October 2017

Implementing Environmental Indexing and Monitoring at the Technological University of Panama

Galahad Michael Wernsing
Worcester Polytechnic Institute

Melanie Lena Dworak
Worcester Polytechnic Institute

Nicholas Emerson Mears
Worcester Polytechnic Institute

Theodore Bradford MacLeod
Worcester Polytechnic Institute

Follow this and additional works at: https://digitalcommons.wpi.edu/iqp-all

Repository Citation

This Unrestricted is brought to you for free and open access by the Interactive Qualifying Projects at Digital WPI. It has been accepted for inclusion in Interactive Qualifying Projects (All Years) by an authorized administrator of Digital WPI. For more information, please contact digitalwpi@wpi.edu.
Implementing Environmental Indexing and Monitoring at the Technological University of Panama

An Interactive Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
Degree of Bachelor of Science

By:
Melanie Dworak
Theodore MacLeod
Nicholas Mears
Galahad Wernsing

October 11, 2017

Report Submitted to:

Professors Maytee Zambrano, Carlos Medina, Guadalupe Gonzalez, and Ariel A. Grey
Universidad Tecnológica de Panamá

Professors Stephen McCauley and James Chiarelli
Worcester Polytechnic Institute
Abstract

The Technological University of Panama (UTP) is positioning itself as a leader in sustainability in Panama. Our team developed a sustainability reporting plan for UTP that allows comparison to other universities and provides clear steps for improvement on campus. We also prototyped a wireless air quality sensor network as another facet of UTP's environmental reporting. Recommendations include offering general sustainability courses, implementing an expanded air quality monitoring network, and installing resource efficient appliances in the ongoing construction.
Executive Summary

Our sponsor, the Technical University of Panama (UTP), is aiming to be a leader in environmental sustainability. Due to recent campus construction and development, UTP’s community is increasingly concerned with its impact on the local environment. UTP wants to improve their resource use efficiency and reduce emissions from construction and vehicles. In an effort to address these desires, UTP began reporting to the University of Indonesia GreenMetric sustainability indexing system in 2013, but the school’s score was not publicized and had little effect. The goal of our project was to effectively implement an environmental monitoring and indexing system at UTP.

Methods

Our project consisted of four main tasks: implementing a campus sustainability index, developing an air quality test case, surveying the school community on sustainability awareness, and generating recommendations for UTP based on our previous work.

![Figure 1-ES. Four components of methodology](image)

Sustainability Index

Determining a sustainability index for the school was necessary to inform sustainability based decisions at UTP. The index must enable the school to accurately assess their sustainability and rank themselves against other schools. We considered creating the school’s own index, the AASHE Stars index, and the University of Indonesia GreenMetric. We compared how the values are calculated, what each index took into account, and why each index was created.

Air Quality Test Case

Prototyping an air quality monitoring system was an important project component. This prototype was designed to provide our sponsor with hard, real-time data on their environmental influence. The monitoring system used sensor modules developed by Libelium; specifically, the Plug & Sense Smart Environment modules. Five times an hour, these modules took readings of CO, CO₂, NO₂, SO₂, O₃. Each hour, the five data points were averaged together and sent off to UTP’s database. The website could then retrieve the data from the database and put it on display.
After ensuring that the system would carry out these basic functions, factors related to large-scale implementation such as range and battery life were tested. Finally, all of this data was compiled into a technical manual for UTP to use in the future.

**Campus Perspectives**

We conducted a campus wide survey to assess the sustainability knowledge and interest in UTP. The survey had separate faculty and student sections, covering interest in hosting a class and taking a class on sustainability, respectively. The remaining questions covered UTP’s knowledge of their own sustainability and gathered first hand recommendations.

**Recommendations**

After gathering information on possible sustainability indices, the air quality test case, and the school wide survey, we created recommendations based on that data. We compared current and previous data submitted to GreenMetric to identify areas of improvement. Based on the limitations of the prototype sensor network, we examined future methods of expanding the system campus-wide. Finally, using the survey data we suggested methods to spread sustainability knowledge across the school and motivate the population to be more conscious of sustainability.
Findings

Below are our findings gathered after the conclusion of our project. We present the GreenMetric as the best index for adoption, the results from the survey conducted on the campus body, and the effectiveness, or lack of effectiveness, of the modules from the air quality case study.

GreenMetric Score

We found that the UI GreenMetric score would be the best choice for UTP to pursue. This is because UTP has similar climate to the University of Indonesia and has been reporting to the GreenMetric for the best three years. UTP’s 2016 GreenMetric score is 3638/10000, placing it 356th out of 516 institutions. UTP’s best section was Setting and Infrastructure, where they scored 57% of the available points. The two lowest scoring sections were Energy and Climate Change, with 19% of points available; and Water, with 16% of points available.

Sustainability Survey

The survey of the UTP community on their sustainability knowledge provided valuable information. The self-reported student knowledge of campus sustainability was, on average, 2.9 out of 5, with 5 being the most informed. There was also an overwhelmingly positive interest in making UTP sustainable. The average student rated the importance of campus sustainability as 4.6 out of 5, 5 being very important. Students indicated a willingness to learn more about sustainability, on average rating their interest as 3.9 out of 5. This signified a lack of education opportunities and an interest in the subject.

Air Quality Case Study

The air quality case study identified a number of restrictions with the equipment at UTP. First, we discovered our five-year-old hardware had exceeded the two-year shelf life of the sensors, causing errors in setup and data collection. Additionally, the modules could not broadcast the advertised range of 7km, restricting sensor location, and failing batteries limited sensor readings. We were only able to measure a subset of recommended variables with available sensors, and acquisition of new sensors from the same company is expensive compared to a solution built by UTP from commercially available components.

Recommendations

Education and Awareness

We recommend a website as a prime platform to publish information regarding environmental sustainability education to the university, as well as act as a data display for the air quality network that will ultimately be implemented on-campus. Additionally, UTP should make their GreenMetric score and score breakdown more available to the community by
displaying it on the website we have provided. Finally, a poster campaign around UTP’s campus would increase the campus body’s awareness of the GreenMetric system.

While UTP does offer 370 courses related to the environment and sustainability, none of them are available to all students regardless of their major. From the survey, we learned the students have interest in sustainability education, with 33 out of 56 students preferring a full course in sustainability. We recommend that UTP develop an intro to sustainability course that is oriented towards non-environmental engineering majors. The website could also be a hub of sustainability information.

Air Quality Monitoring on Campus

After examining expansion plans, we concluded that 21 sensor modules would need to be installed to complete a full heat map of the campus. UTP could omit some of the harder to reach places in the forested areas of campus, but at least one should be left in a forested area for comparative data from the construction site. If the cost for a heat map is too great, the next best option would be to measure the air quality of varying distances from construction sites in order to analyze how construction is impacting campus air quality.

