Embedded Sensors in the Landscape: Measuring On-site Plant Stress Factors

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Abstract: This paper investigates the production of low-cost environmental sensors to collect data on environmental factors influencing plant stress in designed landscapes. Parameters measured include soil moisture, humidity, temperature and solar exposure. A prototype sensor is constructed from available components and installed on a trial site in Sydney, Australia. Data received from the prototype sensor is integrated with a Landscape Information Model to provide ongoing post-occupancy feedback. Results indicate that such sensors are straightforward to assemble, and are cost effective. It is suggested that developing familiarity with this and other sensor applications has potential to improve landscape education and practice. Lack of uptake in the landscape professions is, as indicated by the literature, primarily resulting from lack of training and knowledge barriers. An implementation guide is proposed to address this gap.

Keywords: Digital sensor, IoT, embedded, landscape performance

1 Introduction

The use of embedded sensors to provide real-time feedback and collect data enables new possibilities for designed and built landscapes. There has been prior discussion of the implications and potential of the Internet of Things (IoT) technology in landscape architecture (CANTRELL & HOLZMAN 2015, CANTRELL & MEKIES 2018, ERVIN 2018, LOKMAN 2017, MELSOM 2017, SCHLICKMAN 2021). Despite this, our built landscapes have remained low-tech and embedded sensors and data are typically outside the domain of current practice of landscape architects (WALLIS 2016, CHADDERTON 2020). Although embedded sensors are frequently installed as a component of irrigation or building management systems, collected data is rarely available to landscape architects and is not typically used to inform future designs. In this paper we discuss the topics of site-specific data collection and analysis, embedded systems and the relationship between design and data. Specifically, this paper investigates the use of an embedded sensor network to record environmental factors influencing plant stress including moisture, humidity and solar exposure on a trial site in a residential development. By cross-referencing the sensor data with a Landscape Information Model, data can be collected about the specific conditions under which plants are grown and their performance can be analysed over time. The intention of this project is to develop an open-source hardware and software toolkit to enable data collection in landscape architecture practice and education, to help realise improved performance and quality of design and built outcomes.

1.1 Plant Stress Factors

Landscape architects today aim to address large-scale issues including climate change mitigation and adaptation, biodiversity loss, ecosystem stress and environmental issues (ZEUNERT 2017, FLEMING 2019). Changes to temperature and weather patterns over time will lead current

Journal of Digital Landscape Architecture, 7-2022, pp. 114-121. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-724-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537724012.

heuristics for plant selection based on historical performance to be outdated (BOYER 2019). Predicted increase in the frequency and severity of drought conditions forces landscape architects to reconsider the use of plant species that require irrigation. A more rigorous and data-informed approach to site analysis and plant selection may allow adaptation to a changing climate and provide the most sustainable outcomes by growing plant species that require minimal resource inputs in a specified location on site. Within the living media of a landscape, plants are sessile organisms that lack the mobility to relocate to a more suitable environment. When they are placed in an environment that is outside their optimal range, they experience stress. This stress can slow growth, increase susceptibility to disease and eventually cause mortality (LICHTENTHALER 2004, PRASAD 1997, SAVE 2009). This study explores the application of sensors to investigate factors relevant to vegetation health and performance. Embedded sensors installed during landscape construction can provide data which can be used to create more successful and sustainable planting designs.

1.2 Sensors in the Landscape

Previous investigations of embedded landscape sensors can be separated into two major threads: Cyborg Landscapes, in which the experiential sensory qualities of the site are enhanced or explored through interactivity (ERVIN 2018, LOKMAN 2017, CANTRELL & HOLZMAN 2015) and Performative Landscapes, in which site conditions or performance are optimised through data collection (SCHLICKMAN 2021, MELSOM 2017). Despite these explorations, sensor use in practice is still limited. Ultimately, "perhaps the greatest limitation to sensor use in landscape architecture stems from professionals lacking skills, interest, or confidence in using sensor'' (CHADDERTON 2020).

Open-source sensor kits such as Sensebox.de and Smart Citizen aim both to collect and aggregate data, and to educate citizens and professionals in their application (CAMPRODON 2019), however these examples are not targeted at measuring plant stress factors. Similar low cost, low power sensor networks are used in precision agriculture (RAMADAN 2018). Commercially available garden sensors including models by Koubachi, Edyn and Parrot Flower Power are closed source. By providing an open-source solution specifically targeted at landscape architects, our aim is to increase opportunities in education and uptake in practice.

