UAV Site Surveying: Application of Drone Imagery in the Design Process, Pre- and Post-Occupancy

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Abstract: Unmanned aerial vehicle (UAV) sensing technologies have become increasingly accessible in usability and affordability. The availability of low-cost and highly accurate site scanning technology offers advantages to small scale landscape design projects for site surveying and post occupancy evaluation. Using a private landscape design commission in Baltimore, MD as a case study, this paper explores the application of UAV generated 3D scan models in the design process. The paper reports on methods used to incorporate scan models into a digital design workflow, while discussing opportunities and constraints in their application for design and evaluation. The case study demonstrates the use of scan models as digital twins of project sites in the landscape design process and positions UAV sensing as a feasible approach to generating feedback loops for design process and construction outcome.

Keywords: Digital design, remote sensing, digital landscape, digital twin, post-occupancy evaluation

1 Introduction

Digital models are central to contemporary landscape architectural design practice. While they offer designers the opportunity to generate design proposals, simulate impacts and visualize proposals, the validity of the conclusions is dependent upon the resolution and quality of the input information (ERVIN 2001). The increasing accessibility of unmanned aerial vehicle (UAV) sensing and technologies for processing scanned datasets into 3D models has allowed both students and design professionals to adopt highly accurate site datasets into the design process (SEDLÁČEK et al. 2020). This paper builds on the discourse of UAV sensing and technology applications in three-dimensional digital modelling for landscape architectural practice, through a case study of a landscape design project in Baltimore, MD, USA. It reports on opportunities and constraints in the application of drone imagery for small-scale site surveying within traditional digital design workflows, offering insight on how designers can use UAV sensing at various stages of a design project. Finally, the paper reflects on an experimental approach of using UAV sensing to generate digital twins of pre- and post-construction landscapes to evaluate digital design intent against the physically realized work.

The case study project was conceived as a quick design study, with the full breadth of the design process from concept design to construction administration completed in less than a year. The expedited nature of the private commission created an opportunity to reconsider traditional aspects of the design process beginning with the creation of baseline site survey datasets. Inherently, the profession of landscape architecture relies on abstraction of physical site characteristics and environmental phenomena to make legible our assumptions about the physical world through models that can function as a tool for analysis, design simulation and representation (CANTRELL and MEKIES 2018). Central to the execution of the design project was the need for an accurate site survey that would reflect with great detail the 21 feet (6.4 meters) of relief from Falls Rd to Crowthers St (see Fig. 1), the site's biggest design challenge.

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In lieu of a traditional third-party site survey, the project used UAV sensing to generate a 3D mesh model of the site. This scan formed the basis of the project's 2D CAD linework, 3D digital site model, design prototypes, construction documents and ultimately the augmented physical landscape itself. There is no unified definition of a digital twin, though in its essence the term describes the link between physical and virtual objects (VAN DER VALK et al. 2020). This initial site survey served as a digital twin in the form of a 3D model, which bridged the real-world physical attributes of the site in an accessible and scalable virtual format for the design team.

