Functional Applications of Unmanned Aerial Vehicle Technology in Urban Planning Practice: A PRISMA systematic Review

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1 ABSTRACT

Covid-19 pandemic has arguablely created an opportunity for urban planners to create cities that are more resilient and sustainable. This systematic review was aimed at analysing the potential of Unmanned Aerial Vehicle (UAV) technology as a tool for post-covid-19 urban planning and design. Specifically, the study reviewed the functional application areas that have leveraged the existence of UAV technology since its inclusion in non-military sectors in 2006. PRISMA method was used to retrieve journal articles that were published between 2006 and 2022 from scopus database and a total of 48 journal articles were included in the study. The results of the literature analysis revealed that there is a growing application of UAV technology in urban disaster managemnert, smartcities development initiatives, urban landscape management and urban road transportation management. The study also revealed that there is already a research increase on UAV integration in urban planning from 2019 which signifies the contribution of the pandemic towards UAV adoption. It has also been established that there is an increasing application of Machine Leaning (ML) and Computer Vision (CV) models for UAV data analysis. The study concludes that UAV technology has a lot of potential for improving urban planning processes with regard to time, cost, and safety and hence can be regarded as one of the sustainable tools in post-covid-19 urban planning efforts. Therefore, there is need for robust research to explore its potential in other application areas such as municipal waste management, urban developement control, and urban drainage systems among others. The study also recommends that basic courses on Artificial Intelligence (AI) be introduced in urban planning education to equip urban planners on the emerging AI applications.

Keywords: Unnamed Aerial Vehicles, Urban Planning, Artificial Intelligence, Machine Learning, Computer Vision

2 INTRODUCTION

2.1 Study Background

The impact of the covid-19 global pandemic has generally been seen as two-fold. While a significant proportion of the global population perceived the pandemic as a huge threat, some studies have revealed that the pandemic is an opportunity in some respect (Aboagye et al., 2021; Sharifi & Khavarian-Garmsir, 2020). One of the notable positive contributions of the pandemic is the increase in the invention of new digital technologies or at least an increase in the adoption of the already existing ones across different sectors whose impact has been far more positive in terms of production efficiency and cost-effectiveness. For example, Bukovska et al., (2021) investigated the impact of Covid-19 on technological adoption in the meeting and event industry and established that about 69 percent of the investigated events migrated to virtual or hybrid format and therefore increased the adoption of conferencing technologies. Similarly, Serbulova et al., (2020) and Farrugia et al., (2020) established similar findings in the business and the health sectors respectively.

In cities, Covid-19 pandemic has arguably created a new landscape that some scholars have deemed an opportunity for urban planners to create cities that are more resilient and sustainable (Sharifi, 2020). However, as history suggests, this new landscape is significantly parallel to the crises that gave birth to urban planning profession about two centuries ago (Smith, 2007, 2012; Smith & Lobo, 2019). It therefore implies that achieving the new dream of a sustainable cities calls for new planning techniques that match the current urban challenges. In this study, a systematic literature review was employed to assess the potential of Unmanned Aerial Vehicles (UAV) technology (popularly known as drones) in urban planning practice as planning solution for the development of new sustainable cities. Specifically, the study intended to identify and analyse the functional application areas that have leveraged the existence of UAV technology since its inclusion in the civilian sectors and to understand its prospects for post-covid-19 urban planning and design. Additionally, we also analysed commonly used supporting technologies for performing UAV-based data analysis from the retrieved articles.

2.2 Background of UAV Technology

UAV technology is one of the state-of-the-art innovations that was invented in the 1800s. History indicates that in the past, the application of UAV technology was only limited to military purposes. For example, the first usage of drones was recorded in 1849 during the first Italian war of independence when Australian Empire devised a system of unmanned hot air balloons to drop bombs in Venice (Rakha and Gorodetsky, 2018). Later, the hot air balloons were also used during the American civil war and the Spanish-American war to gather and telegraph reconnaissance. Over time, however, UAV technology has gone through a series of evolutions to accommodate civilian applications. The major turnaround appeared recently in the 21st century when Frank Wang and his colleagues established DJI Technology company in 2006 which started producing drones for personal and commercial use (Mac, 2015). Since then, a lot of sectors including commerce, engineering, mining, and health, have all adopted this technology to improve operational efficiency among other things.

