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Exploring the Use of Aerial Imagery Drone Perspectives for Site Survey and Inventory in Urban Landscape Design

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Information

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Exploring the Use of Aerial Imagery Drone Perspectives for Site Survey and Inventory in Urban Landscape Design

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Abstract

This thesis investigates how the use of aerial drone perspectives can supplement the site survey and inventory stage of urban landscape design. Through a case study, the capabilities of drones in capturing multiple vertical and oblique perspectives of an urban landscape site is demonstrated. The findings reveal both the benefits and limitations of these perspectives for informing and communicating site survey and inventory information.

Oblique aerial drone perspectives are beneficial in providing multiple comprehensive views of an urban site and its contextual landscape. The perspectives can be used for understanding and inventorying site features and conditions. However, ground perspectives and photos may still be necessary. Furthermore, this study shows that oblique aerial perspectives provide the ability to highlight, convey, and present site survey and inventory information.

Additionally, this study demonstrates that drone mapping missions offer multiple high-resolution vertical photo perspectives of an entire urban site, which further facilitates the inventorying and understanding of conditions, features, and patterns. The resulting photos can be processed into an orthomosaic, serving as a complete top-down site perspective and can be used as a base map.

As traditional site survey and inventory methods include the use of open-access databases, this study also demonstrates comparisons to a commonly used open-access database for urban imagery. The oblique, vertical, and orthomosaic drone imagery provides more up-to-date site data and higher-resolution perspectives of urban site conditions in comparison.

A review and analysis of literature and existing studies is also elaborated in this thesis. It discusses the role and potential drones can play in site survey and inventory in urban landscape design by reviewing the advantages, capabilities, limitations, and challenges of drone use and data. It further discusses drone applications and visualization that is relevant for urban landscape design.

This study shows that capturing aerial drone perspectives during a physical site visit can supplement the site survey and inventory stage, without significant investment in additional time. By leveraging the benefits of aerial drone perspectives and considering their limitations, their use can prove valuable in the site survey and inventory stage of urban landscape design.

Key Terms: Drone, Drone Mapping, Site Survey, Site Inventory, UAV, Urban Landscape Design, Orthomosaic

Technical Terms

Base map - a foundational map for reference and overlaying other data, such as aerial imagery or land boundaries

CAD - Computer Aided-Design is drafting software or tools to create architectural and engineering designs

Digital Terrain Model (DTM) - a digital topographic representation of an areas land surface, not including on-surface features

Digital Surface Model (DSM) - a digital topographic representation of an areas land surface that includes on-surface features

Drone - an unmanned aircraft that is remotely controlled and can fly autonomously to perform various tasks, and typically includes one or more sensors

Drone mapping - the process of using a drone to capture vertical aerial images along a planned flight path to create accurate imagery maps of an area

Geographic Information Systems (GIS) - computer-based tools that allows users to display, process, and analyze geographic data or produce maps

Oblique drone photo - an angled aerial perspective picture taken of an area using a drone

Orthomosiaic - an accurate high-resolution aerial image that has been mosaiced together from multiple vertical photos of an area

Photogrammetry - the processing of captured aerial photographs using a drone to create accurate measurements or models of an area

Remote sensing - the collection of sensor related information or data from a remote distance, such as with a drone

Sensor - a component on a drone that enables it to collect various data, such as photography or video

Urban landscape design - the process of planning and designing functional, sustainable, or aesthetically pleasing outdoor spaces in urban areas

Vertical drone photo - a straight-down (or top-down) aerial picture taken of an area from above using a drone

Table of Contents

Introduction

Vertical Image of Houston, Texas, USA Case Study Site

“Drones are becoming pretty standard in our practice, but there’s still a lot of work for landscape architecture to catch up with them on their capabilities. We’re slowly getting there (Antelis, 2022).”

Emily McCoy, Associate Professor of Practice in
Landscape Architecture and Environmental Planning,
North Carolina State University

Background
The site survey and inventory stage is the first and essential stage in the process of urban landscape design. The site survey and inventory stage provides and communicates all the necessary information about the existing conditions, features, and characteristics of a site and its surrounding contextual landscape. Traditionally, this stage involves in-person site visits and on-site observations for data-collection, along with open-access database research conducted as office work (Dinc and Gul, 2022). However, these traditional methods come with some limitations. They offer limited or ground-level perspectives, map-based views, or use low resolution quality data. Moreover, the site perspectives offered may be outdated.

In recent years, the emergence of drones, otherwise referred to as Unmanned Aerial Vehicles (UAVs), has opened up new possibilities for data collection, perspectives, and visualization across various urban applications and landscape-related industries (Tal & Altschuld, 2021; Albeaino et al., 2019; Videras et al., 2021). The potential of drones in the practice of landscape architecture however has only gradually become realized (Kullman, 2018).

The main purpose of this thesis is to explore how aerial drone perspectives can supplement the site survey and inventory stage of urban landscape design.

Problem Statement
Drones have been increasingly used in different applications in the urban context (Albeaino et al., 2019), as well as in the AEC industries of architecture, engineering, and construction (Tal & Altschuld, 2021). However, their adoption in the field of landscape architecture practice has been relatively moderate (Kullman, 2018). Moreover, the connection of drones to the urban landscape design process, and more specifically the site survey and inventory stage within the design process, currently lacks in the state of research. Drone technology today offers unique aerial perspectives and mapping capabilities that must be further explored and discussed in the site survey and inventory context of urban landscape design.

Objectives
The research question for this thesis is:

How can the use of aerial drone perspectives supplement the site survey and inventory stage of urban landscape design?

The first objective of this thesis is to investigate the capabilities of drones in capturing aerial perspectives, specifically vertical and oblique angles, of an urban landscape site. The aim is to identify the benefits and limitations of the aerial perspectives for informing site survey and inventory in urban landscape design. Additionally, this research will explore how the perspectives can effectively communicate site survey and inventory information.

The method of thesis uses a case study to answer the question and objectives. Qualitative methods of analysis are used in the case study.

Scope and Limitations

Important to note as a limitation of this study, the case study will only investigate the capabilities of drones for capturing aerial perspectives, specifically vertical and oblique angles. This investigation aims to provide insights into the benefits and limitations of using drones for informing and communicating site survey and inventory in urban landscape design. The case study uses basic drone equipment to demonstrate results. However, a review of literature in this study analyzes and discusses the capabilities, advantages, limitations, and challenges of drones for informing and communicating site survey and inventory.

The case study research was conducted within a specific geographical area, potentially limiting the generalization of the findings to other contexts.

Broader considerations such as the challenges and regulatory aspects of drone usage will be discussed, but not extensively examined.

Significance

By exploring the use of aerial drone perspectives in the site survey and inventory stage, this research can contribute to the understanding of using drones as a tool in the widely practiced urban landscape design context, and as a supplement to physical site survey and inventory.

Furthermore, the study can shed light on the potential of drones to bridge the gap between traditional survey or inventory methods with emerging technological approaches. Potentially influencing the use of drones in future urban landscape design work.

Intended Audience

This thesis was written to complete the Master of Science in Landscape Architecture for Global Sustainability (GLA) program at the Norwegian University of Life Sciences (NMBU) in Ås, Norway in Spring 2023. The intended audience is students, researchers, and professionals of landscape architecture. Additionally, professionals, researchers, or hobbyists of drone technology. This thesis may also interest academics or professionals of other disciplines, such as urban planning, to understand potential implications of how drone technology can benefit their respective fields.

Inspiration for Thesis Research

During the Autumn of 2022, drone data collection and experimentation was personally conducted for the studio course 'Analysis and Design of Contested Landscape III'. This studio course is required for the Landscape Architecture for Global Sustainability master program at NMBU. The focus of the studio course was a landscape analysis and design investigation of the Haugerud neighborhood of Oslo, Norway.

The background for the studio focus was the Oslo city government planning agency's proposal for changes and development of the urban and public spaces within the Haugerud neighborhood, and adjacent Trosterud area. The planning area is shown on the top right (see Figure 1). The proposal includes changes to roads, pedestrian and cycle paths, and parks. The proposal also includes the development of housing, school, and sport facilities (Oslo Kommune, 2018). Also an aspect of the plan is the wish to reopen a buried watercourse, or the daylighting of a stream, that runs through the Haugerud area (Oslo Kommune, 2018). An overview map of the urban plan and design is shown in the map figure in the bottom right of this page (see Figure 2). The plan is still on-going at the time of this writing.

As a student, drone video and photography was collected during in-person field visits to Haugerud for personal studio work. However, the studio professor requested the sharing of the video and photographs to open the design presentations for the mid-term and final reviews of the studio course.

The video and photographic data proved to be very useful, interesting, and visually-engaging as introduction to the urban landscape of Haugerud for fellow students and the course examiners. It served well as an up-to-date and high detail aerial walk-through of the urban Haugerud landscape. The professor, students, and examiners could see the design investigation landscape in perspectives not offered from existing information, such as maps or open-access information. They were intrigued by the use of the drone in the studio context and the ability to see their study location in an exciting new way.

Since the agency's plans includes the possible daylighting of the buried stream in Haugerud, the drone photographs were used as a site survey and inventory PowerPoint presentation to convey the storm water drainage area of the Haugerud landscape, from the Marka (neighboring forest) through the city center of Haugerud. Four of the slides are shown on the proceeding page (see Figures 3 - 6 on page 12).

Additionally, experimentation with creating an orthomosaic in the area was tested, merging multiple drone photos to create an up-to-date and top-down photographic map for design inquiry, shown in the proceeding page 13 (see Figure 7 on page 13). Also, panoramic drone photography was tested to get a sense of the larger urban context of the Haugerud neighborhood. You can see Haugerud's connection and place within the city of Oslo, all the way to Oslo fjord, in the proceeding page 13 (see Figure 8 on page 13).

The work done in the studio was personally very inspiring. It motivated continued learning and exploration of the tools and capabilities of drones. Further, to explore their potentials in landscape design and within the urban landscape context. Moreover, to explore the use of drones in landscape design as a thesis topic.

Figure 1

Figure 2

Figures 1 and 2 are sourced from:
Oslo kommune (2018). Planprogram med veiledende plan for offentlig rom for Trosterud og Haugerud. Eiendoms og byfornyelsesetaten.
Available at: https://innsyn.pbe.oslo.kommune.no/saksinnsyn/showfile.asp?-jno=2018116952&fileid=8127957 (accessed 21.03.2023)

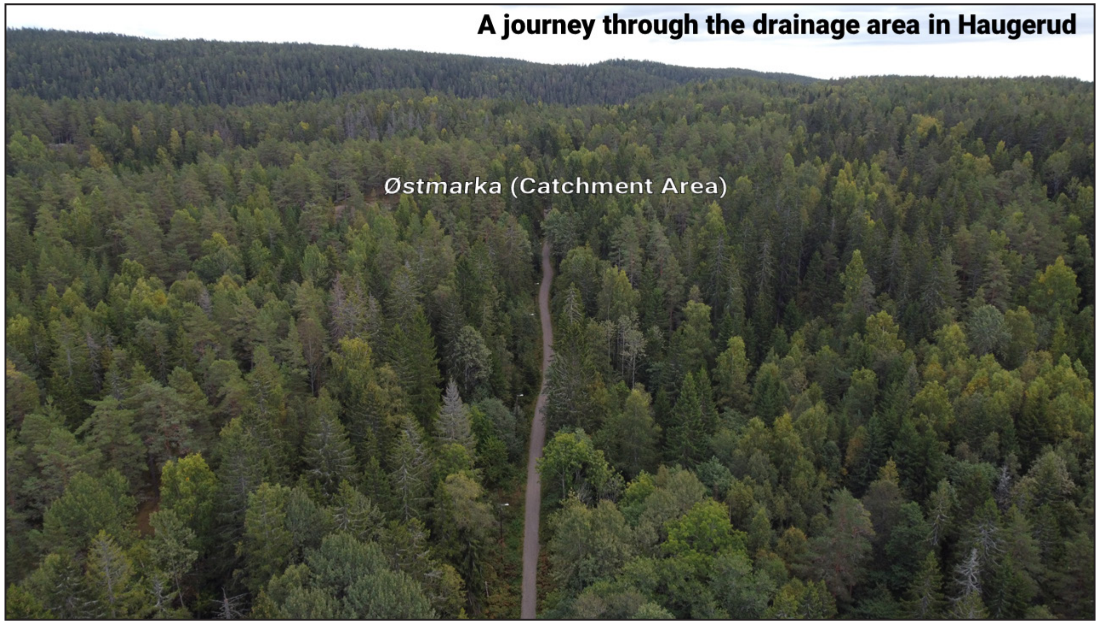


Figure 3

Sutton, C. (2022). Slide 6. Powerpoint Slide. Striking a balance in Haugerud - A Hybrid Stream Daylighting Approach in Oslo. Norwegian University of Life Sciences (NMBU).

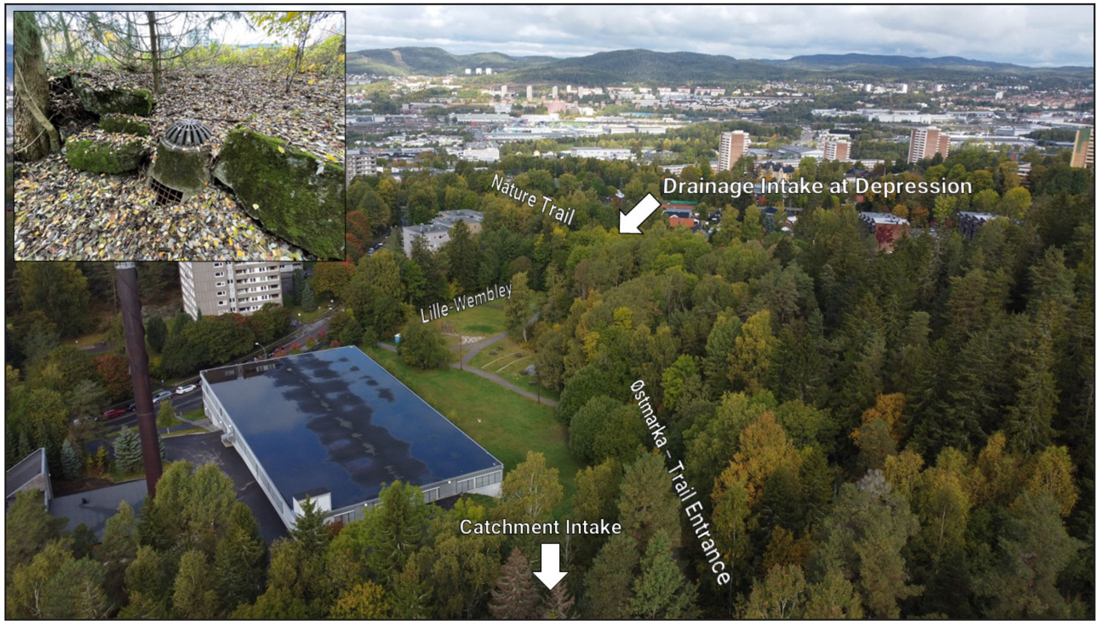


Figure 4

Sutton, C. (2022). Slide 7. Powerpoint Slide. Striking a balance in Haugerud - A Hybrid Stream Daylighting Approach in Oslo. Norwegian University of Life Sciences (NMBU).

Figure 5

Sutton, C. (2022). Slide 8. Powerpoint Slide. Striking a balance in Haugerud - A Hybrid Stream Daylighting Approach in Oslo. Norwegian University of Life Sciences (NMBU).

Figure 6

Sutton, C. (2022). Slide 9. Powerpoint Slide. Striking a balance in Haugerud - A Hybrid Stream Daylighting Approach in Oslo. Norwegian University of Life Sciences (NMBU).

Figure 7
Sutton, C. (2022). Orthomosaic Drone Image in Haugerud, Oslo, Norway. Norwegian University of Life Sciences (NMBU).

Figure 8 Sutton, C. (2022). Panoramic Drone Image of Haugerud, Oslo, Norway. Norwegian University of Life Sciences (NMBU).

Organization of Thesis

This thesis is organized into several sections that proceed this introduction section. They are described as the following:

The 'Site Survey and Inventory in Urban Landscape Design' section provides a review of existing literature related to site survey and inventory in urban landscape design in order to understand the key concepts for this study.

The next section, 'The Role of Drones in Site Survey and Inventory' first reviews and discusses literature related to drones for site survey and inventory to understand their capabilities, advantages, challenges, and limitations. Second, it explores existing literature on the visual communication of drone data as it relates to site survey inventory information and what drones offer. The section ends with a conclusion as an analysis of the findings.

The 'Case Study' section outlines the research design, data-collection methods, data processing, and analysis methods for the case study of this research. Further, this section presents the case study information and findings for the research question and objectives.

The 'Discussion' section further interprets and contextualizes the research findings as well as offers suggestions for future research.

The 'Conclusion' section concludes the thesis as a final summarization of the key findings.

Site Survey and Inventory in Urban Landscape Design

Vertical Image of Houston, Texas, USA Case Study Site

Overview
This overall section presents the key concepts for the research of this study. Additionally, it is a review of literature to provide further understanding for the research question and objectives. It is comprised of two sub-sections.

The following sub-section, 'Site Survey and Inventory in Urban Landscape Design', introduces the relevant literature for site survey and inventory in urban landscape design for this study. First, the sub-section discusses urban landscape design generally for context. Second, it discusses sustainable site planning and design, which is a key underlying theory for understanding the principles of urban landscape design. Third, it elaborates on the urban landscape design process and its stages. Fourth, it further details the site survey and inventory stage of the urban landscape design and conveys its importance. Lastly, the sub-section discusses traditional site survey and inventory methods and data-collection.

This section ends with a 'Conclusion' sub-section.

This overall section is primarily based on LaGro's 2008 book on site analysis for sustainable land planning and design. Additionally, Dinc and Gul's 2022 research on site inventory and analysis in urban landscape design.

Site Survey and Inventory in Urban Landscape Design

Urban Landscape Design
Landscape architecture is a profession that integrates art and science for the management, planning, and design of physical and cultural landscape. It has been a rapidly evolving field to address human and ecological health and well-being (Motloch, 2000). Addressing ecological and human health and well-being is particularly relevant in the urban environment, as urban landscapes play a crucial role in supporting municipal ecological and social systems (Barbosa et al., 2007). Urban environments are already significant areas of human activity and population growth. However, by 2050, 68% of the world's populations are expected to live in urban areas, according to the United Nations (United Nations, 2018). This growing change in the global urban context is significant for the field of landscape architecture. Landscape architects are routinely used to lead projects in urban landscape design, as their skills provide them with unique contextual insight and sensitivity. Many landscape architecture firms base their practice almost exclusively in urban landscape design due to the large demand of projects in the urban context (Waterman & Wall, 2010).

One of the primary goals of landscape architecture projects is to recognize the distinctive features of space, place, and landscape to improve environmental quality. Additionally, to meet the biological, physiological, and psychological needs of the individuals within the surrounding community (Akoğlu & Akten, 2022). Landscape design is the process by which landscape architecture projects are reached (Filor, 1994). For landscape design of sites within the urban environment, the aim must be to improve the well-being of its community as well as minimizing the negative impacts of development to the environment on and off the site (Dinc & Gul, 2022). This process typically follows a sustainable site planning and design approach.

Sustainable Site Planning and Design

Sustainable site planning and design are applied concepts that aim to protect and/or restore degraded natural and cultural resources and minimize negative impacts on the environment (LaGro, 2008). The concepts of sustainable site planning and design are consistently used in the processes and goals of landscape design projects. This is because "landscape design is the creation of responsive, meaningful sustainable, and regenerative landscapes" (Dinc & Gul, 2022, p. 403). Further, since every site is embedded within a landscape, sustainable site planning and design considers its specific context. This involves reducing any adverse effects caused by development of the site by showing regard for the natural and cultural processes of the surrounding landscape (LaGro, 2008).

Using a sustainable site planning and design approach considers the long-term societal, economic, and environmental impacts of a space within the built environment. This is highly beneficial because the approach can yield several societal, economic, and environmental benefits as shown in the figure below. (see figure 9).

