Sensor-y Landscapes: Sensors and Sensations in Interactive Cybernetic Landscapes

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Abstract: Increasingly, both digital and electromechanical technologies are involved in the design, operation, experience, and perception of landscapes and cities. Networked sensors that augment and extend the five basic human senses, primarily sight, sound and touch, and actuators that can control a range of devices and actions, from solenoids, valves, and motors to digital audio-visual and web-site contents delivered to wearable devices, offer new opportunities for monitoring environmental systems, enabling dynamic aspects of landscape experience, and for extending the performative and expressive repertoire of designed landscapes. 'Responsive environments' and 'smart cities' are both examples of this emergent form of 'sensor-y landscapes'. In this paper, an overview of the current landscape of networked sensors and actuators is accompanied by a discussion of their potential combinations and alignment with natural systems, human activities and perceptions, and landscape design intentions, both utilitarian and more aesthetic/conceptual.

Keywords: Sensors, Sensory, interactive, responsive landscapes

1 Introduction

Human experiences and perceptions of landscapes are inherently mediated by the five primary human senses, as well as by social and mental/cognitive processes. Increasingly, more technologies both digital and electromechanical are involved in this mediation, and in the design, operation, experience, and perception of landscapes and cities (ANDERSON & ORTEGA 2016, KARANDINOU 2017). The term 'cybernetic', with the meaning of "control systems based on connected input and output sub-systems, in both machines and living things", can aptly be applied to these developments.

Digital and electromechanical sensors and actuators, together with information networks and computation, present a potent force, challenge, and opportunity to the conception of landscape and practices of landscape design, construction, occupation, and enjoyment. Considering these technologies as "extensions of man", in McLuhan's terms, we are reminded of his assertion in *Understanding Media* that "Any extension, whether of skin, hand, or foot, affects the whole psychic and social complex" (MCLUHAN 1964).

Technologies for digitally networked electromechanical sensors and actuators of many descriptions have blossomed in recent decades, and are responsible for much of the transformative power of mobile phones, robotics, self-driving cars, wearable technology, and other heralds of the 'exponential era' (BBVA). Many people have already experienced motion sensors that control lights indoors or out; or soil moisture sensors that control irrigation systems; or have heard of acoustic gun-shot detectors in urban neighborhoods. They may also carry a sensor-laden smart-phone, or wear an activity-tracking pulse-sensing digital fitness bracelet …

The promise of sensors and sensing as an integral part of landscape designers' and planners' palettes goes well beyond those basic applications. In this paper I present an overview of the

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current landscape of networked sensors and actuators, and discuss their potential combinations and alignment with natural systems, human activities and perceptions, scientific environmental monitoring, and landscape design intentions, both utilitarian and aesthetic/conceptual, in the creation of cybernetic sensor-y landscapes.

2 Sensations and Human Perception

Sensations may be defined as named qualities that are felt or perceived by an organism such as a human. Each of the five broad categories of human sense – visual, auditory, tactile, olfactory, and gustatory – gives rise to a range of reported, named sensations, including e. g. brightness, color, volume, pitch, temperature, fragrance, sourness, etc.

Beyond these primal sensations, human perceptions of landscapes can also include emotional and intellectual reaction, wherein feelings of calm, excitement, gloominess, curiosity, self-reflection, safety or fear, etc. may be engendered. The art of landscape design is partially to anticipate and manipulate these kinds of human perceptions and reactions, through contrivances such as the arrangement of landform, vegetation, water and structures, views, walls and overhangs, materials and lighting, etc. – and, increasingly, networked sensors and actuators. Whether there are universal or one-to-one mappings of sensory stimuli to human response is one of the great imponderables of the design arts; how to design, quantify, and compute with these sensations and sensors is a fertile and challenging ground for experimentation and implementation.

3 Sensory Landscapes

'Sensory landscapes' has been used as a term to describe landscapes and environments that have been designed and deployed specifically to stimulate the senses other than sight alone (WAGENFELD & SINGLEY 2016). Sounds that are embedded in the landscape either from natural sources (e. g. wind and water, birds and insects) or more technological (loudspeakers, chimes, alarms) to engage auditory sense; textures, patterns, and material properties that can be experienced by touching; scents and aromas that stimulate the sense of smell; plants that may be edible for the sense of taste; all are parts of the 'sensory landscape' palette.

