

Beyond Inventory and Mapping: LIDAR, Landscape and Digital Landscape Architecture

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Abstract: Airborne Light Detection and Ranging (LIDAR) applications have rapidly transformed remote sensing and scientific research of landscapes, especially research targeting ecological systems and cultural resources. While used in landscape architecture and landscape research by select research groups, it's not broadly applied as a primary source of information in landscape ecological design and planning projects.

Keywords: Geodesign, LIDAR, GIS, landscape archaeology, virtual reality

1 Introduction

Long applied for science based applications in ecology and landscape ecology, LIDAR (light detection and ranging) has the potential for transformative applications in landscape design, ecological planning, and geodesign as an interpretive tool beyond inventory and mapping. Some research teams are experimenting with the acquisition of these 'big data' for inventoring and mapping landscapes or visualizing urban design (BARTH 2017). Related, innovative research teams have been increasingly exploring non-LIDAR or terrestrial LIDAR 3D point cloud scanning technology (see LI & PETSCHKE 2014, LIN & GIROT 2014, REKITTKE & NINSALAM 2014, REKITTKE et al. 2012 and 2013), but airborne LIDAR sensors are historically expensive and the acquisition of new data requires additional project costs for the processing, management, and analysis of these data. Once captured these data offer significant potential for understanding and interpreting site and regional systems at high resolution. Bridging the potential gap of acquisition to application are thousands of existing LIDAR datasets from around the planet, immediately available for integration into fundamental landscape design and planning research. Allied disciplines, such as landscape ecology, landscape archaeology and preservation are exploring reanalysis of these data with positive results (WEISHAMPEL et al. 2012); however, repurposing these data can limit their use (GOLDEN et al. 2016, JAKUBOWSKI et al. 2013, KRAMER et al. 2014).

Simply, the reuse and repurposing these 'big data' offer transformative opportunities in design, planning, and landscape research. The data source, scope, flight date, and point density are just a handful of factors that can influence the applicability and reliability of these data. Our paper surveys the process and outcomes from several collaborative projects integrating existing airborne LIDAR with other data for landscape design and research at multiple scales. The three projects were developed for very different purposes and demonstrate the broad range in application and source data. Relying on these specific use studies, our paper exhibits the utility and discusses the challenges for the integration of existing LIDAR data at multiple scales and for a variety of outcomes. We summarize some of the key factors that influence

the application of existing data to new projects. We also look to the future of LIDAR and briefly describe the promise presented by a test application of an unmanned drone based LIDAR equipped system deployed by Phoenix LIDAR in 2017 (PHOENIX SYSTEMS 2018).

Our case studies explore three very different LIDAR data sets and applications. First, we describe how existing data, enhanced with pedestrian survey using differential GPS, and geomorphological samples were combined to create a 3D landscape model of San Lorenzo Tenochtitlan, Vera Cruz, Mexico. Relying on processes similar to those described by 3D landscape point cloud research (ORFANOPOLOUS et al. 2014), we combined point cloud data with traditional survey and processed these data to design and print site models of the San Lorenzo and its ecological context. Second, we detail how regional LIDAR data and automated processing was used in multiple projects in Pennsylvania in order to better integrate Building Information Models and geospatial data for rural design and planning coordination. We initiated this project over a decade ago, relying on scripting functions and manual manipulation of LIDAR samples, while more recently relying on LIDAR analyst by Textron Systems (TEXTRON 2016). This project was initiated to quickly go from landscape survey to landscape design and planning (LI & PETSCHKE 2014), but evolved into a more detailed experiment in documenting an historic campus landscape. Third, we discuss a recent project that is repurposing LIDAR samples, originally captured to estimate and refine estimates of above ground carbon storage for the REDD+ (Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) project in southern Mexico (GOLDEN et al. 2016). Reanalysis of these data are revealing a complex coupled natural and human narrative of land use and landscape beneath the tropical forest canopy. Three millennia of households, terracing, reservoirs, and other landesque investments transformed what was once considered a pristine tropical forest into a complex mosaic of land use niches. In this paper, we specifically focus how these data are useful for understanding and communicating the influence and importance of region in landscape design and planning not on the detailed narrative about the past and what we are learning about how these landscapes were shaped. Although we recognize the importance of studying the past to plan for the future (see GOLDEN et al. 2016), the high-resolution samples as described here offer an interpretive window to investigate land use scenarios of appropriate scale in a rapidly changing landscape.