SOCIETY	
	Pedestrian/bicyclist safety
	Opportunities for active living
	Sense of community
	Attractive surroundings
	Safe neighborhoods
	Proximity to public services
	Minimizes negative impacts on surrounding properties
	Protects cultural and historic resources
ECONOMY	
	Attracts investment
	Attracts visitors and tourists
	Adds property value
	Creates marketable experiences
	Quicker real estate sales and rentals in tight markets
	Attracts high-skilled employees and employers
	Less time spent commuting
	Uses land efficiently
ENVIRONMENT	
	Conserves energy
	Protects biodiversity
	Reduces air and water pollution, and urban heat island(s)
	Protects natural processes and sensitive natural areas

Figure 9 Copied and re-formatted for higher visual quality from:
LaGro, J. A. J. (2008). Site Analysis: a Contextual Approach to Sustainable Land Planning and Site Design. 2nd ed. Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

Sustainable Site Planning and Design continued.

Sustainable site planning can be understood as a multi-step selection and design process that guides a thorough understanding of site character and context. It informs where and how to develop a site as a project through several important steps, all the way to implementation (LaGro, 2008).
The process and its steps are visualized as a figure below (see Figure 10).

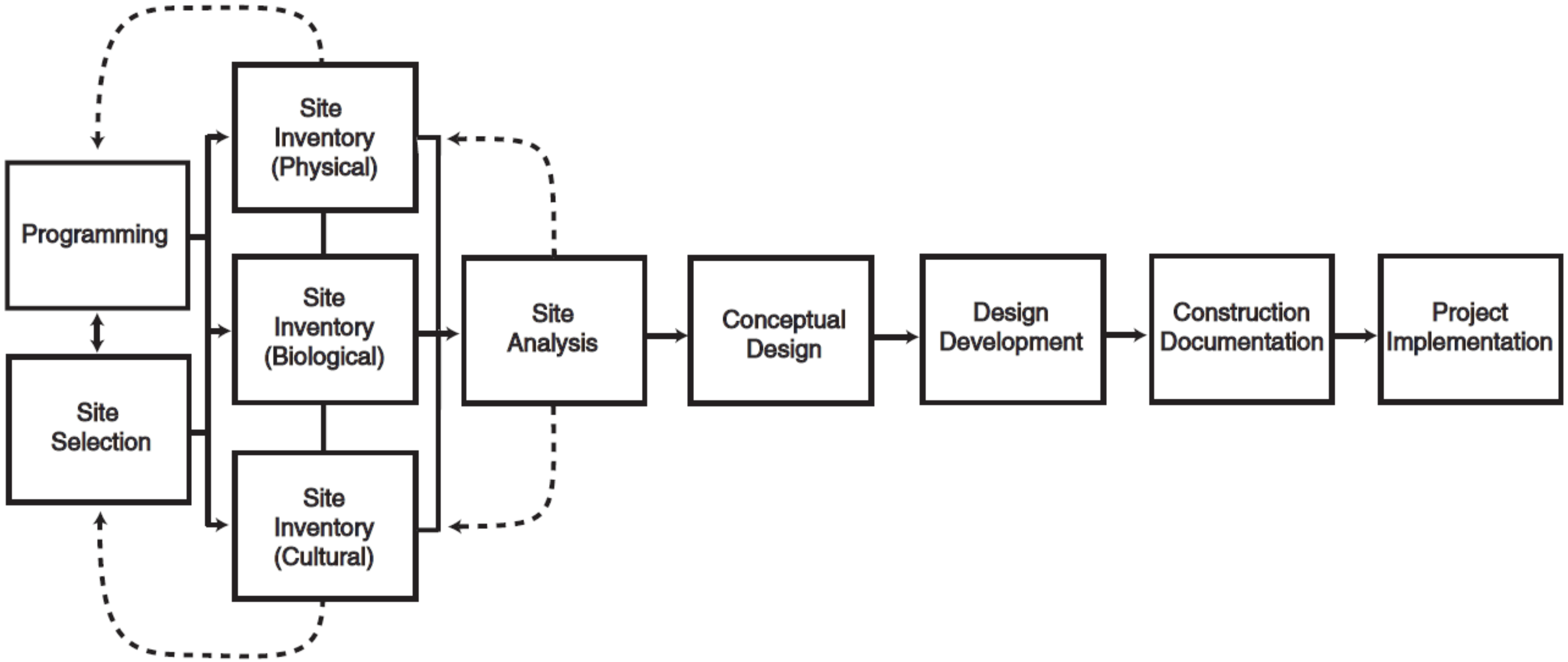


Figure 10 LaGro, J. A. J. (2008). Site Analysis: a Contextual Approach to Sustainable Land Planning and Site Design. 2nd ed. Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

As a concept and process used for the built environment generally, it is relevant in the urban context. Further, it has been applied as a foundation for approaching and conceptualizing the urban landscape design process (Dinc & Gul, 2022). This is elaborated further on the next page.

Urban Landscape Design Process

In 2022, the researchers Dinc and Gul elaborated the process of urban landscape design as stages, using the concepts of sustainable site planning and design. The figure is shown below (see Figure 11). The stages are described in the paragraphs that follow.

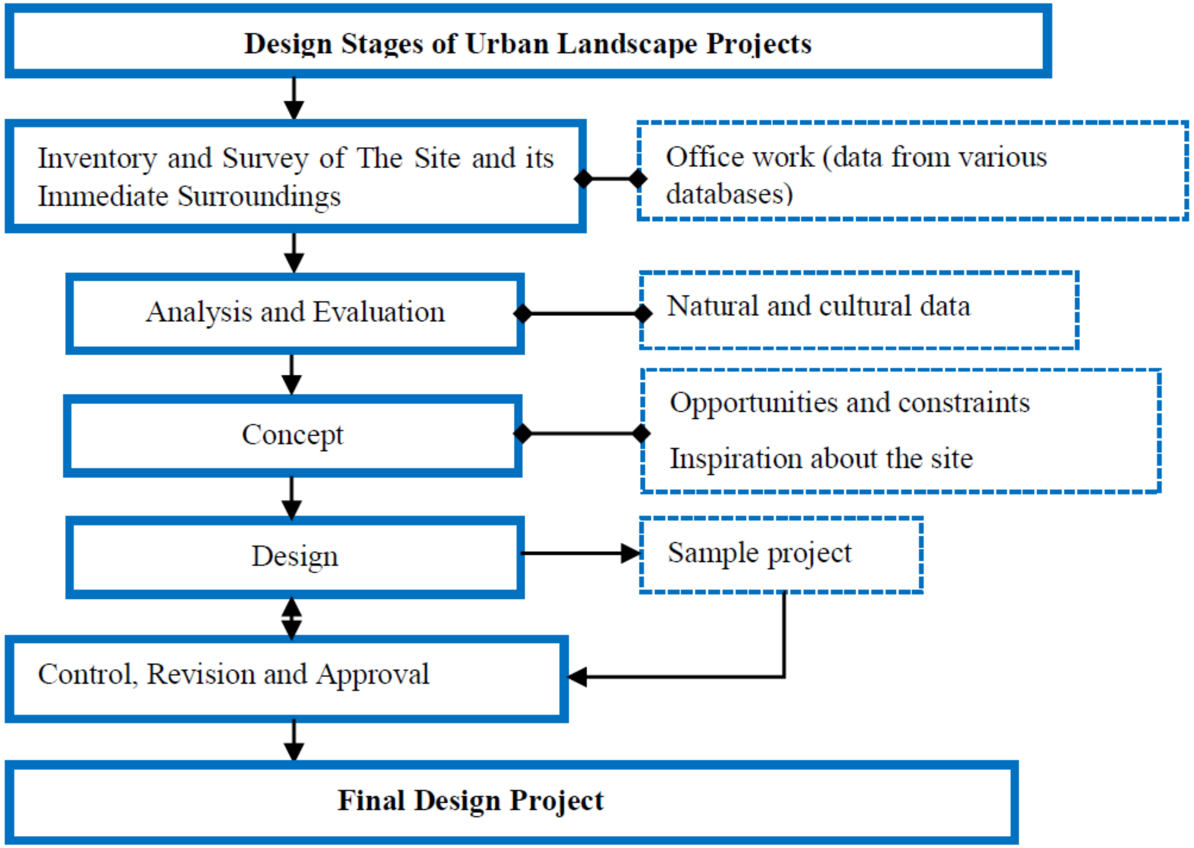


Figure 11 Dinc, G. & Gul, A. (2022). Site Inventory and Analysis in Urban Landscape Design. *Architectural Sciences and Spatial Design*: 401-441.

The first stage of site survey and inventory collects the physical, biological, and cultural data needed for landscape design in the built environment (LaGro, 2008). Additionally, it "provides an objective context for the analysis of the cultural, social, and visual aspects of the landscape, and vital evidence for understanding landscape history, dynamics, and change" (Dinc & Gul, 2022, pg. 404). The main purpose is "to obtain complete documentation of the landscape that will allow us to describe all the elements of the landscape and the interaction between these elements" (Dinc & Gul, 2022, pg. 435 - 436).

Urban Landscape Design Process continued.

The second stage of analysis and evaluation is essential for developing the concept and design ideas for a project (Dinc & Gul, 2022). It is the analysis and evaluation of the work done in the site survey and inventory stage and its collection of natural and cultural data as input. This analysis and evaluation of data identifies the opportunities and constraints of a site. Which further aids in the overall understanding of the site and its surrounding context (Dinc & Gul, 2022).

After the analysis and evaluation stage, the concept stage is important for shaping aspects of the design such as human interest, identity, and integrity. A concept is a well informed idea of what the design should be, and how it should be developed according to the analysis. The concept serves as a framework for the project and guides the landscape design decision-making. It also visualizes and communicates the sites capacity, suitability, strengths, weaknesses, opportunities, and threats (Dinc & Gul, 2022).

The subsequent stage of design is the culmination of the stages that precede it. It is the realization of site survey and inventory, analysis and evaluation, and concept as the potential urban landscape design project. This stage is followed by the control, revision, and approval stage for further scrutiny, revision, and processing, but ultimately concludes as the final design project that is to be materialized in the real world (Dinc & Gul, 2022).

As it is consistent with the concept of sustainable site planning and design, the urban landscape design process and its stages aim to ensure projects are sustainable, functional, and respectful to local identity and context within urban environments (Dinc & Gul, 2022). It is also the typical process urban landscape designers follow.

Site Survey and Inventory

While all the stages of urban landscape design are important for the overall success and completion of a final design project, the initial stage of site survey and inventory provides all the information needed for site analysis, which ultimately serves to maximize the sustainable planning and design potential of a site within the urban environment. Further, it is a critical and essential stage in urban landscape design for a couple of reasons.

The first reason being that a site survey supplies the empirical basis in which design explorations are based (Milligan, 2019). And second, "site inventory is an essential step in understanding the character of the site and the physical, biological, and cultural linkages between the site and the surrounding landscape" (LaGro, 2008, pg. 101).

The term "survey" encompasses both an action and a result. It refers to the act of observing and documenting the characteristics of a landscape (surveying) as well as the representation or model of those observations (the survey itself). Surveying is a process of examining and inventorying the features of a particular site, which helps to understand its current state and potential (Milligan, 2019).

The data to be collected or the types of landscape phenomena to be observed in site survey and inventory may be dependent on the interests of a site or the intentions of a project (Milligan, 2019). The researchers Dinc and Gul compiled a comprehensive list of the natural and cultural data that may be necessary to collect or observe for urban landscape design, shown in the figure below (see Figure 12).

Additionally, the immediate surroundings of a site is an important consideration for site survey and inventory. Site context is important for determining how compatible a site may be with its surrounding land uses (LaGro, 2008).

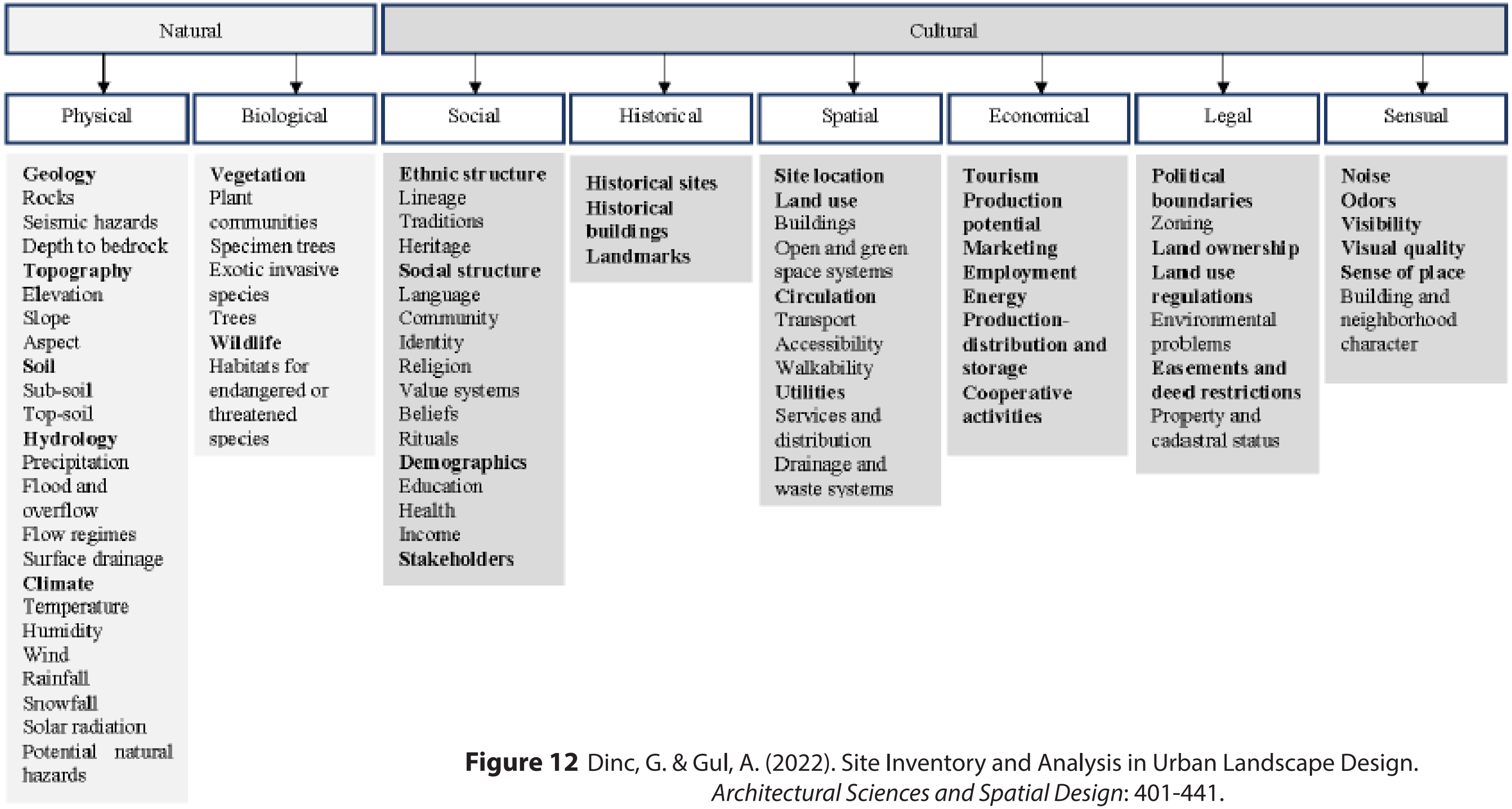


Figure 12 Dinc, G. & Gul, A. (2022). Site Inventory and Analysis in Urban Landscape Design. *Architectural Sciences and Spatial Design*: 401-441.

Traditional Site Survey and Inventory Data-Collection

Site survey and inventory is the reconnaissance and data-collection of a site and its contextual landscape. The researchers Dinc and Gul state that to ensure that the design process is informed by accurate and relevant information from site survey and inventory, all data relating to a site must be obtained in a reliable, up-to-date, and analyzable manner (Dinc & Gul, 2022). Traditional site survey and inventory is often conducted by on-site in-person survey methods and/or through research and data-collection from relevant databases as office work. The representative data that needs to be collected as part of site inventory can be in available in a variety of formats or as different observations collected on site (Dinc & Gul, 2022). Typically, a base map serves as the template for mapping the inventory of natural and cultural data collected, as well as the successive planning and design (LaGro, 2008).

Conclusion

As it serves the analysis stage that then forms the site concept, and ultimately the final design, site survey and inventory is the first and essential stage of data-collection that provides the initial foundation for the overall urban landscape design process. The stage provides the necessary data that ensures that an urban landscape design project is sustainable, fits within its urban context, and meets the needs of its surrounding community. During this stage a wide-range of data may be collected for analysis to develop a concept and final design project that serves the specific interests of a project. Traditionally, the data is collected by in-person survey and observations on-site, and as research from open-access databases.

However, the researchers explain how site survey and inventory is conducted as a process and only generally explain how the data is collected. The researchers do not further detail specific methods for obtaining the different types of comprehensive survey and inventory data.

In order to understand how the aerial perspectives of drones can supplement site survey and inventory as the research question of this study, a review of relevant literature and existing studies was conducted and elaborated in the next section.

The Role of Drones in Site Survey and Inventory

Vertical Image of Houston, Texas, USA Case Study Site

Overview
This overall section is a review of existing literature to provide further understanding for the research question and objectives.

The first sub-section, 'Benefits and Limitations of Drones in Site Survey and Inventory' discusses the literature of drones as an emerging tool for site survey and inventory processes. Moreover, it presents the findings from the limited, but specific literature relating to the use of drones in landscape design. This is to further understand the potential of drones for survey and inventory of urban landscape sites by reviewing their practical and technological capabilities, advantages, and limitations. Also, it discusses drone application areas and use in the urban environment for relevance.

The second sub-section, 'Visual Communication of Drone Data' reviews the literature on how drone perspectives can be utilized to communicate site survey and inventory-related information. It discusses project processes and visual representation techniques that leverage drone data.

This overall section ends with a 'Conclusion' sub-section to discuss key finding and analysis of the literature reviewed. Further it identifies the gaps and limitation in the existing literature, which provides justification for further study in this thesis.

Benefits and Limitations of Drones in Site Survey and Inventory

Capabilities and Advantages of Drone Use and Data
Survey as a craft has been around for millennia and the instruments used to inventory landscapes have changed dramatically over time. In recent decades, there have been remarkable advancements in technology that have greatly improved the ability to measure, collect, record, and present information related to the earth's surface (McCormac et al., 2012). However, in recent times, the most cutting-edge and advanced technology to emerge is drones. Drones have proven to be perfect for conducting tasks such as aerial photography, remote sensing studies, topographical surveys, and mapping that surpasses other technologies in their capabilities (Preethi Latha et al., 2019).

Drones have the capacity to be utilized in numerous applications, particularly within urban environments. With a diverse range of sensors, advancements in data processing, and ongoing drone advancements, their potential uses are expanding continuously (Gallacher, 2017). Also with their ability to fly above urban spaces and be equipped with camera sensor capabilities, drones offer the opportunity to bridge the gap between two-dimensional satellite imagery and ground-based conventional cameras, providing further understanding of urban space. This has great potential for city governments, design firms, and community engagement. Potentials such as accurate site assessments, monitoring capabilities, and capturing both qualitative and quantitative data on various aspects such as land use, open spaces, traffic patterns, community activity, or environmental factors (Jenkins, 2015).

Tal and Altschuld's 2021 book states drones are proving to be a valuable tool for enhancing efficiency and problem-solving, and are rapidly becoming a fundamental and widely adopted tool for professionals and firms in the Architecture, Engineering, and Construction (AEC) industries, of which landscape design is typically associated with (Tal & Altschuld, 2021). Further, that drones are groundbreaking technology for these industries as they offer fresh aerial perspectives on the natural and man-made world, at minimum investment in time and cost. The authors state the several advantages drones offer. The first being that drones have become affordable and offer a high return on investment. The second is their flexibility to be brought on to a site and collect a range of data. The third and arguably biggest advantage is their range and access. Drones can access and collect data from perspectives and vantage points that are either difficult to reach or unreachable without them. Lastly, it is easy and straightforward to integrate drone data into existing project methodologies and workflows (Tal & Altschuld, 2021).