'Sensory gardens' have been made for many years to be embedded in therapeutic environments, based on the premise that some health conditions, e. g. stress, can be ameliorated by suitable sensory engagement (GRAHN & STIGSDOTTER 2009, DE WIT 2016). These gardens and installations have to-date primarily employed the basic six analog elements of built landscapes: landform, vegetation, water, structures, animals and atmosphere (ERVIN & HASBROUCK 2001); and have not been particularly sensor-laden, other than by human occupants, but these sensors obviously could be augmented by electromechanical ones.

4 Sensors

Sensors may be defined as devices that respond to changes in their environment across a range of size and temporal scales, or distinct segments of the electromagnetic spectrum, or various electrical, physical, chemical, and other inputs, by generating an output whose characteristics (amplitude, frequency, voltage, etc.) are in some known and repeatable scaled relationship to their inputs. Their mechanisms and uses are many, including in research and in a wide range of applications and operations.

As a broad generalization, sensors of interest to landscape design may be categorized into distinct types, modelled after the basic five human senses. The vast majority of readily available sensors and sensor systems operate in the first three (sight, sound, touch) (COSTA & PIMENTA 2017); smell and taste sensors have been developed and deployed, but far less frequently – although no less interestingly! The human sense of time is also important, and clocks and timers (measuring either absolute or elapsed time) may be understood as a special class of sensor.

In addition, some sensors detect phenomena outside of the range of human detection: ultraviolet light, certain chemical compounds in the air, radio waves, global location enabled by GPS, and so on. Others add quantification to human sense-able stimuli, such as velocity, acceleration, humidity, light intensity, sound frequency, etc., and may combine two or more measurements, such as in a weather station.

Modern smartphones are already equipped with more than a dozen sensors that are used in a variety of ways to make the phone more responsive to user's behaviors and ambient conditions. See Table 1 for an example of the various basic sensor types supported by the Android platform.

Table 1: Android Phone Sensors – condensed list

Accelerometer	Light	Orientation	Relative_humidity
Ambient_temperature	Linear_acceleration	Pressure	Rotation_vector
Gravity	Magnetic_field	Proximity	Temperature
Gyroscope			

5 Landscape Sensors

Sensors that may offer the greatest promise for landscape design and responsive landscapes, and that are already well established in the market, and for which much technology is well-understood and documented, include: visual, location and proximity, motion, eye-tracking, sound, weather sensors, human health sensors, and sensors of diverse environmental conditions, such as moisture and various chemical sensors, e. g. air pollution, carbon dioxide, et al.

Visual Sensors

Digital cameras are all sensors, too. 'Remote sensing' from air-borne and space platforms (balloons, drones, aerial photography & satellite images) enabled the explosion of small-scale (large-area) landscape planning with detailed information about conditions and changes in regional & planetary landscapes. Today, with advances in computer-vision, facial recognition and more are commonplace in visual sensors.

In the landscape, vision may be from the landscape looking at the environment, visitors, etc; or may be from the visitor's viewpoint, often mediated by a handheld device (e. g. phone). The landscape vision sensor may be able to detect groups, children, animals, etc.; the handheld phone camera, augmented with an Augmented-Reality app, may be able to display additional relevant information from the web, or from a local broadcasting wireless station.

Sound Sensors

Microphones of many descriptions, including specialized applications such as gunshot detectors, migrating bird-call detectors and classifiers, etc., have a range of applications in the landscape. Sound sensors in the landscape may be able to detect activity, identify kinds of users or activities, species of birds, etc.

Motion Sensors

These are perhaps the most familiar and prevalent forms of sensors in the built environment today, especially in their 'responsive' combinations, turning on lights, opening doors, activating fans and fountains, etc. These uses may vary from the purely functional to the whimsically playful. Motion, proximity, and velocity-acceleration sensors can detect the presence of visitors, and levels of activity, as well as wind, earthquakes and landslides, and other phenomena. At an information kiosk, and eye-tracking sensor can determine which parts of a display a visitor is reading or focusing on. Combining vision and motion detectors, some Augmented-Reality devices (e. g. Microsoft Hololens) have developed a kind of sign-language that can be used by humans to communicate with sensors.