The use of remote sensing and LIDAR specifically, offers transformative opportunities for Digital Landscape Architecture. Beyond site inventories and direct site mapping, these data provide detail site-based context for initial model building and evaluation. These data can also be used to rapidly model natural and cultural infrastructure, perhaps providing a firm foundation for enhanced decision making (See PLATT 2014). Finally, these data also offer new and highly detailed perspectives of the importance of scale and region, when undertaking landscape design and planning research. Simply, existing LIDAR data can be effectively leveraged to address big questions informed by 'big data', but we need to be mindful of the opportunities and challenges for effectively repurposing and reusing these data.

2 Three Case Studies Using LIDAR

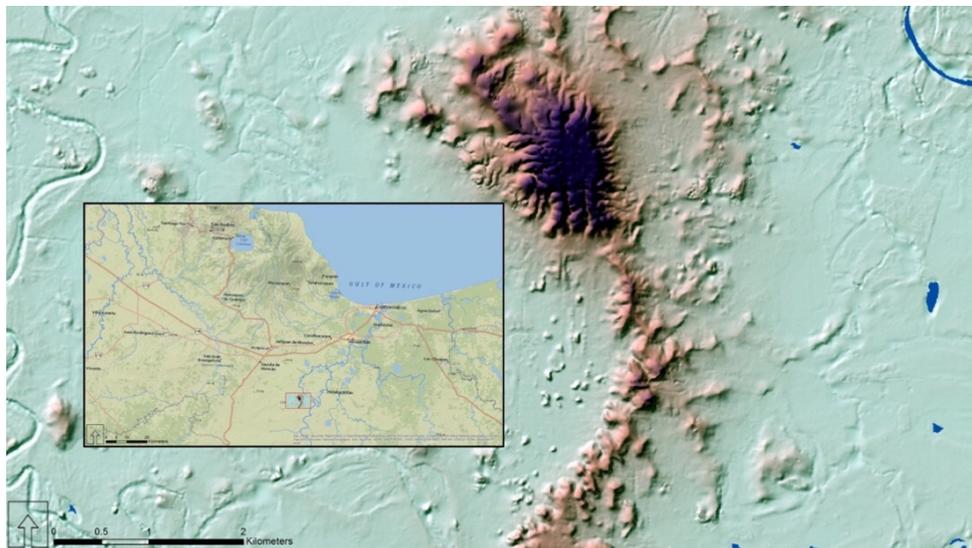


Fig. 1: Digital model of the San Lorenzo and regional ecological context. Inset Map: Location of San Lorenzo, Vera Cruz.

2.1 San Lorenzo, Vera Cruz

For the past decade, we have applied a series of nested geospatial techniques to better understand the development and evolution of the Ancient Olmec city of San Lorenzo and the surrounding regional ecological context (Figure 1). The city and regional landscape offer complex information about landform and hydrological design (CYPHERS et al. 2015). Built on a foundation of more than two decades of excavation, settlement survey and artifact analysis, the geospatial project expands the coverage and confirmed much of what was known about San Lorenzo's evolution and settlement ecology. The project also provided opportunities to re-examine the spatial and temporal patterns of architecture and public space as it relates to San Lorenzo's cultural history (CYPHERS & MURTHA 2014). For our digital sub-surface survey the entire site was surveyed using differentially corrected Global Positioning System (dGPS), gridded and cored for soil. 2062 soils cores were extracted at 10-meter intervals often to depths greater than 10 meters. We combined these data with regional LIDAR to produce a series of virtual models tracking the changing form and massing of the (Figure 2). While these new technologies provide an enhanced picture of San Lorenzo's past, we offer that these data are far more useful and informative when coupled to the decades of traditional research.

Integrating several sources of complex data offered challenges and opportunities for producing a spatially and temporally sensitive digital model. But in order to print and produce a 16 ft² (4 ft X 4 ft) physical model of landform required reduced resolution and some vertical exaggeration (Figure 3). LIDAR data were acquired from Instituto Nacional de Estadística y Geografía, Mexico (INEGI). The LIDAR was part of a country wide mapping effort, so

points were filtered and resampled to 5m horizontal resolution, and only ground points were provided (see Table 1). Our final model was constructed of four wood tiles with each tile measuring 24 in X 24 in X 8 in (Figure 3).