The authors also add that the aerial views drones offer can change our perception of a site, its topography, connectivity, and context. This is significant for industries involved in site design and that typically work in plan view, such as urban landscape design (Tal & Altschuld, 2021).

Early application of drones in landscape architecture research demonstrated their potential for site documentation, design communication, and observation of natural and cultural processes in the urban environment (Rekittke et al., 2013). Within the last 5 years, researchers have further explored and focused on the benefits and advantages of drones for the practice of landscape architecture specifically, however there are limited studies.

Among these studies is from Karl Kullman in 2018, who asserts that the adoption of drones in landscape architecture has been relatively moderate. Kullman offers the explanation "as the most 'grounded of the arts, landscape architecture has a more restrained legacy of engagement with technological innovation than other design disciplines. This reticence is partially a consequence of landscape architecture's customary role as an ameliorator of the negative impacts of industrialization. It also results from working with the medium of the real landscape, whose unruly nature tends to resist both straightforward representation and technological fashion" (Kullman, 2018, p. 906).

However, Kullman's study found some implications and significance of drones for landscape architecture practice. He states that since landscape architecture as a practice is deeply involved in the use of maps to interpret, abstract, conceptualize, and ultimately reconfigure the ground, the functionality of drone technology is notable for the field (Kullmann, 2018). Also that "for landscape architecture, drone-imaging and mapping technology offers on-demand high-definition oblique and planimetric aerial imagery, three-dimensional topographic modeling, and malleable cinematic tracking" (Kullmann, 2018, pg. 914). Imagery and cinematic tracking being photography and video. Kullman also speculates that drones provide the potential for landscape architects to leverage the unique perspectives that drones can offer, such as the birds eye, that goes beyond the dominant traditional cartesian plan view. The birds eye being the oblique and vertical perspectives drones offer. Vertical photos can be used for planimetric aerial imagery.

Kullman emphasizes that the most beneficial and applicable capability of drones for the field of landscape architecture is the ability of drones to produce high-resolution orthomosaics. Orthomosaics being an accurate high-resolution aerial image that has been mosaiced together from multiple vertical photos of an area. He states that this is because prior to the recent technological innovations in consumer drone technology, satellite and airplane methods have had a monopoly on providing the imaging and mapping perspective for the field of landscape architecture (Kullmann, 2018).

In his study, Kullman performs a drone mapping case study to produce orthomosaics of a topographically complex area to demonstrate the significant difference in resolution when compared to dominant satellite or airplane imaging. The result is shown in Figure 13 on the next page (see Figure 13 on page 26). The results visually and numerically demonstrate that drones have a significantly higher quality of landscape imaging resolution than the prevailing and existing methods (Kullmann, 2018).

Further, Kullman compares several other factors of drone imaging to the satellite and airplane imaging methods. The results are shown in figure 14 on the next page (see Figure 14 on page 26). While useful as a comparison in how drones outperform the other methods, the results also show the advantages of drones as a technology for landscape architecture. The most significant advantages of drones being the extremely high image resolution, image detail and quality. The low image capture restrictions as compared to the airplane or satellite, low to no physical obstructions such as clouds, or time constraints to be able to obtain images such as satellite orbit. Also, the potentially very high data refresh rates, imagery can be captured frequently over time and only dependent on user availability. Lastly, the extremely high digital surface model detail. The process of photogrammetry can produce drone imagery into two and three-dimensional models for topographical representation of landscape, for drones the quality is extremely high (Kullmann, 2018).

Drawing the main conclusion from Kullman's study for the benefit of drones to site survey and inventory, Kullman argues that high-quality drone imaging and mapping can shift the focus of current landscape discussion from a primarily satellite-based perspective to the actual site scale, where landscape is both designed and experienced (Kullmann, 2018).

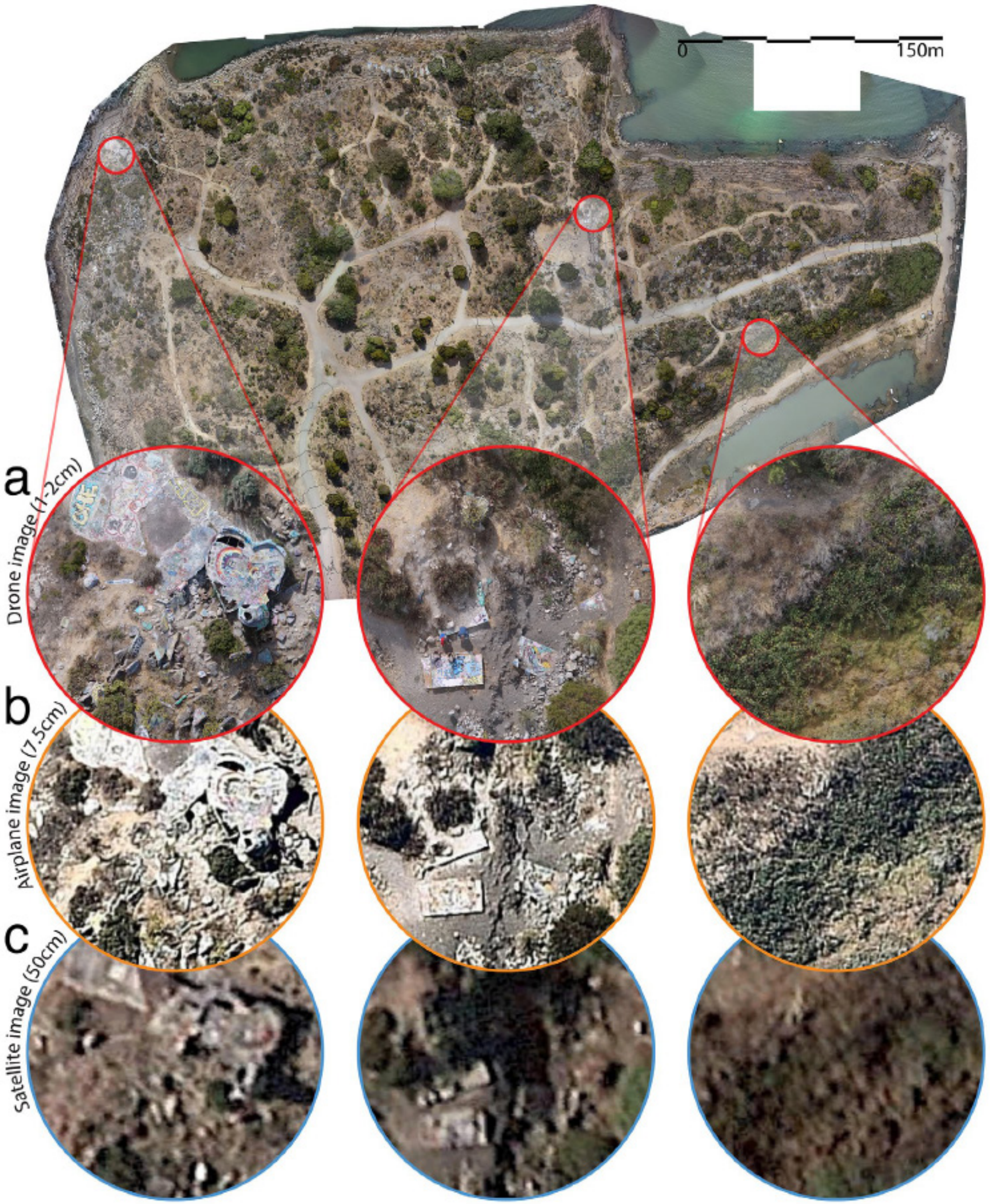


Figure 13 Kullmann, K. (2018). The drone's eye: applications and implications for landscape architecture. *Landscape Research*, 43 (7): 906-921. doi: 10.1080/01426397.2017.1386777.

	Drone imaging	Aeroplane imaging	Airborne LiDAR	Satellite imaging
1. Operating restrictions	*Variable* Restrictions operating near people and no-fly zones are increasingly common	*Medium* Air traffic control restrictions may limit when and where aircraft can fly	*Medium* Air traffic control restrictions may limit when and where aircraft can fly	*Low* Imaging satellite orbit well above territorial jurisdictions
2. Image resolution	*Extremely high* 1–2 cm typical pixel size	*Very high* 7.5 cm typical pixel size (5 cm soon available in some markets)	*Very high* 1–2 metre point spacing typical for online data sources	*Moderately high* 40 cm typical pixel size
3. Image capture restrictions	*Low* Image capture generally not impacted by cloud cover or winds under approximately 25 knots	*Moderate* Cloud cover and low atmospheric visibly limit image capture	*Low to moderate* The low altitudes typically flown for LiDAR capture are often below the cloud ceiling	*High* Cloud cover and with very fast and narrow orbit tracks limits image capture
4. Data refresh rates	*Potentially very high* As often as required but this is contingent on the user's availability to perform on site surveys	*Variable* With online subscription vendors, refresh rates vary significantly	*Variable* Readily accessible LiDAR coverage is patchy but improving	*High but inconsistent* Very fast and narrow orbit tracks and cloud cover limit refresh rate consistency
5. Historical data availability	*Currently low* With the potential to accrue over time as survey data is shared online	*Moderate* Online subscription vendors typically only store their own survey data	*Low* Due to the relatively new application of LiDAR, access to historical data is low	*High but inconsistent* High variation of historical image quality and high variation of data between locations
6. Digital surface model detail	*Extremely high* Photogrammetry detail is improved with the inclusion of oblique and eye level imagery	*Moderate* Aeroplane imagery is used to create Google Earth's photogrammetry 3D Buildings feature	*Very high* Offers additional benefit of higher precision and choice of including or excluding vegetation	*Low* Satellite photogrammetry is used to create Google Earth Terrain

Figure 14 Kullmann, K. (2018). The drone's eye: applications and implications for landscape architecture. *Landscape Research*, 43 (7): 906-921. doi:10.1080/01426397.2017.1386777.

In 2019, Li and Chang explored the capabilities of drones as a tool for landscape architecture research and practice, as they assert that "site surveying and mapping is the foundation for landscape design" (Li & Chang, 2019, p. 39).

Their research demonstrates the advantage of drones to efficiently and economically acquire accurate two-dimensional (2D) and three-dimensional (3D) data. Further, drones have the ability to capture elevation and topographic information, which can provide immediate and accurate survey of sites (Li & Chang, 2019). This is especially the case for small or medium size sites. Li and Chang state that drones bridge the gap between traditional aerial photography and ground engineering surveying (Li & Chang, 2019). They visualize their assertion as a figure below (see Figure 15).

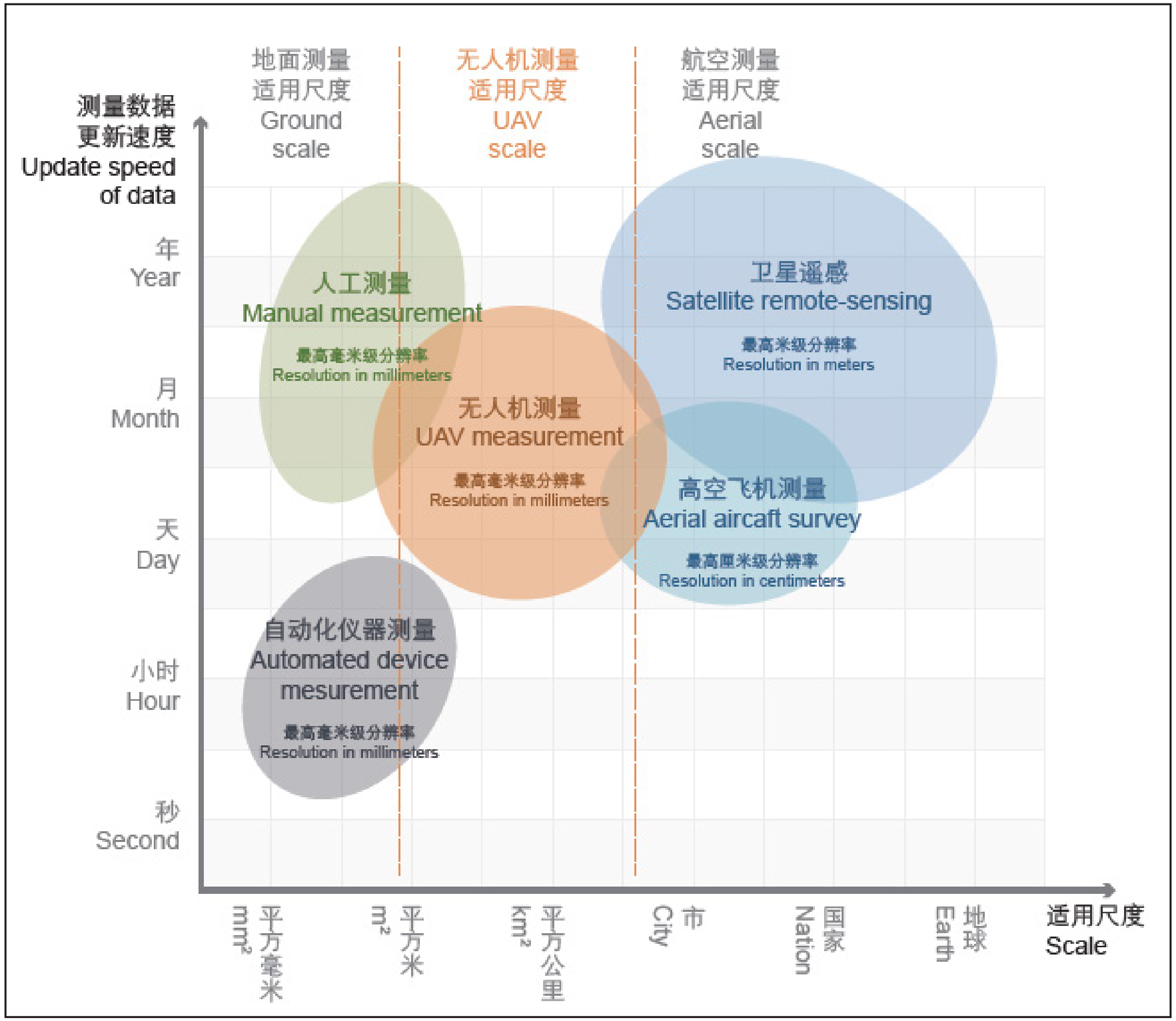


Figure 15
Li, F. & Chang, H. (2019). UAV MEASUREMENT IN LANDSCAPE ARCHITECTURE RESEARCH AND PRACTICE. *Landscape Architecture Frontiers*, 7 (2): 38-54. doi: 10.15302/j-laf-20190204.

Further, drone acquired data “can be stored, processed, analyzed, and visualized in two or three-dimensional formats” (Li & Chang, 2019, pg. 41). This includes orthophotos, digital surface models (DSM), digital terrain models (DTM), or 3D models for landscape research and design (Li & Chang, 2019). The researchers demonstrated this by conducting a case study of an urban landscape in China as seen in the figure to the right (see Figure 16). The case study demonstrates the quality of drone data in the urban context.

As another advantage and benefit noted from Li and Chang, the data collected from drones is very compatible and easily integrates with other landscape design systems or processes, such as the use of GIS and CAD (Li & Chang, 2019).

Li and Chang’s research also organizes and conveys the advantages of drones to be equipped with a range of sensors, image and non-image based (Li & Chang, 2019). The range of sensor types include spectral, meteorological, communication sensors, and other drone operation sensors. The researchers state the advantage of drones to be equipped with various sensors is that they are able to collect very diverse data and produce a variety of products for specific landscape design or investigation purposes. These include LiDAR, thermal, noise, or even temperature (Li & Chang, 2019).

Additionally, that the use of these sensors has research crossover with other disciplines. Crossover they claim may inspire landscape architecture practice. These include mapping and monitoring, ecological research, urban environment, or meteorological (Li & Chang, 2019).

The researchers visualize this in the figure on the next page (see Figure 17 on page 29)

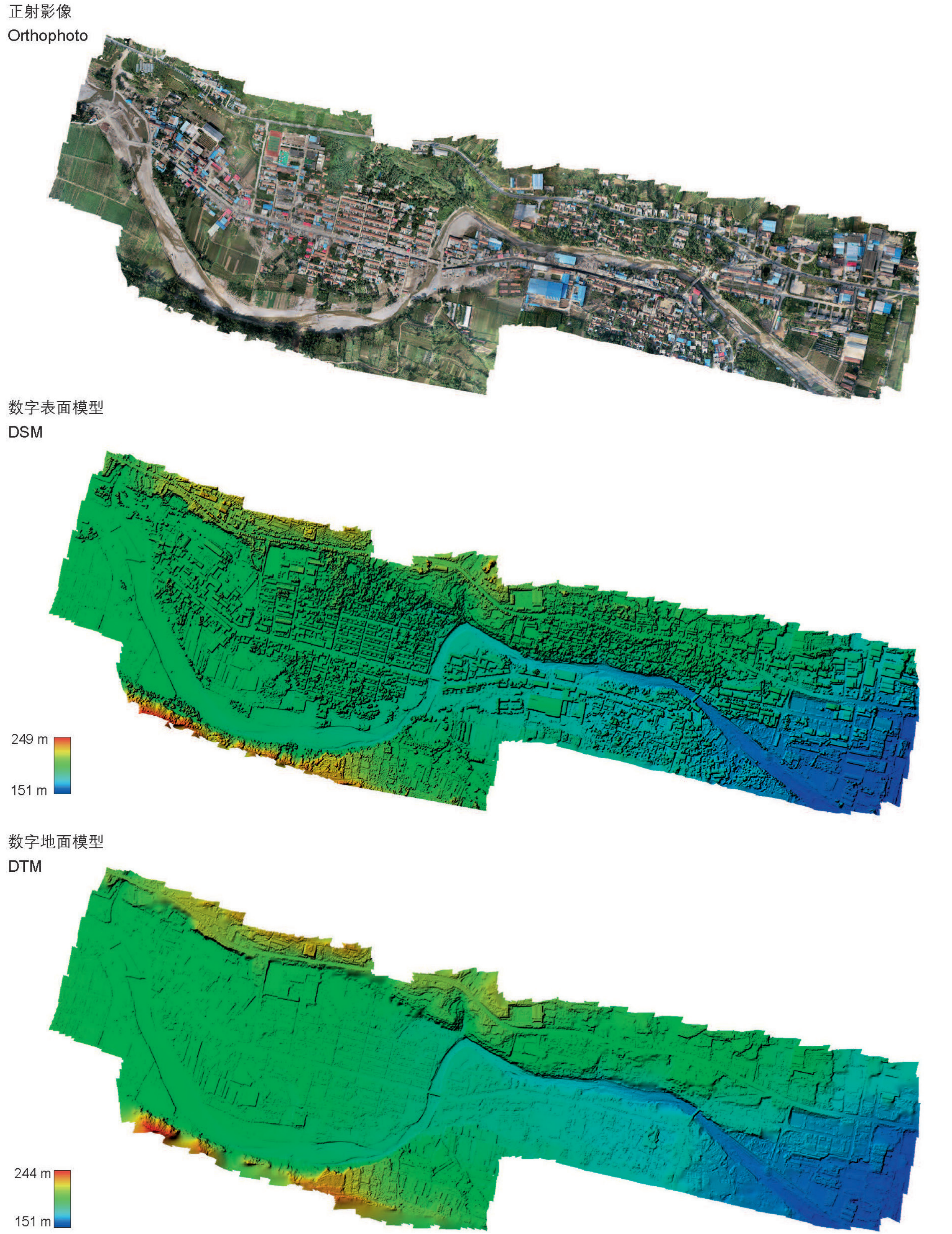


Figure 16
Li, F. & Chang, H. (2019). UAV MEASUREMENT IN LANDSCAPE ARCHITECTURE RESEARCH AND PRACTICE. *Landscape Architecture Frontiers*, 7 (2): 38-54. doi: 10.15302/j-laf-20190204.

