Since the invention of aerial photography, remote sensing has played a significant role in efforts to map the ecology of landscapes. Owing to technological innovations, a wide variety of remote sensing techniques are now available to enhance these mapping efforts. Specifically, this article will engage new techniques of mapping ecological and surface structures across landscapes that have been made possible by the combination of lightweight, inexpensive, and publicly available Unmanned Aerial Vehicles (UAV) with computer vision algorithms.

These technologies now enable “personal” remote sensing on demand by landscape and planning professionals to generate high-resolution 2-D and 3-D maps in both visible and near-infrared spectrums for multiple uses, from initial site assessments to sophisticated landscape analyses supporting coastal erosion control, forestry, and habitat management.

First from balloons and kites, and later with manned aircraft, satellites, and UAVs, new platforms and techniques for remote sensing and mapping have continued to transform the efforts and the thinking of ecologists, landscape planners, and environmental activists. Now, innovative UAV remote sensing and mapping techniques are entering the design discourse, opening new associations, shifting modes of thinking, and potentially altering the trajectories of the theory, history, and cartography discourses within the design profession.

Remote sensing can be a keystone linking the work of designers, urbanists, and ecologists as it employs a visual language and a mode of representation that can immediately be understood across specialization, especially when it accurately replicates real-time dynamics in the physical characteristics of a site. With remote sensing, precise data can be generated to represent both permanent and ephemeral characteristics of a site, offering opportunities for more grounded design development. With remote sensing mapping, terrain becomes more than topography, it becomes a tangible amalgamation of elements, a layering of time, space, and ecology, and the basis for a real-world design process. At multiple levels,
the point cloud topographic model produced by remote sensing technology provides a more holistic view of reality than a conventional layered plan.  

**On Methods**

The introduction of UAVs and 3-D mapping is revolutionizing ecology, allowing a more comprehensive grasp of ecological pattern and process than any prior geospatial methodology. Spatially precise and temporally dynamic, 3-D data enables structural observations to be related to ecological functions, opening up novel spatiotemporal views of ecological phenomena across landscapes. The dramatic evolution in the platforms and flight control of UAVs, their coupling with computer vision, and their migration from military secret to smartphone app have put remote sensing into the hands of those who seek the view from above, from technology enthusiasts to journalists, to environmental professionals, transforming ecological mapping and automating site-specific environmental monitoring.

UAVs enable inexpensive, scale-appropriate image acquisition with resolutions defined more by the application than by technological limits. There has never been a lower cost platform for consistent, site-specific 3-D aerial mapping of environmental phenomena to monitor change either in a single visit or over time. The UAV brings four operational advantages as a mapping tool beyond its relatively low cost of operation: deployment on demand, easy repetition as conditions change, the ability to fly under cloud cover (UAVs fly low and slow), and precision-automated flight plans enabling the acquisition of highly overlapping aerial images needed to support both 3-D reconstructions and “perfect” orthorectified photo mosaics (buildings and trees are seen only from the top, free of lens and height distortions). Data gathered by UAVs at local scales can be georeferenced and integrated with data obtained from traditional maps as well as spaceborne remote sensing tools, seamlessly integrating views and data from local, regional, and global scales.

From the overlapping images collected during a UAV flight, a color-referenced 3-D point cloud, a 3-D landscape geometry, can be generated using "structure from motion" algorithms. Compared with simple, 2-D layers, these 3-D data products, with their more realistic data-rich representation, push scientific studies toward a deeper and more accurate understanding of ecological characteristics.

During the past year, a pilot project at the Harvard Graduate School of Design tested the application of UAV technology at Arnold Arboretum of Harvard University in Boston and Harvard Forest in Petersham, Massachusetts. Typical UAV-based surveys resulted in the production of color-referenced point clouds, orthomosaics, tree canopy height projections, and vegetation maps detailed enough to allow for the identification of plant species. The application of this technology in these two projects revealed the potential for this methodology to become an integral part of landscape analysis. By returning to the site during different seasons of the year, when species can be readily distinguished from one another based on leaf-out times, flowering, and autumnal coloration, an even more finely grained understanding of present conditions of a site and its possible future trajectories were obtained. Given this realization, the central question of this project became, “How can data obtained by remote sensing be best understood, valued, and deployed by designers and planners?”

To date, UAV and computer vision technology—the cornerstones of personal remote sensing—have been applied successfully in population ecology, vegetation dynamics, precision agriculture, archaeology, forestry, and habitat management. These are fields that are best informed through the gathering of precise information in both horizontal and vertical domains, not unlike the information demands of designers working at large scale. The question then becomes, “Can these emerging functionalities shape new and more ‘informed’ forms of design, especially in the fields of landscape architecture and urban design?”

