in the future, and more reliable bundle adjustment can be achieved by using the sparse bundle adjustment package.	NA	Agisoft Photoscan, Microsoft Photosynth

Author	Findings	Implications for Future Work	Hardware	Software
Skondras et al., 2022 [18]	UAVs can fly in urban areas where airplanes cannot operate and produce high-resolution 3D modeling; thus, the use of UAVs is expected to increase in the future.	Future studies could investigate the integration of data obtained from the built environment with local spatial knowledge, as well as the creation of georeferenced and scaled models.	DJI Phantom 4 Pro	Pix4D Capture and Mapper, Blender
Xu et al., 2016 [19]	Using a minimum spanning tree to construct scene correlation network can reduce the computational cost of image matching in Structure-from-Motion (SfM) for 3D scene reconstruction from UAV images while preserving the accuracy and completeness of the final scene geometry.	The computation required for large volumes of images in Structure-from-Motion (SfM)-based methods for 3D scene reconstruction has increased significantly. Future work is needed during the image matching phase, which is among the most time-consuming stages of SfM methods.	Fixed-wing UAV, Canon EOS 5D mark II	Pix4Dmapper, PhotoScan, Micmac
Ferworn et al., 2011 [20]	Commercial off-the-shelf hardware can be used to create a system that aids in disaster response efforts by allowing for aerial surveying and the creation of 3D models.	A more autonomous system could be developed to improve data quality and consistency, with real-time onboard point cloud modeling used to immediately direct search and rescue efforts.	MK Hexakopter 2	Microsoft Kinect video game peripheral
Gatziolis et al., 2015 [21]	GPS-enabled UAVs can be used for precise scaling of reconstructed tree point clouds. Higher image overlap does not significantly improve the accuracy or completeness of tree reconstructions.	Further research is needed for navigation precision in confined areas and obstacle avoidance in forested environments.	APM: Copter, Custom built DJI f550 UAV hexacopter	Mission Planner
Mohd Noor et al., 2020 [22]	The integration of MLS and UAV data can produce high-quality 3D models of building structures for cultural heritage purposes based on results of Malay cities.	The MLS approach can be expanded to capture other elements of the urban environment, such as vegetation, infrastructure, and natural features.	DJI Phantom 3, Topcon IP-S3 HD laser scanner	Agisoft PhotoScan, ESRI City Engine
Manajitprasert et al., 2019 [23]	This study found that the UAV–SfM approach is an effective and accurate tool for modeling 3D cultural heritage based on a case study conducted in Thailand.	Subsequent research could explore the incorporation of oblique images to identify and document minute details, thereby enhancing the effectiveness and precision of this technique as a substitute for laser scanning.	DJI Inspire 1 Pro, Riegl LMS-Z210 scanner	Pix4D, CloudCompare
Remondino, 2011 [24]	The authors found that 3D modeling and scanning technology contributed significantly to the documentation, conservation, and presentation of heritage information.	Developing new algorithms and methodologies can improve the 3D restitution pipeline, increase data storage, and improve the accessibility of geospatial data to non-expert users.	Helicopter, SLR camera	3D Studio Max, Maya, Sketchup, Blender
Yan et al., 2021 [25]	Using an optimized trajectory can significantly improve the performance and quality of aerial 3D urban reconstruction.	Future work could focus on further improving the efficiency and accuracy of the proposed method and extending it to other types of scenes.	DJI Phantom 4 Pro	Unreal4, COLMAP
Koch et al., 2019 [26]	An automatic 3D UAV flight framework can generate high-quality 3D models while ensuring safe flight paths in complex and densely built environments.	Future research could encompass a more flexible strategy for viewpoint placement that includes multiple orientations for each camera viewpoint while taking into account the materials of individual object parts.	DJI Mavic Pro 2	Pix4D, Blender