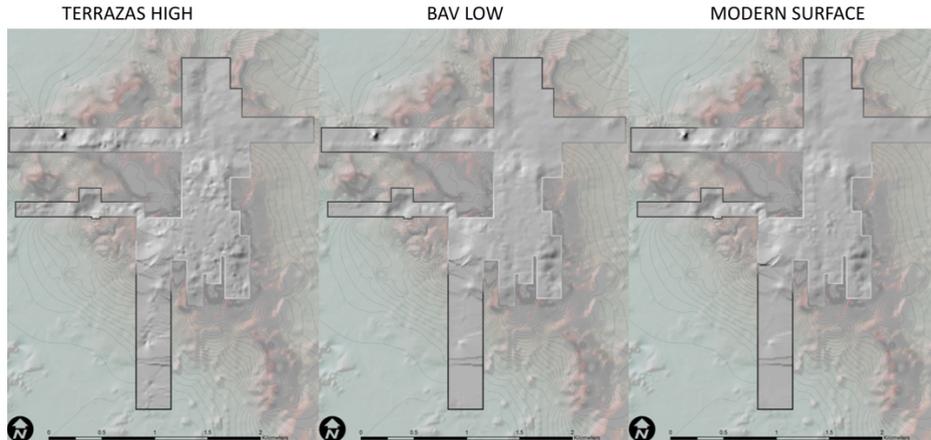


Fig. 2: Three digital models of the San Lorenzo and regional ecological context from early occupation on Left (Terrazas High 1400-1200 BCE) to Modern Surface (representative of the Villa Alta phase (800-1000))

While LIDAR data enhanced regional context for modelling, the source data were filtered and resampled and therefore didn't offer sufficient resolution as a substitute for pedestrian based dGPS survey on itself. LIDAR provided important regional context for printing the model, but in order to best visualize landform, the precision survey data (< 10 cm resolution) was necessary. We also had to exaggerate the vertical information in order to achieve the appropriate vertical fidelity for a useful exploratory model.



Fig. 3: Final Computer Numerical Control Router (CNC router) model and process

Table 1: Summary of LIDAR data sources, resolution, and extent

Project	LIDAR Source	Area of Coverage	Year Acquired	Raw Data?	Average Point Spacing
San Lorenzo, Mexico	INEGI (Federal)	1.964m km ²	2005 to 2010	N	5 meters
Pennsylvania, USA	State Government	119,280 km ²	2004 to 2006	Y	1 meter
G-LiHT REDD+ (NASA)	NASA	Samples from ~144,000 km ²	2013	Y	< .5 meter

2.2 Regional LIDAR and Rural Landscape Models

In 2008, we initiated a Building Information Modelling (BIM) and GIS integration project (MURTHA et al. 2008) focused on developing a collaborative database to link independent computing platforms or programs typically used to manage, analyze, model, and communicate quantitative information about embedded systems. Landscape architects, for example, first designed Geographic Information Systems so that their planning and site designs were embedded within layers of soil, vegetation, demographics, and transportation networks. Architects and architectural engineers rely increasingly on Building Information modelling. Relying on regional LIDAR infrastructure mapping conducted between 2004 to 2006, the core aim of our project was to develop a 3D integrative relational database of buildings and landscape in a rural context. Simply, while limited GIS layers were available and a handful of BIM models were available no integrated 3D model of buildings and landscape existed. This was common in the rural US and our aim was to develop a process to address that exigency. LIDAR data was the foundation for our project. The source LIDAR files were provided by the state government with an average point spacing of 1 meter (see Table 1). LIDAR data was collected during the winter months, with no leaves on deciduous trees. Specifically, we completed the following:

1. Developed a core geospatial database and topographic database of the State College Borough/West Campus Region. Using local LIDAR data as a base we constructed a detailed topographic database for the State College borough. LIDAR data provides highly accurate and well categorized topographic and reflectance information, allowing researchers to develop a detailed 3-D model of the Earth's surface as well as natural and cultural features above the surface.
2. Developed a core building mass model sampling LIDAR. Using local LIDAR we authored scripts to extract building footprints, heights and roof types.
3. Integrate these data with 3-D detailed building information. Using existing BIM buildings and relying on limited field survey and models we constructed.

These data were published as part of a partially public access database via the web using a variety of universal program platforms such as KLM in Google Earth (MURTHA et al. 2008).

