Point Cloud Aesthetics

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Abstract: Point clouds – sets of x, y, and z coordinates – are an emerging medium for representing landscapes. Point clouds generated from laser scans or photogrammetry are algorithmically mediated, indexical encodings of space and color for an instance in time. While previous research has demonstrated the technical viability of point clouds for the empirically oriented practice of landscape architecture, the theoretical implications of this medium for the artistic aspect of our discipline still need to be explored. As a medium, point clouds are unique in terms of indexicality, iconicity, symbolism, and contingency and can be used to represent the dynamic character of landscape in new ways. The point clouds of Rosedown Plantation and Hilltop Arboretum demonstrate the aesthetic, semiotic, and creative implications of this medium for landscape architecture. The point cloud of Rosedown Plantation captures the dynamic character of landscape in ephemera like seasonal color, blossoms, leaf litter, and bare branches. The time series of point clouds of Hilltop Arboretum records changes such as shifting palettes of light and color, the growth and senescence of plants, and corresponding fluxes in biomass and carbon. Through representational strategies such as sectional elevations, transects, time series, and scatter plots, point clouds can hybridize empirical and artistic understanding of landscape.

Keywords: Point clouds, drones, photogrammetry, lidar, landscape dynamics, semiotics

1 Introduction

Point clouds are multi-dimensional; each set of x, y, and z coordinates can have other variables such as red, green, and blue color values. Landscapes can be recorded in precise detail as clouds of billions of points using either laser scanning or photogrammetry. In laser scanning, the three-dimensional position of points hit by laser pulses are calculated based on the orientation of the scanner and its distance from the target points. The distance from the scanner to the point is derived from the time of flight or phase difference of the laser pulse (MORSDORF et al. 2018). Points clouds can also be generated from photographic surveys using photogrammetric techniques such as structure from motion, which reconstructs three-dimensional form from overlapping images taken from different views (ULLMAN 1979, WESTOBY et al. 2012). Often a combination of approaches is necessary. While terrestrial laser scanners can capture the understory of a landscape in minute detail, airborne laser scanners or cameras mounted on drones can efficiently record entire landscapes from above.

Dense point clouds can capture ephemeral details of a landscape such as seasonal leaf color, opening flower buds, the texture of bare branches, and decomposing leaf litter in three dimensions. Given the relative ease of terrestrial laser scanning and drone photogrammetry, a landscape can be surveyed again and again to create a time series of point clouds recording change over time. Thus as a medium point clouds have a unique potential for representing the dynamic character of landscape. GIROT (2019) proposed that point clouds should be a new medium for designing landscape, positing that "designers adopting *cloudism* will step into an overwhelmingly convincing simulacrum of physical reality, space and time; this will enhance their understanding of site, and yield a stronger awareness of ambient aspects and cues".

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2 Theory

A medium is the material, technical, and procedural means of a craft (MCCULLOUGH 1998) and the artistic conventions inspired by these means (DOANE 2007, KRAUSS 1999). A medium both affords and constrains modes of creative production. The technical and material constraints of a medium limit what can be done, focusing attention and setting the scope of craft and artistic endeavor. To be creative in craft is to transgress the limits of a medium, challenging and rewriting its conventions. As a medium, point clouds are not just a data structure, but also a subject - the physical environment - and the set of processes, tools, technologies, and modes of representation for recording it. Each technology for capturing point clouds affords different possibilities. Terrestrial laser scanning can capture the understory of a landscape in fine detail from a human perspective, while drone photogrammetry can capture the canopy of the landscape from a bird's eye view. Likewise, the software and algorithms that generate point clouds simultaneously enable and constrain the creative process. These technologies underpin the point cloud's relationship to its subject – the scene captured in the point cloud. The point cloud is an index, a trace of its subject, a record of light as a space, contingent on framing and chance. It can be immediately legible, an iconic rendering of the scene. As the result of an algorithm encoded as numeric data, the point cloud is also a collection of symbols. The indexical, iconic, symbolic, and contingent nature of the point cloud give it meaning - connecting it to the scene, author, and algorithms. They are the foundation for aesthetic expression in this emerging medium.

2.1 Indexicality

In Peirce's semiotics an index is a sign that is physically or causally connected to what it represents. Indices "show something about things, on account of their being physically connected with them" (1998). As its physical imprint, a footprint is an index for a foot. Smoke is an index for a fire; if you see smoke, then you know that it has been caused by a fire. A photograph, as a record of light captured on photographic film or a digital image sensor, is an index that is both physically and causally connected by rays of light to the scene that it represents. Indices are a trace of the real. As Susan Sontag wrote, "[a] photograph is not only an image (as a painting is an image), an interpretation of the real; it is also a trace, something directly stenciled off the real, like a footprint or a death mask" (2011). Pure indices signify presence and connection – nothing more. They are just a sign that something existed. As a trace, independent of other meaning, they have an inherent authenticity, a claim to truth.