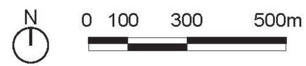
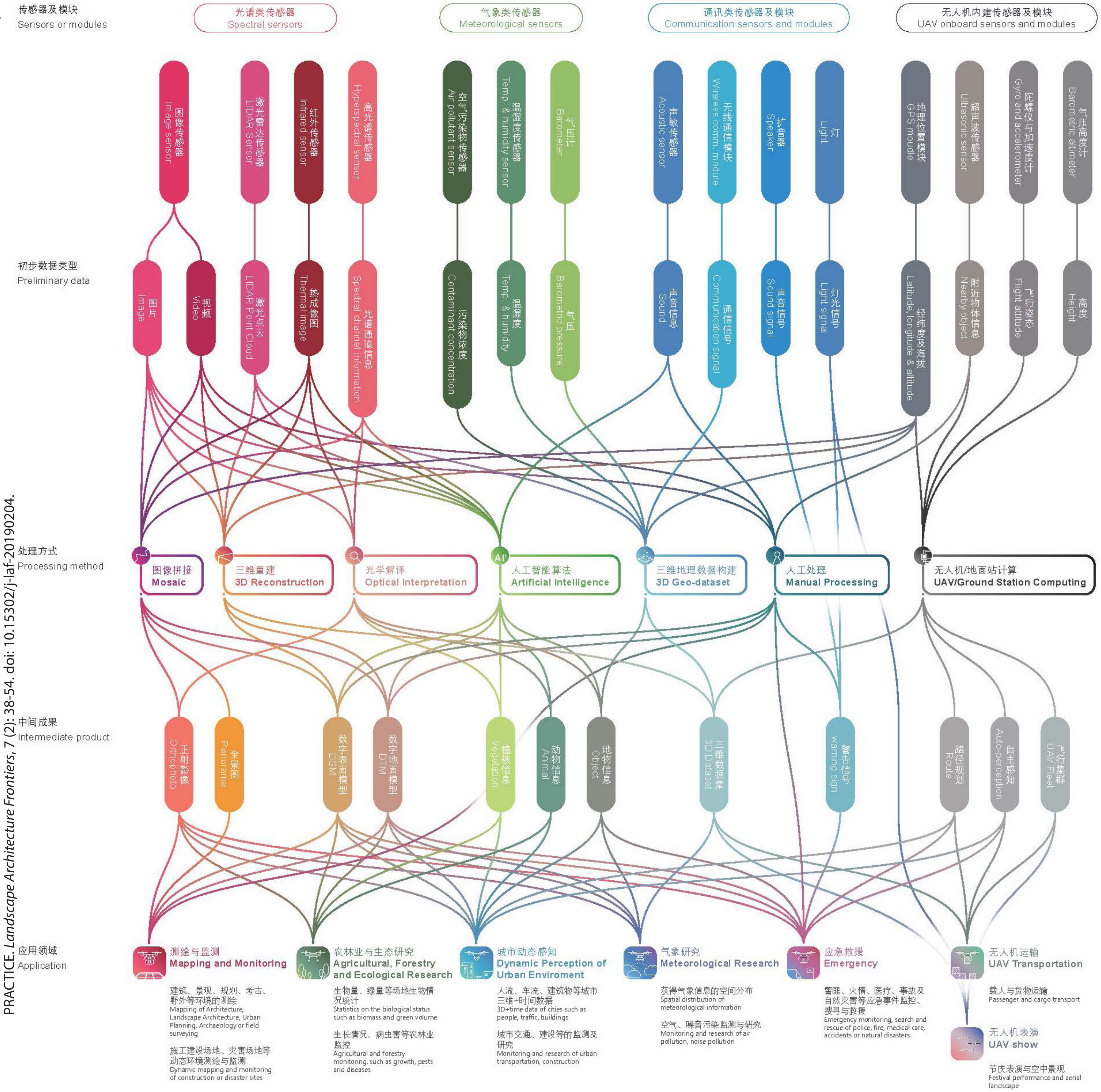


Figure 17



Li, F. & Chang, H. (2019). UAV MEASUREMENT IN LANDSCAPE ARCHITECTURE RESEARCH AND PRACTICE. *Landscape Architecture Frontiers*, 7 (2): 38-54. doi: 10.15302/j-laf-20190204.

Limitations and Challenges of Drone Use and Data

Using drones and their data as a tool for site survey and inventory comes with potential limitations and challenges.

Of the challenges or potential limitations of drones is being able to discern the difference between their ability to produce good looking data versus good quality data. Drones are capable of producing high quality and visually appealing data, such as the photography and 3D visualization previously mentioned. However, it is important for users to be able to understand how accurate the data they are producing actually is. This is most relevant when using drones to produce site measurements or 3D models, but often drone data can be confused or understood to be more accurate than it actually is. In some cases, it may be necessary to make use of ground control points or post-processing techniques to achieve higher accuracy (Tal & Altschuld, 2021).

Drones are cost-effective and can offer a high return on investment, through their benefits and time-saving. However, their initial costs may be high for some, especially with more sophisticated data-collection goals or equipment. Also, consumer drones have become more user friendly, but they still may require practice, training, or licenses for new users to start adopting them (Tal & Altschuld, 2021). This may come at additional costs of time and investment in actual application.

Drones also have maximum flight times depending on battery life or power supply. This has potential to inhibit what may be achievable in terms of data-collection or flight purpose. Battery life can be further impacted or reduced depending on weather conditions, such as strong winds (Tal & Altschuld, 2021). Weather conditions can also limit the ability to fly, which may make drone use less reliable when needed. Air temperature, wind speed, precipitation, and other atmospheric phenomena do have the potential to reduce drone operations, especially in time sensitive cases (Gao et al., 2021).

Using drones in urban environments come with more potential limitations and challenges. There are major risk concerns and issues with safety, security, and privacy of their use in urban areas. The issues with security and privacy may take time to settle. However, the safety risks to people and infrastructure may hinder their permitted use in urban areas for the foreseeable future. The most concerning issues of using drones is the potential for malfunction, mid-air collisions, and damage to people and property. Additionally, there is some level of risk with wildlife (Gallacher, 2017).

Since the early 2000s, nations have implemented varying regulations for using drones. With the common goal of regulations among nations being to minimize risk to other vehicles using airspace and to avoid risk for people and property on the ground. These regulations limit or restrict drone operations and their use of airspace. As well as imposing administrative measures to fly drones such as permissions, licenses, or data collection authorizations (Gallacher, 2017). In the modern day, this is especially common and applicable in urban areas around the world. In the USA for example, there can be a mixture of rules at different levels of government that can potentially confuse what is allowable and where for drone operation. Additionally, there can be a common confusion if it is allowable to fly drones over private property (Tal & Altschuld, 2021).

In addition, public perception of drones also present significant challenges despite a level of public awareness that drones have many applications. They are widely viewed by the public as risky machines used for killing, invaders of privacy, or as toys instead of tools (Aydin, 2019). Other emerging issues with drone use in urban environments have also influenced public perception such as noise, visual pollution, and technology misuse (Watkins et al., 2020).

To use drones in the urban environment, the benefits of using them must outweigh their risks. The balance between risks and benefits can only be discovered through continuous investigation or wider adoption of drone usage (Volovelsky, 2014). The practice of urban landscape design is one of many fields that could benefit from the societal approval or investigation of drone usage.

Drone Applications and Relevance to Urban Landscape Design

The selection of data to be gathered during the inventory stage of landscape design projects is typically determined by designers, planners, or a team with diverse expertise. A multidisciplinary team for landscape design projects may include a diverse range of specialists such as ecologists, hydrologists, arborists, land surveyors, transport consultants, or engineers (Heal et al., 2016). Urban landscape design projects, can potentially have a lot of overlap or input from other practices or disciplines in terms of the comprehensive data that may need to be collected, analyzed, and communicated. Recent reviews of the state of drone application research has shown considerable use cases that are relevant for urban landscape design, especially as it relates to survey and inventory.

Research has shown that drones have many application areas and uses cases in the AEC domain. Some of these include infrastructure inspection, transportation, cultural heritage, city and urban planning. Within these applications, they have shown to have various uses for data collection from building inspection, traffic surveillance, historic landscape preservation, cartography, or cadastral surveying (Albeaino et al., 2019). Additionally, a review of research on drone applications in the urban environment has also uncovered various uses cases. These include construction monitoring, mapping, 3D modelling, energy efficiency, urban remote sensing, and structural damage detection (Videras et al., 2021).

Focus areas very common to landscape design have also been studied. Recent research has shown great potential of drones for urban storm water management, such as asset management, water measurement, and model parameterization (McDonald, 2019). Additionally, drones have shown potential to improve the practice of restoration ecology with vegetation and habitat mapping, assessment of plant health, monitoring wildlife populations, and assistance in refining restoration objectives throughout all restoration project stages (Robinson et al., 2022).

Visual Communication of Drone Data

Project Processes

Using a drone at any stage of a project is applicable, but it has been observed that incorporating drones early in the process easily integrates into an established workflow in AEC projects. Drones and their data can play a significant role in informing design choices, revealing concealed or difficult-to-spot elements, offering clarity on potential conflicts, and can remain useful throughout the entire duration of projects (Tal & Altschuld, 2021). They can be described as a "full cycle" tool in the AEC industries from project start up, development, construction, and operations. Meaning they can be used from the conception of a project to its on-going monitoring, even after its realized development.

Further, they can be used to communicate information throughout project stages. Drone imagery and data can be used to generate and convey project proposals in the early stages, but has been particularly applied in the concept phase of projects with 2D or even 3D visualizations (Tal & Altschuld, 2021). Shown in the figure on the next page is an 2D annotated drone image for a landscape project proposal (see Figure 18 on page 32). Also shown on the next page is a drone image with an overlaid and generated 3D concept of a project (see Figure 19 on page 32).

Figure 18

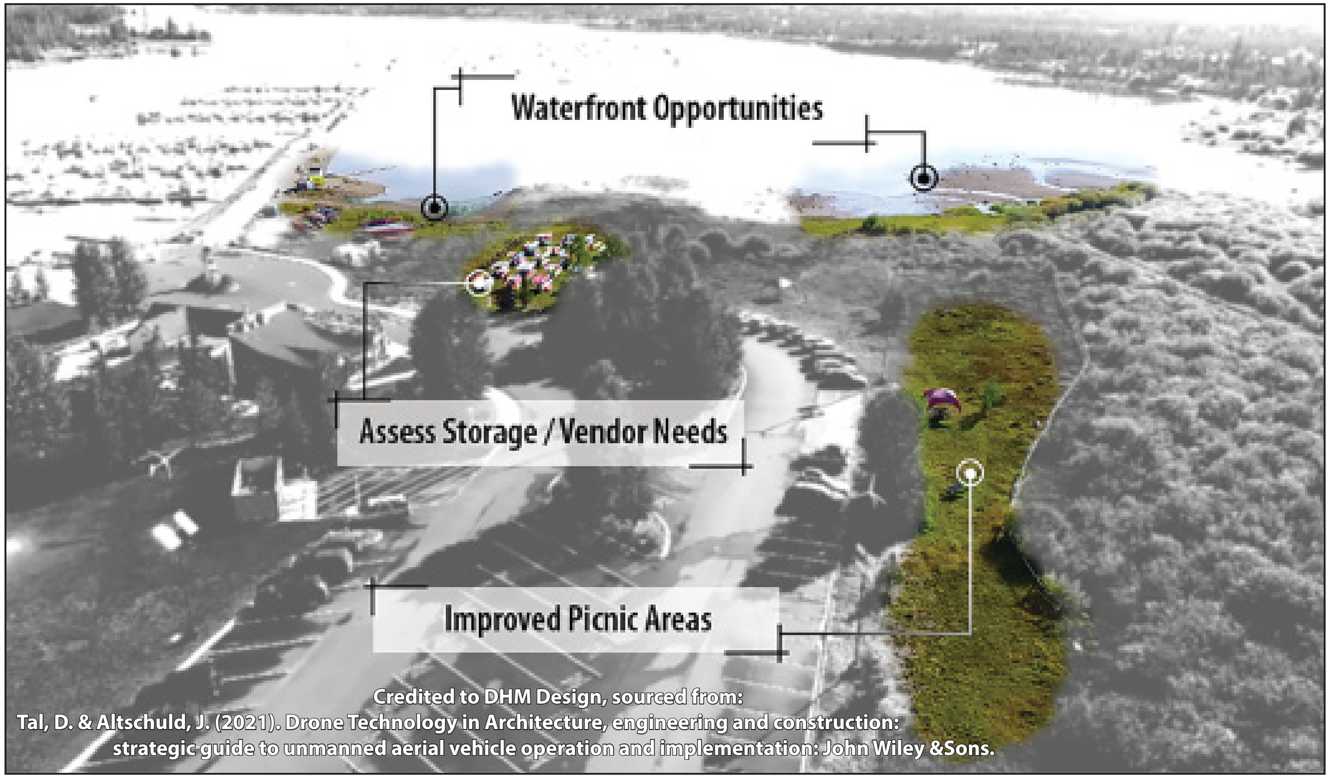


Figure 19

Visualization and Communication of Drone Data in Site Survey and Inventory

Milligan's 2019 study on the use of drones in site survey in landscape design states that "drone surveying is one way of sensing the landscape-of perceiving and making sense of what is-that can be evaluated in terms of what it does and does not do" (Milligan, 2019, pg. 34). He argues that drones and their surveys are complimentary to the landscape architectural tradition of observing and mapping the site directly and have expanded the range of what can be observed (Milligan, 2019). Milligan further argues that the fundamental task of surveying "consists of translating the qualities of the landscape medium into a cartographic and representational medium that is communicable to others" (Milligan, 2019, pg. 21).

Moreover, Mulligan argues "differences in how site surveys and maps are made, the phenomena they document and how they are used are structured by disciplinary concerns and practices. What a landscape survey is or can be has radically expanded over time, particularly in the last few decades, due to the plethora of new techniques and technologies for sensing the medium" (Milligan, 2019, pg. 20). And further states "what a landscape survey is-meaning what phenomena can be sensed and perceived-has radically expanded as a realm of geographic and design inquiry, which in turn has ontologically disrupted what a landscape survey is, as map, model, dynamic interface, or other type of representational thing" (Milligan, 2019, pg. 21).

To summarize Milligan, site survey in landscape design has evolved over time as new techniques and technologies have become available for surveying and representing landscape. It has been shaped by different disciplinary concerns and practices, which has ultimately expanded what site survey can be in practice. Also, the evolved understanding and inclusion of new technology has changed what site survey representation can be for design investigation (Milligan, 2019).

Drones can potentially collect a variety data and be processed to visualize and communicate site survey and inventory information in different ways. Drone imagery and videos are core components, offering unparalleled perspectives and efficient visual analysis. Photos and videos can be valuable for gaining a comprehensive understanding and a broader view of a site during analysis (Tal & Altschuld, 2021). For example, a 2016 study showed that using 360 video in particular with drones can be used to successfully aid in conducting site analysis, especially effective when coupled with additional resources about a site (George, 2016).

Currently, drones are often equipped with cameras capable of capturing high-resolution imagery, reaching up to 4K, which is exceptional image quality and detail (Tal & Altschuld, 2021). As mentioned from Kullman, drone imagery can be captured at different angles, including vertical and oblique (Kullman, 2018). Oblique imagery has shown to be particularly effective at creating common understanding of landscape amongst different stakeholders for planning purposes in past research. It was found that observers are able to interpret oblique imagery easier than vertical imagery, as vertical may require more experience with interpretation (Kleinschroth et al., 2022).

Further, drone photography can be processed using techniques in different ways for visual communication. Images can have overlaid or superimposed information for different purposes. Techniques for adding information are annotations (as shown previously in Figure 18 on page 32), matching photos with 2D drawings or even 3D models, matching photos with hand sketches, or simply photoshopping images (Tal & Altschuld, 2021).

As shown from the Kullman and Li and Chang research, drones can develop orthomosaics and topographic datasets. Information from drone photography is used in the photogrammetric processing of orthomosaics that can generate datasets to communicate elevation and topography (Tal & Altschuld, 2021). Further, this information can be processed to generate contours to communicate topography as line work. An example of drone generated contours from an orthomosaic is shown in a figure in the next page (see Figure 20 on page 34).

Photogrammetry can also be used to create 3D models that can be used as representational site survey. The 3D models can be zoomed into and panned around to digitally see different perspectives and topography of a site. An example of a drone generated 3D model of an urban site is shown on this page (see Figure 21).

As drone data easily integrates with GIS, the topographic data can be further processed into additional information, including slope and aspect. Slope data represents the varying steepness or incline of terrain. Aspect represents the direction in which a slope faces, indicating the orientation of the terrain with respect to the cardinal directions. An example of a slope data set from past experimentation of an urban property site is shown on the next page (see Figure 22 on page 35). An aspect data set of the same site is also shown on the next page (see Figure 23 on page 35).

Figure 20
Tal, D. & Altschuld, J. (2021). Drone Technology in Architecture, engineering and construction: A strategic guide to unmanned aerial vehicle operation and implementation: John Wiley & Sons.

Figure 21
Skondras, A., Karachaliou, E., Tavantzis, I., Tokas, N., Valari, E., Skalidi, I., Bouvet, G. A. & Stylianidis, E. (2022). UAV Mapping and 3D Modeling as a Tool for Promotion and Management of the Urban Space. *Drones*, 6 (5): 115.

As previously mentioned from Li and Chang's research, drones can be equipped with a range of sensors that can communicate or visualize different design investigations (Li and Chang, 2019). A couple of sensors that have been increasing in relevance and could be used in the urban environment for site survey and inventory are the use of infrared or thermal. Infrared sensors and NDVI image algorithms can be used to analyze the health and vitality of vegetation or moisture in an area, an example of a dataset is shown on the next page (see Figure 24 on page 35). Thermal sensors can be used to visualize heat indexes in an area, such as heat distribution and hot spots, that include features such surfaces, roofs, and vegetation (Tal & Altschuld, 2021). An example image of a thermal sensor data is shown on the next page (see Figure 25 on page 35).

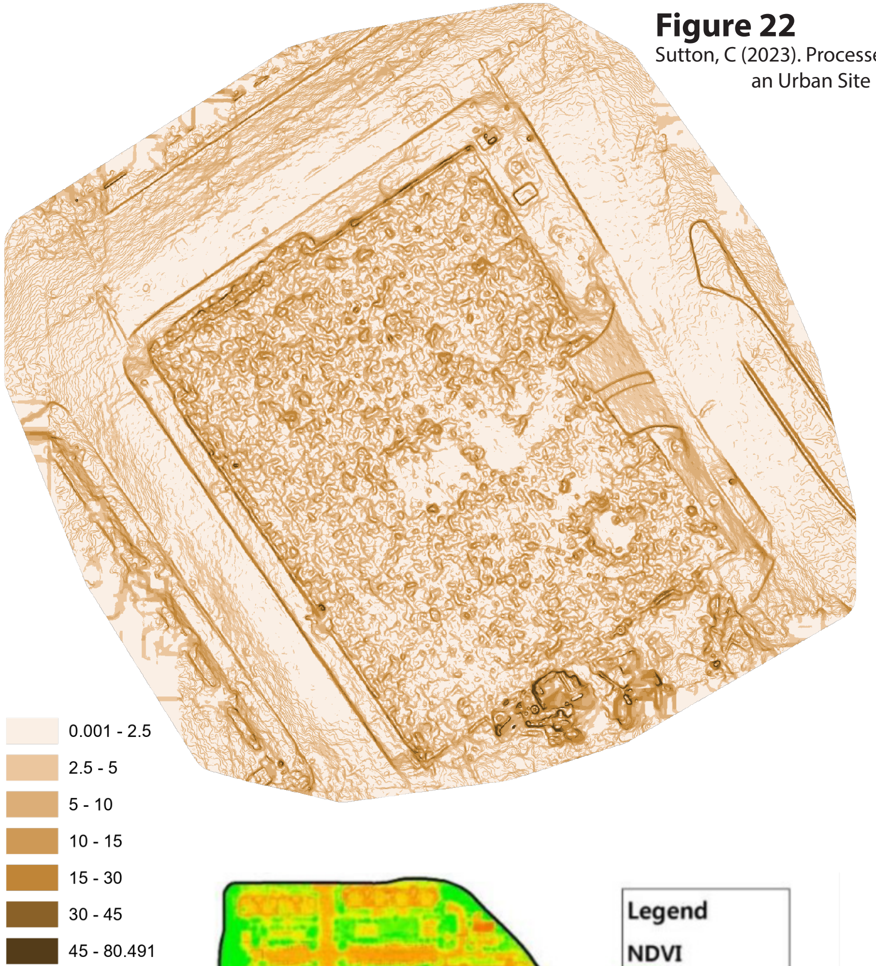


Figure 22
Sutton, C (2023). Processed Slope Data of an Urban Site in San Antonio, Texas, USA.