In 2014, we revisited this modelling process, now relying on the same data, but now leveraging tools built in LIDAR ANALYST by Textron Systems (TEXTRON 2016). We used the same LIDAR data set and developed a process to move from source .las files to City Engine (Figure 4). We performed the following tasks in LIDAR ANALYST: 1) Extract Bare Earth;

2) Extract Building Footprints; 3) Extract Trees, including stem/crown height and diameter; 4) Extract Roof Height and Type; and, 4) Extract Forested Areas. These features were combined with a single Building Information Model and imported into City Engine (Figure 3). While the process was not seamless, we were able to quickly and efficiently import the LIDAR derived information into City Engine. Rules based modelling for trees and buildings provided a quick and efficient regional model.

In just 6 years, the results of our modelling process using the same data were substantially improved. Automated tools and the integration of City Engine transformed the efficiency of our procedures and results. The model was still limited and we identified the limitations of the model when we attempted to integrate these data into an historic model being developed to exhibit advancements in virtual reality and augmented reality. The challenges with the LIDAR model was primarily related to two factors: 1) the low resolution of the source data (1 m point spacing) produced unreliable results for tree placement, forested areas, and the integration of buildings into the topography; and 2) the timing of the LIDAR flights, i. e. with no leaves on the trees, further produced unreliable results for trees and forested areas. Unlike traditional aerial survey, we would recommend LIDAR infrastructure surveys be performed at a higher resolution and when leaves are visible so that data uses could extend beyond infrastructure survey, and so that more accurate and precise models can be quickly produced.



Fig. 4: Left: LIDAR generated City Engine model of campus and town illustrating building masses trees, roofs and roof types. Right: Enhanced rules city engine model.

2.3 Above Ground Carbon and Cultural Landscape

In 2013, investigators from NASA and the Woods Hole Oceanographic Institute collected LIDAR data using NASA-Goddard's GLiHT system over an extensive swath of the Maya region (Figure 5) acquired to estimate above ground carbon storage (COOK et al. 2013, HERNANDEZ-STEFANONI et al. 2015, WHRC 2016). Simply, when the samples are combined with traditional hyperspectral remote sensing significant accuracy and precision of biomass calculations can be performed. The samples run from southwest to northeast from interior Campeche and Chiapas to the Gulf of Mexico and are bisected by two additional transects running west to east (Figure 5). Linked together, the combined tiles crosscut the critical ecological and cultural regions of the lowlands connecting documented sites throughout the Maya lowlands. Importantly, the samples also transect large areas of unknown and understudied archaeological regions (GOLDEN et al. 2016). We are repurposing LIDAR samples, originally captured to estimate and refine estimates of above ground carbon storage for the REDD+ (Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in

developing countries) project in southern Mexico (GOLDEN et al. 2016). Reanalysis of these data are revealing a complex coupled natural and human narrative of land use and landscape beneath the tropical forest canopy.

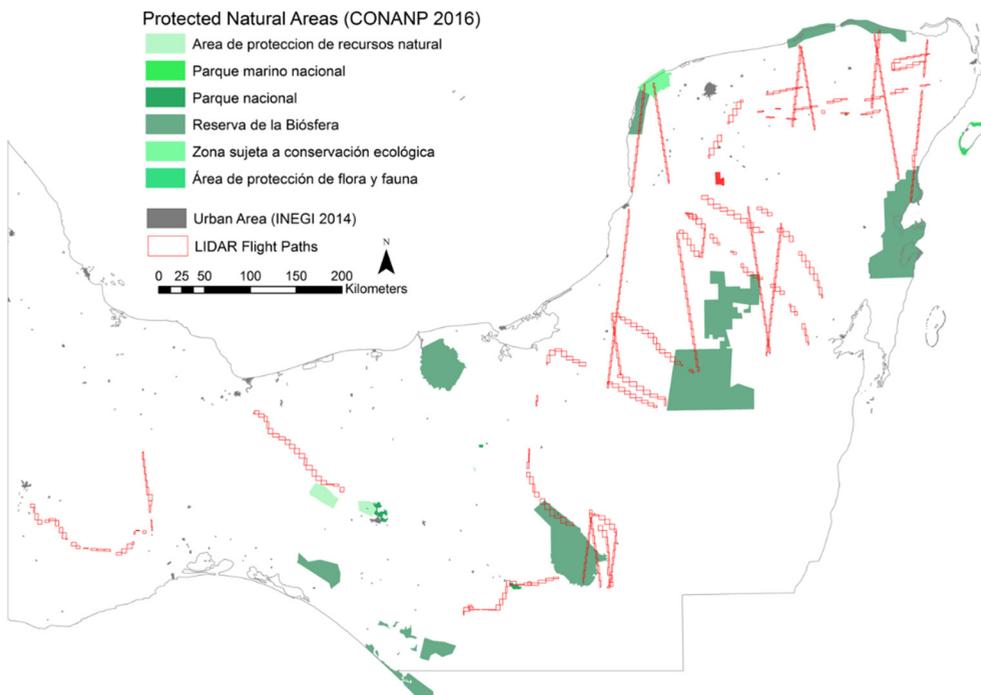


Fig. 5: LIDAR samples collected by NASA as compared to Natural Protected Areas (CONANP 2016)