We recommend monitoring the following air quality variables around campus due to their risk to respiratory and cardiovascular health: particulate matter (PM 2.5 and 10), carbon dioxide (CO₂), carbon monoxide (CO), ozone (O₃), nitrogen dioxide (NO₂) and sulphur dioxide (SO₂). We recommend avoiding the Libelium modules in the future due to their limited shelf life as well as their comparatively steep pricing. We conducted a cost analysis of the Plug & Sense Modules and calculated cost of the Plug & Sense at $3711 per module, while a homemade module would cost about $125. The considerably reduced price does require additional labor to fabricate the modules, but UTP teaches Arduino design so there is no doubt that homemade alternatives would be feasible. Overall, we believe that using homemade Arduino sensor modules would save UTP considerable funds and debugging time.

Sustainability Initiatives to Increase UTPs GreenMetric Score

We highly encourage UTP to continue their use of the GreenMetric indexing system. Given the past use of the index by UTP and the similarities in climate and location between UTP and UI, we believe the GreenMetric is the most suitable fit for the university.

Implementing water efficient toilets and taps in the buildings currently under construction would reduce UTP’s water use at a smaller cost than retrofitting existing buildings. Using water efficient fixtures in the new building could also increase the GreenMetric Water section score by up to 10% of total possible points.

If the UTP employed smart building technology in their new buildings (e.g. self-monitoring air conditioning and light use) the school’s score would rise. Although this would take a lot of labor and planning to implement, UTP’s energy costs would directly go down.
Acknowledgements

We would like to take the time to express our gratitude to the individuals that have made this project possible. Our consultants at UTP, Professors Maytee Zambrano, Carlos Medina, Guadalupe Gonzalez, and Ariel Grey, worked patiently with us through many project iterations and hardware malfunctions. Our project advisors, Professors Stephen McCauley and James Chiarelli, kept us sane and focused on our goals. Antony García Gonzalez kindly shared his office space and expertise with us. Cristela Gaitán aided translation and student outreach efforts. The Universidad Tecnológica de Panamá graciously provided us with the opportunity to complete this IQP. Finally, we would like to thank our families for their support, financial and otherwise, throughout this endeavor.

Authorship

Melanie Dworak, Theodore MacLeod, Nicholas Mears, and Galahad Wernsing all contributed writing and research to this document. Below is a work breakdown.


Theodore MacLeod - Author of the introduction and sections on environmental sustainability in the background. Created citations, table of figures, and table of tables.

Nicholas Mears - Wrote Technical Manual. Author of methods, findings and part of deliverables.

Galahad Wernsing - Acted as section co-editor for the entire paper and wrote the abstract.
# Table of Contents

Introduction ............................................................................................................................................... 1

Background ............................................................................................................................................... 2

Environmental Sustainability .................................................................................................................. 2

Panama City’s Sustainability Challenges ............................................................................................... 2

Sustainability Efforts at the Universidad Tecnológica de Panamá ....................................................... 3

Air Quality Concerns on UTP’s Campus ............................................................................................... 4

University Sustainability Programs ......................................................................................................... 5

Universiti Teknologi Malaysia .............................................................................................................. 6

University Sustainability Indices ........................................................................................................... 6

AASHE STARS Ratings ............................................................................................................................ 7

University of Indonesia GreenMetric ..................................................................................................... 7

Environmental Monitoring ...................................................................................................................... 8

Air Quality Variables ............................................................................................................................... 8

Smart Cities ............................................................................................................................................... 8

Methodology ............................................................................................................................................ 10

Stakeholder Perspectives ......................................................................................................................... 10

Air Quality Case Study ............................................................................................................................. 10

Findings .................................................................................................................................................... 13

UTP Administrative Perspectives ........................................................................................................... 13

UTP Community Survey .......................................................................................................................... 13

Sustainability Knowledge ......................................................................................................................... 14
Table of Figures

Figure 1: Satellite image of Universidad Tecnológica de Panamá.................................3
Figure 2: Elevated Walkway on UTP’s Campus .................................................................4
Figure 3: Cerro Patacon Dump on Fire.................................................................5
Figure 4: A Plug & Sense module mounted with its solar panel.................................11
Figure 5: Meshlium and Plug & Sense Network Model....................................................12
Figure 6: Histogram of fields of study from student responses..................................14
Figure 7: Bar graph of self-reported knowledge on sustainability.................................15
Figure 8: Pie chart of student rankings on least important areas of focus.........................16
Figure 9: Pie chart of student rankings on most important areas of focus.........................16
Figure 10: Pie chart of type of preferred sustainability education.................................17
Figure 11: An example of a possible heat map of campus.............................................19

Table of Tables

Table 1: 2016 UI GreenMetric Rank for the Technical University of Panama.............18
Table 2: Comparative data on the UI GreenMetric for UTP and other universities........19
Table 3: Pros and cons analysis of creating sensors using Arduinos...............................22
Table 4: Cost analysis of using Arduino sensors vs. using Libelium sensors.................
Introduction

Panama City is a vast metropolis with half its population in the city proper and half in the surrounding suburbs (Political-Administrative Division of Panama, 2010). Due to its layout, the province of Panama has a widespread highway system which allows travel between the city outskirts and the city proper. With the constantly expanding infrastructure of Panama City, emissions created by construction (Oka, Suzuki, & Konnya, 1993) and vehicle emissions (Borrego, Martins, Tchepel, Salmim, Monteiro, & Miranda, 2006) threaten air quality. The deterioration of air quality is cause for concern for people living within the city due to the respiratory and cardiovascular hazards these emissions cause. To combat the pollution to both air quality, as well as to reduce greenhouse gas emissions, Panama signed the Paris Climate Accord. This accord established national goals which institutions within the country, including the Technical University of Panama, assist in meeting to improve pollution and sustainability.

Sustainability or sustainable development, a concept defined at the 1980 World Conservation Strategy, is a metaphorical dome that is supported by three pillars: economic, social, and environmental sustainability. The conference defined sustainable development as, “meet[ing] the needs of the present generation without compromising the ability of future generations to meet their own needs” (Moldan, Janoušková, & Háč, 2012). The Technological University of Panama aims to be a role model of environmental sustainability within Central America by becoming one of the first educational institutions in Panama to use air quality and environmental data from their campus to inform and track sustainability improvements.