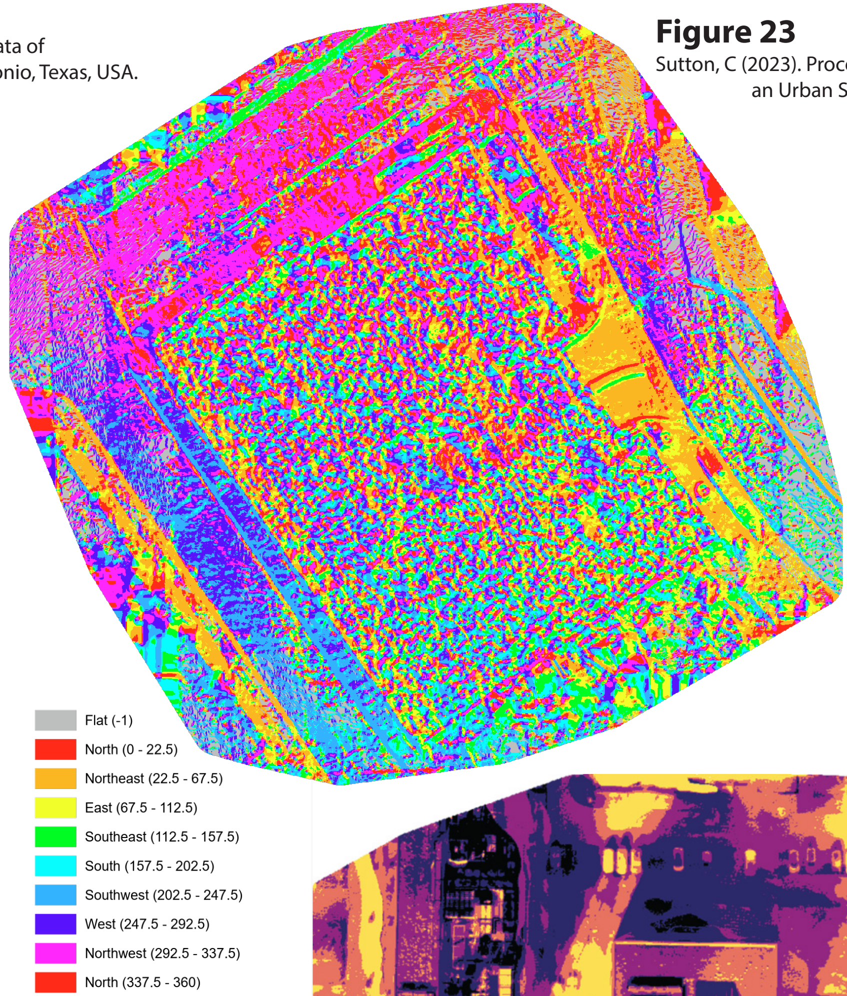


Figure 23
Sutton, C (2023). Processed Aspect Data an Urban Site in San Antonio, Texas, USA.

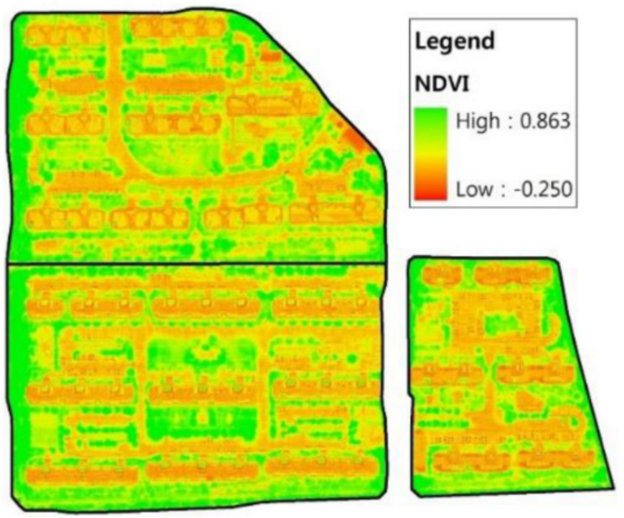


Figure 24
Lee, G., Kim, G., Min, G., Kim, M., Jung, S., Hwang, J. & Cho, S. (2023). Vegetation Classification in Urban Areas by Combining UAV-Based NDVI and Thermal Infrared Image. *Applied Sciences*, 13 (1): 515.

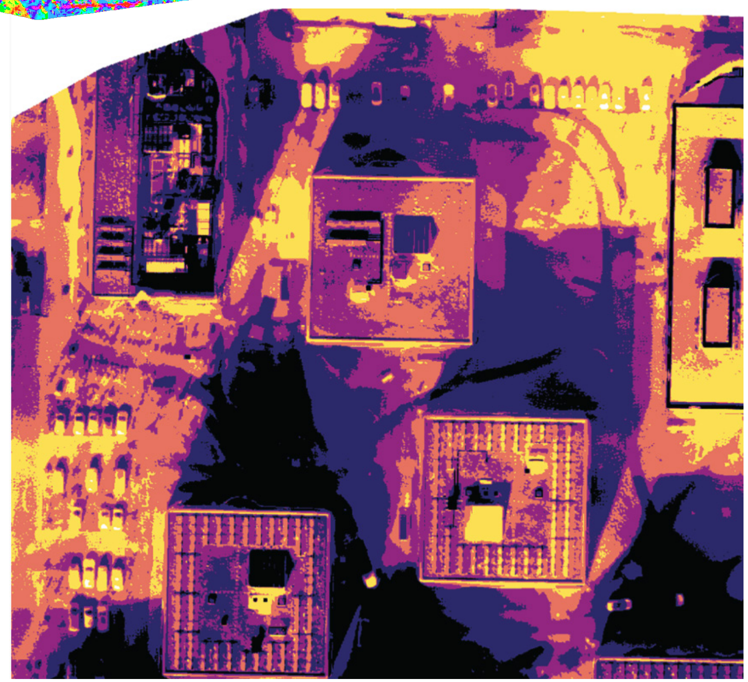


Figure 25
Tal, D. & Altschuld, J. (2021). Drone Technology in Architecture, engineering and construction: A strategic guide to unmanned aerial vehicle operation and implementation: John Wiley & Sons.

Conclusion

A review of literature shows that drone technology offer significant advantages and potential as a site survey and inventory tool in urban landscape design. They are innovative for aerial photography, topographical surveys, and mapping. Their functionality is very applicable in AEC industries and within urban environments. Drones provide fresh perspectives, high return on investment, and integration into project workflows and other tools like CAD or GIS. They produce high-resolution photography and orthomosaics, efficiently and economically acquire 2D and 3D data, and can collect more specific information through various sensors, all of which can be used for analysis.

Limitations and challenges of drones as a potential site survey and inventory tool include differentiating visually appealing data from accurate data, high initial costs of equipment or training, limited flight times, safety and privacy concerns, and varying regulations. Overcoming the potential challenges of their use in urban environments and gaining further societal approval requires investigation and wider adoption of drone technology, including for urban landscape design.

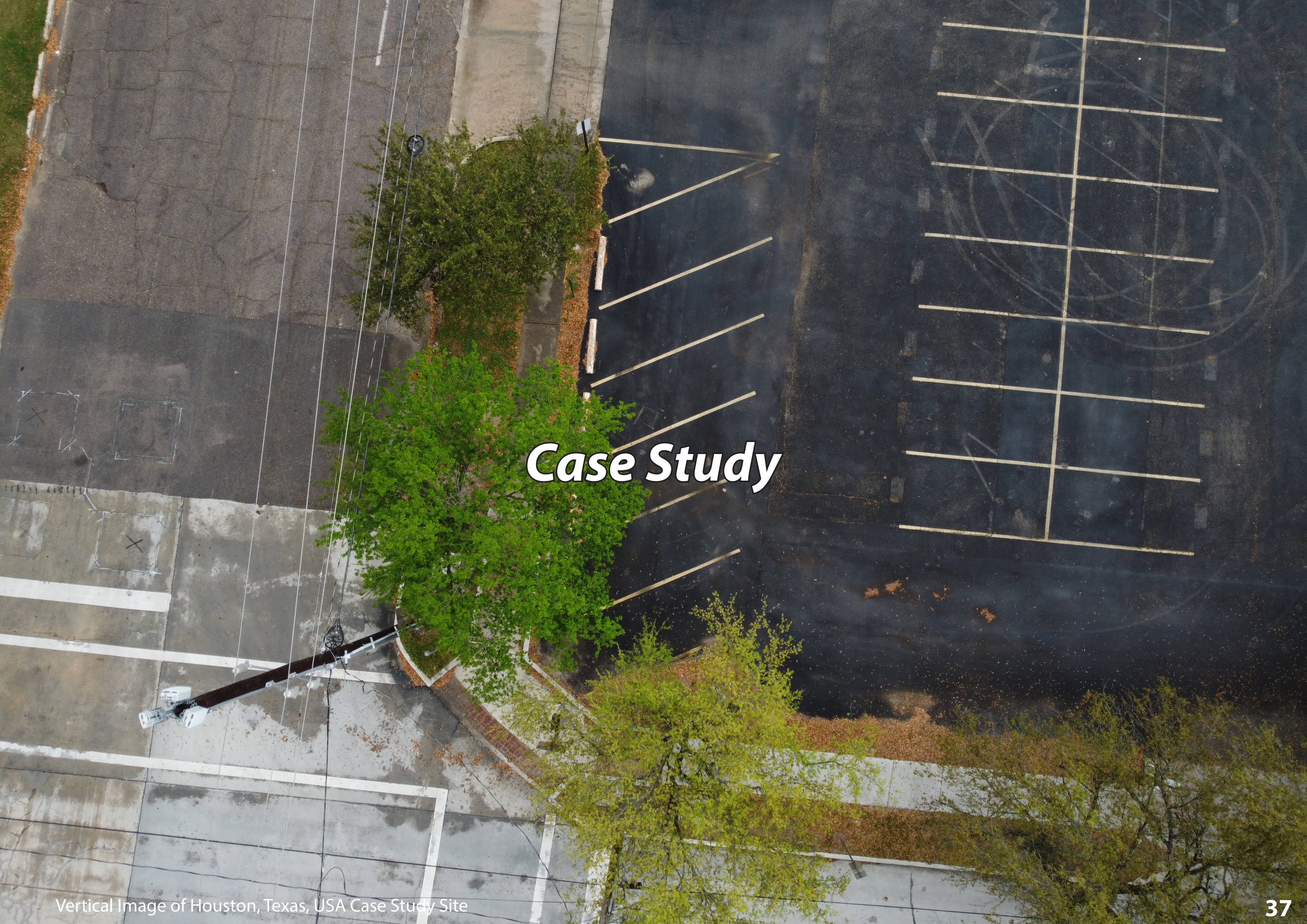
Drones have expanded the possibilities of communicating and representing landscape, or landscape data, in various ways. This is achieved through their potential for diverse data-collection, processing, and visualization techniques. Drones and their data can enhance site surveying, mapping, and design processes, making them a potentially valuable tool in urban landscape design if utilized, despite challenges or costs.

While surveying and inventorying is determined to be the foundation for landscape design, the current state of existing studies on drones as a tool specifically for landscape design is still quite limited. The existing literature and research discusses the use of drones and their data, in general, for landscape architecture. Although the available literature discussed the capabilities, advantages, and potentials of drones, further research can be conducted to verify and explore their use and data in the context of site survey and inventory in urban landscape design.

As aerial perspectives and photography are core components of drones, more research can also be done to investigate their benefits and limitations for informing site survey and inventory in urban landscape design. An investigation of vertical, oblique, and processed orthomosaics in a physical site survey within the urban site context must be conducted for findings. Also, as site survey and inventory uses on-site perspectives or even open-access database imagery resources, comparisons can be made with drone perspectives in the urban context.

The literature also showed that drone photography can be used to communicate information through different techniques and throughout different project stages. An of exploration of using drone perspectives to specifically communicate site survey and inventory and contextual information in the urban environment must be investigated and demonstrated.

A case study detailed in the next sections is used to further explore these gaps and the research objectives of this study.



Case Study

Vertical Image of Houston, Texas, USA Case Study Site

Overview
The purpose of this overall section is to outline the methodology, tools, and findings of the case study. The 'Methodology' sub-section discusses the research design, case study selection, data collection/processing, and analysis methods used. The 'Description of Tools' sub-section describes the tools used to develop the case study. The 'Case Study Findings' sub-section demonstrates and describes the research findings of the case study.

The main purpose of this thesis is to explore how aerial drone perspectives can supplement the site survey and inventory stage of urban landscape design.

The objective of this thesis is to investigate the capabilities of drones in capturing aerial perspectives, specifically vertical and oblique angles, of an urban landscape site. The aim is to identify the benefits and limitations of the aerial perspectives for informing site survey and inventory in urban landscape design. Additionally, this research will explore how the perspectives can effectively communicate site survey and inventory information.

The purpose of this case study is to further explore these objectives.

Methodology

Research Design
This study is a qualitative research approach with a case study of an urban landscape site. This approach was chosen to explore the research question and objectives in a practical way, as drones are a physical instrument and urban landscape is tangible.

A physical site visit of an existing urban landscape site was conducted with basic drone equipment to explore the capabilities of drones in capturing aerial perspectives, vertical and oblique, to identify their benefits or limitations for informing site survey and inventory.

Oblique and vertical photos of the site were collected and processed with relevant software. The process of gathering data was reflected on. Additionally, the oblique and vertical drone photos were visually analyzed for the research objectives. Comparison with open-access imagery is also used.

The case study selection, data-collection methods, data processing, and analysis is further detailed in the next pages.

Case Study Selection

The case study site and location is in downtown Houston, Texas, USA.

The case study site was chosen due to its location within highly representative urban landscape. It is located in a concentrated built-up area, with significant buildings, infrastructure, a range of land uses, and social and economic activity. The case study site is characteristic of where a typical urban landscape design project might occur, such as a public park, square, or other public space. Additionally, it was chosen due to less limitation to investigate the research question. The regulatory nature of drone use in downtown Houston has restrictions, but has less restriction on drone operation overall compared to other potential urban locations.

The case study site can be described as one square block of downtown Houston, Texas. It is made three plots of land with three different physical addresses. The site is made up of a mix of trees or shrubs, open grass area, vehicle parking lots, pedestrian sidewalks, and utility infrastructure.

Criteria for selecting the site were considerations of drone flight risk, privacy, and data quality. Site location options were investigated with web applications to inform on local regulations for permissible drone use. Additionally, the web applications were used to determine and avoid drone flight issues with potential obstacles, such as buildings or infrastructure (DJI Fly Safe., 2023, Google Earth., 2023). Further, the location was chosen for considerations of obtaining good quality data and personal privacy. The site had good potential for no on-site activity during the visitation in an area generally busy with urban activity, such as pedestrians, car-traffic, or other uses. The site met all the criteria.

It is important to note that there was no urban landscape design plan or project occurring at the site during data-collection. In this study, the site served as hypothetical location for a potential urban landscape design project in order to conduct the research.

More information on the site is presented in the 'Case Study Findings' sub-section, that follows the 'Description of Tools' sub-section.

Data-Collection Methods

An on-site drone flight was conducted to collect data for this study in early March 2023.

The case study site was visited in person to conduct drone data-collection flights using a DJI Mini 2 drone. In-person observations and investigations of the site was conducted before drone flight operation to further determine physical obstacles, safety concerns, or limitations. As a potential limitation to data capture, the drone had to be flown at allowable regulatory height and navigated to avoid infrastructure, such as power lines.

During the drone flight operations, vertical and oblique drone photographs were collected. A visual representation of vertical and oblique drone photo perspectives is illustrated in the figure below (see Figure 26). The drone was flown into positions to face the camera sensor at each of the sides of the site, while also avoiding interference with obstacles. Oblique drone perspectives were captured to obtain a drone photo of each side of the site, in order to gain a full visual perspective of the site in the photos.

Additionally, a drone mapping mission was programmed using the Maps Made Easy iPhone application. A drone mapping mission is a planned drone flight to capture a series of vertical photos of a location within a personally customized boundary, using an aerial imagery base map for reference. The customized boundary was drawn to include the whole site. This was for the purpose of capturing the vertical photography for the entirety of the site, and to produce an orthomosaic from the photographs.

The tools used for data-collection are further described in the 'Descriptions of Tools' sub-section section on page 42. The flight data for the drone mapping mission is shown and further described on a proceeding page in the 'Case Study Findings' sub-section.

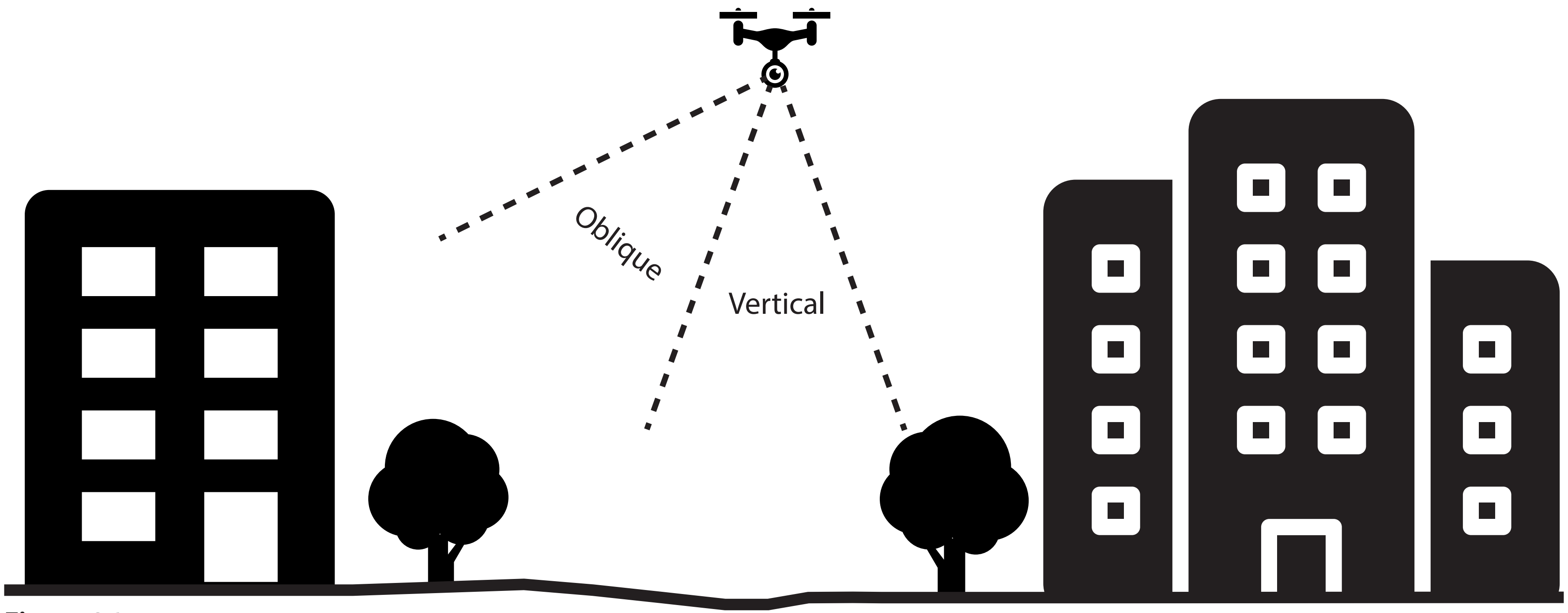


Figure was created using creative commons svgs
Available at: https://www.svgrepo.com/svg/477382/drone-15
Available at: https://www.svgrepo.com/svg/490033/building
Available at: https://www.svgrepo.com/svg/513181/building
Available at: https://www.svgrepo.com/svg/481537/tree
Creative Commons License https://www.svgrepo.com/page/licensing/

Figure 26

Data Processing Methods

The drone photos were captured in JPEG file format and did not need additional processing. However, the vertical photos collected from the drone mapping mission were copied and further processed into an orthomosaic using WebODM. The orthomosaic was then brought into ArcGIS Pro to be further processed into an exportable map for this document.