Weather Sensors

The applications of weather stations and sensors in the landscape are many and various, ranging from early warning systems to automated deployment of shading or rain-covering devices, for example. Sensors of various other environmental conditions include the ability to detect soil moisture and deploy automatic watering systems, or flood sensors to deploy automatic floodgates, sensors to detect pollution and noxious gases, or fires, etc.

Human / Health Sensors

Fit bit, Android phone, and other such devices increasingly include health-related sensors of human physiology and behavior (heart rate, body temperature, blood pressure, walking and climbing activity, etc.); these can form the basis for customized and localized information and individual experiences in the landscape. Such 'intimate sensing' can enable an explosion of responsive-environment design, at the larger-scale (smaller sizes: site, human, and even larger scales).

RFID tracking, Cell-phone, Bluetooth, GPS Sensors, etc.

Many emergent network and communications technologies enable communications between things, (hence the 'Internet of Things', or 'of Everything') and so support a wide range of tracking applications, for surveillance, entertainment, edutainment, and scientific environmental monitoring. Wireless-sensor-networks (or WSN's) are becoming a standard part of the urban and commercial landscape; their extension into the built and natural landscape is only a matter of time…

Sensor-laden landscapes designed, built, augmented, and experienced with the help of sensors and actuators may be called '*sensor-y landscapes'* to distinguish them from more conventional 'sensory landscapes' described above. As an example, the interactive walkways that have been installed in otherwise depressing hallways in underground airport structures use human motion and proximity sensors connected to LED lights, projectors, and even sound systems, to enliven otherwise uninspiring environments.

The value of these sensor-y landscapes for scientific research and monitoring is obvious, too. In Northern Arizona, at BioSphere 2, the Landscape Evolution Laboratory is observing the evolution of a constructed landscape over time. "Those observations are made possible by the array of more than 1800 sensors and sampling devices that are installed on, within, or above each landscape. The sensors enable monitoring of water, carbon, and energy cycling processes, and the physical and chemical evolution of the landscape at sub-meter to whole-landscape scales" (BIOSPHERE2).

6 Actuators

Actuators are electromechanical devices, that convert an electrical signal into some physical effect, again across the five basic senses: visual, auditory, tactile olfactory, and gustatory. As with sensors, the first three kinds of actuators are the most familiar and widely used types.

For each type of sensor, there is an equivalent type of actuator: Visual actuators are typically lights, projectors and displays/screens; auditory actuators loudspeakers, bells buzzers, clappers, and etc.; tactile actuators various forms of pressure sensors, buttons, 'touch-panels', etc. (Heat-emitters may be considered a form of tactile actuator, too.). Olfactory actuators, or 'odor emitters' are technically feasible but very little developed or deployed; and gustatory, or 'taste-emitters' are hard even to imagine …

Other forms of actuators may operate outside of the human perceptual range, emitting electricity, radio waves, or magnetism, etc., which are best perceived by other electromechanical devices (receivers). These forms are the most involved in wireless-sensor-networks, and in the increasingly important role played by information-emitters (sometimes called 'beacons') in the landscape.

7 Responsive Circuits and Devices

Responsive circuits and devices are constructed by combining one or more sensors with one or more actuators, with some connecting wiring or communications. Typically, the output from the sensor(s) becomes the input to the actuator(s), usually with some logical or algorithmic control or modulation. See Figure 1. The familiar occupancy/motion-sensor and light-control combination is perhaps the most widely experienced such device; or the light-sensor connected to light-bulb, to turn lights on in the dark and off during the light hours. Sprinkler systems that are activated based on soil-moisture sensors, perhaps augmented by temperature sensors, rainfall sensors, and on-line weather-forecasts are also familiar landscape systems. This basic formation – sensor input from the environment; sensor output to actuator input; actuator output back into the environment – is the basis of an endless variety of responsive systems, which may be of functional utility, aesthetic value, or conceptual interest in responsive landscape design, and are at the core of so-called ‘smart cities’, smart houses, autonomous cars, cybernetic landscapes, etc. (DENARDIN 2009, PIERCE & ELLIOTT 2008).