1.3 Objectives

This study seeks to create a template for a prototype sensor network that can be used by landscape architects to collect data on environmental factors linked to plant stress and success on project sites. It hopes to address both an educational gap, and a gap in real-world data on plant performance in built landscapes. The goal is to provide a more robust post occupancy monitoring of plant success and failure with the aim of creating a dataset to inform future designs. Specifically, it asks:

1) What is a useful and appropriate sensor node to monitor plant stress factors, for use in education and practice, that requires minimal specialised equipment, skills and expense for production?
2) How can sensor data be integrated into existing design software packages and linked to vegetation performance in post-occupancy to inform future designs?

2 Methodology

2.1 Overview

This project proposes the development of an open-source hardware and software package for the collection of site-specific sensor data that is useful and relevant to performative landscape architecture. By minimising the cost and skill-set required for the application of this sensor-kit, it may be possible to increase education, utilisation and data collection to inform the next generation of landscapes. The methodology used consists of four parts:

1) A process of sensor selection using a multi-criteria assessment comparing available components to plant stress factor variables.
2) Design development to meet constraints for outdoor sensor installation including weatherproofing, battery life and data collection.
3) Test installation on site and monitoring for a period of one month.
4) Data input into a landscape information model including the plant species and performance observed at each sensor location.

2.2 Sensor Selection to Monitor Plant Stress Factors

Table 1: Sensor Selection Matrix

Parameter	Sensor Options	Temporal variability	Cost	Outcome
Soil Moisture	Capacitive Soil Moisture Sensor	High	Low	Include. Capacitive model offers much greater corrosion resistance than resistive models.
pH	Grove Analog pH sensor	Low	High	Exclude. Requirement for manual operation and high cost.
NPK	NPK sensor	Low	High	Exclude. High cost and low variability over time.
Temperature (air)	DHT22 Temperature and Humidity Sensor	High	Low	Include. High variability and low cost.
Humidity		High	Low	Include. High variability and low cost.
Solar Radiation	UV Wireless sensor	High	Med	Include. High variability and low cost.
Salinity	Ezo-EC	Low	High	Exclude. Manual operation required.
Wind	Adafruit Anemometer	High	High	Exclude. Mechanical complexity and high cost.

Sensor parameters were selected that are most likely to impact plant survival and performance. Key factors identified as affecting stress and survival in plant species are: maximum temperature, minimum temperature, solar radiation, water, salt and wind (AMISSAH 2014, BOYER 2019, GARCIA-NAVARRO 2004). Other key considerations of plant performance in a given location are found in the soil composition. Soil data has not been included in the analysis as the majority of built landscape projects in urban areas utilise a high proportion of imported soil mixes with predetermined composition. In addition, while soil composition is essential to plant performance, it changes at a much slower rate than other environmental parameters such as sunlight, water, temperature and humidity and is therefore less suited to real-time data collection (CHADDERTON 2020). Consequently, this research focuses on non-soil-based factors.

Table 1 above shows an evaluation of environmental variables that could be considered plant stress factors, and the sensors used to monitor their change over time. For these reasons, the following variables were selected for monitoring: soil moisture, temperature, humidity, solar radiation. This is consistent with the recommendations in the literature (RAMADAN 2018).

