Sensors in the Landscape: A Peatland Perspective

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Abstract: Sensors are an emerging technology which can measure environmental phenomena that is otherwise imperceivable to human senses and can alone or with actuators be a powerful experiential, research, or communication tool for landscape architecture projects. Using a comparative analysis of three case studies of sensor-embedded peatland landscapes, as well as interviews with landscape architects, architects, engineers, urban ecologists, and ecologists who utilize sensors in their landscape-related projects, this paper enumerates some of the sensors that are typically deployed in disparate landscape projects and proposes future opportunities for sensor use in the landscape architecture profession.

Keywords: Immersive environments, sensors, peatland

1 Introduction

1.1 Sensor Background

This paper builds on ERVIN'S (2018) article "Sensor-y Landscapes: Sensors and Sensations in Interactive Cybernetic Landscapes," wherein he discusses the emergence and potential of "Sensor-y Landscapes". This paper discusses the use of sensors in several landscape-related projects as a means to discern how landscape architects and other practitioners in related fields are using sensors now, and proposes how landscape architects might better utilize sensors in our work in the future.

Landscape architects operate with a broad understanding of people, technology, systems, and ecology, and wield the tools necessary to create spatial experiences that resonate with people both aesthetically and psychologically. Sensors are an emerging technology which can measure environmental phenomena that is otherwise imperceivable to human senses. By changing the way we understand the environment, sensors have the capacity to change how, where, and when landscape architects might intervene in the landscape. While other related fields such as architecture, engineering, urban ecology, and art are utilizing these new tools, landscape architects been slow to incorporate their use into the discipline. Landscape architects such as WALLISS (2018) have written about innovations in digital design practice generally, and others have written more specifically about art and design installation projects that have utilized sensors (CANTRELL & HOLZMAN 2015). CANTRELL & MEKIES (2018, 2017) in *Codify* questioned how sensor data might lead to a new way of viewing the landscape, while LOKMAN (2017) discussed how digital technologies such as sensors can create cyborg landscape. However, none of these authors delved deeply using built examples to posit how sensors can transform the discipline and practice through monitoring, experience enhancement, and increasing communication.

1.2 Peatland Background

Sensor embedded peatlands were selected as visitation sites for several reasons. Firstly, peatlands are a critical wetland ecosystem type in terms of climate change and biodiversity. While peatlands cover only 3 % of earth's land area, they hold twice as much sequestered carbon

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as all of earth's forests, which cover approximately 30 % of earth's land surface (IUCN 2018, CARLOWICZ 2012). Peatlands are under threat by humans due to peat's value as a fuel and agricultural soil amendment, the desire to use carbon rich peatlands as agricultural fields, and a general ignorance regarding peatlands climatic importance. The harsh, nutrient-poor conditions of peatlands makes them home to endemic fauna and flora and contributes to their unique natural beauty (MINAYEVA & SIRIN 2012). Secondly, in North America there are several prominent peatland sites embedded with sensors for research, restoration, and responsive environment purposes; three areas of opportunity for the landscape architecture profession to engage with.

2 Methods

The project was performed through a comparative study of sensor use in diverse landscape contexts at two scales. These scales included a series of interviews with practitioners in landscape architecture, architecture, ecology, and environmental engineering, and sensor manufacturing; and site visitations to three sensor-embedded peatland case study sites. Interviews and case study site visits were supplemented by a review of selected literature on peatlands and sensors, and landscape-related sensor-utilizing precedent projects. Interviews with practitioners were used as a primary source for learning about how sensors are currently deployed in different landscape and design contexts (Table 1). Contacts were selected through online and literature review research, as well as word of mouth, and were interviewed in-person, over-the-phone, or via skype.

Table 1: List of Non-Site Interviewees

Profession	Firm/Organization
Ecological Engineer	Biohabitats/Bioworks
Architect/Urban Ecologist	Kieran Timberlake
Landscape Architect/Urban Ecologist	University of Connecticut
Climate Engineer	Transsolar
Landscape Architect	Stoss
PhD Ecological Engineering	Université Laval/PERG
National Design Director for Landscape Architecture	General Services Administration (GSA)
Strategic Sales Specialist	ONSET Computer Corporation

In addition to interviews with practitioners, three peatland landscapes were visited in August 2019 to observe the use of sensors in the field. Respectively, these three visited sites were the Tidmarsh Living Observatory in Plymouth, MA; the Marcell Experimental Forest (MEF) in Grand Rapids, MN and its Spruce and Peatland Responses Under Changing Environments (SPRUCE) experiment; and a handful of peatlands undergoing restoration by the Peatland Ecology Research Group (PERG) around Quebec, Canada. Site visits to each of the three case study sites lasted between two and three days and entailed a guided tour of the site(s) conducted by a researcher. The tour was complimented by one or more formal interviews or a series of conversation regarding the sensors and/or actuators employed at the site and the peatland ecosystem. Each site visit was documented in the field via writing, sketches, and photographs.