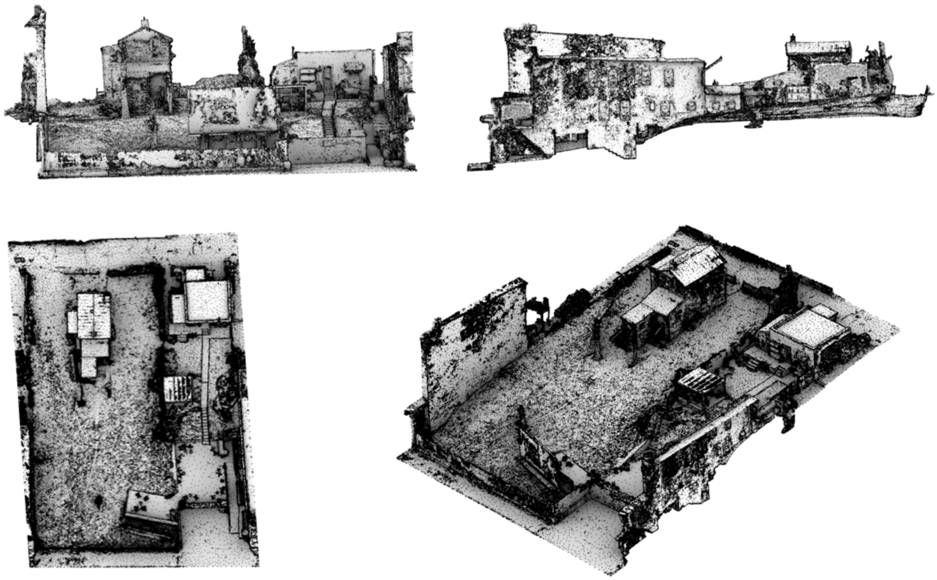

Fig. 1: Viewports (Front, Right, Top and NE Parallel Projection Axonometric) of pre-construction site scan point cloud and mesh model in Rhinoceros 3D (1,615,070 vertices)

2 Application of Survey Data in Design Process

2.1 Data Inventory

The digital twin helped inform incremental design inquiries about spatial relationships of the existing site condition and offset the need for additional site visits, while limiting the use of site photography review. In contrast to digital twins with real-time or incremental data input, the scan model represents a singular moment in time, which helped minimize input datasets and simplify site analysis. Throughout the design process, the need for further abstraction of the scan model proved necessary for conceptual and schematic design scenario testing and visualization. While point cloud datasets and meshes from UAV sensing have been well documented in recent years, their application within the full scope of a design and build project merits further investigation. Highly precise point cloud models are excellent aids in the design process but can often be challenging to begin to test scenarios with.

Fig. 2 diagrams the process of data abstraction and codification used within the design workflow to develop and test design schemes with an eye to articulating and inventorying a built project. The following design workflow is broken down into six stages of design operations which correlate to traditional landscape architectural design phases. Each phase is further explained through a series of criteria articulating the subject of the operation, the drawing format, information or dataset within the operation and the actions that the designer takes within the respective design stage.

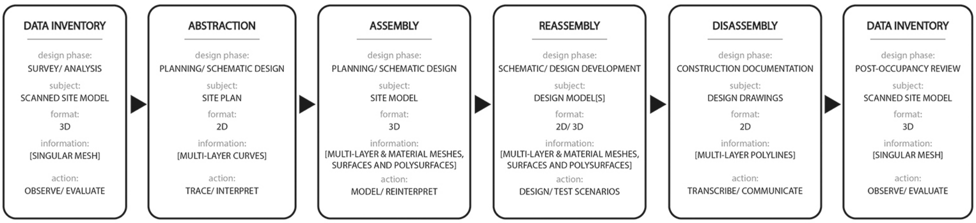

Fig. 2: Design process articulating the use of pre- and post-construction site scan mesh models within traditional landscape design practice workflow. Adapted from (URECH et al. 2020).

The first step in the design process involved opening the scanned site model in RhinocerosTM, a versatile NURBS based modelling software that can interpret and open a wide variety of three-dimensional model types (MCNEEL 2021). In this case, the scan file, saved as an OBJ file type was opened in RhinocerosTM, allowing the site to be observed and evaluated in 3D space within defined UTM coordinates. The site model, comprised of geo-referenced point clouds and a triangulated mesh with 1,615,070 vertices, was used to evaluate the existing condition of the site as part of the 'data inventory' phase.

2.2 Data Abstraction

To move forward with a design proposal the mesh model was simplified using lines, polylines and curves in the 'abstraction' phase. These vector-based datasets were used to trace and interpret the traditional elements of a landscape design pallet: landform, vegetation, water, and structures (architecture and infrastructure) (ERVIN 2001). These elements were visually evaluated using all available viewports (Front, Right, Top and Perspective) in RhinocerosTM and ultimately traced in the 'Top' viewport to generate a traditional plan view interpretation of the site as a 2D base map or site plan.

