Point-Cloud Modeling: Exploring a Site-Specific Approach for Landscape Design

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Abstract: The paper discusses point-cloud modeling as a digital design method in the field of landscape architecture. Technological development in the last decade facilitates the acquisition and handling of high-precision 3D data collected with laser-scanning. Point-cloud modelling uses the laser-scanned data to precisely replicate and manipulate the environment in the form of 3D point-cloud models. It engages the characteristics of form and scale of a physical site and results in a transformative workflow linked to the present condition of the site. The design method employs point-cloud models as a tool of analysis, modelling and design. By representing the physical form of a place, point-cloud models may offer a return to the roots of the landscape profession, establishing a direct contact between the form of the site and the invention of the design. The method introduces a new approach in digital modelling that could make a significant contribution in crafting future landscape design solutions.

Keywords: Point-cloud modelling, digital design method, LiDAR

1 Introduction

The physical form of the landscape represents a considerable challenge for designers to work with. Current landscape design approaches encompass the complexity of the environment by reducing it to orthographic projections or by producing object-based 3D models optimized by levels of detail. The lack of means to address the actual form of the site may affect design possibilities to improve existing spatial qualities. As a result, contemporary landscape architecture is mainly represented in two dimensions and uses planar views to communicate design intentions. This graphical convention stems from the lasting practice of ichnography and cartography, developed to represent the environment on scale drawing. At present, maps have evolved into an intermediary support between the field and a project in the making. In the same way, computer visualization – or *rendering* – has become a means of communicating a final design in the form of an artist's impression. In contrast, traditional landscape designs such as the renaissance garden were developed directly with the spatial composition of the site by using measuring tools such as ropes, levels and other surveying devices. Losing direct relation to the spatial context is intrinsic to the tools of planar representation, as they preclude designing in perspective and arranging elements of the landscape in space.

Landscape and ecological design gained new methods with the introduction of overlay mapping in the 1960s, using maps as a tool of exploration and employing Spatial Analysis and Geographic Information System, first explored by the application of synagraphic mapping (STEINITZ & ROGERS 1970). At the same time Computer-Aided Design introduced the 2D digital drawing type and was quickly followed by its extension into the realm of 3D with wireframe and solid modelling. These currents prevail in contemporary practice in landscape planning and design and influence how decisions are made on the basis of maps, plans and object-based models. Methods of 3D modelling allow for new ways of interacting with the landscape and play a central role in establishing digital modelling as a means of integrating

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science into design development (WALLISS & RAHMANN 2016). 3D modelling methods enabled new ways of perceiving and practicing with the landscape. They played a central role in establishing digital modelling as a way of integrating spatial aspects with scientific measures in the development of designs (ANTROP 2013). A series of modelling techniques have emerged for topography and other polygon-based objects. The techniques include parallax mapping, lofting, generation and manipulation with procedural or coding methods, and direct modelling with editing tools for 3D geometry.

In spite of the efforts to create a precise representation of the landscape, site documentation remains limited and raises questions about how to grasp the complex dimension of the landscape. Current design practice uses standard site documentation such as pictures, videos, aerial photography, GIS maps and digital terrain models. This site documentation provides limited information of the three-dimensional form of the site. For this reason, current literature still proposes sketches and hand drawings as a means to represent landscape features such as embankments, slopes, terraces, groves and meadows (DEE 2004, SULLIVAN 2008, LOIDL & BERNARD 2014). The lack of knowledge about the actual shape of the landscape corresponds to a gap in design approaches able to manipulate the spatial and site-specific qualities of the landscape.

2 The Physical Quality of Point-clouds Models

The concept of *model* is at the core of the holistic quality of a point-cloud model. The English word *model* was borrowed in the 16th century from the French word *modèle*, originating from the Latin *modulus*. Etymology connects *model* to “measure” and “mould”, both related to the replication of the form of an object. According to BRUNET (1993), a model is a simplification of reality and has the operational purpose of both constructing and representing reality in order to act, to predict or to explain. Narrowing the definition to *specific model* that describes a single organization – such as the representation of a structure or a form – Brunet claims that the function of the specific spatial model is to “grasp the object’s own structure”. Since the point cloud model was reconstructed using field measurements, it returns to the origins of the word *model*, understood as a mold from real objects. This particularity of the point cloud model is the starting point of a site-specific design approach. Point-cloud modelling takes advantage of the spatial information in laser-scanned models to transform the landscape. This information describes with high precision the physical form of the landscape as it appears at present, shaped by natural processes and human activities over time.