**On Design**

The design disciplines negotiate precise scales that often can be best addressed through personal remote sensing. The use of remote sensing in design and the friction between the two fields can revolutionize the process of gathering and monitoring spatial data that can be used to inform design development. As a modeling tool of extraordinary precision, it can expose the “tectonics” of a site. In combination with other techniques of observation and analysis, it can project a new, more up-to-date direction for design.

Design aims to give form and lend shape to all elements that influence a site. Typically, however, design lacks a fine scale of time. This can be a crucial factor, as landscape architecture interventions (like ecology itself) are inseparably bound up with time. Can analysis informed by remote sensing be the method that narrows the gap between reality and design? Surely, it takes design a step closer to reality just by sheer virtue of its ability to enable precise understanding of the physical reality of terrain and vegetation across large sites. The potentials of this method within design lay in its ability...
Above: Point cloud aerial perspective, Common Meadow, Petersham, Massachusetts, October 2014. Left: Flight path for an automated flight, Common Meadow, Petersham, Massachusetts, October 2014.
to identify and correlate up-to-date land use and land cover classifications at both the local and regional scales.

Ease of data collection is a major operational advantage that UAV mapping brings to the table for designers. Low operation cost and user-controlled scanning enables repetitive point cloud acquisitions many times across a site on the same day or at least many times per season. By simply associating multiple point clouds with their geolocation, 3-D datasets transform into 4-D datasets, as the variable of time is added to the design equation. This generates the potential for mapping the ephemeral characteristics of a site and, through modeling, of evaluating the specific changes and processes that take place within that site, such as the ebb and flow of tidal waters, seasonal plant changes, animal migration patterns, or the spread of plant pathogens across a landscape, thereby resulting in new associations during design development. With personal remote sensing, we now have the capacity to design for the temporal: this radically shifts the thinking that has characterized design discourse up until this date.

Aerial images traditionally have been crucial for understanding and negotiating landscape and urban scales. But can architects and planners produce credible results when feeding their designs directly into a point cloud? Is this to become a new testing method for design interventions? Personal remote sensing can combine the best aspirations of the design discipline with the best ambitions of mapping, imposing scale-appropriate, efficient, and systemized thought and action. It might even support a new conception of sustainable design, as dynamic elements of a site can now be registered and ephemeral ecological associations can now influence the scale and form of a design.

By modeling and evaluating the dynamic and the ephemeral, designers can better understand the physicality of the landscape. We are in need of the spatial and temporal precision offered by these new methods: we can no longer afford to ignore the reality of the terrain or to get carried away by intellectual concepts that are independent of the site. Remote sensing can become a significant research topic within design-related disciplines. It is a topic that can be placed in between territory, site design, and ecology, with the perception of geography always present. It is time to bring remote sensing into design and thereby reshape both.

The fields of landscape ecology, landscape architecture, urban planning, and urban design stand at a juncture where innovative technologies provide new methods of site analysis that must be dealt with through emerging, new representational techniques. Traditionally designers dealt with ecology and landscape through the static means of the master plan, with a layering of predefined (and most of the time outdated) datasets. Might we now design in near-real-time frameworks, incorporating datasets updated on demand as the design process unfolds? Potentially these technologies will offer new dynamic tools for the practice of design, bringing us one step closer to realizing the “informed” landscape that fully expresses...
the dynamic articulation of ecological and human processes on a given area of interest.¹²

These new mapping techniques differ from earlier practices. Personal remote sensing is an operational methodology that brings the designer into the physical site, back to fieldwork, whether directly or virtually through 3-D reconstructions.¹³ And as a methodology, it has the capacity to question and challenge the techniques and toolsets inherited from the past, just by injecting realistic site data and visualization into the praxis. No longer purely speculative, these new mapping techniques help designers go beyond simply portraying preliminary scenarios to conceiving of credible concepts.

A mixture of remote sensing and traditional mapping techniques has the potential to produce more interesting results and more workable data than either method by itself. Scale thinking based on mapping can alter the typical priorities that drive design, thereby generating new links between design and cartography and, depending on the scale, new connections between architecture, geography, and ecology. Whereas the images generated from a point cloud can be aesthetically pleasing, their true value resides in the data on actual surface cover that they contain and in their ability to enrich the abstract information found in planning documents and maps that have governed design decisions up until now.

**On Potentials**

The conversation currently taking place within the design discourse will no doubt uncover some critical questions related to the usefulness of remote sensing to the field. We anticipate accelerating advances in the monitoring, modeling, and representational techniques related to the ecologies of disturbance, density, complexity, and flux, all at the scale of cities, landscapes, ecosystems, and isolated projects. Any misgivings will be revisited in the course of time, as academics and professionals alike become more familiar with—and more dependent upon—these new tools. But it is clear that spatial modeling has the potential to offer designers a unique reading of urban environments.