Additionally, the collected oblique perspective photos were processed using Adobe Photoshop and Illustrator to add visual elements of information gathered from traditional site survey and inventory method, in this study, research through open-access databases. The information was collected from open-access databases, that include the local government's GIS web maps or Google Maps. This method was used to creatively explore potential ways drone perspectives can be used to effectively communicate site survey and inventory information.

Analysis Methods

The process of flying the drone and gathering data was reflected on to understand how the use of drones can supplement site survey and inventory. Additionally, the collected oblique and vertical drone photos were visually analyzed in order to interpret the benefits and limitations of informing site survey and inventory. Dinc and Gul's comprehensive data list from the site survey and inventory literature (on page 21) was also referenced to determine the benefits of capturing specific site inventory data. Comparisons between the collected drone photos were made between open-access database imagery, that includes Google Street View, Google Earth, and Google Maps.

The oblique drone photos were visually analyzed to determine how they could be used to communicate information gathered from open-access databases as mentioned from the processing methods. This involved identifying relevant site survey and inventory themes or features that could be conveyed in the photos, such as the presence of vegetation, infrastructure, and surrounding elements. Dinc and Gul's data list was also referenced for this.

Descriptions of Tools

DJI Mini 2 (Drone)	The drone used for this study is a DJI Mini 2. The drone manufacturer is the China based company DJI. The specific model of the drone is the Mini 2. It weighs 0.249 kilograms (249 grams). The drone classification is a multi-rotor quad copter. The drone has fully stabilized 3-axis gimbal equipped with an on-board camera sensor. The camera sensor can take photos with a resolution of 12 megapixels. The drone is operated by an external DJI remote control that must connected and used with a smart phone (DJI., 2023). For this study, the remote control was connected to an Apple iPhone 12 mini smart phone (Apple., 2020) using the DJI Fly App for display, navigation, and the operational commands for the drone.
Maps Made Easy (Software Application)	Drones Made Easy is a company that provides software and services for the purpose of drone mapping and surveying including the Maps Made Easy iPhone Application (Drones Made Easy., 2023). The Maps Made Easy iPhone application was used to program the drone mapping flight plan instructions to the drone remote control for the vertical photographic data collection of the case study.
WebODM (Software Application)	WebODM is an open-source drone-data software tool designed to process drone-captured images for the production of maps (orthomosaics), geo-referenced point clouds, 3D textured models, and other data (OpenDroneMap., 2023). The software was used in this study to process the vertical photographic data collected during the site visit into an orthomosaic.
ArcGIS Pro (Software Application)	ESRI's ArcGIS Pro is a desktop geographic information system (GIS) software used to visualize, analyze, and manipulate 2D and 3D geographic or spatial data (ESRI., 2022). The software was used in this study to create and export maps of the case study and orthomosaic.
Adobe Photoshop/ Illustrator (Software Applications)	Photoshop is a desktop software application by Adobe used for photo/pixel-based image editing and manipulation (Adobe., 2023). Illustrator is desktop software application by Adobe used for vector graphics creation and modification (Adobe., 2023). These two softwares were used in this thesis to edit the oblique drone photography of the case study. Both softwares were used to add visual elements of site survey and inventory.

Case Study Findings

In this sub-section, the case study information and findings are presented.

The Houston drone flight and data-collection was conducted around 10am on March 7th, 2023. The weather conditions were overcast and slight precipitation, which is common weather for March in Houston. The drone flight and data collection lasted around 20 - 25 minutes of total flight time, however 20 or so minutes of additional time was given for investigating safe drone operation. The case study site location and address information is shown in the map figure below (see Figure 27).

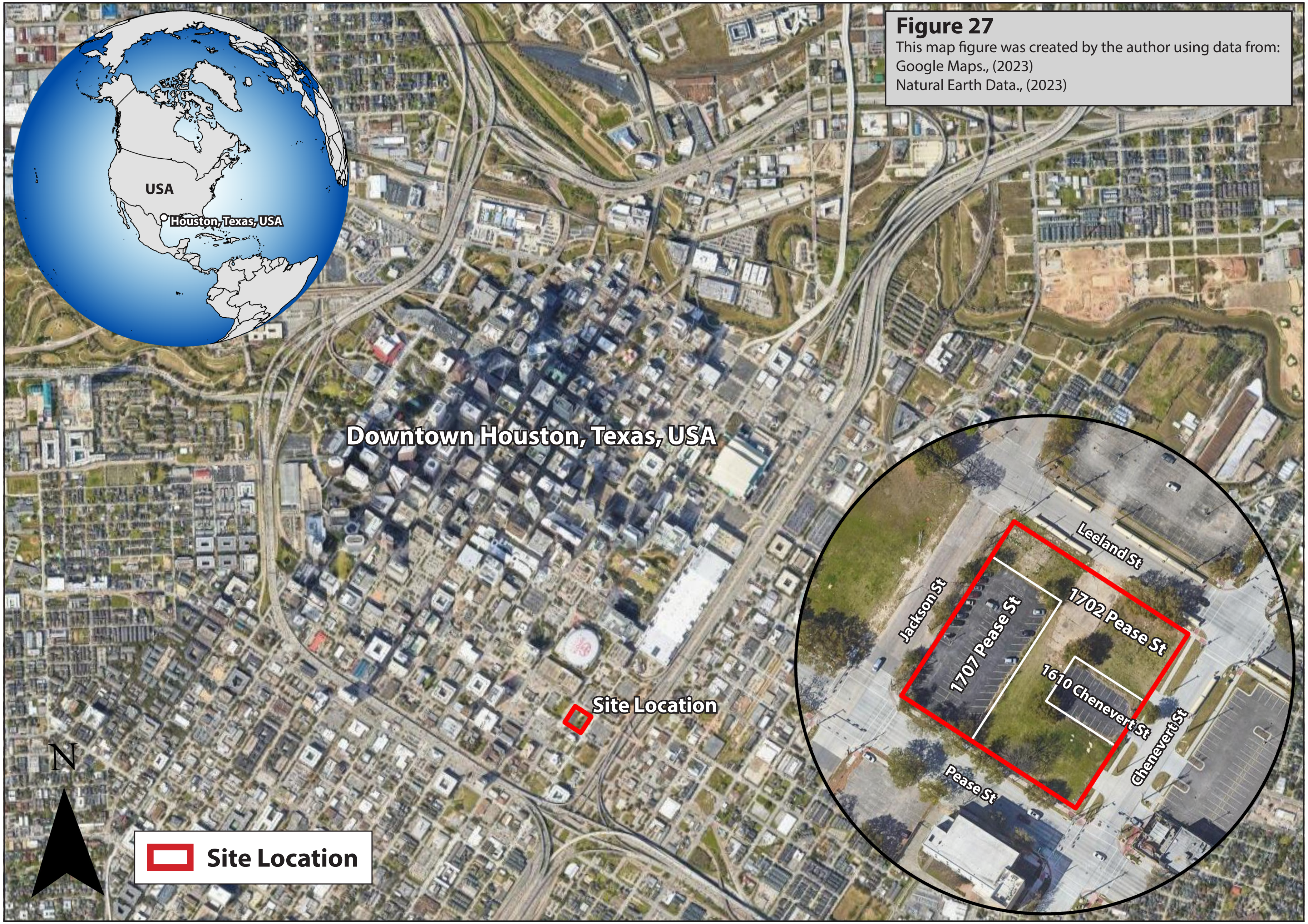
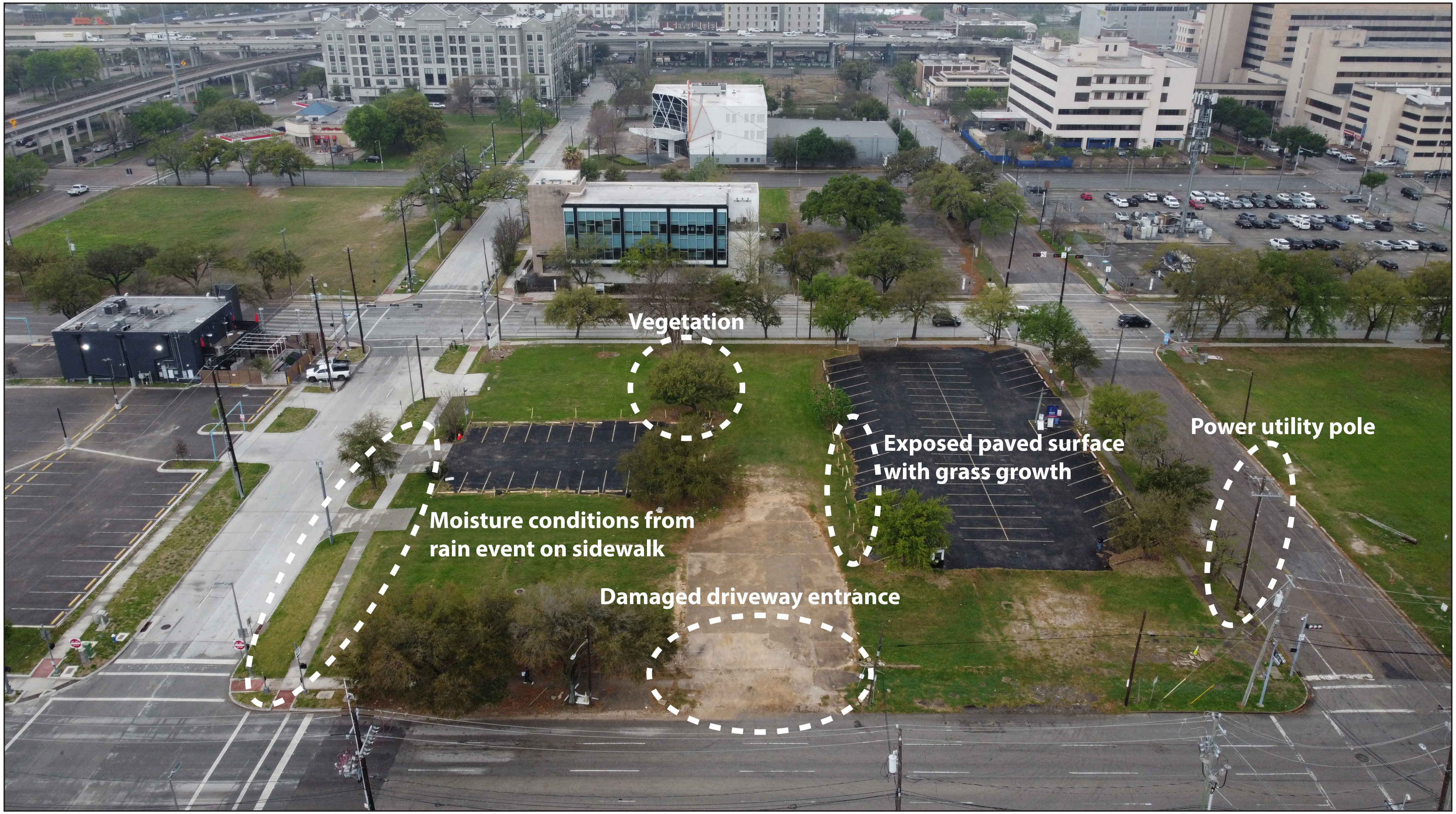


Figure 27
This map figure was created by the author using data from:
Google Maps., (2023)
Natural Earth Data., (2023)

Benefits and Limitations of Oblique Drone Photos

The collected oblique photos demonstrated that using a drone during a physical site visit means obtaining unique high-resolution site perspectives or views that would not be accessible through traditional photography or on-the-ground observations. While only a few oblique photos were collected for this study, the site visit and drone flight showed that nearly endless perspectives of the site were possible to obtain, aside from where the drone may have faced potential obstacles such as power lines or buildings, or exceeding the regulatory allowable height of drone flight operation.

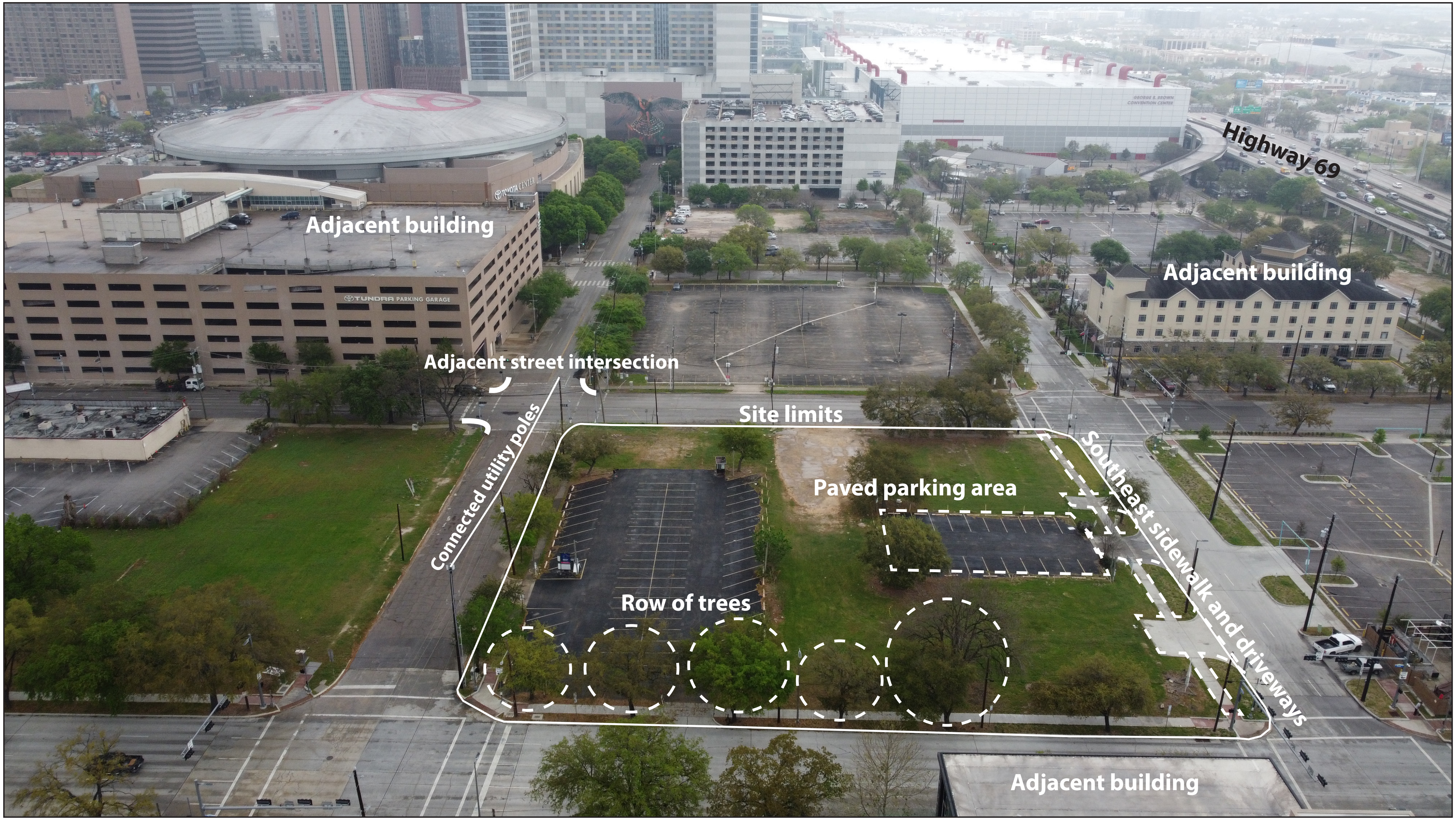
For urban landscape design, the benefit of being able to obtain multiple perspectives make it easier to inventory features, evaluate site conditions, or find potential design challenges. In the Houston site, inventory features and design challenges such as utilities, vegetation, and ground conditions are clearly visible in their existing state at the time of the visit. Example observations are indicated by the dashed ovals and text in the case study oblique photo below.



View of site from northeast

The oblique drone photo perspectives make it easier to understand the layout and patterns of the urban site and its surrounding urban landscape, including the streets, infrastructure, vegetation, or buildings. Example observations are indicated with white and dashed lines or ovals in the oblique site photo below.

Another finding is that the oblique drone perspectives show comprehensive high-resolution and up-to-date views of the entire site in single images, including its immediate or larger context. These perspectives are not offered in this level of clarity and quality with other methods, especially with the dominant 2D perspective used for landscape design. In the Houston site, an entire block of the downtown and all its elements have been captured in single images with a drone. This type of perspective is not achievable on the ground.



View of site from southwest

Shown in a figure on this page is a ground level view at the Houston site to demonstrate the limited vantage points of being on-the-ground (see Figure 28 on this page). The image is from Google Street View, where even with 360 degree capability, the comprehensive view of the site is not achievable.

Since a traditional site survey may use open-access databases for site perspectives and information, such as Google Street View, the imagery available may not be very recent, which may show outdated site conditions. This street view image in Figure 28 is what was currently available at this location on site, with a capture date from October 2019, whereas the site visit was done in March 2023.

Comparing the Google Street view figure, top right, with one of the oblique drone photos, on the bottom right, and shows a shrub that is missing in comparison, demonstrating outdated site conditions.

Another example is shown on the next page from another location at the site with Google Street View imagery (see Figure 29 on page 47).