In research fields related to the physical form of the landscape such as forestry, archeology, and geomorphology, various data sources support scientific and quantifiable investigation. Most of these disciplines rely on GIS applications to store, analyze and manage information based on geographic locations. Hydrological modelling, cartographic modelling and map overlay allow to produce single-factor maps for analysis. In the late 90s, scientific investigations started to implement laser-scanning technology, or LiDAR, for their need of more precise geospatial data of the environment. The laser-scanned data is stored in lists of XYZ coordinates that can be filtered to analyse tree canopy, terrain or vegetation patterns. Laser-scanning is now widely applied in geospatial disciplines thanks to its capacity to collect data essential to landscape management and planning. As a consequence, laser-scanned data is being collected at city and country levels and openly distributed by institutes throughout the world, to develop research and gain precise information of the environment[1]. The increasingly widespread use of laser-scanning across disciplines indicates that the data is becoming a new common ground for any application that draws from physical and geospatial information.

For a long time, laser-scanning was not used to directly produce 3D models. However, since their first use for remote-sensing of the landscape, point-cloud data has been used in part to create geo-referenced landscape models such as 3D terrain models (PATZSCHKE 2003). In the last two decades, the use of point-cloud models developed rapidly thanks to increasing computational power allowing to handle an ever larger number of points. Within a few years, point-cloud models evolved from a medium difficult to handle (SHEPPARD 2004) to an efficient tool applicable to a broad variety of landscapes (SCHEIBLAUER 2014). These models have been used first for analytical purposes. Then they have been used for interactive visualization to show a proposed landscape geometry embedded into a point-cloud context (FRICKER ET AL. 2011). The Heartspace Project at the University of Sheffield employed laser-scanners to digitize the site and to design elements within.

It is possible to manipulate point-cloud models to simulate change in the landscape, using for example editing and simulation techniques developed at the Landscape Visualization and Modelling Lab at the ETH Zürich (SPIELHOFER 2017). The representative and performative qualities of point-cloud models has been demonstrated on a fluvial design in Jakarta by developing tools of point-cloud modification and visualization (LIN 2016). It is now possible to produce point-cloud models repetitively at rapid pace and increasing densities[2]. This challenges the role of the model, which could play an important role in supporting site-specific analysis and simulation to inform design. The widespread use of point-clouds across geospatial disciplines indicates that the medium is becoming a new common ground and can inform designers of the state of a geographical reality (GIROT 2018).

2.1 Understanding the Site

Using terrestrial laser scanning allows to personally collect point-cloud models to precisely represent the site. Landscape architects can gain site-specific knowledge either by personally operating terrestrial laser-scanning devices to generate topographical geometry (LI 2014) or by employing unmanned aerial vehicles to map a site (CURETON 2016, 52-58). The procedure of personally collecting models allows flexibility and independence for assembling digital landscapes (LIANG ET AL. 2014) but also changes the relationship between the designer and the site, as design and fieldwork overlap (PIROKKA 2015, REKITTKE 2015).

1 Examples include the Netherlands eScience Center that made country-wide LiDAR accessible on an online platform (MARTINEZ 2015), and the University of the Philippines that is collecting and classifying Open-LiDAR to map flood hazard on the archipelago (TUPAS 2016). Automated detection allows to process laser-scanned models by running biomass measurements, building reconstruction or flood simulation.

2 The New York University released in 2017 a high resolution Open-LiDAR dataset of the city of Dublin. The laser scanned data is about 30 times as dense as a typical data set at a resolution of around 300 points per square meter (LAEFER 2017).