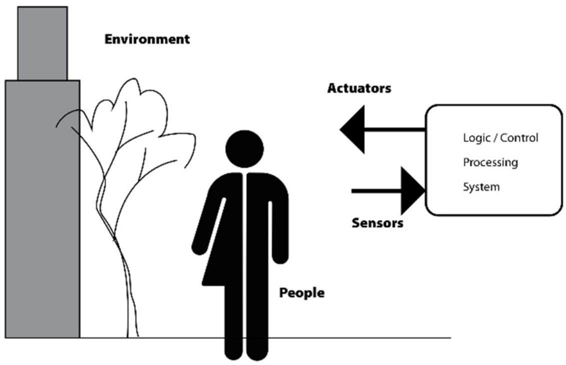


Fig. 1: Basic Sensor-Logic-Actuator system

The pervasive presence of sensors and actuators in all manner of built environments and devices, and of network connections to things, not just computers or smart phones, has led to the term ‘Internet of Things’, or IoT. This development has been supported, perhaps even fueled, by the proliferation of small, inexpensive, do-it-yourself electronics and robotics, based on technologies such as the ‘Arduino’ and ‘Raspberry Pi’ processors – small powerful inexpensive microprocessors that are specially designed to enable interfaces to physical, digital and analog devices, sensors, and actuators. Once the purview only of electronic hobbyists, these devices are now appearing in art, architecture, automotive and industrial design; even in fashion (“wearable computers” embedded in clothing, even shoes, that can sense temperature, activity levels, and other environmental phenomena, as well as more intimate bodily sensing, of heart rate or blood pressure, e. g., and adjust size, shape, coloration, accordingly…).

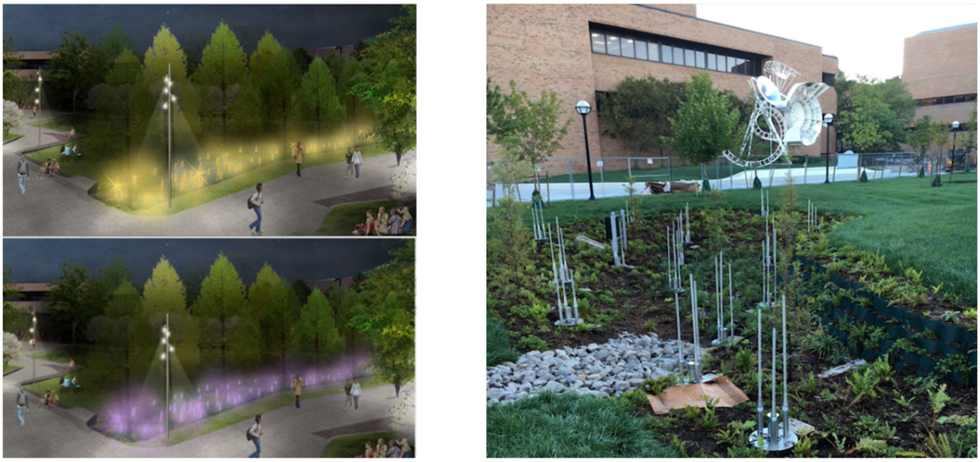
Designing not just the electromechanical functions of such devices, but their human-computer and sensor-actuator interfaces is a distinct field of its own. It is not a stretch to suggest that landscape architects, too, should be involved on this revolution.

8 Responsive Landscapes

Responsive landscapes are those environments that combine sensor networks and actuators to provide interest, beauty, comfort, and engagement for visitors, occupants, users. These sensor networks typically are controlled by some central or distributed set of algorithmic and logical (or perhaps random) controls, that generate the outputs and thereby the perceived sensation(s) of the space. The range of possible responsive landscapes has only begun to be explored, analyzed, and understood (CANTRELL et al. 2016). Some such responsive landscape technologies, such as flood-control, automated irrigation, or pollution monitoring, may be seen as purely instrumental, or utilitarian. Other examples may seem more artistic, or expressive, in their intent.