Here the remapping of site features through tracing and interpretation serves a double purpose: it serves as both an abstracted representation of site features and as a seminal method in the design process to take measure of the site's complexity (SALERNO 2019). Further, it allows the designer to actively consider elements of the site in both subjective and objective contexts through their visual transcribing (AMOROSO 2015). In addition, the act of interpreting and abstracting the scan model can supplement the initial physical site visit by affording the viewer vantagepoints and scales of investigation that would not be physically possible in a human body on site, such as birds eye perspectives or worm views. These new perspectives afford designers the ability to consider aspects of materiality, slope, tectonics, and atmospherics in contexts beyond traditional human perception, with the potential to inform future site design.

2.3 Data Assembly

Once the fundamental aspects of the project site were traced and organized as individual layers they were modelled in 3D. The 'assembly' phase involved the crafting of new abstracted and materially separated extrusions, surfaces and polysurfaces reflecting the conditions of the original scanned site model. Once modelled, the schematic and design development phases of the project were able to be explored through the generation of new topographic mesh models by manipulating vector contour information. In this phase, the shift to 3D space from a traditional 2D base file allows the designer to consider all aspects of proposed interventions within 3D space, while allowing for an ease of assessing and communicating design intent to stakeholders when a desired design direction is achieved (LIN and GIROT 2014).

The assembly of the 2D data into abstracted 3D special datasets allows the designer to 'push' and 'pull' the scale of existing objects on site prior to formally testing design scenarios. In many ways the assembly of the abstracted data is an initial opportunity to actively test design gestures while measuring site features to understand the relationship of dominant features to one another. The end product of the data assembly phase is a 3D RhinocerosTM model comprised of extrusions, surfaces and polysurfaces that are organized into layers representing traditional elements of a landscape design pallet as discussed in section 2.2. These colour coded layers abstract and break the topology of the initial scan model, allowing for site elements to be considered both individually and holistically, with the ability to be modified or removed individually.

2.4 Data Reassembly

The 'reassembly' phase is realized in 2D and 3D design scenarios. The initial design proposals were communicated as 2D analogue sketches, which were transcribed in RhinocerosTM first as 2D lines, polylines and curves and then modelled in 3D as extrusions, surfaces and polysurfaces. Once integrated into the existing site model the proposals are evaluated in real time by orbiting and taking perspectival views, ultimately communicating design proposals to the client. Design proposals were communicated through a series of drawings generated primarily in Adobe Illustrator for vector-based diagramming such as plans, sections and axonometrics. Lumion, a 3D visualization software that uses mesh information imported from RhinocerosTM as a Collada file was used for raster-based perspectival and atmospheric drawings. Although block proxies were used in RhinocerosTM for the representation of trees and shrubs as spatial elements of a site design, Lumion was used to create more realistic vegetation and further test planting design scenarios against project goals.

Three schemes were proposed, all of which worked to unify the site by taking advantage of the steepness using terracing to help the space feel intimate yet open and connected through sightlines. The selected proposal, 'Piedmont Meadows', introduced a series of switchback ramps and stairways to weave together gathering spaces and terraces. The proposal called for a variety of materials including wooden decking and amphitheatre seating, gravel terraces, and lawn, which allows for flexibility to play host a range of events and experiences.

2.5 Data Disassembly

Following the selection of a desired design direction the project moved to 'disassembly', where the three-dimensional model is transcribed back into two-dimensional vector information to communicate the design intent to the construction industry through traditional means of construction documentation. In this case, the project was first manually transcribed in RhinocerosTM using the Make2D command to project 3D site information back into simplified 2D vector datasets. Once exported from RhinocerosTM as a .dwg file the project was further refined in AutoCAD, a commercial computer-aided drafting software developed by Autodesk, for final construction documentation in the form of traditional sheet-sets that included a grading plan, material plan, planting plan and site sections. The hardcopy construction sheet-sets were referenced by the construction team to interpret physical site work done using heavy machinery, excavating equipment and power tools on the approximately 6,000sqft site.