Similarly, the built environment sector has also leveraged the existence of UAV technology. Many studies documenting the application of UAVs in the built environment have shown that this technology can be successfully applied in building inspections, construction project monitoring, and infrastructure crack detection among others. For example, Patel et al., (2021) investigated the potential application of remotely Unmanned Aerial vehicles in construction management. In their study, they used a mobile-piloted drone to capture digital images of a seven-floored building that was under construction. Using a Pix4D software, they analysed the images and concluded that UAVs have the capability to capture building information like slab length, column dimension, and building area. UAVs also have secondary capabilities such as monitoring construction progress and updating project schedules. Again, Rakha & Gorodetsky, (2018) investigated how UAVs can be used to remotely detect cracks in buildings to facilitate maintenance planning. Drone-mounted cameras were used in the study to capture infrared images of a buildings. After analysing the infrared images, they concluded that UAV technology has the capability to effectively detect building cracks of all kinds and magnitude. Generally, the built environment sector is primed for growth in UAV applications, (Albeaino et al., 2019).

3 RESEARCH METHODS

To achieve the study objectives, the we adopted a systematic review approach. PRISMA protocol was used to retrieve journal articles related to UAV technology and urban planning from Scopus database. Scopus database was preferred, on one hand, for its wide coverage which guarantees comprehensiveness in the search results on the targeted subject (Onososen and Musonda, 2022). On the other hand, PRISMA protocol was preferred for its widespread acceptance, comprehensiveness, and wide variety of applications in numerous academic disciplines as well as for its ability to improve the accuracy and transparency of academic literature reviews (Samuel Adeyinka-Ojo, 2021; Shahruddin and Zairul, 2020).

To obtain comprehensive results from the literature search, the following search combination was used: “Drones OR unmanned aerial vehicles OR unmanned aerial systems AND urban planning” AND “Drones OR unmanned aerial vehicles OR unmanned aerial systems AND city planning” AND “Drones OR unmanned aerial vehicles OR unmanned aerial systems AND town planning”. A total of 664 papers were identified and 48 journal articles were included in the study after applying various screening criteria. Figure 1 shows the PRISMA flow diagram which summarises the search process. The 48 journal articles were classified into three research categories: application research, process optimisation research and mixed research. In the results and discussion section, we focused on the papers under the “application research” category.

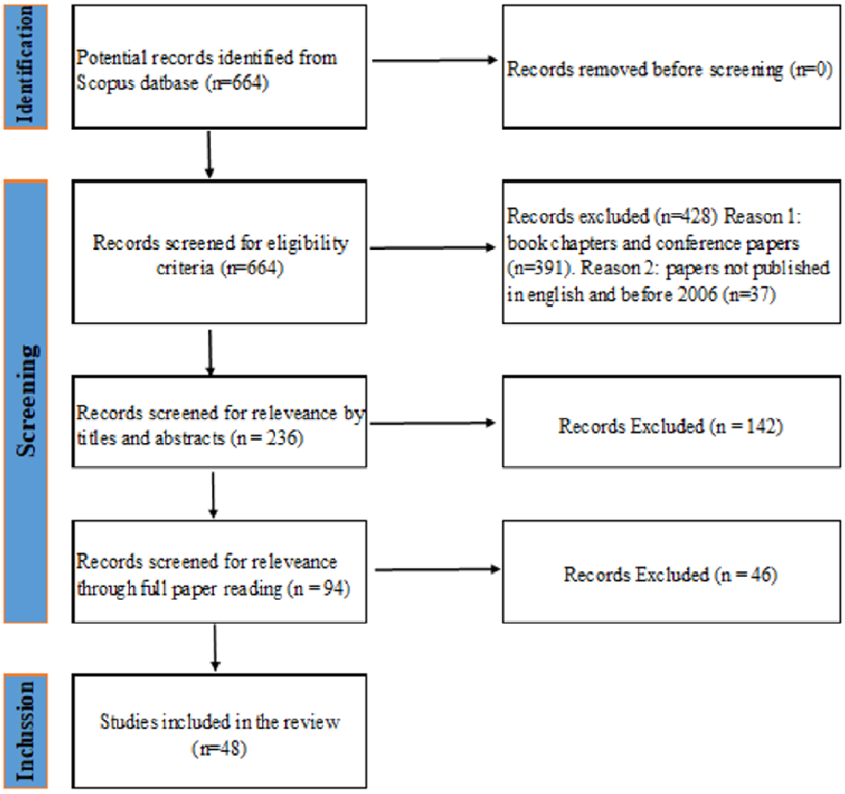

Fig. 1: The PRISMA flow diagram.