Our team undertook the development of a campus sustainability framework for Electrical Engineering department outlining steps that the university could take to become more environmentally sustainable. The two following components provide the framework left for UTP to continue the construction of a further reaching campus sustainability model. The first component of the project consisted of further adoption of the GreenMetric, a comparative index specifically suited to the university. This index informed university decision-making towards more environmentally sustainable programs. A case study in the form of a prototype air quality monitoring system provided the university with a basis for future expansion of the campus sustainability index we provided. General sustainability education was advised for all students on campus regardless of field of study. These initiatives will help UTP in furthering their GreenMetric score and their efforts in sustainability.
Background

In this section, we begin with a description of Panama’s geography and demographics. Next, we introduce our sponsor, UTP, and explore how our project fits into its sustainability goals. We then examine a variety of air quality factors and consider variables that similar studies have identified as important. Finally, we conclude with an overview of monitoring systems and their use to sustainability.

Environmental Sustainability

Environmental sustainability is “seek[ing] to improve human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded, in order to prevent harm to humans” (Moldan et al., 2012). Moldan’s narrative is founded on the Earth’s finite amount of space, and therefore finite resources. By limiting growth, a balance in the ecological economic framework of the planet can be maintained. As a result, sustainability is not an end goal, but rather an ongoing effort of monitoring waste output during development. The OECD Environmental Strategy for the First Decade of the 21st Century (Moldan et al., 2012) established four central criteria for environmental sustainability:

- Regeneration, or the responsible use of renewable resources;
- Substitutability, or the efficient use of non-renewable resources whose use is limited so to be easily substituted by renewable resources;
- Assimilation, or the limitation of release of hazardous or damaging waste products so to not exceed the natural assimilative capacity of the environment;
- Avoiding irreversibility, which is the inability to undo damage done to the environment.

These four components constitute the effort of environmental sustainability.

Panama City’s Sustainability Challenges

A driving force for UTP’s campus sustainability initiative is the recent growth of Panama City. Panama’s population and urban development have both grown rapidly in the past 100 years; the average yearly population growth in Panama skyrocketed to 2.1% after the construction of the Panama Canal in 1911. Agriculture and post-World War II trade boosted commercial opportunity and therefore population growth, the latter of which peaked at over double the yearly global average in the early 1960s (World Bank, 2017). Panama’s population and economy have continued to expand faster than the global average in the decades since. Throughout all of this development, there is little evidence of focus on large-scale sustainability. Population increase and construction both negatively impact air quality through direct pollution from construction projects and increased demands on transportation and other human services. There are relatively few published air quality measurements for Panama City to track the effect of the city’s growth on the surrounding environment. UTP, located on the outskirts of Panama
City, faces many of the same pollution concerns as the city proper. As a technical university, UTP is uniquely suited to act as a sustainability leader in the region.

Sustainability Efforts at the Universidad Tecnológica de Panamá

The Technological University of Panama was founded as a state-chartered university, formerly called the Engineering School of the University of Panama. It became an independent institution in 1984 and is currently the second largest university in the country.

UTP’s main campus is situated on 60 hectares (0.6 km²) of largely undeveloped forest as shown in Figure 1. The campus is currently comprised of three buildings, with an additional three under construction. An important concern of the UTP administration is minimizing the campus’ impact on the surrounding forests. The main campus has been constructed to allow large amounts of foot traffic on sidewalks and elevated walkways (Figure 2), minimizing the use of forested land. These efforts are first steps in the pursuit of creating a greener, more sustainable campus.

Figure 1: Satellite image of Universidad Tecnológica de Panamá (Google Maps, 2017)
Air Quality Concerns on UTP’s Campus

The large forested areas of UTP mitigate some air pollution on campus, but UTP’s air quality is still affected by the urban surroundings. The campus is adjacent to a major highway and shopping center and both generate large volumes of vehicle emissions throughout the day. In addition, many students commute to campus using either their own cars or taxis, contributing to spikes in air pollution during rush hour. Air pollution is affected by factors other than traffic; for instance, the ongoing construction projects release particulate matter into the local atmosphere. Located near campus is the Cerro Patacon landfill, an incinerator facility with poor environmental management. The most immediate impact of the landfill is ground-based pollution, such as overflowing wastewater ponds. When the landfill catches fire, it releases large amounts of toxic chemicals (APF, 2013) into the atmosphere, such as nitrogen and sulfur dioxide. The most recent large fire was in 2013; more than 30 acres caught fire across 4 days, and the smoke cloud produced reached as far as Colombia (Campagna, 2013) (see Figure 3).
Universities around the world implement models of environmental sustainability. As leaders in technology and research, universities have an obligation to practice environmental sustainability; they have the resources, personnel, and technological experience required to implement sustainable designs (Kosta, 2017). Universities also serve as a guide to sustainability for younger generations, through education. In the past decade, colleges and universities worldwide have implemented sustainability goals and plans aimed at both maintaining a healthy institution and supporting a worldwide sustainable future. The University of Chicago (U. Chicago, 2017) and the University of Michigan (U. Michigan, 2017) both publish sustainability plans and metrics that are largely centered around environmental concerns. Harvard University (Harvard, 2017) has made efforts to become a leader in on-campus sustainability. Harvard set a number of goals for campus structure by 2020, including major reductions in greenhouse gas emissions, waste per capita, and water usage. In 2016, Harvard met its goal for greenhouse gas emissions and is on track to meet their 2020 deadline for others as well. The state of Massachusetts also published a guide to practices for a more sustainable campus, covering a wide range of topics including bicycle programs and waste management initiatives (Sofer & Potterm, 2008). The University of Ohio has a course on sustainability metrics, which, “addresses the use of metrics, data, and indicators to measure sustainability and track progress” (U. Ohio, 2017). Outside of the United States, universities in Malaysia and Indonesia have produced
sustainability indices in an effort to combat global climate change and pollution. In her book, Sustainable Development Research at Universities in the United Kingdom, Kosta claims that, “universities have been credited with the moral obligation to promote sustainability” (Kosta, 2017) as they provide a platform to train the future generations in sustainability education. Universities are an enclosed society which new societal changes can take place to then later be scaled up to apply to larger society, and possess the freedom to undergo new ideas (Kosta, 2017).

Universiti Teknologi Malaysia

Particularly similar to UTP, the Universiti Teknologi Malaysia (UTM) has made notable strides in environmental sustainability. UTM is a few miles away from Singapore, a large port city comparable to Panama City, and situated in a climate similar to UTP’s. The university reports their sustainability efforts to the University of Indonesia’s GreenMetric and scores in the top 20%.

UTM has conducted significant research into sustainable construction for their climate, which could be useful to UTP as they double the number of buildings on campus. UTM outlined key sustainable construction ideas: “Education and training should incorporate sustainable development concepts,” and, “the development of tools to help in decision making.” (Shafi, Ali, & Othman, 2006). These two qualities should be incorporated in UTP’s plans to improve their sustainability efforts. The first is a quality that UTP impacts as an educational establishment, and the training of their students in sustainable practices will help panama incorporate sustainability into their development. The latter is some of the reasoning behind our air quality test case; the data can be used to monitor the environmental impact of construction. An air quality monitoring system is one of many tools that can be used to determine the sustainability of construction.