When the site construction was completed in accordance with construction documents and construction administration, the project was re-scanned using the same UAV scanning methods as initially undertaken. The scan model, as seen in Fig. 3, concluded the final 'data inventory' phase as further discussed in section 2.6. This secondary drone scan upon construction allows for designer, client and contractor alike to evaluate design intent against contractor interpretation as well as document any in-situ design changes during construction administration prior to the construction of proposed architectural structures at the top of the slope.

Fig. 3: Viewports (Front, Right, Top and NE Parallel Projection Axonometric) of post-construction site scan point cloud and mesh model in Rhinoceros 3D (1,029,881 vertices)

2.6 Data Re-Inventory

This final phase puts emphasis on the opportunity for post occupancy evaluation (POE) as part of a core design process. While POE is often associated with assessing human users' interaction with designed environments, it also can be used to account for the effectiveness of designed physical factors in meeting project goals (ZIMRING and REIZENSTEIN 1980). The secondary scanned model can be transcribed using the 'abstraction' methods mentioned above to create 2D information to directly evaluate the as-built condition against the proposed design drawings as seen in Fig. 4. This final phase can serve as an important educational opportunity for all stakeholders involved in the project, while taking stock of the built project on day one of completion, with the opportunity to continue to monitor and evaluate the landscape over time.

Fig. 4: 2D linework evaluating design proposal drawings in Construction Documentation phase (left) given to contractor, transcribed 2D linework from post-construction drone scan (center) and overlay of datasets (right)

Landscape has long held an intimate relationship with knowledge and data; it is the mapping of this data and scientific knowledge that has blurred the boundary between landscape and datascape, resulting in the making of landscape from the information that forms it. (PICON 2013). While it can be proposed that our digital tools may in time change the physical attributes of our built environment, it is currently more evident that our digital tools change the perspectives by which we understand and interpret our environment (PICON 2013). The data inventory and re-inventory phases of this design method were fundamental in the design of the project, offering an understanding of the site's quantitative and qualitative attributes. These new datasets afforded the design team multiple new perspectives and vantage points, giving the team an opportunity to intimately understand inerrant features of the site that guided the design direction, with the documented construction result serving as a vital feedback loop for the construction and design team alike. Future iterations of the method on projects with larger scopes and longer timeframes could call for multiple UAV scans during the construction phase to evaluate construction progress against design intent to yield more accurate project construction.

3 Discussion

UAV scanning and photogrammetry are by no means new to design and planning. Perhaps the earliest well applied method of this form of scan-design-scan feedback loop was the work of Atelier Girot. Their work on the Sigirino AlpTransit Depot used highly expensive, professional grade drone scanning, with a project budget of $20 million Euros, and spanning nearly two decades (GIROT 2013).

By contrast, the data inventory method showcased in this paper using a single day 3D spherical laser scanning (LiDar) to deliver a polygonal model and registered point cloud suitable for import into CAD cost $500 (USD) per scan. This cost included travel related expenses with a turnaround of 3-5 business days after completion of the onsite scanning effort. As demonstrated in this case study, recent advancements in laser scanning technology and UAVs have made it possible to replicate previously expensive and highly technocratic design methodologies with consumer level UAV scanning technologies for small and medium size sites.