4 RESULTS AND DISCUSSION

4.1 Publications by Year

Scopus Analyst tool was used to analyse the 48 sampled journal articles to understand their distribution in terms of year of publication. Figure 2 summarizes the results. According to figure 2, about 92% of the sampled articles were published within the last five years between 2018 and 2022. From 2006 to 2017, only four studies (8%) related to UAVs and urban planning were published. This shows that UAV technology adoption for urban planning purposes is still a novel development. However, the trend shows a growth in the sense that from the year 2017, the publications have been increasing at a steady rate. If this trend continues, the technology might be widely adopted in few years to come. This aligns with the predictions by CIO Tech Outlook, (2020) that adoption of UAV technology across various industries such as agriculture, logistics, photography, mining, construction, and surveillance is going to increase at a rapid pace in the years to come. The steady boom of publications between 2019 and 2021 might also be attributed to the Covid-19 pandemic which necessitated minimization of physical contact between people.

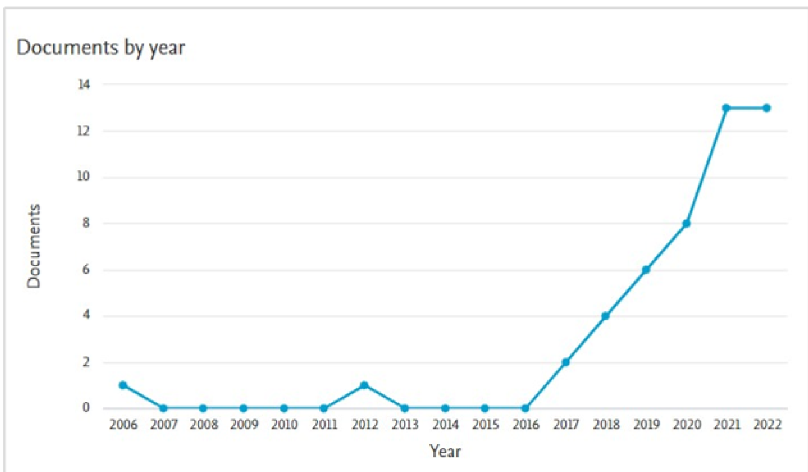

Fig. 2: Distribution of the sampled articles by year of publication. Source: Author, 2023.

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4.2 Emerging Research Categories

A comprehensive thematic analysis of the sampled papers was conducted to understand the key research categories relating to UAV technology and urban planning. The study derived that UAV research in urban planning can be categorized into three main groups: process optimization research; application research; and mixed research. Process optimization relates to all studies that are aimed at optimizing or improving the efficiency in the processes of integrating UAV technology in urban planning and management. For examples, some studies focused on developing algorithms or models for UAV flight path planning to ensure efficiency in energy consumption and increase flight time of UAVs in big cities; or algorithms for collision avoidance such as tall buildings in cities; or algorithms for multi-UAV communication when the targeted flight area is wide. Some process optimization studies have also focused on developing algorithms for post data (image/video) processing such as image segmentation or feature extraction (Boonpook et al., 2021; Pilinja Subrahmanya et al., 2021; Vazquez-Carmona et al., 2022). On the other hand, application research includes studies that relate to the actual usege of UAV technology to solve real-life urban problems. For example, Ullah et al., (2021) applied UAVs to map the extent of bushfire disaster to inform policy formulation for post-disaster recovery initiatives. Saputra et al., (2022) also employed UAV technology to simulate a flooding event and model the potential impact on vulnerable communities Indonesia to inform policy formulation for disaster prevention preparedness strategies. Lastly, the mixed research category includes those studies that involve the development of process optimization tools such as flight path or image processing algorithms but also involve the testing of the developed toolkits to solve real-life urban problems and ascertain their performance (Aljehani and Inoue, 2019; Escobar-Silva et al., 2022; Zhao et al., 2022).