Author	Findings	Implications for Future Work	Hardware	Software
Duan et al., 2021 [27]	UAV data were used to generate a real 3D model and extract the lake boundary, enabling accurate representation of the lake's actual scene.	Future work could explore the potential of automatic driving technology in lake estimation.	DJI Phantom 4 Pro, Huawei no. 3/Apache 3	Bentley Context Capture Center 4.4, DP-Modeler 2.3
Jo and Hong, 2019 [28]	Combining terrestrial laser scanning and UAV photogrammetry into a hybrid technology can enhance the reliability and applicability of 3D digital documentation and spatial analysis for cultural heritage sites.	Further investigation is required to decrease positional inconsistencies between the two survey technologies and assess how they vary depending on various scales and geomorphic environments.	Leica Aibot X6, Sony Alpha 6000, Trimble R6 Model 3	Agisoft PhotoScan Profesional Edition
Papadopoulou et al., 2021 [29]	Using a digital elevation model (DEM) as a source of information for designing UAV flight plans tailored to the topography of each geosite can offer significant advantages over conventional image collection methods.	Subsequent research might focus on developing a fully automated algorithm based on the DEM of the study area.	DJI Phantom 4 Pro	AgiSoft Metashape Professional Edition, ESRI ArcMap, CloudCompare
Templin and Popielarczyk, 2020 [30]	UAV-based photogrammetry is a cost-effective and efficient approach for accurately scanning, surveying, and capturing reality in 3D when documenting cultural heritage.	Future work could include exploring possibilities of using higher-resolution cameras for better results.	DJI Phantom 4 PRO, Sony RX100 II, Leica ScanStation C10	CloudCompare, AgiSoft Metashape Professional Edition, Cyclone
Liang et al., 2017 [31]	This study found that UAV 3D modeling with high-resolution RS data can accurately calculate the three-dimension green quantity (3DGQ) of urban green spaces based on a case study conducted in China.	Future work should include more time points to improve accuracy in the use of 3DGQ in urban green space design and planning.	Zero UAV YS09	Pix4D

2. Main Application Analysis

One important application of UAV photogrammetry is damage assessment and reconstruction of cities [32]. Building destruction is a common byproduct of war and natural disaster. It is very often the case that original drawings and pictures that directly reflect the original appearance of the buildings cannot be found. Therefore, researchers can only use other materials to compare and restore them step by step. In this context, UAVs can be applied to a city's post-war reconstruction; photogrammetry allows researchers to create highly accurate models of ancient buildings and antiquities, while 3D models provide comprehensive digital data for infrastructure repair. Remarkably, despite the evident potential of UAVs in this domain, there is a surprising lack of scholarly articles specifically addressing this application. Further research and exploration in this area could significantly enhance the understanding and utilization of UAV photogrammetry for urban reconstruction endeavors.

Several challenges have been encountered in the use of photogrammetry to preserve cultural heritage. Many ancient and older heritage buildings have often undergone significant structural and appearance changes due to weathering, and may be fragile, making surveying difficult. In addition, recording details such as carvings and colors require close-up observations, which can be challenging. The remote and complex locations of many ancient buildings pose difficulties when manually setting up surveying equipment. Direct contact with fragile historic sites and ancient buildings can cause irreversible damage. UAVs provide a safe and non-contact solution for surveying and mapping, potentially revolutionizing the digitization of cultural heritage protection. The use of UAVs not only has the potential to enhance 3D documentation for the preservation of cultural resources, it could translate into new modes of historical interpretation through enhancements to virtual reality and augmented reality.

3. Common Themes

A number of studies have focused on using UAVs to map and model cultural heritage objects, urban spaces, and disaster sites with the goal of preserving, managing, and reconstructing historical sites in the future. While several studies have discussed the advantages of oblique photogrammetry over vertical photogrammetry in achieving higher accuracy in mapping, others have emphasized the necessity of developing systems that incorporate advanced technologies, such as 360∘° cameras and LiDAR technology, in order to generate precise representations of real-world environments [33].

Among the articles, many have common themes; for example, Li, 2018 [10] demonstrated the application of UAV photogrammetry in urban and regional planning, while Erenoglu et al., 2018 [14] studied the use of UAV technology for 3D modeling in relation to urban planning. Zhang et al., 2022 [15] presented a drone system empowered with artificial intelligence for real-time 3D reconstruction. Kikuchi et al. [13] created a method for visualizing urban 3D models through an outdoor augmented reality digital twin approach that provides low latency between the controller and the augmented reality digital twin device. In the context of historic preservation, Kikuchi et al., 2022 [13], Tariq et al., 2017 [11], and Berrett et al., 2021 [12] all focused on creating 3D models of historical sites using UAV photogrammetry and other technologies. Karachaliou et al., 2019 [9] developed an HBIM model of a museum using UAV photogrammetry, while Tariq et al., 2017 [11] used UAV photogrammetry to produce 3D models of archeological sites in Pakistan. Berrett et al., 2021 [12] developed a hyper-realistic 3D model of a university campus in the USA using UAV techniques in combination with other technologies. Li, 2018 [10] and Erenoglu et al., 2018 [14] both aimed to investigate the accuracy of UAV-based 3D modeling in urban planning, while Zhang et al., 2021 [15] focused on developing a real-time 3D reconstruction system using UAV technology. Kikuchi et al., 2022 [13] developed an outdoor augmented reality digital twin approach for public participation in urban design decision-making processes.