4 Conclusion and Outlook

This paper has demonstrated methods for using UAV site surveying to generate digital twins of pre- and post-construction landscapes to offer insight on design process and outcome. These methods can help assess project success and accuracy through post occupancy evaluation using 3D scan models. It showcases how advancements in scanning technology allow UAV site scanning to be used as a feasible method for site design and evaluation. Although the use of this design workflow is feasible and somewhat easily applied with a skilled design team, there are many phases of the workflow that could be optimized or automated to lessen the need for manual user input in abstracting, assembling, reassembling, and disassembling design proposals. It can be concluded UAV imagery for site surveying and post occupancy evaluation offers substantial upside and important insight into the digital landscape design process. The use of UAV imagery as a viable form of site surveying can continue to be more broadly explored through varying project sites, goals, and scales to discover further opportunities and constraints in its application.

The use of digital twins can help design professionals and the construction industry assess what has been built, how to maintain the landscape over time and offers compelling opportunities for the future digitalization of the construction industry (SHILTON 2021). So long as the construction industry remains primarily analogue, the novelty explored in this design method is in the ability of highly accuracy and spatially precise models to inform design thinking and process. Given the trajectory of UAV sensing from once highly expensive and difficult to operate technologies to readily available consumer level products, the future of digitized landscape construction is promising. While there is discrepancy between design intent and built works that can result from user error and machine tolerances, the rise of autonomous construction vehicles and large format 3D printing are promising technologies to further develop highly accurate built landscapes that more accurately bridge digital inputs and physical outputs.

References

AMOROSO, N. (2015), Representations of the Landscapes via the Digital: Drawing types. In: AMOROSO, N. (Ed.), Representing Landscapes: Digital, 3-27. Routledge. https://doi.org/10.4324/9781315731858-8.

CANTRELL, B. & MEKIES, A. (Eds.) (2018), Codify: Parametric and Computational Design in Landscape Architecture. Routledge.

ERVIN, S. M. (2001), Digital landscape modeling and visualization: A research agenda. Landscape and Urban Planning, 1-4 (54), 49-62.

GIROT, C. (2013), Dépôt AlpTransit, Sigirino. Atelier Girot. http://www.girot.ch/wp-content/uploads/2013/04/Sigirino-portfolioF.pdf (October 20, 2021).

LIN, E. & GIROT, C. (2014), Point cloud components: Tools for the representation of large scale landscape architectural projects. In: BUHMANN, E. et al. (Eds.), Peer Reviewed Proceedings of Digital Landscape Architecture. Wichmann, Berlin/Offenbach, 208-218.

MCNEEL, R. (2021), Rhinoceros 3D (Version 7.0) [Windows]. Robert McNeel & Associates. www.rhino3d.com.

PICON, A. (2013), Substance and structure II: The Digital culture of landscape architecture. Harvard Design Magazine, 36, 124-129.

SALERNO, R. (2019), Representing and Visualizing in Landscape, between Hard Sciences and Humanities. 5, 23-32. 10.26375/disegno.5.2019.05.

SEDLÁČEK, J., KLEPÁRNÍK, R. & KOPŘIVOVÁ, I. (2020), When Does the Point Cloud Become a Real Tool for a Landscape Architect? Teaching Experience with Bachelor and Master Student Programmes in Landscape Architecture. Journal of Digital Landscape Architecture, 5-2020, 254-261.

SHILTON, M. (2021), Digital Futures in Landscape Design: A UK Perspective. Journal of Digital Landscape Architecture, 6-2021, 316-323.

URECH, P. R., DISSEGNA, M. A., GIROT, C. & GRÊT-REGAMEY, A. (2020), Point cloud modeling as a bridge between landscape design and planning. Landscape and Urban Planning, 203, 103903.

VAN DER VALK, H., HAßE, H., MÖLLER, F., ARBTER, M., HENNING, J. L. & OTTO, B. (2020), A Taxonomy of Digital Twins. In: AMCIS.

ZIMRING, C. M. & REIZENSTEIN, J. E. (1980), Post-Occupancy Evaluation: An Overview. Environment and Behavior, 12 (4), 429-450. https://doi.org/10.1177/0013916580124002.