Point clouds generated by laser scanning or photogrammetry are algorithmically mediated, indexical encodings of space and color at a moment in time. Point clouds are indexical because they are physically and causally connected by pulses of light to what they represent. Like photographs they represent a trace of the real, captured by light, in a way that is immediately legible. Point clouds, however, are unique in being interactive, three-dimensional records of space. A point cloud is not an image, but rather data – multidimensional data that can be rendered as an image. As interactive media, point clouds can be navigated through, manipulated, clipped, filtered, composited, styled, dimensioned, and annotated. As data, point clouds have a unique indexical authority – they record presence as the exact position of things in space. Their points exist in a coordinate system designating space, rather than a picture frame designating a view. Point clouds' indexicality, their truth claim, seems so authoritative

as to be hyperreal, displacing reality – they are used as definitive records, as evidence, as substitutes for things lost, and to fabricate replicas (DIAO & NING 2020).

2.2 Iconicity

An icon is mimetic, a likeness. Point clouds are iconic because they look like what they represent. Their iconic nature is unique because of their fidelity, inherent three dimensionality, and resulting immersivity. Unlike photographs, point clouds are not flat; as multi-dimensional data that can be interactively rendered on displays or in virtual reality, they have an immersive sense of depth. Unlike other three-dimensional digital media, point clouds have an indexical link to the scene captured that imbues them a greater sense of authenticity and fidelity and grounds their iconic claim to faithfully represent reality.

What does it mean to "step into an overwhelmingly convincing simulacrum of physical reality, space and time" (GIROT 2019)? Will hyperreal simulacra really enhance landscape architects' "understanding of site, and yield a stronger awareness of ambient aspects and cues" (GIROT 2019)? Rather, if "[s]imilitude is a dream and must remain one, in order for a modicum of illusion and a stage for the imaginary to exist" (BAUDRILLARD 1994), then point clouds, as a hyperreal simulacra, seem to usher an aesthetic crisis of creativity, an "end of the imaginary" (BAUDRILLARD 1994).

Point clouds, however, are imperfect icons with noise, systematic errors, occlusions in capture, and voids. By their very nature as a collection of points in space, there is empty space between each point, a discontinuity that does not exist in reality. Their incompleteness makes point clouds a fundamentally abstract medium, countering their hyperrealism. To form an image, individual points can be rendered as pixels, squares, or circles or clusters of pixels can be blended together through splatting (BOTSCH et al. 2005, SCHÜTZ 2016) or interpolation (SCHÜTZ & WIMMER 2015). The resulting image is pointillist – points cohere into surfaces and clusters of colors blend together. The remaining gaps between clusters of points give the image a ghostly sense of transparency, revealing the distant points behind them. There is rich aesthetic tension between the point cloud's hyperreal detail and depth and the painterly abstraction with which it is rendered.

2.3 Symbolism

Symbols are signs given meaning only by conventional standards. While the scene captured in a point cloud may have symbolic significance, point clouds themselves are inherently symbolic since they have been encoded as digital data. Scanned point clouds are transformed from light into waves of electrons, processed by algorithms, and stored as symbolic data structures. While "[i]t is common for critics of digital media to note that in digital media the indexical link between image and represented object is irrevocably severed" (MARKS 1999), a wave of electrons still connects the point cloud to its referent. Digitization is a mediation, rather than a rupture. The transcription of photons into bits, rather than irrevocably converting an index into a symbol, algorithmically mediates meaning (SODERMAN 2007). The point cloud remains a pure perceptual index of the referent, while as a conceptual index it becomes symbolically mediated by algorithms. The conceptual index – the trace of ideas – becomes a mark not only of the scene, but also of the author and the algorithms. A mark to be decoded and interpreted.

2.4 Contingency

Contingency is the "quality or condition of being subject to chance and change, or of being at the mercy of accidents" (OXFORD ENGLISH DICTIONARY 2021). With its roots in the Latin contingere, to touch or to happen, contingency is a fundamental character of the index. To indicate presence, there must be a touch or a happening. The moment this happens may be subject to the whims of chance. In its uncertainty, the contingent connotes the freedom of possibility and thus the potential for creativity. When the shutter of a camera opens and closes or when laser pulses trace the contours of a scene, what is captured is contingent upon atmospheric conditions, the play of the light and shadow, gusts of wind, the fall of rain, and chance passersby.