Figure 3 summarizes the classification of the sampled articles based on their thematic categories. The figure shows that the majority (48%) of UAV research in urban planning deals with process optimization. This means that the technology is still developing, and full integration has not been achieved yet. However, a significant proportion (42%) of application research was also recorded meaning that there is concurrency between research and application. The remaining 10% of the sampled studies were classified as mixed research.

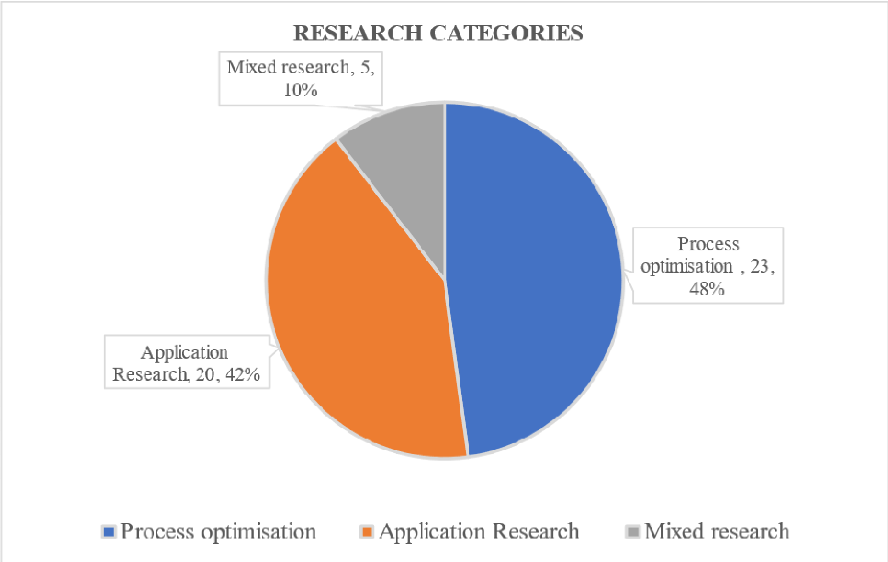

Fig. 3: Emerging Research Categories in UAV Application in Urban Planning

4.3 Functional Application Areas of UAV Technology in Urban Planning Practice

As stated earlier, the study also intended to uncover the common functional areas of UAV technology application in urban planning discipline to derive its prospects in post-covid-19 urban planning and design. It has been established that the major areas of application include Urban disaster management (23%), smart cities development initiatives (19%), urban landscape management (15%), and urban road transportation management (13%). Landcover change analysis and Urban Heat Island (UHI) mapping are the least exploited application areas with a 2% score each. These results imply that there are still a lot more functional areas within the urban planning domain where UAV technology has not been explored yet. Therefore, further research is necessary to explore more application areas. Table 1 summarises the identified areas of application and the major ones are expounded in subsequent sections focusing only on those studies that involve practical usage of drones rather than optimizing the process of UAV integration.