Three millennia of households, terracing, reservoirs, and other landesque investments transformed what was once considered a pristine tropical forest into a complex mosaic of land use niches (Figure 6). The high-resolution samples offer an interpretive window to investigate land use scenarios of appropriate scale in a rapidly changing landscape. At its core, our project is a study of household and community, resilience and persistence. We are spatially investigating human environment interaction, relying on terraces and settlement patterns to understand the complexities of the lowland coupled natural and human system. Specifically, using these data we are measuring: 1) How do humans respond to abrupt environmental change? and 2) How do humans perceive and react to changes in the natural environment over short- and long-terms?

The information recorded from this reanalysis is potentially transformative. The high-resolution data offer critical insight into the complexities of landscape change and the scale of that change through time. For example, we examined how these data compared to protected areas in southern Mexico. Only fifty-five of the sampled areas fall within the boundaries of areas considered as Protected Natural Areas (as defined by CONANP). Forty-seven (47) have overlap with the subcategory of Biosphere Reserve, while three are in National Parks, and

five are located in an ecological conservation area. Greater than 90% of the flight paths fall in areas outside of protected zones in the lowlands. Despite this observation these samples fall in the core of our planet's critical above ground carbon storage, thereby tightly integrating the above ground biomass (the present) with the complex and critical coupled natural and human narrative found beneath the canopy (the past). Households and communities hold the key to the conservation of this important resource.

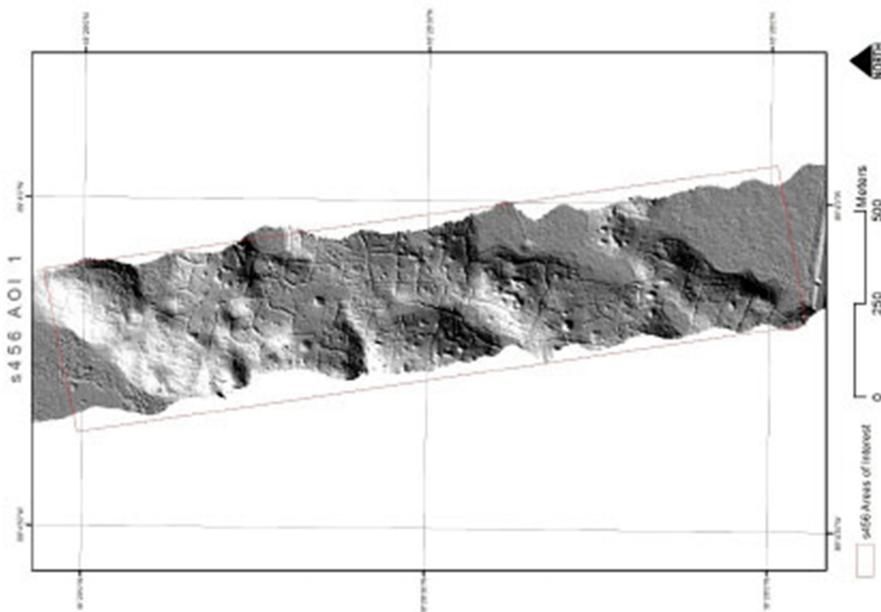


Fig. 6: Processed hillshade of REDD+ LIDAR from southern Mexico. LIDAR analysis exposed intricate systems of households and terracing offering new perspectives on regionalism, design, and planning.

3 Discussion

There are hundreds of LIDAR datasets available throughout the planet that can offer critical perspectives on landscape architecture, geodesign, and landscape research. Resources such as the NOAA (US National Oceanic and Atmospheric Administration) Coastal Management Program (<http://coast.noaa.gov>) and the Open Topography Project (<http://www.opentopography.org>) in addition to local and regional institutions could provide valuable data for use in design and planning at multiple scales. The data may be limited in scope. For example, data provided by NOAA are limited to coastal resources and primary studies of sea level rise, while open topography restricts access to sensitive data sets. Putting scope and availability aside, each data set must be evaluated for its own limitations.