As indices, point clouds are contingent on what happened to be captured, their meaning relying in part on the accidental. As icons, point clouds' meanings are contingent upon aesthetic choices and artistic interpretations in response to the dialectic of hyperrealism and abstraction. As algorithmically mediated symbols, the meanings of point clouds are contingent upon their processing. This transforms point clouds into reflexive indices, that refer not only to the scene captured, but also to their author and algorithms. The indexical, iconic, and symbolic contingency of point clouds is generative, forming a creative space between author, algorithm, and environment. The generative potential of point clouds as a medium lies in creatively transgressing the constraints of the technology, for it is the algorithmic nature and limits of the medium that create room for meaning. By challenging point clouds' purely representational nature as evidence of space and color at a particular instance of time, the medium can become a creative tool for design and artistic expression. Just as photomontage can be used to create imaginary scenes that draw on photography's indexicality and iconicity, point clouds can be cut apart and reassembled to design new landscapes (HURKXKENS et al. 2015, GIROT et al. 2018, URECH et al. 2020).

3 Representing Landscape Dynamics

As a medium, point clouds can capture and represent change over time in unique ways. With point clouds time can be recorded and represented as either a discrete event or a series of events. While individual point clouds record space during discrete events, time series of point clouds record how space changes over time. Point clouds can be represented statically as still images, dynamically as animation, or immersively with interactive viewers. For a single point cloud these modes afford representational techniques such as perspectives, sections, elevations, and transects that can be used to study space and identify the mark of time. Time series afford additional techniques such as temporal sequences of transects and three-dimensional scatter plots of numeric data that reveal how landscape phenomena play out over longer spans of time.

3.1 Events

A point cloud from photogrammetry or laser scanning is an indexical record and iconic representation of space for an instance of time. An instance, rather than an instant, because it can take seconds, minutes, or even days to capture a scene. As an instance of time, a point cloud captures a relatively short period of time and encodes it as a discrete event. As records of short periods of time, laser scanned point clouds can capture phenomena in action such as the choreography of raindrops falling during the seconds or minutes of a single scan (GIROT 2019). In capturing ephemera such as the shape and color of leaves and nascent flower buds, point clouds can record the effect of processes and traces of time in the landscape. As indexical records of ephemera, point clouds are indices of indices for leaf litter is an index of decomposition and a gully is an index for erosion. Individual point clouds rendered as perspectives can capture the ephemera of landscape with iconic legibility and indexical authority akin to photography, albeit with higher dimensionality. The three-dimensionality of point clouds enables reductive, analytical studies, such as elevation, sectional elevation, and transect renderings in orthographic projections. Interactive viewers such as Potree, a render engine for streaming and rendering massive point clouds in a web browser (SCHÜTZ 2016, SCHÜTZ et al. 2020), give the audience agency, enabling them to freely explore scenes, cut their own section-elevations or transects, or don head-mounted displays for a more immersive experience in virtual reality.

Rosedown (Fig. 1) is a two hundred acre site in St. Francisville, Louisiana with the well preserved remains of an antebellum plantation dating from 1834 including the main house, ancillary buildings, and formal gardens (HISTORIC AMERICAN BUILDINGS SURVEY, HISTORY OF EARLY AMERICAN LANDSCAPE DESIGN 2021). The point cloud of Rosedown represents the dynamism of the landscape and the accumulation of its history, demonstrating the potential and the limits of the medium for preservation. As a simulacrum, the point cloud of Rosedown portrays the accretion of a hundred and eighty-seven years of construction, planting, restoration, and interpretation, marked by the striking absence of the enslaved workers' quarters, cemetery, and church. These losses render the point cloud an unfaithful representation (BLANKENBAKER & BESLER 2014) of the plantation as a production landscape. The point cloud, however, captures the complexity and temporality of landscape in the convoluted branching structure of live oaks, drapery of spanish moss, seasonality of flowers, texture of bark, and a profusion of leaves (Fig. 1b). With its overwhelming detail and noticeable occlusions, this point cloud highlights a relationship between the noisy and imperfect, but rigidly structured formal gardens and the natural logic of irregular plants, all abstracted in a pointillist style that coheres noisy details into an impressionistic rendering of light. The rockery was captured in enough detail to show its flowers in bloom, decomposing leaf litter underfoot, and weathered conglomerate rocks (Fig. 1a). These details begin to show the landscape's dynamic character, its semiotic richness beyond its tectonic form and symbolism. The architecture also holds indexical detail - close examination of a slave staircase reveals the imprint of enslaved footsteps, worn in the wood, an index of their presence and toil (Fig. 1c-d). Despite the erasure of the enslaved people's quarters and community, the point cloud still reveals marks of their presence and evokes their labor. These renderings use the analytic, indexical, and iconic character of point clouds to tell intertwined spatial and emotional narratives.