3 Findings

3.1 Sensor Use in Design Contexts

Through interviews with practitioners in landscape architecture, architecture, ecology, and environmental engineering, and through the analysis of precedent projects, it became apparent that sensors were being used for one, or a combination of three purposes: 1) monitoring, 2) experience enhancement, or 3) communication.

Landscape monitoring via sensors can occur in a project for ecological, design, and economic purposes. Biohabitats is a firm specializing in regenerative design that has been using sensors for ecological monitoring in several projects. As part of their Georgia Tech Eco-Commons project, they have spec'd ONSET sensors to monitor light conditions (as a proxy for canopy cover) and soil moisture across the site, as well as water temperature and level in wetland cells. In their Baltimore Harbor project, Biohabitats used sensors to continuously monitor dissolved oxygen, salinity, temperature, conductivity (pH), and chlorophyll A to gauge the health of the harbor. The General Services Administration (GSA 2017) of the US federal government is exploring using sensors for site commissioning to ensure that its landscapes sites, like its buildings, function as intended – environmentally, socially, and financially. In its white paper on the topic, the GSA lists collecting data on local weather conditions (e. g. air temperature, relative humidity, precipitation, wildfire risk), water use (e. g. water balance, capture/re-use, irrigation rate, discharge rate), and water flow rate (e. g. discharge rate, runoff volume) as opportunities for continuous monitoring. Kieran Timberlake is an architecture firm which has utilized sensors for an array of purposes including to monitor soil moisture and heat transfer in green roofs. By monitoring at various depths in the green roof media, above and below the waterproof roof membrane, and within the building itself, they were able to research both the thermal comfort and ecosystem services provided by the green roof system. Merritt Chase is a landscape architecture and urban design firm who's Take a Seat! project in Pittsburgh, PA used GPS location tiles installed in lightweight movable chairs to track peoples preferred seating patterns along the riverfront. The data from this project ultimately influenced the location of fixed seating.

Sensor use for experience enhancement can be accomplished passively or actively. Architecture firms like Kieran Timberlake and engineering firms such as Transsolar frequently uses sensors to increase building energy performance, as well as to modulate the microclimates and perceived temperatures of indoor and outdoor spaces for comfort. In addition to this work, Transsolar has worked on a series of light-scape, cloud-scape, and scent-scape installations which use sensors and actuators to manipulate temperature, airflow, and light. Höweler + Yoon is an architecture firm which has built several landscape installations that use sensors and actuators create interactive objects for patrons. Best engaged with at night, their Swing Time and White Noise White Light installations both use movement as a catalyst to change the color or brightness of a lit object. Similarly, Stoss Landscape Urbanism has used precipitation sensors in its Eda U. Gerstacker Grove project to cue lights and transform the atmosphere of the space during rainfall events.

Communicating sensor information to stakeholders or the public is often done through the use of actuators (e. g. lights, speakers, etc.) which in turn creates an enhanced experience too. Höweler + Yoon's upcoming Float Lab installation will use light, sound, and movement to create a new form of educational experience that aims to connect visitors with an underwater ecosystem. Artist JEREMIJENKO and architect BENJAMIN'S (2009). "Amphibious Architecture" communicated water quality and fish presence in NYC's East River to people on the shore via bobbing tubes fitted with dissolved oxygen and motion detection sensors below the water's surface and LED lights above. BIERSTEKER (2018) is another artist who, in his project "Voice of Nature," translates ambient environmental phenomena into an engaging visual for visitors. The data from a dozen sensors deployed on a tree is used to create digital tree rings in real time which are displayed on an LED screen next to the tree, reflecting how the tree is responding to current conditions. "Particle Falls," by Andrea Polli and Chuck Varga and "Calling the Glacier," by sound artist Kalle Laar are two other digital art projects which convey environmental information to the public. "Particle Falls" uses laser projections on buildings to visualize local small particulate (PM2.5) pollution, while "Calling the Glacier" transmits unedited sound from a microphone on a distant glacier directly to a hotline caller (ZERO1 2010, LINDEMANN 2013).