Figure 28 Google Street View., (2019)


View of site from northeast

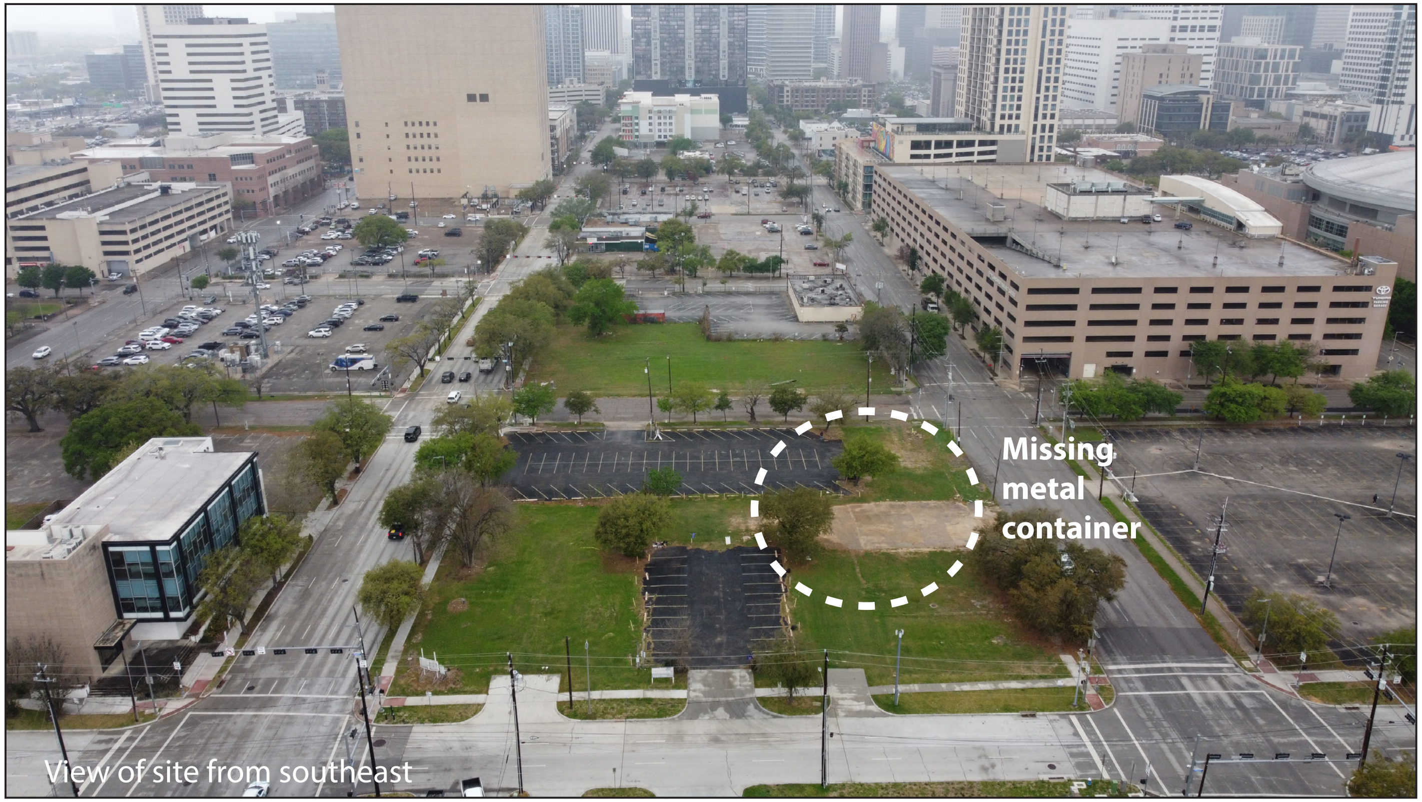
The oblique drone photo used for comparison with Figure 29 is shown on the bottom right. The Google Street View imagery had a capture date of January 2023 compared to March 2023 of the drone site visit. A metal container is shown missing from the site just two months later.

While the Houston site conditions are not dramatically different from what is seen in the available open-access Google imagery, this is not always the case in other locations. Some urban locations around the world often have no Google Street view imagery, very low resolution or limited perspective aerial imagery, or imagery that shows considerably out-of-date site conditions.

Important to acknowledge however that repeat site visits with drones and a collection of aerial perspectives over longer periods of time could be useful in urban landscape design projects to see changing conditions. Also, a review of past or historical satellite or airplane imagery might also have its purpose and benefits.

Other examples of comparisons with open-access Google imagery and the case study site are shown in proceeding pages of this sub-section.

Figure 29 Google Street View., (2023)



Ground perspectives and ground site photos may of course still be necessary for urban landscape design. It is likely necessary to obtain even closer images of features on site, even with the significant scale and high resolution of drone photos. Although, thorough photo vantage points and zooming into the oblique images may enhance this. Drone perspectives could also have obscured views of features or conditions on site, where one may want to see under or around other site features, such as trees for example. This is further evident in the vertical photos discussed in proceeding pages of this sub-section.

Drone perspectives alone cannot provide the sense of being on the site that that an in-person site visit already provides or ground photos may provide. Additionally, obtaining ground level, eye level, or horizontal field of views, would be redundant with drones during in-person site visits and traditional photography. This is to get the in-person view or sense-of-place on the ground for a design concept, such as seeing the surrounding urban environment and being a person present in the site. However, the collected oblique photos in the case study provide angled site perspectives that give a sense of the three dimensional urban environment in and around the site. You can get a sense of scale and size of the site in relation to its surroundings. The contextual information that the oblique drone photos provide shows how the site fits into its urban environment and relationship to connected or nearby features. The oblique photos show site and site context characteristics, such as colors, textures, designs, and topography that may be used for analysis to develop design concepts.

Specific information in other formats, other than photos, is typically needed as part of the site survey and inventory stage in urban landscape design projects. However, other site inventory data points can be sensed or evaluated in the oblique perspective photos, such as neighborhood character, nearby landmarks, and the circulation of the site, such as its accessibility or walkability. The potential benefits in observation that can be made from reviewing oblique photo perspectives is significant for supplementing a physical site survey and gaining a higher understanding of the site, literally and figuratively.

As stated previously, the oblique perspectives collected by a drone are not offered in this level of quality with other methods. No other method offers these types of vantage points with the relatively low effort and investment in time. The only comparison at this time may be Google Earth, which may be used as an open-access database resource for site survey and inventory.

A comparison to a collected oblique perspective and the similar site perspective that can be obtained from Google Earth is shown on this page. The oblique photo on the top right and the Google Earth perspective on the bottom center (see Figure 30).

Google Earth is effective at achieving similar vantage points, but this comparison demonstrates the significant benefit or difference when using a drone. Similarly, to using 2D satellite or airplane imagery, the Google Earth comparison shows how inventory features on site may not be visible or accurately represented in open-access database information. Examples of this are the poorly rendered or missing utility poles on site, poorly rendered vehicles, and relatively low render quality trees and shrubs. This is shown with white ovals and text in Figure 30.

Finally, the oblique photos simply show that drones provide actual photos of the site and the urban landscape, not a representational model. Meaning the true reality of a site is captured at the time of data collection.

Benefits and Limitations of Vertical Drone Photos

The flight data from the Houston drone mapping (vertical photo data-collection) is shown in the figure on this page (see Figure 31).

The drone mapping mission lasted a total 597 seconds of total flight time (9 minutes and 56 seconds). For a site survey and inventory already incorporating a physical site visit, that amount of time would be insignificant for the added benefits with the drone. It was also performed with relative ease. The programmed altitude was 28.2 meters (92.5 feet). The flight was programmed to take a photo every two seconds. A total of 139 images were captured during the course of the flight, with 136 vertical photos of the site. The flight was programmed in this manner to achieve significant image overlap to produce a high quality orthomosaic of the site.

The customized boundary drawn to command the flight path of the drone mapping mission is screen-shotted from the Maps Made Easy app is also shown on this page (see Figure 32). The transparent orange polygon represents the boundary, the white lines represent the flight path of the drone for positioning, and the blue lines and dots represent the flight path of image capture.

Link to the Mission this Flight was flown as a part of.

Flight	
Mission	1605 Jackson St
Public	✖
Public Views	None
Programmed Flight Altitude	28.20 m
Altitude ATL	Max: 29.70 m, Min: -2.30 m
Altitude ASL	Max: 55.60 m, Min: 23.60 m
Waypoints Programmed	22
Waypoints Visited	21
Overlap	80/80
Duration	597 s
Takeoff Point Elevation	25.85 m
Max Range	125.97 m
Max Speed	10.30 m/s
Total Distance Flown	1.4 km
Satellites	Min: 19, Max: 25, Avg: 24
App Version	MPP_pro_5.4.14_022420231
App Device	Device: iPhone 12 mini iOS: 15.6.1
Terrain Aware	No
Manual Restart Point Used	No
Switched Out of Flight Mode	Yes
Virtual Stick	Yes

Camera	
Camera	MavicMini2Camera
Imaging Mode	Active Connect
Ground Smear	Max: 17.10 cm, Avg: 1.30 cm
Images Triggered	137
Images Received	139
Videos	0
Filename Range	DJI_0859.JPG to DJI_0997.JPG

Aircraft	
Aircraft	DJI Mini 2
Aircraft Name	DJIMini2
Aircraft Firmware	01.05.0000
Aircraft Serial Number	3NZCHAP00373JG
Aircraft Pitch	Max: 30.70°, Min: -25.40°
Aircraft Roll	Max: 21.10°, Min: -13.80°

Battery	
Battery Temp	35 to 43°C
Battery Power	85% down to 49%
Battery Firmware	07.74.01.04
Battery Serial Number	3QFPHASCA30FHR

Figure 31 Maps Made Easy., (2023)

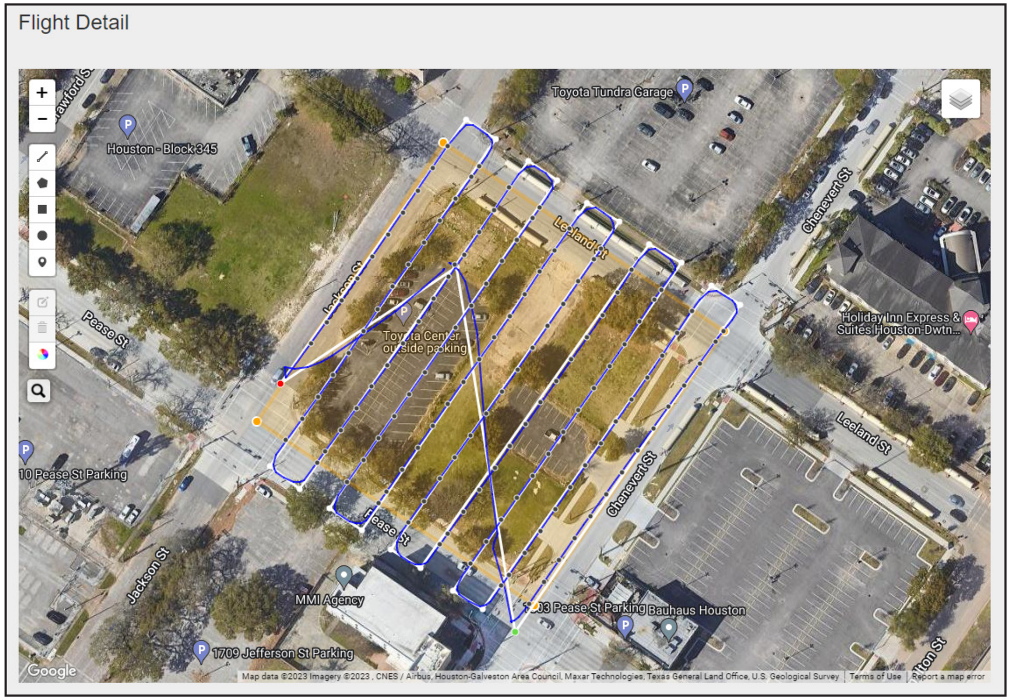
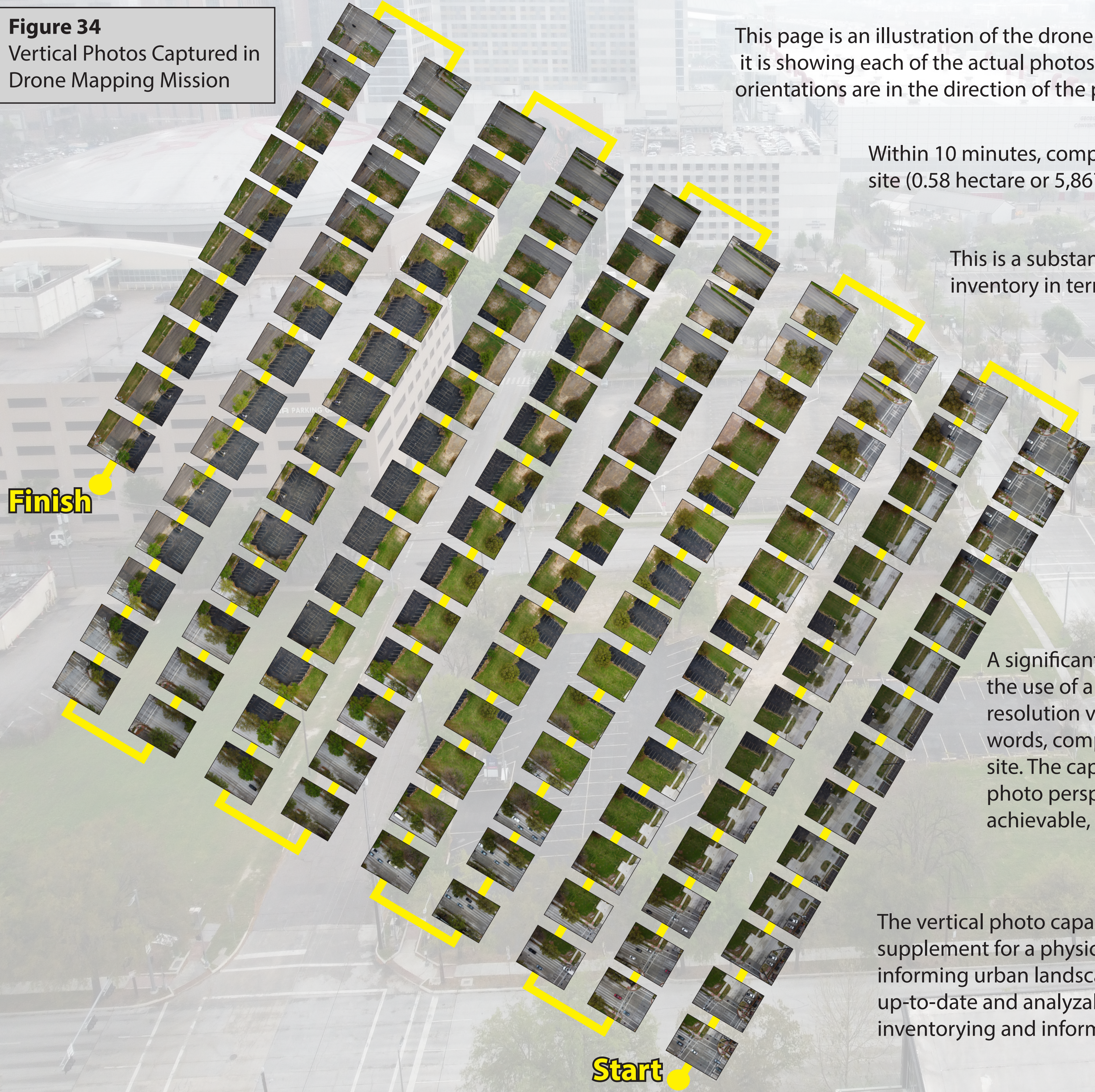


Figure 32 Maps Made Easy., (2023)

For further clarity, the flight path of vertical image capture is represented in the figure on the next page, with Google Maps satellite image as a reference (see Figure 33 on page 51).

Figure 33
This map figure was created by the author using data from:
Google Maps., (2023)

Figure 34
Vertical Photos Captured in Drone Mapping Mission



This page is an illustration of the drone mapping mission from start to finish. However, it is showing each of the actual photos taken along the flight path. Each of the photo orientations are in the direction of the path from start to finish.

Within 10 minutes, complete vertical photography of the 1.45 acre site (0.58 hectare or 5,867.9 square meters) was achieved.

This is a substantial supplement to a physical site survey and inventory in terms of benefits and investment of time.

A significant finding from this case study exercise, is that the use of a drone and mapping mission provided a high resolution vertical photo of every part of the site. In other words, comprehensive photo documentation of the entire site. The capability of obtaining these multiple top-down photo perspectives of a site is only practical, and perhaps achievable, with the use of a drone.

The vertical photo capability supports the use of drones as supplement for a physical site survey and inventory and benefit for informing urban landscape design. Each vertical photograph is an up-to-date and analyzable perspective of the site that can be used for inventorying and informing site qualities.

Further, the vertical photos can help determine existing features, patterns, and relationships. They are also useful for identifying inventory elements from Dinc and Gul's list. Two of the vertical photos are shown larger on this and the next page.

In the vertical site photo on this page, the broken sidewalk on site can be seen in a perspective that makes it more fully identifiable than it was on the ground. It is indicated by the dashed ovals.

In the vertical photo on this page, clear distinctions from vegetation surfaces and paved surfaces can be seen. Additionally, cracks and gaps in the pavement can be seen with high clarity as indicated by the dashed ovals. As stated previously from the oblique photos however, it may be necessary to see under or around objects like trees where a drone perspective may be obscured, such as the tree in the bottom center of the image.

Moreover, all of the vertical photos collected can be mosaiced, or in other words merged, into a geometrically accurate orthomosaic of the site that has been corrected for perspective and distortion. Using WebODM, the orthomosaic of the case study site was processed with ease and didnt require extensive software knowledge. The processing was completed under half an hour. A visualization of what is described is shown in the bottom center of this page.

As Kullman emphasized and asserted in his study from the literature, the most beneficial and applicable capability of drones for the field of landscape architecture is the ability of drones to produce high-resolution orthomosaics. Additionally, that high quality drone imaging and mapping can shift landscape architectural discussions to the actual site scale in which landscape is experienced and designed (Kullmann, 2018).

This was further evaluated in this study, whereas Kullman's case study was not in the urban environment. Shown in the figure on the next page is the orthomosaic produced from the vertical photos of the case study site (see Figure 35 on page 56). It used as a comparison with the Houston case study as seen in Google satellite imagery on the page that follows (see Figure 36 on page 57). Both are shown in the exact same scale and directional orientation.

It is useful to compare the drone orthomosaic imagery, as a traditional site survey and inventory may commonly use open access imagery such as Google. Google satellite imagery can be considerably high resolution and is a free open-access imagery source for GIS software or through web browsers. In urban locations in particular, Google can be a significant resource for imagery of urban landscape. Higher resolution satellite or airplane imagery of the site may be possible to obtain at a potentially high cost from other providers, but would still only be comparable to the drone orthomosaic.

This exercise indicates that minimal investment of time in a physical site survey with the use of a drone can result in a complete high-quality drone orthomosaic image of the site for informing urban site inventory, which can also be used as a base map for the urban landscape design process.

The Google satellite imagery that was most up-to-date in their database at the time of this study was produced on January 14th, 2022. The drone orthomosaic is visually significant, as it is higher resolution and more up-to-date than the Google satellite imagery. This is evident from feature comparisons in both images, such as the cylindrical construction object on the streets. The sites textures and features on site are also clearer, such as the sidewalk or the concrete wheel stops in the parking lots. These examples are shown with dashed white ovals and text in the figures on the next two pages.

For reference, the drone orthomosaic is 0.2 meters of area (20 centimeters) per pixel, or 0.65 feet per pixel.