GENERAL AREA OF APPLICATION	SPECIFIC TOPICS TACKLED	NUMBER AND PERCENTAGE OF SAMPLED ARTICLES	SOURCES
Urban Disaster Management	Earthquakes, Flash floods, Volcanos, landslides, gully erosion, typhoons, bushfires,	11, 23%	(Aljehani and Inoue, 2019; Assis et al., 2020; Gudino-Elizondo et al., 2018; Huang et al., 2017; Li et al., 2012; Qadir et al., 2021; Saputra et al., 2022; Ullah et al., 2021; Wang et al., 2018; Wu et al., 2020; Zhan et al., 2018)
Smart Cities Development Initiatives	Smart Health; Smart transportation; smart energy; smart governance;	9, 19%	(Ahmed Hamza et al., 2022; Aloqaily et al., 2022; Dudek and Kujawski, 2022; Liu, Zhu, et al., 2022; Nelson and Grubesic, 2020; Sultonov et al., 2022; Templin and Popielarczyk, 2020; Teng et al., 2021; Vazquez-Carmona et al., 2022)
Urban Landscape Management	Monitoring urban vegetation cover	7, 15%	(Alvarado-Robles et al., 2022; Behera et al., 2022; Escobar-Silva et al., 2022; Feng and Li, 2019; Lee et al., 2021; Wu et al., 2021; Zhao et al., 2022)
Urban Road Transportation Management	Road traffic management; road infrastructure management; parking spaces management	6, 13%	(Coifman et al., n.d.; Jalayer et al., n.d.; Javadi et al., 2021; Li et al., 2019; Liu and Zhang, 2021; Luo et al., 2019)
Building Data Inventory	Identification and extraction of buildings and building attribute data from UAV images using various algorithms	4, 8%	(Ahmed et al., 2020; Boonpook et al., 2021; Pilinja Subrahmanya et al., 2021; Vacca et al., 2017)
Urban Security and Safety	Urban surveillance and security patrol	3, 6%	(Huang and Savkin, 2020, 2021; Liu, Bao, et al., 2022)
Urban Recreation	Parks and other public open spaces management	2, 4%	(Park, 2020; Rodríguez et al., 2022)
Urban Environmental Monitoring	Environmental quality monitoring; chemical pollution mapping	2, 4%	(He et al., 2019; Zhao et al., 2018)
Landcover Change Analysis	Mapping urban landcover changes overtime	1, 2%	(Hassan et al., 2020)
Urban Heat Island Mapping	Mapping urban surface temperatures	1, 2%	(Dimitrov et al., 2021)
Others	Cadastral data verification; energy optimization in built environments	2, 4%	(Arjoune et al., 2021; Cienciała et al., 2021)

4.3.1 UAV Technology in Urban Disaster Management

The nexus between cities and disasters is unequivocal. In general, urban areas tend to suffer more fatalities and economic losses from disasters than rural areas, possibly due to the aggregation of people, infrastructure and assets, urban expansion, and inadequate management. According to UNDES (2019), more than half (58%) of the world cities have a high level of exposure to at least one type of natural disaster such as cyclones, floods, droughts, earthquakes, landslides, and volcanic eruptions. With 68% of the global population projected to live in cities by 2050 (UN-Habitat, 2022), it transpires that cities or urban areas in general remain the central focus of disaster risk management. Besides, the rapid and often unplanned expansion of cities is exposing more people and economic assets to the risk of disasters and the effects of climate change (World Bank, 2012).

When it comes to urban disaster management, the current study has revealed that UAV technology has been used in managing different kinds of both natural and man-made urban disasters such as urban flooding (Gudino-Elizondo et al., 2018; Li et al., 2012; Saputra et al., 2022); typhoons (Wu et al., 2020); earthquakes (Assis et al., 2020); landslides (Huang et al., 2017; Wang et al., 2018); and bushfires (Ullah et al., 2021) among others. Aditya et al, (2022) applied UAV technology in urban flooding modelling in the small town of Java in Indonesia. Images from drones were used to create landcover maps and generate Digital Elevation Models (DEM) for simulating flood impact and predict the probability and the gravity of flooding events. Similarly, Li et al., (2012) used UAV images to simulate the potential level of impact that a dam break disaster from mass movement would have caused in Xiaojiaqiao city in China to inform future disaster preparedness strategies. Wua et al., (2020) used drone images to assess the level of damage from typhoon disaster in Xiamen city in China. From the images, they were able to map and compute the extent of disaster damage for recovery planning purposes. The study concluded that drones could provide technical and decision-making support for urban disaster emergency rescue, ecological restoration, environmental monitoring and for urban planning in general. Furthermore, Gudino-Elizondo et al., (2018) applied drone technology to quantify and measure the attributes of gullies in urban areas after a storm event in Los-Laureles Canyon Watershed, in Tijuana, Mexico. Using various image analysis techniques, they were able to map the gully network extent and estimate different gully parameters such as gully heads. This informed the planning of recovery actions by various urban stakeholders.