Several studies have demonstrated the potential of UAV photogrammetry in creating realistic 3D models of historical buildings, with Tariq et al., 2017 [11] using photogrammetry to develop accurate 3D models of archaeological sites in Pakistan and Karachaliou et al., 2019 [9] using UAV photogrammetry to create an HBIM model of the Averof's Museum of Neohellenic Art in Greece. Erenoglu et al., 2018 [14] further investigated the accuracy of UAV-based 3D modeling and found it to be reliable and adaptable to different 3D modeling applications.

A number of studies have explored the use of UAVs to aid in disaster response, including Ferworn et al., 2011 [20], who suggested the use of readily available hardware to develop a system that can capture aerial data on disaster sites and create 3D models, potentially enhancing the effectiveness of existing disaster response techniques and guidelines. Soulakellis et al., 2020 [34] examined and proved the feasibility of using drone-based Structure-from-Motion (SfM) methods to aid in post-earthquake recovery. Similarly, Zhang et al., 2022 [15] presented their development of an artificial intelligence-empowered drone system that achieves real-time 3D reconstruction, which could be used for practical applications for data analysis and decision-making.

Studies have shown that UAVs have great potential when combined with other technologies. Campbell, 2018 [16] demonstrated the use of drones, photogrammetry, and virtual reality (VR) in documenting and preserving cultural artifacts at the Lelu ruins in Micronesia. Additionally, a UAV system powered by artificial intelligence with the ability to perform real-time 3D reconstruction of urban cities was presented in [15]; using a combination of depth fusion and visual–inertial odometry, this system allows for improved 3D model quality and interactive navigation guidance.

4. Common Method and Model

The utilization of UAVs in urban planning and protection involves various methods, technologies, and models for image processing and modeling analysis. These methods contribute to the effectiveness and efficiency of UAV-based data collection and analysis.

Several key studies have highlighted the innovations in this field; for instance, one study presented a multi-UAV coverage path planning method for 3D reconstruction of post-disaster damaged buildings [35]. The methodology involved generating camera location points surrounding targeted damaged buildings, filtering and sorting these points, and optimizing routes to balance flight distance and time. The proposed method outperformed conventional overhead flight with the nadir-looking method, resulting in higher-quality 3D models. This study highlights the importance of UAVs along with their role in capturing high-resolution images and detailed information for assessing damage situations in specific areas.

The integration of OpenStreetMap (OSM) data with the Advanced Land Observing Satellite-2 World 3D-30 m (AW3D-30) digital surface model (DSM) has demonstrated substantial potential for scientific research, in particular due to the increasing size of OSM data and the global coverage of AW3D-30 [36]. This study emphasized the need for a global completeness assessment of OSM data in order to enhance its utility, acknowledging concerns about data quality, as OSM data are primarily contributed by non-professionals. Nonetheless, OSM remains a valuable source of 2D building data, especially in regions where authorized building data are not freely available.

In terms of data extraction and surface reconstruction, Pix4Dmapper software (version 4.8) is commonly used for transforming images collected by UAVs into various outputs, such as 3D point clouds, orthomosaics, and DSMs [18]. The software employs computer vision and photogrammetry techniques to process geo-tagged images and generate dense point clouds, 3D meshes, and textured models. Additionally, Blender (version 4.0), an open-source 3D render software, can be used to enhance the photorealism of 3D models generated by Pix4Dmapper. Blender enables texture mapping, lighting adjustments, denoising filters, and other rendering enhancements to produce high-quality visualizations.

Another study proposed a city-scale digital twin approach for future landscape visualization using AR and drones. The method involved rendering AR with occlusion handling, using a detailed city 3D model on a server PC using software such as Unity (version 2020.1.7) and Metashape (version 1.6.0), and integrating it with an AR device to generate both first-person and overhead views [13]. The IoU segmentation metric was used to evaluate the accuracy when handling occlusion. The proposed method can enable free AR viewpoints and multiple-stakeholder participation in urban design projects.

These examples demonstrate the ongoing technological innovations in image processing and modeling analysis for UAV-based urban planning and protection. The integration of OSM data with AW3D-30 DSM, multi-UAV coverage path planning methods, and advanced software tools such as Pix4Dmapper and Blender showcase the evolving capabilities and quantitative effects of UAV image processing and modeling. These advancements contribute to the generation of accurate and detailed spatial information, facilitating informed decision-making and planning in urban environments.

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