3.2 Comparative Analysis of Case Study Sites

The three visited case study sites share several similarities and differences in terms of overseeing organizations, project goals, sensor deployment. The Tidmarsh Living Observatory is a non-profit organization that came out of a partnership between a private land owner and the MIT Media Lab's Responsive Environment group, in conjunction with other institutional partners. Similarly, PERG is a partnership between the Canadian university scientific community, the Canadian peat moss industry, and federal and provincial agencies. The MEF is solely a government entity, overseen and managed by USDA Forest Service, and SPRUCE is a US Department of Energy project coordinated through Oak Ridge National Lab.

The Tidmarsh Living Observatory and the PERG peatland sites are all ecological restoration sites. The Tidmarsh Living Observatory is being returned to a wetland after existing as a cranberry bog for 100 years, and the PERG sites are either former, active, or experimental peat extraction sites where peat is mined for use as a soil amendment (MIT Media Lab 2018). The MEF is a long-term ecological research site established in 1962 to study the ecology and hydrology of peatlands (USDA FS1 2007). The MEF has six paired peatlands – three control and three where experiments are conducted. Each include a wetland and upland forest watersheds. On one particular peatland the SPRUCE experiment is simulating the effects of increased temperature and atmospheric carbon dioxide on peatlands to understand the potential impacts from climate change (USDA FS2 2018). Each of the three case study sites was formed due to glaciation.

Sensor deployment across each case study sites is informal and irregular with the exception of the SPRUCE experiment at the MEF. Here sensors are deployed systematically across the different climatically conditioned chambers. Sensors deployed at Tidmarsh are primarily wireless nodes, save a small weather station and a Distributed Temperature Sensing cable. This contrasts with the sensors deployed at the MEF which vary throughout the forest based by project. In addition to the SPRUCE experiment, the MEF hosts a USFS SMART Forest weather station and a National Atmospheric Deposition Program (NADP) Network site. Moreover, water table height, air temperature, and relative humidity are measured at each peatland. Both PERG and MEF have an Eddy Covariance system in one peatland to measure CO^2 and CH^4 flux. The sensors deployed at the PERG peatland sites are used for a range of specific purposes, and not uniformly across all sites. Some active extraction sites use soil temperature and moisture sensors within piles of extracted peat as a means to prevent peat from spontaneously combusting. The sensors deployed at the Tidmarsh Living Observatory and PERG sites are both primarily custom designed and built, whereas the sensors deployed across the MEF are commercial sensors from Campbell Scientific. Table 2 lists the sensors observed while visiting the three case study sites.

Table 2: List of Sensors Deployed Across Three Case Study Sites

Measurand Detected by Sensors	TLO	MEF	PERG
Carbon Dioxide		X	
Methane Flux		X	X
Carbon Dioxide Flux		X	X
Small Particulate ($PM_{2.5}$, PM_{10})			
Visible Light	X	X	
Infrared Light	X		
Long and Short Incoming and Outgoing Radiation	X	X	
Photosynthetically Active Radiation		X	
Ultraviolet Radiation	X	X	
Precipitation		X	
Relative Humidity	X	X	
Soil Moisture	X	X	X
Soil Temperature	X	X	X
Water Temperature	X		
Air Temperature	X	X	
Rhizotron			
Water pH	X		X
Water Level Height	X	X	X
Sound	X		X
Atmospheric Pressure	X		X
Porewater Pressure		X	
Wind Speed	X	X	X
Wind Direction	X	X	X
Motion	X		
Dissolved Oxygen	X		
Redox Potential	X		
Conductivity	X		
Diurnal Tree Diameter Change		X	
Sap Flow in Trees		X	

Sensor use at these three case study sites can be understood as serving a purpose of monitoring, experience enhancement, and/or communication. At the Tidmarsh Living Observatory, sensors are being used for all three purposes. Institutional partners in the hard sciences are monitoring sensor data to understand different aspects of the wetland's restoration over time. Climate, soil, water, and other environmental data as well as audio and video are captured and made accessible on the Tidmarsh Living Observatory website (MIT Media Lab 2018). Researchers at the MIT Media Lab's Responsive Environments group are also using the data to create new multimodal sensory experiences for people at different spatial and temporal scales. These enhanced experiences have taken real-time and historical sensor data from the marsh and manifested in projects such as “DoppleMarsh,” an online virtual reality wetland; the “ListenTree” installation which conducts real-time marsh sounds through a remote tree, and “HearThere,” a wearable device that relays sound data from microphones throughout the marsh to a wearer across time and space (MAYTON et al. 2017, DUBLON & PORTOCARRERRO 2014). At the MEF, sensors are used strictly for monitoring and research purposes; data is communicated to the public through scientific papers. Sensor use at the PERG peatland sites fall somewhere in between that of the Tidmarsh Living Observatory and the MEF. Sensor data is primarily for monitoring and research purposes, but can be used to inform action or interventions on the site. A sensor in a hot pile of drying peat might dictate that the pile needs rewetting, or a low water level in an experimental bog will trigger a pump to supply more water.