4.3.2 UAV Technology and Urban Landscape Design and Management

Urban landscape management is defined as the management of open spaces and greenspaces, like residential green spaces, parks, playgrounds, etc. (Anguluri & Narayanan, 2017). Modern urban landscape management approaches incorporate various technologies to achieve sustainability goals and UAV technology is one of them. Research has shown that UAV technology can be successfully applied to estimate vegetation growth in urban green spaces, classify vegetation cover in an urban area, and map the distribution and trends in landcover changes. In this regard, Escobar-Silva et al., (2022) used drones to estimate grass growth in urban green spaces. The study involved integrating UAV technology and GIS to model and predict the growth of Bahia grass in Southeastern Brazil to facilitate the planning of grass cutting and mowing by city managers. Besides predicting growth, UAV technology was also able to capture vegetation parameters such as Leaf Area Index (LAI), soil water content, biomass, and evapotranspiration rate. It was also established that using this model would have a cost-cutting effect on landscaping processes.

Lee et al., (2021) developed vegetation detection model using UAV images. In this study drones were used to capture multispectral images that were then used to classify urban landcover to identify and analyse the distribution of vegetation in urban areas to support decision making in urban regeneration programs. The results showed that the model was able to differentiate real vegetation from other vegetation-like features such as green roofs and artificial grass. Related studies were also conducted by Feng & Li (2019); Zhao et al., (2022); and Robles et al., (2022). In their approach, they integrated UAV capabilities with other supporting technologies such as photogrammetry and Machine Learning models to reinforce UAV capabilities to identify, map the distribution, and compute vegetation parameters in urban green spaces.

4.3.3 UAV Technology and Urban Recreation

UAV technology has also been successfully applied in urban recreation. Rodríguez et al., (2022) applied drone technology to measure thermal comfort in an urban public space in Huelva, Spain. Thermal comfort simply means the level of comfort by public space users with park heat levels. Drones mounted with thermal cameras and sensors were used to collect infrared images of a public open space to measure thermal comfort. The estimated figures of mean radiant temperatures from the images were verified with the ones collected in real-time and the results showed high accuracy. It was then concluded that, this aerial thermography can be adopted as a way of measuring thermal comfort. Another drone technology application in urban recreation was conducted by Park, (2020). In this application case, drones were used to assess the level of park use in terms of number of people who use urban parks and their characteristics such as gender and age group at different times of the day and different days of the week. Drones were used to collect High Definition (HD) videos of the selected parks which were later assessed by a professional video assessor. By using this method, park use related information were collected at a lower cost compared to physical observation.

4.4 UAV Data Processing Tools and Techniques

A thorough analysis of the commonly used UAV data (Images and videos) processing techniques was also conducted in this study. An initial assessment revealed that about 90% (43 articles) of the sampled studies involved some sort of images/ video processing to achieve the intended objectives. The remaining 10% (8 articles) did not involve any data processing mainly because they are optimization research and their main study objective was merely to develop algorithms to improve some processes for UAV integration such as flight path planning (Qadir et al., 2021; Vazquez-Carmona et al., 2022) or to improve multi-UAV communication in urban an environment (Liu, Bao, et al., 2022; Teng et al., 2021). For the former, it has been established that to achieve maximum efficiency, the adoption and use of UAV technology in urban planning discipline is constantly fused with other supporting technologies. Out of the 43 studies that involved processing of UAV images and/ or videos, only 5% (2 articles) involved the use of human intelligence for the analysis. In one study, Park, (2020) assessed the level of park use in terms of number of people who use parks and their characteristics such as gender and age group at different times of the day and different days of the week. He used UAVs to collect High-Definition videos of the selected publics parks which were later analysed by a professional video assessor to extract the park use related information. Further analyses were also conducted to assess the correlation of park use and the attributes of the surrounding environments or neighbourhoods. In the other study, Jalayer et al., (2019) used UAVs to capture images for inspecting and inventorying interchanges assets as a way of minimizing Wrong Way Driving (WWD) crashes on road interchanges. A visual analysis of the UAV images was used to identify the presence or absence interchange assets such as installed road signs, pavement markings, and geometric features and their condition.

However, for the rest of the studies (95%) various supporting technologies, other than human intelligence, were used. These technologies have been classified into five main groups: GIS-related technologies; Machine Learning (ML)/ Computer Vision (CV) technologies; Photogrammetry technologies; mixed technologies; and Others. Figure 4 summarizes the results.

GIS related technologies involve the use of Geographic Information Systems software to process UAV images to achieve research objectives. The commonly used software under this category was the Esri ArcMap. Only one study (Wu et al., 2021) applied a different GIS software, ENVI 5.3 Version, to analyse UAV images. Studies that used GIS related technologies accounted for 19% of the total articles.