UTM also studied efficient ways to deploy a smart monitoring system in their buildings, called Intelligent Building (IB). They focused on balancing comfort and efficiency, specifically in air conditioning. They claim the IB design is, “conducting assessment of user comfort criteria, followed by energy efficient priorities” (Majid, 2012) in order to effectively save on energy. By balancing energy needs and user comfort, the IB reduces energy requirements while effectively managing indoor temperatures.

University Sustainability Indices

Companies, governments, and teaching institutions are all interested in sustainability. As a method of comparison, some organizations publish sustainability guidelines or indices. Our team found a number of general guidelines published by both government and private sector establishments. Specific to colleges and universities, two leading indices are used internationally: The Association for the Advancement of Sustainability in Higher Education’s Sustainability Tracking, Assessment & Rating System and the University of Indonesia’s GreenMetric.
AASHE STARS Ratings

The Association for the Advancement of Sustainability in Higher Education (AASHE) publishes and manages a sustainability guideline for participating universities, the Sustainability Tracking, Assessment & Rating System, or STARS (AASHE, 2017). The STARS system allows comparison between colleges and universities while also adapting scores to each institution’s unique situation. STARS is scored as a percentage of points earned, with points available in the areas of Academics, Engagement, Operations, and Planning & Administration. Participants can also earn up to four percentage points as an Innovation and Leadership bonus in addition to their total score. Of 857 participating institutions, the majority are located in the United States. Participation is voluntary and scores are updated yearly. Updates are provided to AASHE through the efforts of both designated sustainability coordinators and the larger community.

University of Indonesia GreenMetric

The University of Indonesia (UI) developed the GreenMetric sustainability index in 2010 as a regional alternative to the US Green Report Card. The university found the Green Report Card excellent for US climates, but developed a system of their own to specifically suit a university environment and differing climates. UI also found the Green Report Card’s scoring system unsatisfactory, as it utilized a grading system (A to F) rather than a more exhaustive cumulative scoring system. UI wanted their scoring system to allow for quick comparisons on individual criteria as well as the overall score, a trait that would encourage competition between institutions. The GreenMetric generates a score out of 10,000 from six different categories: Setting and Infrastructure (15%), Energy and Climate Change (21%), Waste (18%), Water (10%), Transportation (18%), and Education (18%). In 2016, 516 countries reported to the UI GreenMetric (UI, 2016). While created in Indonesia, the majority of the reports were from Europe (150), followed closely by Asia (109). The index is free to use and relies on self-reported data. Reporters are not required to provide data for all sections on the rubric; however, leaving sections blank can reduce their score.

The Setting and Infrastructure section of the GreenMetric assesses a university’s green environment policy and accounts for 15% of the GreenMetric score. In summary, this section accounts for the size of a campus in area, level of infrastructure, and campus population. A university’s sustainability budget is also taken into consideration.

Energy and Climate Change policy makes up 21% of the GreenMetric score. The aim of this indicator is to audit the energy efficiency of the campus, in technical operation of appliances and functions around campus, and the reduction of superfluous energy consumption. The implementation of Smart Buildings, renewable energy production, and greenhouse gas reduction programs also contribute to this section’s score. A submission of the total carbon footprint from the last 12 months is also requested.

The Waste category is 18% of the GreenMetric score and is largely comprised of recycling and garbage programs. The category is broken into six separate components: a campus recycling program, a toxic waste recycling program, organic waste treatment, inorganic waste treatment, sewage disposal, and campus paper and plastic reduction.

The Water category only accounts for 10% of the GreenMetric score. Its components are water conservation, water recycling, use of water efficient appliances, and treated water reuse.
The overall aim in this category is to encourage reduced net water use around the university campus.

Transportation accounts for 18% of the GreenMetric weight. Its aim is to indirectly decreased carbon emissions from the campus. It takes into account the amount of traffic in and out of the university, bicycles on campus, reduction of private vehicles, and campus transit systems. Reducing the number of people using private methods of transportation is the largest goal of the transportation component.

Education is the newest GreenMetric criterion and is 18% of the GreenMetric score. The goal of this section is to put sustainability education into the curriculum of the university. The score is calculated from the ratio of environmental sustainability conscientious classes offered to total classes offered, funds spent on sustainability curriculum, and the existence of a variety of university-endorsed sustainability literature and events.

**Environmental Monitoring**

UTP was interested in developing a detailed environmental monitoring and indexing system alongside their broader sustainability efforts. They had equipment specifically for monitoring air quality variables and saw these tools as a first step in a general campus monitoring system. Both the air quality monitoring and the broader network need defined variables and measurement techniques to be useful for the UTP community.

**Air Quality Variables**

Gases emitted by construction and burning fossils fuels can negatively impact both human health and the surrounding environment. Panama City’s crowded roadways reveal a heavy reliance on fossil fuel-based transportation, posing a large concern for local air quality. Several gases and particulates impact both health and the environment, making them critical to an air monitoring network. According to the US EPA (EPA, 2014) and the Clean Air Institute (CAI, 2012), a non-profit non-governmental organization which outlines goals for improving global air quality, variables important to local air quality are particulate matter, Ozone, Nitrogen Oxides, Sulphur Oxides and Carbon Oxides. These pollutants are all emitted by vehicle engines and particulate matter specifically is emitted in high volumes by construction work. Poor air quality caused by these pollutants is hazardous to the cardiovascular and pulmonary systems of humans and animals. (See Appendix C for exposure limits).

**Smart Cities**

Another recent development in sustainability is the concept of a “smart city”. Although the term is loose and widely used, the 45th Hawaii International Conference on System Sciences states that, “A smart city denotes an instrumented, interconnected, and intelligent city.” (Chourabi, Gil-Garcia, Pardo, Nam, Mellouli, Scholl, Walker, Nahon, 2012), stressing the use of sensors and networks. The conference also stressed the environmental role of such a system:
“Core to the concept of a smart city is the use of technology to increase sustainability and to better manage natural resources.” (Chourabi et al., 2012).

The smart city idea has been adapted to university campuses as well, mostly surrounding energy consumption and building sustainability. The University of Brescia in northern Italy is a leader in bringing automation and monitoring to their campus. Their smart campus building’s core goal “is to enhance the synergy and thus the performance of the building through the application and the implementation of efficiency measures by different systems working in a network.” (De Angelis, Ciribini, & Paneroni, 2015). The campus smart building successfully reduced energy use by 37.3% compared to the usual building consumption merely by allocating energy more efficiently. Implementing a similar system at UTP would reduce energy costs to the school and pollution from electricity generation.
Methodology

Our project primarily focused on helping UTP organize and improve on-campus sustainability efforts. The key project objective was determining a sustainability index for UTP to follow as a means of self reporting, which required a thorough understanding of the stakeholder perspectives. The secondary focus of our project was a small-scale effort to gather air quality data through a sensor network. This air quality test case allowed us to illustrate the campus’ effect on air quality in real time, and provide the university with an example. Our project investigated the UTP community’s level of sustainability knowledge, and evaluated using a campus-wide survey. Ultimately, a framework for continued sustainability efforts on campus was successfully established, including both a sensor test case and recommendations for broader indexing and educational initiatives.