Landscape Architect Chris Reed, principal of Stoss Landscape Urbanism, describes a recent project for an interactive garden on a university campus, with sensors for light, temperature, and soil moisture levels: "the infiltration garden 'reed lights' (colored LEDs in custom sculptural stainless-steel holders) respond to ambient temperature and to rainwater entering the gardens. The colder the temperature, the more intense the glow. When rainwater enters the gardens, the lights flicker. All are controlled by a weather station sensor in the quad."

This combination of weather sensor, algorithmic control, and colored LEDs visually represent the moisture-temperature combination in the garden, adding an atmospheric aesthetic effect, as well as a kind of conceptual information content to the installation. See Figure 2.



a) b)

Fig. 2: Infiltration Garden (Courtesy of Stoss Landscape Urbanism, used with permission)
a.) concept showing variable colored lighting
b.) installed LEDs and sensory devices

In Melbourne, Australia, the annual "Vivid Light Show is a collaborative and interactive experience for both artists and the public using light, sound and touch as the media. Sound sensors have been used to detect number of people nearby and a vine of mirrors and light gradually opened and closed in proportion to their volume. Others have done the opposite, requiring silence from guests, as the projects were 'shy' " (HABERFIELD).

At the Digital Landscape Architecture (DLA) 2017 Conference in Bernburg, Germany, I presented an 'interactive light tree', consisting of an acrylic frame, covered with computer-addressable LED lights, controlled an Arduino microprocessor and several motion and sound sensors. The lights varied in color, intensity and pattern, from a simple light-green pulsing 'waiting' mode to a dynamic animated rainbow-colored 'excited' mode; the progression from 'waiting' through 'growing', to 'excited' is controlled by an algorithm using sensed sound and motion. This interactive tree, together with a live jazz band, inspired one conference participant to attempt to 'dance' with it (ERVIN). See Figure 3.

Fig. 3: Digital Light Tree (photographs by the author)

9 Sensor-y Landscapes

Mostly landscape designs and sensory gardens up to the present time have been 'all-natural' – using the familiar palette of landform, vegetation and water, etc. Sensors and actuators may be considered as components of 'structure' (or infrastructure) in the landscape, but also may be embedded in the soil, or in water or vegetation, etc. Perhaps a seventh element – combining "sensors, actuators, information networks, and algorithms" – needs to be added to the six-element litany (ERVIN & HASBROUCK 2001) for the twenty-first century.

Sensor-laden – or *'sensor-y'* – landscapes offer the potential of expanded creative and expressive palette for designers, enhanced and ever-more-precise and specific functional performance of landscapes, and a new realm of aesthetic and conceptual engagement for landscape design and city planning. See Figure 4.