Machine leaning/ computer vision technology involve the utilization of ML/ CV algorithms or models to perform image/ video analysis such as object segmentation, and feature extraction. In this study, it has been established that 44% of the total studies utilized ML/ CV algorithms to perform UAV image analysis. Deep learning algorithms such as You Only Look Once (YOLO), and Artificial Neural Networks (ANN) are the commonly used algorithms that were identified in most studies.

Photogrammetry technologies were classified as those technologies that support the pre-processing of UAV images such as image alignment and generation of orthophotos for further analysis. In this study, only 12% (5 articles) relied entirely on photogrammetry technologies for UAV image analysis. Agisoft Photoscan, Agisoft Metashape, and Pix4 Desktop Mapper software were commonly used under this category.

The mixed category involved an integration of multiple technologies to perform image/video processing. For example, Boonpook et al., (2021) integrated photogrammetry technology (Pix4 Desktop Mapper) and ML/CV based technologies (Deep Learning) to automatically extract buildings data from UAV collected images. On the other hand, Assis et al., (2020); Gudino-Elizondo et al., (2018); Lee et al., (2021); Nelson & Grubesic, (2020); and Wu et al., (2020) integrated various photogrammetry technologies with GIS technologies to analyse UAV images and videos in their respective studies.

From the analysis, it can be concluded that ML/CV is the most used processing technique in modern urban planning research and practice. Although Machine Learning is relatively a new branch of technology, its growth in application is rapid and has more potential for a technological takeover.

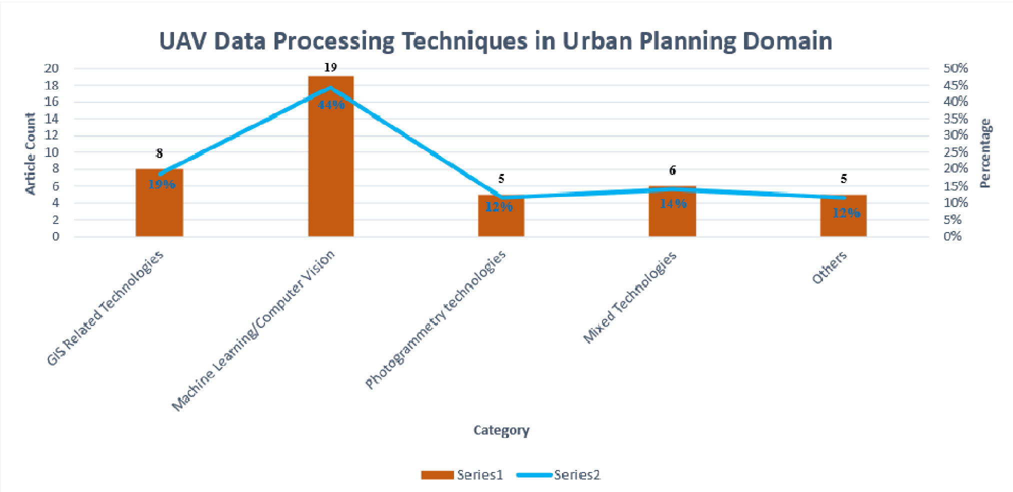

Fig. 4: Common UAV Data Processing Techniques in Urban Planning Research.

5 CONCLUSION

This study intended to review functional applications of UAV technology in Urban planning practice and understand its potential for post Covid-19 urban planning and design by using a systematic literature review approach. The results have shown that there are many success stories of UAV technology in different urban planning related area so far. Among the common areas discovered include urban disaster management, smart cities development initiatives, urban landscape management, and urban recreation. The study has also shown that there is a growing trend in UAV research in urban planning, including process optimization research, which signals high potential for future adoption of the technology in urban planning sector. The study has also revealed that there is a growing integration of Machine Learning models alongside Geographical Information Systems as the major techniques for UAV data analysis. Therefore, this study concludes that, UAV technology has a lot of potential and can be adopted as one of the sustainable tools for post covid-19 urban planning and design to carter for the increasing need for less physical contact between planning officials and city residents when executing planning roles.

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