4 Discussion

4.1 Limitations of Sensor Use in Landscape Architecture

One of the constraints inhibiting the inclusion of sensors into landscape architectural practice is the limited array of sensors that can continuously monitor phenomena. This limited array is due in part to cost constraints, instrumentation size, and the state of current technology. For example, most soil nutrient and gas analysis currently need to be performed in a laboratory. Samples can be taken using sensor-controlled systems, but those samples must be retrieved by a scientist. This occurs at the MEF for gasses dissolved in soil (CO^2 and CH^4) and ground water (NO_x), as well as cations, anions, nutrients, and mercury captured in precipitation as part of the National Atmospheric Deposition Program. Future technologies (e. g. NASA Mars rovers) may make in-field analysis of these chemicals and other phenomena feasible. Additionally, there are certain environmental conditions that can be continuously monitored but typically change occurs very slowly (e. g. soil pH or CO^2 concentration), and thus, continuously monitoring these conditions with sensors does not always make sense. Perhaps the greatest limitation to sensor use in landscape architecture stems from professionals lacking skills, interest, or confidence in using sensors.

4.2 Potential Opportunities for Sensor Use in Landscape Architecture

The interviews and site visits conducted during this project have displayed that sensors can be used in landscape contexts for monitoring, experience enhancement, and/or communication. Several design firms such as Höweler + Yoon are already employing sensors for these purposes to a certain extent, but there are additional opportunities for their use. As the GSA is starting to explore, sensors can be used to monitor landscape architecture projects to verify claims made by landscape architects about the ecological or social benefits a project will accomplish. These results can additionally be used for business development and marketing to solicit prospective clients, thus helping to secure future work or funding. As digital art projects such as “Amphibious Architecture” or “Calling the Glacier” show, sensors and can enable the collection, transformation, and dissemination of environmental information to the public on a deeper intellectual and emotional level. These projects both reveal environmental phenomena and landscapes, local and global respectively, that would not otherwise be perceivable to the human senses, and foster awareness of and engagement with the core issues. When applied to landscape architecture, the sensor-intervention paradigm employed across the PERG peatland sites could expand the landscape profession in terms of the duration of a landscape project as it is monitored and changes over time, the role we play in terms of intervening, and how we can practice on projects remotely from the site. The Tidmarsh Living Observatory and the SPRUCE experiment both relate to FELSON & PICKETT'S (2005) concept of the "designed experiment," where a landscape is designed for aesthetic or functional use, and with embedded scientific research questions aiming to discover new knowledge. Finally, as landscape architects are designers of spaces that are to be experienced by users, sensors and actuators provide a still unrealized potential for experience enhancement. Beyond creating objects that move, light up, or make noise, the MIT Media Lab has shown sensors can be used to extend a person's ability to experience natural phenomena, or to spatially or sensorially augment an experience.

5 Conclusion and Outlook

The use of sensors in landscape architecture practice is still nascent, but practitioner interviews, precedent analysis, and site visits, have revealed a range of sensors and typical intentions for their use across a variety landscape-related projects. It is also clear that sensors and actuators have great potential as landscape architectural tools for monitoring and research, landscape intervention, experiential enhancement, and communication including education and marketing. Each of these paths hold many opportunities for future research, but a core question that might be asked is when should sensor data be transformed into one sensory stimulus instead of another, and how does that choice inform audience perception of the data communicated.

As landscape architecture is now designated as a STEM field, and as digital technology and the Internet of things becomes ever more pervasive in our personal and professional lives, landscape architects must add sensors and actuators to our design tool belt. The profession has repeatedly embraced other digital tools such as 3D printing; and adjacent disciplines such as architecture, engineering, art, ecology are already using sensors and actuators in landscape-related projects. Sensors and actuators have the potential to reveal beauty and performance of landscapes such as peatlands beyond the aesthetically observable. Through translation, sensor data can be communicated to audiences near and remote, leading to new lenses of landscape valuation, and methods of design.

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