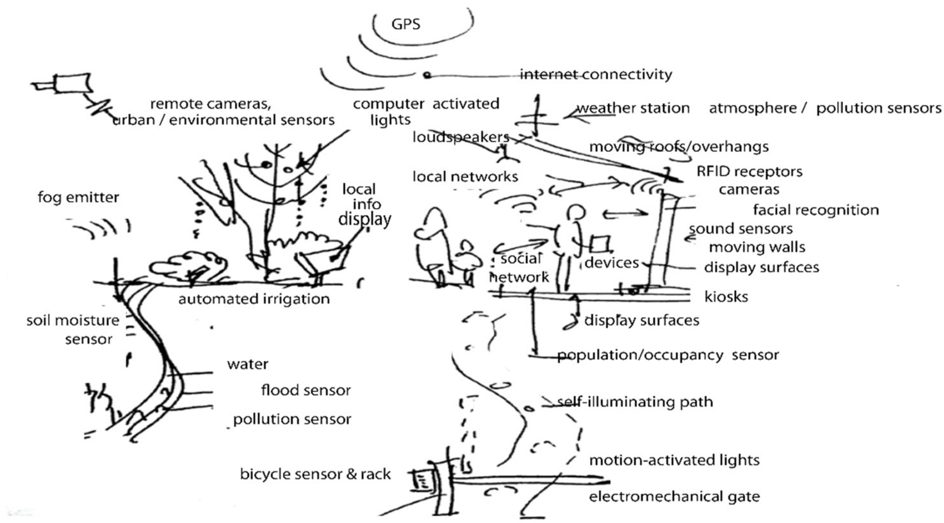


Fig. 4: Illustrative Sensor-y Landscape Schematic

There is obviously an argument and a sentiment that since humans evolved for eons in non-sensor-y landscapes, then naturally those must somehow be the most well-tuned to human experience and health; and a corollary rejection of the insertion of sensors and actuators into landscapes as being harmful, debasing, or irrelevant. At the same time, we know that humans are tool- and technology-using beings, and have flourished at least partly because of that advantage. Hence it is at least worth considering that the landscapes and gardens of the future will not be only 'nature reserves', but can begin to employ an ever-wider panoply of digital and electromechanical means and devices, already at work in other aspects of human civilization and daily life, to generate their effects and achieve their ends: of providing comfort, safety, pleasure, aesthetic and other stimulation, and opportunities for social interaction as well as immersion in nature. Sensors and actuators in interactive cybernetic landscapes may prove, in McLuhan's terms, to truly affect "the whole psychic and social complex."

10 Questions and Conclusions

The development and deployment of sensor-y cybernetic landscapes is just in in its infancy in 2018. Compelling examples are still rare and hard to find, and may seem more like 'landscape art' than 'landscape architecture' *per se*. But it is hard to escape the conclusion that, with the current trajectory of proliferation of sensing and computing devices in every aspect of daily life, and not just for the leisure-class, or the over-privileged few, that these are eminently eligible media for landscape architects to begin to work with and with which to expand the definitions of 'landscape' and 'landscape architecture'. In so doing, there are inevitably be deep questions of appropriateness, agency, and intent.

Some of these include:

> How will humans adapt to changing conceptions and instantiations of landscape – e. g. 'bionic' versus 'all-natural' ones? Will such technological developments only be intrusive and un-welcome? Or will the benefits and stimuli be compelling?
>
> As 'social-networking' increasingly acquires a spatial component, what are the implications on landscape users and groups, behaviors, perceptions…? How can sensor-y landscapes benefit and contribute to social networks?
>
> With programmed and algorithmic control, will sensor-y landscapes have faults, bugs, viruses, and vulnerabilities, much as software does today? If so, what are reasonable measures of precaution and responsible practice? Are there more- and less- fitting or appropriate places, roles, and uses for sensor-y landscapes?

Sensors and actuators in the landscape can be used to provide or augment basic human-needs-oriented services – for purposes of shelter, comfort, community, and engagement; involving aesthetic, intellectual, curiosity-based, and information-motivated pleasures. The basic human senses – primarily of sight, sound, and touch – can be emulated and augmented by electromechanical sensors, and stimulated by electromechanical actuators, such as those enumerated above, in a variety of ways, under computer/algorithmic control. Those algorithms may be purely artistic, didactic, or functional in intent, or more powerfully, involving some combination of all three. While we are unlikely to take the same joys from a 'digital light tree' as we are from a 'majestic oak tree', and it is a mistake to believe the former is ever intended to 'replace' or even 'mimic' the latter; nonetheless there is no denying that the usual palette of landscape designers is already diverse in its scale and character; and that the modern technical information era has brought a set of new human needs, desires, and realities that landscapes must respond to, along with a new set of tools, technologies, and materials for doing so.

Sensor-y landscapes, across all scales and in many environmental and social conditions, hold the promise of dramatically expanding landscape designers' palette of tools and techniques. Just as 'remote sensing' enabled the explosion of small-scale (large-area) landscape planning with detailed information about conditions and changes in the regional and planetary landscape, so 'intimate sensing' can enable an explosion of responsive-environment design, at the larger-scale (smaller sizes: site, human, and even micro- and nano-scales.) Human senses and sensations have long evolved in 'all-natural' landscapes, and so the insertion and emergence of electromechanical and digital components (sensors, actuators, displays, algorithmic controls, et al.) in interactive cybernetic landscapes may be unsettling to and rejected by some, while endlessly fascinating and embraced by others. As with any technology, power and promise come along with potential peril; the design challenge is to maximize the former while minimizing the latter. The proof will be in the creation of sublime sensor-y landscapes!

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