The design process using point-cloud modelling requires a preparatory phase to produce an initial point-cloud model of the existing site. This phase involves collecting data with terrestrial or aerial laser scanners and reproducing the landscape in digital form. The construction of a composite point-cloud model from multiple laser-scanned datasets is then performed on a computer (figure 1). This operation consists in combining datasets and correcting alignment, orientation and geo-location. The operation produces a unique point-cloud model with the required density for the design extent.

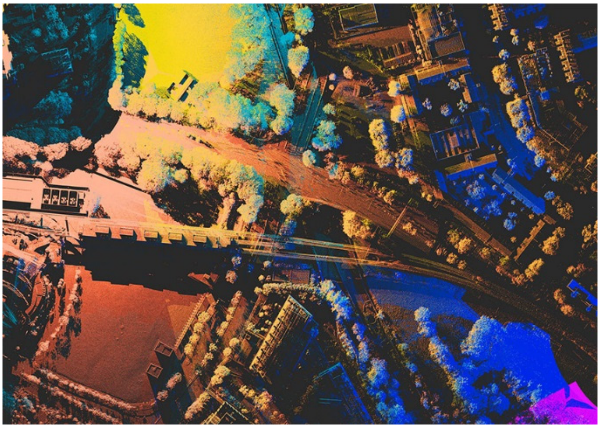

Fig. 1:
Manual and automatic registration allows to link multiple sets of terrestrial and aerial laser-scanned data – shown here in 5 colors – to the same geographic location

The assembled point-cloud model is used to analyse the landscape form. By using modes of visualization and colouring to emphasize shapes, densities and heights, the model can reveal landscape features and patterns that are not perceptible to the naked eye. Due to their particle structure, point-cloud models are well suited for segmentation in the form of sections, classifications or cut-out objects. This allows to move sections in real time through the model and to expose the inner structure of the landscape where ground, plants, buildings can be set in relation. By measuring height differences or sectioning through the vegetation mass it is possible to reveal logics inherent to the shape of the landscape. The directions of water flow can be determined by measuring height differences in the topography. Inclination and curvature of buildings can be assessed with orthogonal projections. Unique features, like existing breezeways through vegetation and topographic traces from former infrastructure, can be recognized by cutting the point-cloud model. The site-specific properties observed in the model are useful to develop design intentions and to plan the site transformation with more control.

2.2 Designing with the Form of the Landscape

The design approach using point-cloud modelling goes beyond the aim of producing a visual composite. It employs the point-cloud model as a structural expression of a site, where a detail of the model relates to the entire context. Point-cloud modelling involves manipulating geo-referenced data points in a spatial coordinate system by selecting, cutting, adding, or deleting points from the digital model. The manipulation requires to follow determined steps of transformation and assemblage. The method integrates scanned point-cloud models with edited point-cloud models that are either reassembled or generated by software.

After the preparatory phase of the design process, the initial point-cloud model is edited to integrate design intensions. The site-specific transformation uses the existing terrain and vegetation cover as a reference for developing the new landscape form. The transformation phase consists of three steps. First, the initial point-cloud model is deconstructed in entities serving distinct modelling purposes such as meshing or cloning. Actions to segment areas, to filter object types and extract the topography are performed by processing software such as Cloud Compare and LAStools. This step helps to work with the identity of the site because it allows to include in design the findings revealed in the analysis.

Second, the design draws from the form of the point-cloud model at different levels to conduct a site-specific transformation. In the case of the topography, the filtered points are conventionally used to build a surface mesh that is then modified with polygon editing software such as Rhinoceros 3d. The modified topography is then used to arrange point groups, consisting of vegetation and man-made objects, on its surface (figure 2). Features segmented into individual objects or groups are either moved manually or cloned through generative functions to recreate vegetation patterns and composites. The composition is achieved by cloning point-cloud objects in Cinema 4D with the Krakatoa plug-in. This step allows to manipulate the existing landscape model in three-dimensional space by precisely working with the landform and by developing new spatial configurations.