For our project in San Lorenzo, the data provided important regional context for developing our model, but could not replace traditional topographic survey. At 5-meter resolution, we

are able to conduct many analyses, but needed the high precision data to understand the changing patterns of architecture and space of the ancient city. Detailed models can be used for tangible and interactive learning regarding real-world landscape function and processes, (see: <https://geospatial.ncsu.edu/osgeorel/tangible-landscape.html> and www.simtable.com). Potential for design process time savings, e. g. less time building existing conditions models, equals more iterating analysis, design, and impact assessments.

The work in Pennsylvania proved useful as the local government considered questions of building heights and visual changes to the landscape from new development. But the data were not sufficient resolution to accurately and precisely model buildings and landscape for integration into a virtual reality historic model of campus and community.

Finally, while the samples in lowland Mexico, initially collected to study above ground carbon stocks, offer only 300-meter-wide vignettes. These data are potentially transformative. They not only are useful for analysing the distribution of forest types, structure, and density as part of the REDD+ program, they offer important details about the past in order to inform the present. Any future conservation efforts in the region must involve careful consideration of bottom up strategies, thereby linking household and community to regional conservation. Moreover, these data allow us to fully engage Turner's (2009 and 2016) Land Architecture (Land Systems Architecture) for planning, design, and research in the lowlands where complex coupled natural and human narratives of place offer sustainable and resilient opportunities. As Turner writes, "A sustainable [Land Architecture] delivers the environmental services while maintaining or improving the economic performance of the land uses without threatening the base function of the environmental systems to deliver the services in the first place..." (TURNER 2009, 2). Interestingly, the extent of these data are the same geographical context where Turner first started investigating household, land use and resilience more than four decades ago (TURNER 1974).

4 Conclusion and Outlook

The use of remote sensing and LIDAR specifically, offers transformative opportunities for Digital Landscape Architecture. Beyond site inventories and direct site mapping, these data provide detail site-based context for initial model building and evaluation. These data can also be used to rapidly model natural and cultural infrastructure, perhaps providing a firm foundation for enhanced research. Finally, these data also offer new and highly detailed perspectives of the importance of scale and region, when undertaking landscape design and planning research. Simply, Existing LIDAR data can be effectively leveraged to address big questions informed by 'big data'. Mindful of three specific use studies, this paper demonstrates some of the opportunities and challenges for effectively repurposing and reusing these data.