Stakeholder Perspectives

There were two main stakeholders in our project: UTP administrators and the student body. To ascertain the administrative perspective, we met regularly with our faculty sponsors to communicate project goals and receive suggestions and feedback. One of the main goals of the faculty sponsors was a sustainability index for the university. To develop a sustainability index for UTP, we first researched what sustainability metrics or indices already existed, both for general use and specific to university campuses. We compared the AASHE STARS index to the UI GreenMetric to determine which sustainability index would best suit the university’s needs.

We created a survey to gather perspectives from the broader UTP community. While largely the same in overall structure and content, two versions of the survey were administered: one for faculty with targeted questions about curriculum at the school, and one for students with targeted questions regarding sustainability education (Appendices H and I). The survey was built using Google Forms, allowing for two main distribution methods: a campus-wide email with a link to the survey, and posts on UTP social media sites. Google Forms also includes built-in data processing. We closed the survey after 71 responses.

Air Quality Case Study

On-campus air quality is an important area of sustainability to UTP due to its effects on both human and environmental health. To measure air quality around campus, a prototype sensor network was developed using sponsor-provided hardware. This network would allow for real-time monitoring and reporting of air quality data throughout campus, and it provides an example from which broader lessons about campus sustainability monitoring can be generated.

The cornerstone of the wireless monitoring network was the Waspmote Plug & Sense series of sensor modules developed by Libelium. We used the Smart Environment module, designed to measure air pollutant concentrations and weather-related variables. Each Smart
Environment module can use up to six different sensors (See Appendix A) and has a solar panel attachment that charges the internal battery with sunlight. The Smart Environment module is programmed with code that defines what the device is measuring, how often it is measured, and how the data are relayed to the network router. The sensor modules were mounted outdoors as shown in Figure 4 below.

Figure 4: A Plug & Sense module mounted with its solar panel. (Wernsing, 2017)

The Smart Environment modules can communicate via a number of wireless communication methods, including Bluetooth and ZigBee. We created our network using ZigBee communication, which allows for reliable data transmission from the modules to the Meshlium, a custom router developed by the same company. The Meshlium is the hub of communication in the sensor module network. It receives data from the sensor modules and stores it in a user-chosen database.
Figure 5: *Meshlium and Plug & Sense Network Model (Mears, 2017)*

To properly measure the chosen variables, we first had to configure the Plug & Sense modules. We consulted online documentation and forums for information detailing sensor control and communication with the Meshlium. The Libelium site included an online code generator for basic code which made it easy to both learn the programming libraries and quickly test the modules (see Appendices G and I for more information).

Data collected by the Meshlium needed to be transmitted to a database so that our website could accurately convey the information in real time. The database and website were set up on UTP’s own server and domain. (See Appendix G for information on debugging the database).
Findings

The findings detail the administrative perspectives regarding the air quality monitoring network, the student perspectives from the UTP community survey, technical details from the air quality case study, and implications from UTP further following the UI GreenMetric. After carrying out the survey, developing an air quality test case, and searching for an index that UTP could use to assess and compare their sustainability efforts with other universities, we came to certain conclusions. An index was found and insight on how to improve the score on that index was determined. The survey conducted was very informative into the student body’s knowledge of sustainability as well as their interest in learning more. Lastly the feasibility and effectiveness of an air quality test case was evaluated and presented to our sponsors.

UTP Administrative Perspectives

Our sponsor desired a sustainability index tailored to the environment of UTP. The university also wanted a wireless sensor network, using provided hardware that focused on air quality. Additionally, we determined that a platform for communicating indexing and sensor data to the student body was necessary. A website was defined as a deliverable to address these needs in conjunction with a survey to gauge students’ existing knowledge of, and interest in, sustainability topics. Our sponsor also stated that the index would be used as a presentation point for suggesting policy changes to school administrators. With this in mind, pre-existing sustainability indices were investigated to allow for easy data comparison between UTP and other institutions.

UTP Community Survey

The survey provided insightful information on the student and faculty bodies’ knowledge on sustainability and their interest in learning or teaching more on the subject. The survey was 78.9% student responses, and 21.1% faculty and staff responses, with a wide range of different majors taking it. The survey was sent out by word of mouth, a campus-wide email, and on the UTP students’ Facebook group. A total of 71 responses were gathered and analyzed to make recommendations to the school about student and faculty sustainability knowledge and education. Students from a variety of majors responded to the survey, as shown in Figure 6.
Sustainability Knowledge

The first question of the survey asked: How would you rate your knowledge of sustainability topics? (i.e. air quality, water quality, energy use etc.). This allowed us to measure community knowledge of sustainability topics and awareness of its causes and impacts. On a scale from one to five with one being no knowledge and five being very versed the students averaged a 2.9, indicating a moderate level of knowledge and slightly below average (see Figure 7).
Figure 7: *Bar graph of self-reported knowledge on sustainability (increasing, 5 is highest)*

**UTP’s Level of Sustainability**

Next, the survey analyzed students’ grasp of UTP’s sustainability. A series of questions asked how sustainable or environmentally destructive UTP is, and asked in what area UTP is most sustainable. The responses matched the school’s GreenMetric score, indicating UTP is a bit below average campus sustainability. Students ranked UTP at 2.9 out of 5 for overall sustainability.

The questions on specific areas of sustainability revealed differing thoughts among students. The students identified waste management and electricity use as the two largest areas for improvement, with 71% of students picking one of the two. This matched UTP’s GreenMetric score, the school scored worst in the Energy and Climate Change and Waste Management sections. However, UTP students did not agree on the school’s best area, with nearly a third of students answering “I don’t know”. This reported lack of knowledge suggests an educational program could inform the student body and provide tools to more accurately gauge sustainability.
Figure 8: Pie chart of student rankings on least important areas of focus

Figure 9: Pie chart of student rankings on most important areas of focus
Sustainability Education

Most students are interested in academic courses on sustainability, with an average interest of 4.1 out of 5. 59 percent of students would prefer a full course over a shorter seminar or day class, and only 14% were uninterested in all those options.

![Pie chart of type of preferred sustainability education](image)

Figure 10: *Pie chart of type of preferred sustainability education*

Open Ended Responses

The open ended questions allowed students to input their personal opinion on sustainability at UTP. Many students had ideas similar to our recommendations for sustainability improvements at UTP. Most of the ideas and suggestions dealt with waste management and electricity use. Students commented that the air conditioning in the school is set too cold and not very efficient. One student in particular also commented on smart grid and city technology and recommended UTP work towards introducing these concepts on campus.