2.3 Sensor Unit Design Development

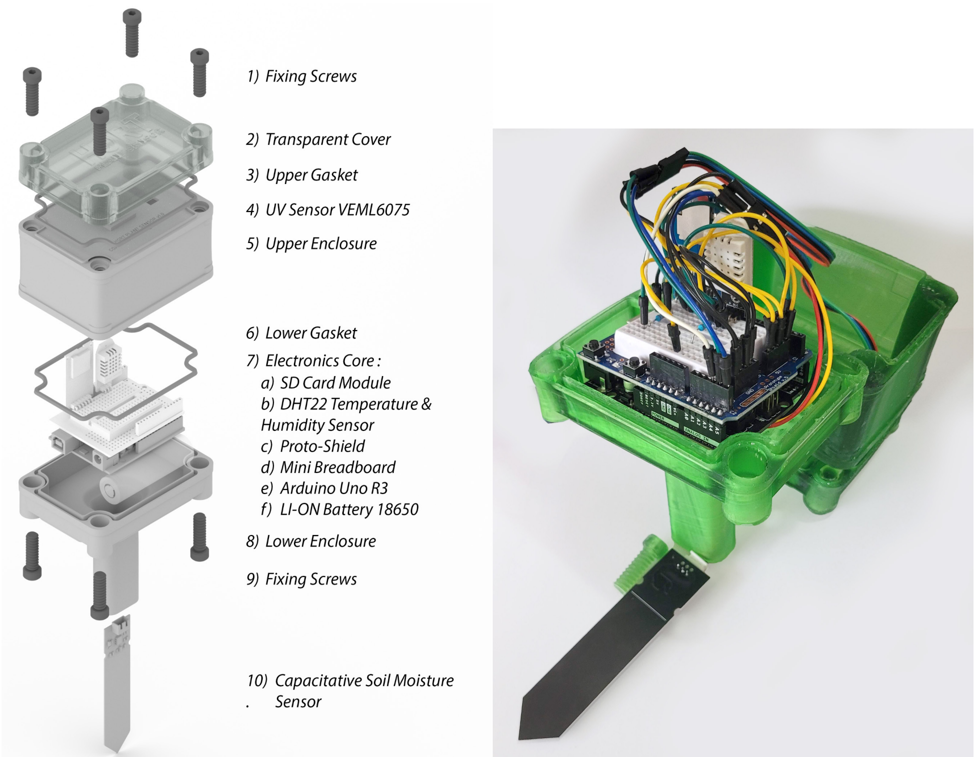

Fig. 1: (Left) Exploded view of Arduino-based sensor modules. (Below) A photo of the completed sensor module before test installation. These figures illustrate the development of the environmental sensor modules installed for the trials.

Sensor modules were constructed using the Arduino Uno platform. This platform was selected due to its widespread use in educational environments and range of support materials available. The module can be constructed by students or professionals with no soldering or prior electronics experience. Prototypes were developed to arrive at a design that met the maximum number of required criteria at the lowest possible cost. Key design considerations included weatherproofing and sensor elevation above soil to prevent ingress of water or contaminants. Battery power was required as wired power will not be available on site. Batteries must last at least as long as the monitoring interval so that they can collect data continuously until replaced. The use of a low-power Arduino library to power sensors only while recording data significantly extends the operation period. Environmental data from soil moisture, temperature, humidity and photographic sensors is recorded on the SD card for manual collection during site inspection.

2.4 Site Installation and Monitoring

Sensors were installed at four locations on a trial site in Sydney with varying aspect, canopy cover and microclimatic conditions. The total area of the site is 5200m2. Sensors were installed directly in ground with care taken to ensure no local obstructions are present to impact sensor readings.

Fig. 2:
Assembled prototype sensor installed at test site location C. Sensors were installed directly in ground and are self-supporting.

2.5 Data Collection on Vegetation Performance & Integration into LIM

Data from the sensors was measured at 30-minute intervals and recorded to an on-board SD card in CSV format, allowing it to be interpreted by a range of software. Data was collected manually from the SD card at 48-hour intervals. A script was developed in Grasshopper to translate the raw sensor data in CSV format into a variety of visual outputs. Locations of each sensor were input into a Landscape Information Model (LIM) and used to generate maps of conditions recorded on site.

3 Results

Table 2 shows a sample of the data recorded from the sensor modules on a test site. In this example, capital letters (A) denote sensor locations shown in the site maps below. Variables are as follows: t – temperature in degrees Celsius, h – relative humidity as a percentage, l – ambient light in lux, sM – Soil moisture as a % of total saturation.

Table 2: Extracted data from environmental sensors on test site

Datetime	t(A)	h(A)	l(A)	Sm(A)	t(B)	h(B)	l(B)	Sm(B)	t(C)	h(C)	l(C)	Sm(C)	t(D)	h(D)	l(D)	Sm(D)
20210203073000	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06
20210203074500	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06
20210203076000	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06
20210203077500	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06	28.7	0.14	310	0.06