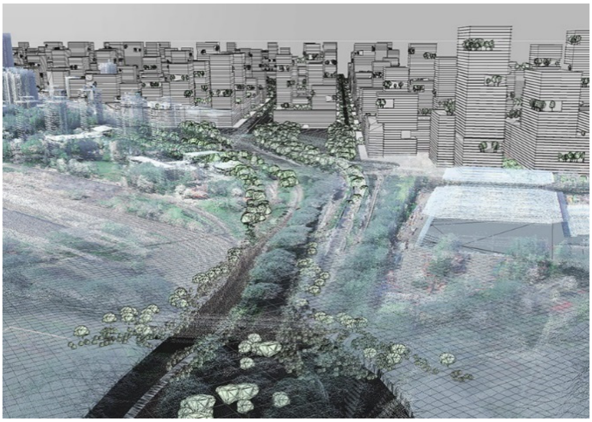

Fig. 2: A surface model is developed and manipulated based on the topographic information and land cover of the point-cloud model

Third, the parts are reassembled to form a new point-cloud model containing the design. Polygon meshes with coloured textures and illumination are converted to synthetic points with software such as Lazpoint for Cinema 4D or Cloud Compare. The modified topography and the new arrangement of landscape features are merged as a single whole object. Using the geographical coordinates, the new landscape model is then combined with the unchanged context of the initial point-cloud model. This step merges the design with the existing landscape and produces a holistic three-dimensional model used to create drawings and visualizations. The multiple scales included in the same model are used to produce overview and detail plans (figure 3).

The three steps of the transformation phase are iterated throughout the design process. This approach allows changes to be made as the project progresses, to combine variations and to include all scales of the design within the same model. With the manipulation of a point-cloud model, its role shifts from a static source of information to a transformative medium. This new interaction with point-cloud models enables landscape designers to take game-changing decisions during the design process as they can test their designs in context and adapt them with precise special knowledge. The strong aesthetics and the exact spatial relations of the models shift the spatial appraisal of a design to an earlier stage and allow fast feedback for design decisions to be taken. In this way, the point-cloud model allows to construct a spatial composite that encompasses all scales of a design, contextualizing a detail feature such as a path or a grove in larger entities such as a city skyline or mountain landscape, all in the same georeferenced system.

Fig. 3: The design modelled in three dimensions is projected in plan view and provides geographic information for height indications and contour lines

Point-cloud modelling makes it possible to address the spatial complexity of the landscape at multiple scales. While traditional drawing types address each scale specifically, point-cloud modelling encompasses the scale of a tree and the scale of a city within the same model. The trans-scalar quality of point-cloud models changes the interrelationship between landscape features apparent at different scales and may so increase design choices. In this way, designers can approach a wide range of landscape forms, such as the microtopography found in polder landscapes or alluvial plains, as well as the macrotopography found in the morphology of a valley.

3 Conclusion

In the process of a landscape design, gaining understanding of the site is an elementary step for taking design decisions (Li et al. 2014). Point-cloud modelling brings the process of designing closer to the reality of the place. Employing a point-cloud model as a base structure for design allows to describe and to integrate landscape features with their site-specific characteristics and opens new themes for modelling that were hitherto not accessible. The laser-scanned model provides the basic information for a site-specific design and refines the designer's choice by enhancing the understanding of landscape features. Point-cloud modelling reveals the physical form of any kind of environment, from bare topography to dense vegetation or highly urbanized land. The workability and the strong aesthetics of point-cloud models shifts the spatial appraisal of a design to an earlier stage and gives fast feedback to which important design decisions can be taken. Testing variants directly on the digital site helps to develop a project best adapted to its context. With the ability to bring closer the analogue reality to the virtual model by collecting, appending, detailing and transforming site-specific data as the project progresses, this design approach develops the values present on the site.

The ability to work with site-specific features will significantly advance current approaches in design practice and offer innovative potentials for more accurate landscape design production. Using site analysis and design investigation methods, the research stretches between a topological exploration of the landscape and creative techniques for the design process. This new approach could play a role in asserting the position of landscape architecture as a discipline for shaping the environment. The significance of the point-cloud model as a place-making instrument is tangible and could represent the next step in blending digital techniques with analogue studies. By representing the physical form of a place, the medium of point-clouds may offer a return to the roots of the landscape profession, establishing a direct contact between the form of the site and the vision of the designer. It may become the long-sought mediator between disciplines, containing their differences inside a common whole.

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