On the topic of waste management, students highlighted the lack of recycling in all campus buildings. UTP does not pay for a recycling service so all of their waste goes to the landfill. Some students further recommended organic waste separation so that food waste could be composted.

Faculty Responses

Faculty responses were similar to student responses on overlapping questions. Specific faculty questions included gauging the importance of further sustainability education at UTP and the nature of that education. The faculty responses indicated they value sustainability education with the average importance of 4.5 out of 5. Faculty agreed with students on the preferred type of education: 47% preferred a complete course on sustainability.
UI GreenMetric

Two of the indices specific to colleges and universities are widely used: AASHE STARS and the University of Indonesia GreenMetric. We decided that GreenMetric was better for UTP than STARS for a number of reasons. First, STARS was developed in the USA while GreenMetric was developed in a more tropical climate. Even though STARS is used by universities in tropical climates, it was not developed with tropical climates in mind. Additionally, GreenMetric is more widely used outside of the USA than STARS and can provide a more varied set of comparisons for UTP. Since one of the uses of the index is to compare UTP to other universities, using GreenMetric as UTP’s sustainability index will provide more accurate and more varied comparisons than STARS.

While searching for universities that reported to GreenMetric and are similar to UTP, we discovered that UTP already submitted data to GreenMetric, although their adoption of the index had not affected their policy and was not publicized throughout campus. The lack of publicity on campus decreased the effectiveness of the index.

UTP’s Current GreenMetric Standing

After discovering UTP was already reporting to the GreenMetric, we collected their data from prior years from the UTP administration. UTP has room for improvement, in 2016 they ranked 365th out of 516 reporting universities, with a total score of 3,638 out of 10,000.

Table 1: 2016 UI GreenMetric Rank for the Technical University of Panama

<table>
<thead>
<tr>
<th></th>
<th>Rank</th>
<th>Total</th>
<th>Infrastructure</th>
<th>Energy</th>
<th>Waste</th>
<th>Water</th>
<th>Transportation</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTP</td>
<td>356</td>
<td>3638</td>
<td>856</td>
<td>408</td>
<td>648</td>
<td>155</td>
<td>902</td>
<td>669</td>
</tr>
<tr>
<td>Maximum</td>
<td>516</td>
<td>10000</td>
<td>1500</td>
<td>2100</td>
<td>1800</td>
<td>1000</td>
<td>1800</td>
<td>1800</td>
</tr>
</tbody>
</table>

One of the most important aspects of the UI GreenMetric is easy score comparison. UTP is in the bottom 30% of GreenMetric reporting universities. Its total score of 3638 was less than half of the world leader, UC Davis, which scored 8398 points. UTP’s worst score was in Energy and Climate Change, Waste, and Water sections. In 2016, the top three scoring universities all had perfect scores in Waste; UTP only received about a third of the possible points. The next highest university, the University of Pesci, scored nearly double UTP in the Waste section. U. Pesci almost tripled UTP’s score in their worst section, Water. UTP did particularly well in Campus Setting and Infrastructure, scoring more than half of the possible points and significantly more than U. Pesci.
**Table 2: Comparative data on the UI GreenMetric for UTP and other universities**

<table>
<thead>
<tr>
<th>University</th>
<th>Rank</th>
<th>Total Score</th>
<th>Infrastructure</th>
<th>Energy</th>
<th>Waste</th>
<th>Water</th>
<th>Transportation</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>UC Davis</td>
<td>1</td>
<td>8398</td>
<td>1257</td>
<td>1340</td>
<td>1800</td>
<td>932</td>
<td>1687</td>
<td>1382</td>
</tr>
<tr>
<td>U. Pecsi</td>
<td>355</td>
<td>3640</td>
<td>579</td>
<td>587</td>
<td>1275</td>
<td>425</td>
<td>622</td>
<td>152</td>
</tr>
<tr>
<td>UTP</td>
<td>365</td>
<td>3638</td>
<td>856</td>
<td>408</td>
<td>648</td>
<td>155</td>
<td>902</td>
<td>669</td>
</tr>
<tr>
<td>U. Latvia</td>
<td>512</td>
<td>1603</td>
<td>1339</td>
<td>214</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
</tr>
</tbody>
</table>

![Visual representation of UTP’s 2016 score](image)

**Figure 11: Visual representation of UTP’s 2016 score**

**UTP Report Analysis**

We analyzed prior GreenMetric submissions from UTP and determined which areas could easily be improved, and which ones the school would need to invest in to gain points.

One of the easiest ways to increase score in the education section was to create a website, which we had already prepared for UTP. The website was designed to promote and report sustainability around campus and display our air quality test case data. The GreenMetric points would be achieved by hosting the website we made on UTP’s domain (See Website section in Deliverables), thus making it accessible to the UTP community.

Another area of improvement is the waste management category. Many universities achieve a perfect score in this category. Another IQP in Panama this year worked with UTP to
plan a waste sorting and awareness plan, which will help to increase UTP’s score in the future. They conducted analysis of the school’s current waste management and determined the makeup of their waste by weight. They then determined proper waste sorting procedures and found recyclable exporting companies for UTP to use.

One potential path for improvement involves UTP’s current construction. Implementing sustainable systems from the outset is easier than retrofitting an existing building. The new construction reveals an opportunity to implement a more efficient water system including efficient fixtures and water recycling, both of which are categories within the water section of the GreenMetric.

Air Quality Data

The objective of our work on air quality monitoring was not to create a final system for UTP, but to explore existing capacities and create an easily expandable basis for further work. We only deployed one functional sensor module, but the framework for future development was created so UTP can expand the system to gain insight into air quality variables around campus.

Capabilities of the Sensor Hardware (Plug & Sense)

An important step in creating the sensor network was identifying and documenting the capabilities of the Libelium hardware so that UTP can develop a larger scale system that works within the hardware limitations. The modules are less capable than advertised and difficult to operate consistently.
The transmission range of the modules was tested to be far shorter than stated in Libelium’s technical guide. The ZigBee communication range was advertised as seven kilometers but our own testing determined a maximum range of 100 meters with clear line of sight. This provided module placement constraints because they needed to be within one hundred meters of the Meshlium or another module.

The lifespan of the modules was another factor necessary to quantify. The modules we used were five years old and operated with an obsolete version of the API. They would not consistently run our code and we had to replace the batteries in all of the modules, some of which still had other failures. None of them could enter low power mode, causing power failures when the modules were left on overnight. When the modules ran out of power the code would have to be re-uploaded manually, in spite of the technical manual indicating otherwise. Some of the sensors were not accurate, particularly the carbon monoxide readings. The Libelium website recommends sensors be replaced every three months to two years, depending on usage. Finally, some of the modules did not have functional clocks or had other hardware issues we could not solve. This left us with one fully working module for much of our testing.