3.2 Time Series

A time series of point clouds can be collected by repeatedly surveying a site with lidar or photogrammetry. Time series enable change over time to be analyzed visually and quantitatively. Change over time can be represented through a sequence of iconic, yet analytic point cloud renderings such as transects, each representing a discrete event in time. Time series of point clouds can be numerically analyzed using methods like temporal aggregation (GEBERT & PEBESMA 2014) and temporal map algebra (GEBERT & PEBESMA 2017) to study spatiotem-

poral phenomena. Thus change over time can also be represented quantitatively with numerical analyses of spatiotemporal phenomena rendered as three-dimensional scatter plots. Three-dimensional scatter plots are another type of point cloud – sets of x, y, and z coordinates generated by numerical analysis that represent data spatially.

The time series of point clouds for Hilltop Arboretum (Fig. 2) in Baton Rouge, Louisiana records the evolution of a newly established meadow. This time series of point clouds with x, y, z, red, green, blue, near infrared, and red edge values was collected over the course of a year with monthly aerial surveys by drone. The time series of transects through the set of point clouds for Hilltop Arboretum is a visual record of the growth and senescence of plants through the seasons. These transects represent the changing structure of landscape with the indexicality and iconicity of photography, the analytic quality of architectural drawings, the depth and interactivity of three-dimensional models, and a level of detail unique to point clouds (Fig. 2a-c). The time series was also numerically analyzed using remote sensing techniques, temporal aggregation, and map algebra to study photosynthetic activity, the growth and decay of biomass, and carbon cycling. The data from these analyses were rendered as three-dimensional scatterplots. These scatterplots are purely conceptual indices whose perceptual links to the landscape have disappeared. Despite their intensive algorithmic processing, they still retain indexical links to the landscape as data that record traces of its processes. They represent a trace of an idea such as the process of growth and senescence or the flux of carbon, rather than the look and physical structure of the landscape. Three-dimensional scatterplots of vegetation indices, biomass, and carbon stocks were overlaid with the transects to represent the dynamics of the landscape both visually and quantitatively (Fig. 2d). By modeling the scatter plots as point clouds, abstract data visualizations can be combined with reductive, yet iconic graphics to form a composition in a single medium.

4 Conclusion

As a medium, point clouds owe their empirical value to their indexical authority and (imperfect) iconic legibility, while their artistic potential lies in their indexical and symbolic contingency. As perceptual indices that look like the scenes they record, point clouds can approach simulacra of reality. As conceptual indices that record the echo of an idea, point clouds can encode and if deciphered reveal the progress of time, natural processes, emotional narratives, and traces of their author and algorithms. The aesthetic power of the medium lies in the tension between perceptual and conceptual indexicality. The semiotic complexity of point clouds affords a multiplicity of meaning held in aesthetic tension for the audience to decode. The point cloud renderings of Rosedown Plantation are an evocative documentary – they reveal traces of enslaved people's labor juxtaposed against the grandeur of a plantation house and its landscape; they highlight the artifice of formal gardens and their ultimate subsummation into the chaotic structure of nature. The representational strategies used for Rosedown draw an interpretative narrative out of empirical data. The point cloud renderings of Hilltop Arboretum, while still evoking the beauty and ephemera of a meadow, are more rigorously analytical with their orthographic transects and quantitative data visualization. The representational strategies used for Hilltop draw on the methods of landscape architecture and ecology to illustrate the evolution of landscape over time. As a medium for landscape architecture, point clouds afford novel ways of recording, visualizing, understanding, and designing for change.



Fig. 1: Point Cloud, Rosedown Plantation, St. Francisville, Louisiana, USA, 2021. Viewer: https://xyz.cct.lsu.edu. Data: https://doi.org/10.17605/osf.io/4t2uk.



Fig. 2: Time Series – January, June, August, and peak annual biomass (kg/m²); Hilltop Arboretum, Baton Rouge, Louisiana, USA, 2020. Viewer: https://xyz.cct.lsu.edu. Data: https://doi.org/10.17605/osf.io/7jcsz.

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