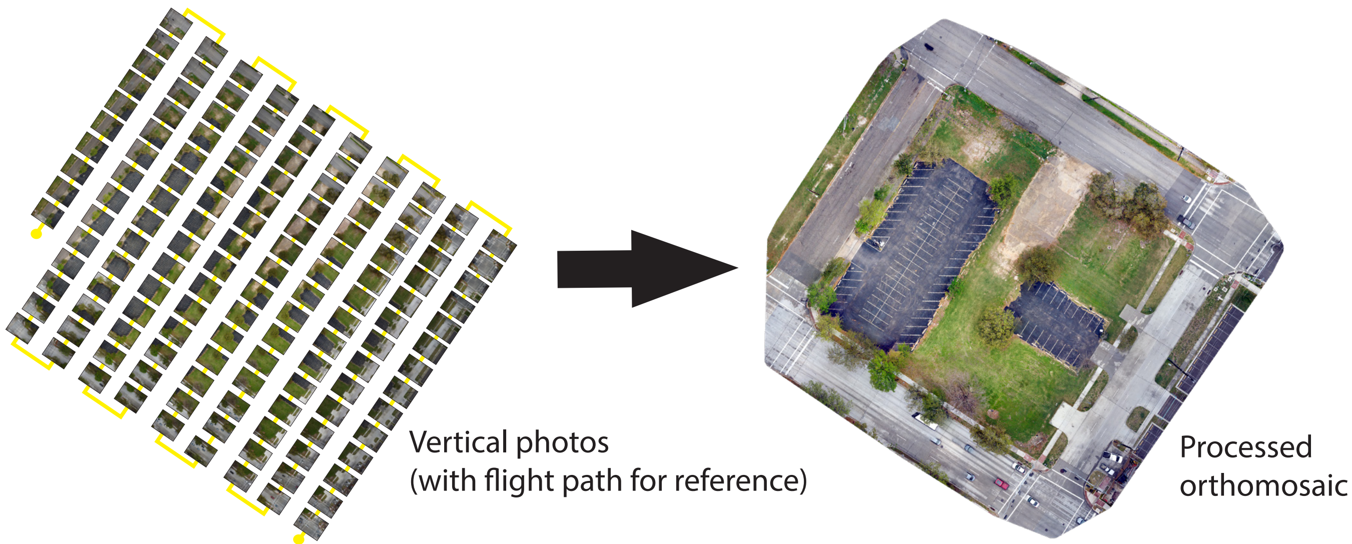


Figure 35
Processed Orthomosaic of Case Study Site

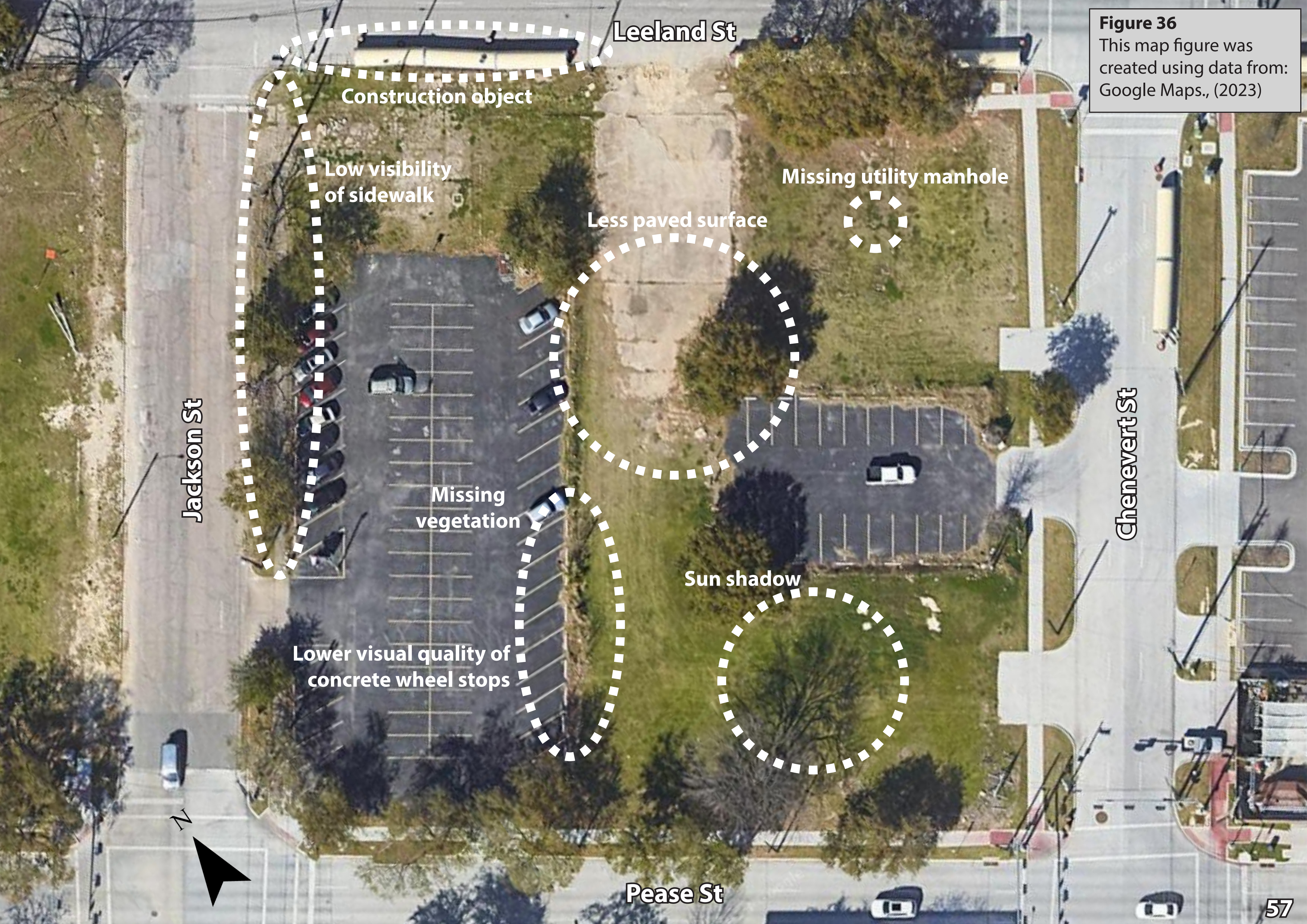


Figure 36
This map figure was created using data from: Google Maps., (2023)

Exploration in Communicating Site Survey and Inventory Information with Oblique Perspectives

As an objective of this study is to investigate how the aerial drone perspectives can effectively communicate site survey and inventory information, a creative exploration using the oblique perspective photos was conducted and is presented in the proceeding pages as figures.

A finding of this study is that oblique drone photo perspectives give great ability to highlight and inventory features not easily seen or immediately obvious from other perspectives. Alternatively, the ability to present site information and context in perspectives not offered with other methods. Visual elements of the urban site and landscape can be emphasized or highlighted, making it easier to identify various site survey and inventory features such as buildings, roads, and other infrastructure. Essentially, the oblique photos show the potential to be an effective and new type of mapping medium for site survey and inventory in urban landscape design.

With the unique drone site photo perspectives, and added visual elements of site inventory, it would be possible to quickly and easily communicate important information to others, such as clients or colleagues, without the need for extra explanations. As part of traditional site survey and inventory, data and information is collected from the physical site visit and various open-access sources. Drone photos can be used to supplement or complement the information gathered during the site survey and inventory stage for better understanding and communication.

On the proceeding pages, are a few explorations developed for the case study (see Figures 37 - 40 on pages 59 - 62). A legend for each figure has been added under each figure for further understanding of the visual elements.

Figure 37 Post-processed image of the Houston site

Google Maps., (2023)

In this oblique drone photo (see Figure 37), the physical property boundaries and addresses are shown for the site. The surrounding neighborhood of landmarks, businesses, and properties were also added. The surrounding context of cultural elements around the site are important for informing what is around to analyze and develop concepts for the site. Google Maps was used to identify the surrounding inventory of buildings and landmarks.

LEGEND

Site Location

Site Properties

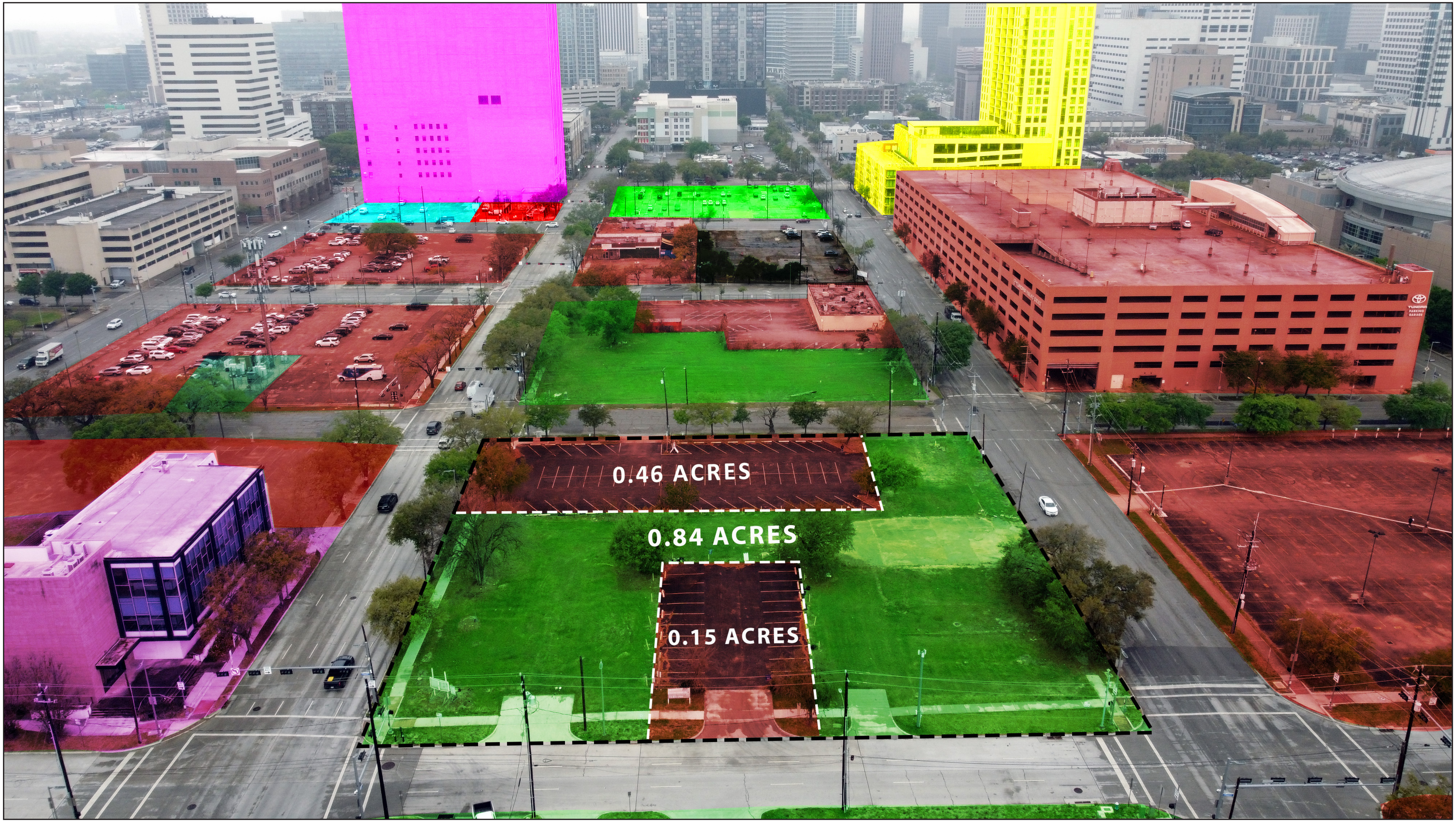


Figure 38 Post-processed image of the Houston site

City of Houston GIS., (2023);
Harris Appraisal District Parcel Viewer., (2023)

This oblique image (see Figure 38) conveys the plot size and boundaries of the site. Also added is the sites current land use designation as well as the surrounding land use designations of adjacent properties. This images indicates how much space is available on site and how the site fits with surrounding land uses. The land use information was collected from the City of Houston's GIS web application viewer. The plot boundaries and information were collected from the Harris County Appraisal District, the land and tax administrator for the city of Houston.

LEGEND

- Site Location
- Plot Boundaries
- Commercial
- Residential
- Undeveloped
- Office
- Industrial
- Unknown

Figure 39 Post-processed image of the Houston site City of Houston Tree Inventory., (2023)

The Houston site has multiple features that include utilities and vegetation. Highlighted in this oblique image (see Figure 39) are the pole and ground utilities that are important inventory elements or constraints for analysis to develop a concept for the site. The driveways are noted as access and parking areas labeled. Also inventoried are the multiple trees and shrubs on site. The species were verified using the City of Houston's tree inventory map, those that indicate tree or shrub were not verified from the map.

LEGEND

Drainage

Vegetation

Utility Pole

Figure 40 Post-processed image of the Houston site

Google Maps., (2023)

In this oblique image (see Figure 40), the spatial inventory elements of circulation and transport were added. The dashed white lines with arrows communicate the flow and direction of vehicle traffic around the site to get a sense of movement that could shape a concept. Additionally, highlighting the pedestrian access of sidewalks and crosswalks, as this may shape how the site would be developed for pedestrian use and access. The information conveyed in this image is from Google Maps, but also from observations in the photo.

LEGEND

- Site Location
- Street Traffic Directional Flow
- Pedestrian Sidewalk
- Pedestrian Crosswalk

Discussion

Vertical Image of Houston, Texas, USA Case Study Site

Overview
The purpose of this overall section is to interpret and contextualize the research findings as well as offer suggestions for future research.

The first sub-section, 'Discussion of Findings' interprets the main results and key findings, and aligns with literature presented. Secondly, it discusses the context and significance of the research. Lastly, it addresses limitations of the study.

The second sub-section, 'Suggestions for Future Research', discusses potentials for future research following this study.

Discussion of Findings

Interpretation of Findings
As from the literature on site survey and inventory in urban landscape design, the purpose of site survey and inventory is to obtain complete documentation of a landscape and to be able to describe all the elements (Dinc and Gul, 2022). Also, that "site inventory is an essential step in understanding the character of the site and the physical, biological, and cultural linkages between the site and the surrounding landscape" (LaGro, 2008, pg. 101). Moreover, site survey and inventory data should be obtained in a reliable, up-to-date, and analyzable manner (Dinc and Gul, 2022). This study showed from literature review and the case study that drones can play a role in site survey and inventory in urban landscape design. The findings from the literature and case study reflect the potential of drones with these ideas regarding the purpose and nature of site survey and inventory.

The case study specifically showed that high resolution oblique and vertical photo perspectives can be obtained as an effective means of visual documentation to describe the elements of an urban site. The photographic perspective data that drones collect can be a visual tool to develop further understanding of site conditions, inventory, and relationships on and around the site. This overall study has shed some light on the potential challenges or limitations of drone data and drone use in the urban environment, however they can be reliable tool and do produce data that is analyzable. The case study demonstrated that aerial drone perspectives do have some limitations, however the images do provide visual data of the site that is up-to-date, especially when compared to a modern and commonly used open-access resource for imagery. However, the findings of this study support the use of aerial drone perspectives as a supplement in site survey and inventory, not necessarily as the only means of information. They can be a useful addition for urban landscape design that incorporates physical site visit.

Drones can serve as a useful and modern tool for urban landscape designers in practice. Their purpose is not to clutter the sky or perpetuate subpar designing and shaping of urban spaces with flying buzzing machines. Instead, they may act as an extension of a designer's vision, offering a holistic view of the urban spaces they aim to thoughtfully shape. Equipped with aerial drone perspectives, landscape designers can grasp the "bigger picture" of the urban spaces they work with. The aerial drone perspectives can provide clarity and enhanced understanding, enabling them to make more sensible and informed decisions that contribute to creating healthier, more livable, and sustainable urban environments.

Context and Significance
This study serves as a contribution to drone and urban landscape design research as an addition to existing literature on these topics. It provides new connection to the specific use of drones within urban landscape design, and more specifically the site survey and inventory stage. The current state of studies was lacking in this regard. Further, this study has highlighted from the existing literature the potential role drones can play in the site survey inventory stage of the urban landscape design process.

Most notably demonstrated is how the collection and use of aerial drone perspectives, vertical and oblique photos, can supplement a physical site survey and inventory as well as communicate site survey and inventory related information.

Limitations
The case study research was conducted within a specific geographical area, there may be potential for limited generalization of the findings to other urban contexts, such as denser urban areas for example. Also in other places, there may be more potential for unwanted data interference or distortion, like car traffic or users on site. Also, the case study site and its surrounding area did not have any major topographical differences, and is a relatively flat urban area.

The case study specifically investigated aerial photographic perspectives of drones, vertical and oblique angles, for insights into their benefits or limitations in site survey and inventory urban landscape design. The perspective photos were only used, processed, and analyzed as described in the case study methodology. The case study was not an investigation of the full potentials of photographic drone data processing.

Also, the case study work was not a comprehensive investigation of all potential drone capabilities and sensors that could be used for site survey and inventory in urban landscape design.

Suggestions for Future Research

With regard to the use of drones in urban landscape design, there is still vast potential for further research that may be uncovered from literature review. However, the main focus of this study was on the benefits and limitations of aerial drone perspectives of drones for informing site survey and inventory in urban landscape design. Also how the perspectives can effectively communicate site survey and inventory information. Reflection on the work conducted in this thesis revealed potentials that are offered as suggestions for future research.

Studying the user perception and effectiveness of aerial drone perspectives for supporting landscape design work amongst landscape designers, researchers, or students has much potential to be investigated. Perhaps further research on the site survey and inventory stage, other stages of the design process, or throughout all stages in urban landscape design. Researching aerial drone perspectives on case studies of existing urban landscape design sites or potential urban landscape design sites that are larger, more complex, or dynamic could also be investigated.

Further research may also be to develop a protocol, guide, or process for proper and effective drone use to support site survey and inventory in urban landscape design. This is especially relevant with their currently contentious nature and difficulty to use them in practice in urban areas. If used properly, and the benefits of drones is consistently demonstrated, perhaps it can influence regulatory to be more accommodating to practices like urban landscape design.

With more sophisticated drone technology, you can collect and produce even more types of data or information for design inquiry. There is still room for investigations in to the full potentials of drones to support site survey and inventory. This could be a deeper dive into the different types of inventory data or inventory categories presented by Dinc and Gul for example. A closer look at how drone technology and data could be used in their full capacity, or to what level they can be used for comprehensive site survey and inventory may also be a future undertaking.

The case study in this thesis specifically used a camera sensor and discussed aerial drone perspectives of photography and orthomosaics. Video, 360 video, virtual reality, and artificial intelligence are other technologies that can utilize drone camera sensors. These other advancing technologies could be investigated for site survey and inventory potentials, or in general for urban landscape design, but not were not mentioned or extensively discussed in this study.

Conclusion

Vertical Image of Houston, Texas, USA Case Study Site

Conclusion

This thesis investigated how the use of aerial drone perspectives can supplement the site survey and inventory stage of urban landscape design. The first objective of this thesis was to investigate the capabilities of drones in capturing aerial perspectives, specifically vertical and oblique angles, of an urban landscape site. The aim of this objective was to identify the benefits and limitations of the aerial perspectives for informing site survey and inventory in urban landscape design. Additionally, this research explored how the perspectives can effectively communicate site survey and inventory information.

The case study findings demonstrated the ability of drones to collect multiple oblique high-resolution site perspectives that are not achievable through traditional photography or on-the-ground methods. This makes it easier to inventory features, identify conditions, or potential design challenges. The oblique photo perspectives allow for a full view, or comprehensive imagery, of the site in single images, and also show site context. However, it is likely necessary to obtain even closer images of features on site or have the perspective and sense-of-place of being a person on site that is typical in urban landscape design.

The collected oblique photos in the case study provided angled perspectives that give a sense of the three dimensional urban environment in and around the site. This enables one to have a sense of scale and size of the site in relation to its surroundings. Additionally, the oblique drone perspectives provide contextual views of the site, and how the site fits into its urban environment and relationship to connected or nearby features. It is possible to determine site and site context characteristics, such as colors, textures, and topography. Other site inventory data points can be evaluated in the oblique photos, such as the circulation of the site.

The case study additionally demonstrated findings from vertical photo perspectives. The drone mapping provided multiple high-resolution top-down perspectives of every space and corner of the site. This multiple top-down perspective photo documentation of a site is only practical with the use of a drone. The perspectives can also be obtained in a short amount of time. These perspectives can help further determine features, patterns, or relationships on site. However, the vertical photos could have obscured views. The vertical photos in the case study were also processed into a complete high-quality drone orthomosaic image of the site. The benefit being further informing of the urban site for inventory as a complete high-resolution vertical site image. It could later be used as a base map for the on-going urban landscape design process.

The case study also demonstrated that with either oblique or vertical perspective photos during a physical site visit you gain an up-to-date view and understanding of the site at the time of visit. When compared to a commonly used open-access database resource for high-resolution urban imagery, the drone perspective photos showed more up-to-date site conditions, and were higher quality.

A creative exploration of using oblique drone perspective photos to convey site survey and inventory related information was exercised in this study. This was explored as an additional finding of the oblique photos, in that they provide the ability to highlight and inventory features not easily seen, immediately obvious, or able to be presented in such a way with other methods. The findings shows that the oblique photos can be used as an effective means or medium to communicate site survey and inventory information when accompanied with open-access research.

This study demonstrated the potential of obtaining and using aerial imagery drone perspectives to supplement site survey and inventory, however it is only the beginning for future research into how drones can support urban landscape design.

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27) Case Study Map of Houston, Texas USA
This map figure was created by the author using data from: Google Maps., (2023) and Natural Earth Data (2023)

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