It was important to measure how long a module could run on a single charge. We determined that if the module was running at the original data collection rate it would run for about a day and half on one full charge. However, the sensor modules would not become fully charged during the day so we lowered the sampling frequency to increase the effective battery life, potentially through the night. During Panama’s rainy season the sun might not come out for days, which poses a battery level risk to the module running continuously. To avoid re-uploading the code every time they ran out of charge, a larger battery and a larger solar panel would need to be installed.

After much outdoor testing we confirmed the modules are weatherproof and fairly easy to set up. The idea of a modular sensor network is very handy and simple to set up once all of the development has been completed. Hopefully with newer modules the network will be more useful than frustrating. The handling of all of these issues is described in detail in the total debugging process as described in Appendix D.

Data Collection Protocol

The final protocol took five readings from each sensor at the beginning of every hour. It averages all of the data taken into one reading for each sensor and sends it via ZigBee to the Meshlium to be held in the database. The code has a function that works around the low power mode bug specific to the hardware we worked with. We supplied another function designed to work on modules without this issue and set an alarm every hour for the module to wake up.

Custom Sensor Implementation

Another potential expansion option is custom modules based on Arduino microcontrollers and compatible sensors built by UTP. A benefit of this implementation is substantially reduced costs and increased customization opportunities. Wi-Fi would allow the school to connect the modules to their own network, making it more convenient for deployment. Depending on the Arduino model used, it is possible that more than six variables could be measured. Developing an Arduino module would take more time and development than
deploying the Libelium system. The Arduino would need a weatherproof case that allowed gathering of outside air quality data. Additionally, the module would need to be fully assembled, wired, and programmed. These additional tasks are already completed with the Libelium modules.

<table>
<thead>
<tr>
<th>Arduino Pros and Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>● Cheaper</td>
</tr>
<tr>
<td>● Can connect to Wi-Fi</td>
</tr>
<tr>
<td>● Customizable</td>
</tr>
</tbody>
</table>

*Table 3: Pros and cons analysis of creating sensors using Arduinos*

**Cost Analysis of Arduino vs Plug & Sense**

In an effort to inform UTP’s hardware choices for a full air quality monitoring system, the cost per module was calculated and used to estimate costs for developing a campus-wide system. An initial goal of our sponsors was to produce a heat map with our test case. Although we lacked the equipment to accomplish this, we kept this goal in mind as we designed a plan for future expansion.

A heat map would be based on a grid of modules deployed every 100 meters across campus. Twenty-one modules would be required to cover the active campus, approximately 700 meters by 300 meters as shown in Figure 13. The router would be stationed in Edificio 1, at the center of campus (center tile in Figure 13) so no other router would have to be purchased due to the sensor modules ability to daisy chain. Some modules in more remote sections could be omitted due to the difficulty of deploying solar powered equipment in a densely forested area.

![Figure 13: An example of a possible heat map of campus, showing the module’s location. (Google Maps, 2017)](image_url)
The Plug & Sense modules are expensive, so we considered the alternative Arduino system in the cost analysis to compare other prices. The cost of each module was calculated assuming all desired sensors are purchased and disregarding delivery and upkeep costs. The Arduino price does not include wiring, power supply, or weatherproof container in its total.

Table 4: Cost analysis of using Arduino sensors vs. using Libelium sensors

<table>
<thead>
<tr>
<th></th>
<th>Board</th>
<th>CO</th>
<th>CO2</th>
<th>NO2</th>
<th>Temp</th>
<th>PM</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug &amp; Sense</td>
<td>$700</td>
<td>$310</td>
<td>$743</td>
<td>$310</td>
<td>$28</td>
<td>$1,620</td>
<td>$3,711</td>
</tr>
</tbody>
</table>

The Arduino cost would be higher than in table 4 due to wiring, solder board, power supply, and case, but those costs are not likely to exceed $30. It should also be considered that the Plug & Sense sensor attachments have a lifespan of three months to two years, requiring annual maintenance funds. No sensor lifetime documentation exists for the Arduino sensors, but it is likely to only require recalibration and not replacement. If the sensors must be replaced, they are significantly cheaper than the Plug & Sense equivalents.

Without maintenance, the estimated full deployment price of the equipment was calculated by multiplying the module unit price by total required units. The estimated price of the Plug & Sense deployment would be $77,931, while the Arduino system would be approximately $2,600. If maintenance is calculated by assuming that the sensors would last their maximum lifespan, then each Plug & Sense would cost $1,856 a year, while each Arduino would cost only $28.50 a year.
Recommendations

After two months working at UTP we left our sponsors with a few recommendations based on our tests and studies. We had recommendations on fully deploying the monitoring system. Some of the recommendations are on the physical modules and their reliability, others on module placement. Other recommendations were improvements to UTP’s GreenMetric score, based on previous reports and survey results.

Air Quality Monitoring Network Recommendations

The test case we worked with was difficult to set up and we had to document the process for potential users. The modules do not age well, even with little use for five years they fail to work properly and hold at most 10 hours of power in the cloudy Panamanian climate. The modules did not last for more than two days in a row because of the cloud cover that blocked the solar panel. Even if it was cloudy for only half the day, the solar panel still was unable to charge the module to full power. The modules were very unreliable, a possible fix would be to upgrade all of the equipment, but it is very expensive to replace all of the devices using Libelium hardware.

Our team’s final recommendation on the air quality system to UTP was to avoid Libelium sourced hardware and experiment with making their own Arduino monitoring devices, which are significantly cheaper and much more versatile. The price of making an Arduino sensor module equivalent to the Plug & Sense was 40 times less than the Plug & Sense modules. It is also possible to have measurements that include both ozone and particulate matter, which is not possible with current Plug & Sense hardware.

The students and professors in the UTP Electromecanica department have experience programming and wiring Arduinos, meaning minimal time and effort will be needed for them to develop and manufacture the modules. The Arduinos also had the ability to connect to Wi-Fi which solves transmission range limitations of the Plug & Senses through the use of building Wi-Fi relayers.

If UTP continues with the Libelium system, we recommend they read our maintenance manual and place the current modules in a location with good sunlight and easy access. They should try to place the modules in the areas marked in our example heat map (see Figure 13 in the previous section). The areas vary in type of local environment (e.g. by road, by construction, in the forest, etc.) so that the heat map or displayed data represents a variety of UTP environments in order to determine how sustainable that certain area is.