Remote sensing should never be conceived as a stand-alone operation: rather, it should always be used to support the design and planning processes as part of a larger context. The greatest potential for further introduction of these tools in the design discipline lies beyond the technological innovation of UAVs. The reprocessing and reinterpretation of raw digital imaging and other data can become a framework for reexamining the use of aerial images in the world of design, and data availability can become a decisive rather than a limiting factor in any future application of remote sensing in the design discipline.

Numerous types of accurate, up-to-date, and high-resolution remotely sensed data can be readily accessible and can be integrated in open-source geospatial libraries (for example, the geospatial libraries linked to each figure in this text). The availability and distribution of data can enhance the collective and communal nature of the
Right: Point Cloud Perspective, Brooklyn Bridge Park, Brooklyn, New York, March 2015. As this perspective image reveals, the resolution that a point cloud carries qualifies it as a valuable tool for land use and land cover classification. Below: Pier 1, Brooklyn Bridge Park, Brooklyn, New York, March 2015. Five years after the opening of the park, Michael Van Valkenburgh Associates can use this image to evaluate the success of their design implementation. Opposite: Property Map, Vegetation and Ecological Functioning Units, Bussey Brook Meadow, Arnold Arboretum of Harvard University October 2013. By observing the true orthographic aerial photograph one can start identifying ecological and human processes that take place within the area of interest.
design discipline. This shifts the conversation toward the importance of effective data management and archiving. Due to their large size, UAV data products generate limitations in data sharing. Future efforts must be focused on increasing not only the accuracy but also the availability of datasets for designers. By creating data repositories that can often be managed by libraries, the process of data sharing can be smoothed, enhancing the exchange of research methodologies and ideas.

By increasing the availability of practicable and user-friendly datasets, designers can standardize and automate a process of design analysis that will convert remote sensing into a more effective tool for identifying landscape patterns related to form, use, and cover. Remote sensing reveals potentials related to the observation, design, and maintenance of ecological systems and strategies for landscape development. There is an urgent need for in-depth process understanding and for a more profound, precise, and time-based knowledge of land use decisions that drive the urban structure. To fulfill this need, it is likely that novel approaches toward an increasingly “interactive remote sensing” will become a reality. Monitoring might even happen at the scale of the individual landowner to solve the problem of site accessibility. The designer, as well as other end users will benefit from this. They will be able to update and monitor shared collaborative datasets at any given time, for a close-to-optimal design development process. This interactive form of mapping will be critical for evaluating the success of site restoration and design implementation, cultivating spatial intelligence that helps people better understand and share information about places, and ultimately will transform design information in ways that promote more effective collaboration.

Above: Overlaying site topography with point cloud, Bussey Brook Meadow, Arnold Arboretum of Harvard University October 2013.
An online library including all geospatial data from the scanned sites can be found at: https://dataverse.harvard.edu/dataverse/gsd_designdata.


04. A point cloud is a set of data points in a specific coordinate system. In a 3-D coordinate system, these points are usually defined by X, Y, and Z coordinates and are often intended to represent the external surface of an object.


06. With regard to the military uses of remote sensing technology, see Laura Kurgan, *Close Up at a Distance: Mapping, Technology, and Politics* (Brooklyn, NY: Zone Books, 2013), 482.

07. A color-referenced point cloud is one where, in addition to having X, Y, and Z coordinates, has RGB values, which are carried by each point. For “Structure from motion” and 3-D Visualization, see Snively et al., "Scene Reconstruction and Visualization from Community Photo Collections," Dandois and Ellis, "High Spatial Resolution"; Gregory P. Asner, Roberta E. Martin, Christopher B. Anderson, and David E. Knapp, "Quantifying Forest Canopy Traits: Imaging Spectroscopy versus Field Survey," *Remote Sensing of Environment* 158 (2015): 15–27.

08. The project began as part of Peter Del Tredici’s fall 2014 Research Seminar in Urban Ecology. The work received the Penny White Project Fund award, which allowed students to travel to Baltimore to train at Ecosynth, a lab led by Erle C. Ellis that specializes in UAV remote sensing. During the development of the pilot project, students and their advisors collaborated closely with Janina Mueller, Data Librarian of the Frances Loeb Library. The Ecosynth team at UMBC (http://ecosynth.org) was supported by NSF grant DBI 11-47089.


14. Ibid.


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**Michalis Pirokka, Erle C. Ellis & Peter Del Tredici**
Figure 6: Point cloud Top View, Hemlock Hill, Arnold Arboretum of Harvard University September 2014.
https://data.minke.harvard.edu/dataset/7ed_decagndata

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