A,B,C,D = Sensor Locations

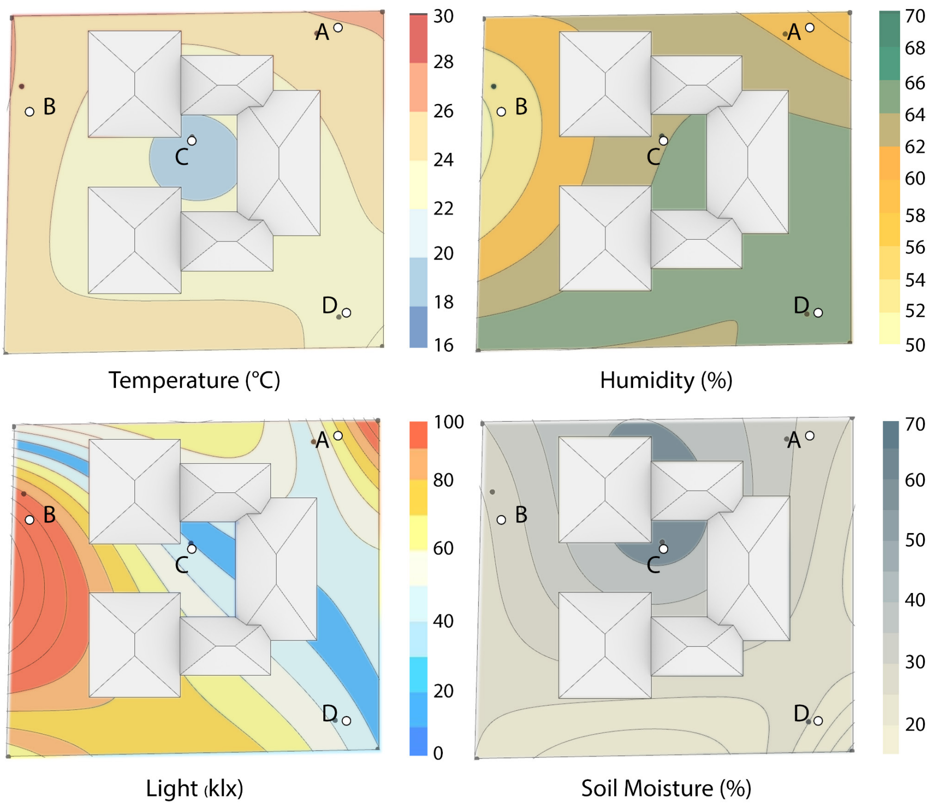

Fig. 3: Environmental Analysis maps of subject site showing average sensor values across a selected 12-hour period during daylight hours

The above data was translated into a series of contour maps of site conditions by overlaying average sensor values onto specified sensor locations in a site model. Values are interpolated between sensor locations. These maps have been coloured manually as a visual aid to interpreting results. Direct visualisation of site data in the LIM allows for analysis of planting success and comparison to simulated environmental studies. This provides an educational interaction with environmental conditions determining plant success and failure on site.

4 Discussion and Conclusion

Initial findings suggest that the method outlined above is a viable approach to collecting data on the environmental factors affecting plant performance in a trial landscape. The sensor design developed is functional and is able to be produced with minimal cost and experience. Future development will investigate alternative arrangements including the use of a single base-station with low-cost extenders. The integration of a solar power module would allow for ongoing operation in remote conditions. Requirement for manual collection of data from the onboard SD card limits the number of sensors in operation. In the future this may be addressed through the use of LoRaWAN network capability. Future development may also include the production of a more specialised PCB design to reduce component cost at scale.

There is a balance between the cost of additional sensor nodes and the resolution of the collected data. A high resolution of sensors would be cost and resource intensive. Alternatively, a single sensor can be moved to multiple locations on a single site, and data aggregated to create a map of conditions. As the cost of electronic components continues to decrease the application of these sensors may increase over time. Access to sensors installed in building management and irrigation systems would provide an alternative route to data collection, however this is not typically available to landscape architects in practice. There are a number of constraints to providing access to data collected under private ownership. Many new urban developments include 'smart city' networks of digital sensors and data collection that generate public datasets. The addition of sensors that track plant stress factors to these networks may improve vegetation performance in the built environment and provide wider access to data.

The interpretation of raw sensor data directly into a landscape information model is a useful tool for education and discussion. These outputs may be compared to predicted results from environmental simulation tools such as Ladybug for validation. The intention is that this would primarily provide feedback on plant success in the site establishment phase over six to twelve months. This feedback would then be used to inform future species selection under similar conditions. A longer period of observation from plant installation onwards would give a more informative assessment of vegetation performance. Further development is required to predict the performance of designed planting schemes against real outcomes. Ultimately, with the addition of embedded sensor networks to our built landscapes, designers may be empowered to take on the role of stewards rather than just initiators.

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