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References

- BARTH, B. (2017), 3-D Scanning and the Holographic Landscape. *Landscape Architecture Magazine*, 56-58.
- CONANP (2016), Areas Naturales Protegidas de Mexico. <http://sig.conanp.gob.mx/website/pagsig/anp/nal/index.htm> (accessed March 15, 2016).
- CYPHERS, A., MURTHA, T., NOGUERA, J., JIMENEZ, G., GUEVARA, E., DI CASTRO, A., GRACIA, B., BAIZABAL, V., LUNAGOMEZ, R., BORSTEIN, J., SIMONDS, S., ORTIZ, M. & FIGUEROA, J. (2014), *Atlas Digital de la Zona Arqueologica de San Lorenzo*, Vera Cruz. Universidad Nacional Autonoma de Mexico. Ciudad Universitaria, Mexico DF. 56 pages and 1 DVD (4.7 GB). ISBN: 978-6070263262.
- GOLDEN, C., MURTHA, T., COOK, B., SHAFFER, D. S., SCHRODER, W., HERMITT, E. J., ALCOVER FIRPI, O. & SCHERER, A. K. (2016), Reanalyzing environmental lidar data for archaeology: Mesoamerican applications and implications. *Journal of Archaeological Science: Reports*, 9 (Oct. 2016), 293-308, ISSN 2352-409X. <http://dx.doi.org/10.1016/j.jasrep.2016.07.029>.
- JAKUBOWSKI, M. K., GUO, Q., COLLINS, B., STEPHENS, S. & KELLY, M. (2013), Predicting Surface Fuel Models and Fuel Metrics Using Lidar and CIR Imagery in a Dense, Mountainous Forest. *Photogrammetric Engineering and Remote Sensing*, 79 (1), 37-49. <https://doi.org/10.14358/PERS.79.1.37>.
- KRAMER, H. A., COLLINS, B. M., KELLY, M. & STEPHENS, S. L. (2014), Quantifying ladder fuels: a new approach using LiDAR. *Forests*, 5 (6), 1432-1453. <https://doi.org/10.3390/f5061432>.
- LI, P. & P. PETSCHKE (2014), From Landscape Survey to Landscape Design – A Case Study in Nanjing, P. R. China. In: WISSEN HAYEK, U., FRICKER, P. & BUHMANN, E. (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich*. Wichmann, Berlin/Offenbach, 232-239.
- LIN, E. & C. GIROT (2014), Point Cloud Components – Tools for the Representation of Large Scale Landscape Architectural Projects. In: WISSEN HAYEK, U., FRICKER, P. & BUHMANN, E. (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich*. Wichmann, Berlin/Offenbach, 208-218.
- MURTHA, T., MESSNER, J., MURAMOTO, K., KALISPERIS, L., FLOHR, T., DIMOND, K. & WEISSMAN, D. (2008), <http://www.engr.psu.edu/ae/cic/gisbim/index.html> Geospatial BIM Project Website (accessed January 27, 2018).
- ORFANOPOULOS, G., BERNHARD, M. & MARIC, O. (2014), Digital Tectonics, an Instrument for CNC Milling Efficiency and Experimentation. In: WISSEN HAYEK, U., FRICKER, P. & BUHMANN, E. (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich*. Wichmann, Berlin/Offenbach, 224-231.
- PHOENIX SYSTEMS (2018), <https://www.phoenixlidar.com>. Accessed February 1, 2018.
- PLATT, R. V. (2014), Wildfire hazard in the home ignition zone: an object-oriented analysis integrating LiDAR and VHR satellite imagery. *Applied Geography*, 51, 108-117. <https://doi.org/http://dx.doi.org/10.1016/j.apgeog.2014.03.011>.
- REKITTKE, J. & NINSALAM, Y. (2014), Head in the Point Clouds – Feet on the Ground. In: WISSEN HAYEK, U., FRICKER, P. & BUHMANN, E. (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2014 at ETH Zurich*. Wichmann, Berlin/Offenbach, 198-208.

- REKITTKE, J., PAAR, J. & NINSALAM, Y. (2013), Brawn and Technology under the Urban Canopy. In: BUHMANN, E., ERVIN, S. M. & PIETSCH, M. (Eds.), Peer Reviewed Proceedings of Digital Landscape Architecture 2013 at Anhalt University of Applied Sciences. Wichmann, Berlin/Offenbach, 12-21.
- REKITTKE, J., PAAR, J. & NINSALAM, Y. (2012), Foot Soldiers of Geodesign. In: BUHMANN, E., ERVIN, S. M. & PIETSCH, M. (Eds.), Peer Reviewed Proceedings of Digital Landscape Architecture 2012 at Anhalt University of Applied Sciences. Wichmann, Berlin/Offenbach, 199-210.
- REKITTKE, J., PAAR, J., NINSALAM, Y. & LIN, E. (2013), Digital Reconnaissance. *Journal of Landscape Architecture*, 8 (1), 74-81.
- TEXTRON (2016), <http://www.textronsystems.com/what-we-do/geospatial-solutions/lidar-analyst> (accessed June 30, 2016).
- TURNER, B. L. (1974), Prehistoric Intensive Agriculture in the Mayan Lowlands. *Science*, 185, 118-124.
- TURNER, B. L. (2009), Sustainability and forest transitions in the southern Yucatán: The land architecture approach. *Land Use Policy* (2009). doi:10.1016/j.landusepol.2009.03.006.
- TURNER, B. L. (2016), Land system architecture for urban sustainability: new directions for land system science illustrated by application to the urban heat island problem. *Journal of Land Use Science*, 11 (6), 689-697. doi: 10.1080/1747423X.2016.1241315.
- WEISHAMPEL, J. F., HIGHTOWER, J., CHASE, A. F. & CHASE, D. Z. (2012), Use of Airborne LiDAR to Delineate Canopy Degradation and Encroachment along the Guatemala-Belize Border. *Tropical Conservation Science*, 5 (1), 12-24.
- WHRC (2016), Above Ground Forest Carbon Stocks in Mexico. Woods Hole Research Center. Data: <http://whrc.org/publications-data/datasets/aboveground-forest-carbon-stocks-in-mexico/> (accessed March 15, 2016).