If developing the system further with new Libelium hardware, the school should aim to purchase the newer v15 Smart Environment Pros instead of the currently outdated v12 Smart Environments. The Pro has the ability to measure dust and particulate matter, which the v12 units cannot, and also should have a working low power mode and alarm which allows it to last longer than the current modules.
Recommendations for Improving UTP's GreenMetric Score

The GreenMetric provides a nice structure to encourage sustainability throughout campus due to competition. We determined some areas of their score would be easy to gain points in, through analysis of their past 3 years scores and considering what similar universities did differently than UTP.

The most immediate way UTP could increase their score is by implementing the sustainability website we developed and including it in the proposed educational sustainability website, which is a criterion in the Education category of the GreenMetric. We were able to give them a basis for showcasing their sustainability developments and research, and a display for the air quality test case we created.

Another possible way for UTP to improve their score is to take advantage of the current development of their campus. Three buildings were being built on their main campus at the time of writing. Implementation of sustainable systems is easier in current development than existing parts of campus because items do not need to be replaced, but can be installed from the outset. One of the easiest improvements UTP can implement in these new buildings is water efficient bathroom utilities, such as lower water use toilets and sinks, as well as replacing paper towels with hand driers which are already used in some parts of UTP.

UTP could also improve their score by developing a smart building system to monitor and automatically regulate the electricity use in these new buildings. Intelligent/Smart buildings have their own score in the Energy and Climate Change section of the GreenMetric. They could also attempt to recycle water in these buildings which would increase the water category score in in the GreenMetric.

UTP could also implement a waste management program proposed by another WPI team at UTP (Grande et al., 2017). Their plan included introducing a waste bin that sorts recyclables from other waste. They also designed a sorting center so that they can fully sort their trash sustainably and found companies that would reliably take care of the recyclables instead of taking it all to the Cerro Patacon dump. Finally they started a poster campaign to spread awareness of the initiative.

Another straightforward way to gain points in the GreenMetric is to promote bike traffic on campus, through purchasing more bike racks and a possible bike share program. Additionally, the school could cut down traffic by making public transportation more accessible on campus and encouraging carpools.

Our final recommendation to UTP is based in our survey results. The survey determined that knowledge on sustainability was low to average and that interest in a class on sustainability was high. The survey determined that a complete course was the most common preference on education. We recommend that UTP offer a general sustainability class for all students because a variety of majors answered our survey and the results still indicated general interest in a course on sustainability to be high.
Deliverables

In addition to the recommendations generated above we produced a website for sustainability and air quality reporting, a maintenance manual for how to implement a developed monitoring system, and recommendations for UTP to increase their GreenMetric score and overall campus sustainability.

Website

A website is necessary to communicate two purposes to the UTP community: To display UTP’s GreenMetric score, and act as the data monitoring platform for UTP’s monitoring system. In addition to these two goals, the website will be used as an educational resource for the community.

While our project only provided the framework for the website, it has been developed to the point where completing the website should require minimal programming experience. The only remaining changes necessary to the website are its content, as the technical component is largely complete.

The website homepage should provide an overview of the website’s goals and generally convince the visitors that sustainability, and UTP’s role in it, is important. The GreenMetric section is designed with seven subsections, corresponding to the categories of the GreenMetric:

- Overview
- Setting
- Energy
- Waste
- Water
- Transportation
- Education
- Survey and Recommendations

Each of these sections should include details on what the GreenMetric takes into consideration and explain UTP’s progress in that specific category, in addition to UTP’s current score in that area. The overview will speak specifically about UTP’s overall score.

The air quality section has three subsections:

- Overview
- Air Quality Variables
- Sensor Data

The overview section should explain the relevance of air quality and briefly explain UTP’s current air quality monitoring system. The overview should also prominently display key graphs from sensor data. Air quality variables should cover the variables that are being monitored, their causes, and their effects on human and environmental health. Finally, sensor data should display detailed data received from the sensor network.
Maintenance Manual

To ease future sensor network development and configuration, we developed a maintenance manual. The manual covers Libelium basics in order to eliminate code writing and streamline sensor module configuration. The maintenance manual also contains site-specific instructions on network implementation and website connection. All final code developed by our project is included.

The manual covers all of the bugs and problems encountered while prototyping the system. It could also be used to run the system with new equipment, although it would not be totally accurate in that case due to hardware updates. The code is commented to show both solutions to bugs and code for properly working modules (see Appendix F for maintenance manual).
Conclusion

The Technical University of Panama is in an excellent position to become a leader in sustainability within Panama. Building construction offers an opportunity to increase sustainability across campus. UTP publishing their GreenMetric score will bring awareness to the campus, and create incentives to adhere more closely to the index. The test case provides a technical example to UTP for furthering their measurement and indexing capabilities. Based on the community survey, providing general sustainability education will increase sustainability awareness around campus and directly increase UTP’s GreenMetric score. These efforts in construction and renewed efforts in their utilization of the GreenMetric will put the university on track for an environmentally sustainable future.
Citations and References


EPA, U.S. Environmental Protection Agency (2014, March). AQI, Air Quality Index. Office of Air Quality Planning and Standards, Outreach and Information Division. From


Mears, N., (2017) Data transmission and display model. Originally sourced from Libelium Waspmote Plug & Sense Quick Overview v5.7 (Libelium, 2016).


The Ohio State University (2017). School of Environment and Natural Resources. From https://senr.osu.edu/courses/enr-3900.


Wernsing, G., (2017). *In an attempt to save the trees.*

## Appendices

### Appendix A: Sensor Analysis

<table>
<thead>
<tr>
<th>Port</th>
<th>Variable</th>
<th>Effects</th>
<th>What causes levels to change?</th>
<th>Selected Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Temperature</td>
<td></td>
<td></td>
<td>Temperature</td>
</tr>
<tr>
<td></td>
<td>Carbon Monoxide (CO)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Methane (CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ammonia (NH3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquefied Petroleum Gasses (Ethanol, Isobutene, H2, CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Pollutants 1 (C4H10, CH3CHO2H, H2, CO, CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Pollutants 2 (C8H16CH3, H2S, CH3CHO2H, NH3, H2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alcohol Derivatives (CH3CHO2H, H2, C4H10, CO, CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Humidity</td>
<td></td>
<td></td>
<td>Humidity</td>
</tr>
<tr>
<td>C</td>
<td>Carbon Dioxide (CO2)</td>
<td></td>
<td></td>
<td>CO2</td>
</tr>
<tr>
<td>D</td>
<td>Nitrogen Dioxide (NO2)</td>
<td></td>
<td>esthme, ozone, nutrient pollution, acid rain</td>
<td>NO2</td>
</tr>
<tr>
<td>E</td>
<td>Ozone (O3)</td>
<td></td>
<td>bronchitis; vegetation suffers</td>
<td>Ozone (O3)</td>
</tr>
<tr>
<td></td>
<td>Hydrocarbons (VOC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oxygen (O2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Carbon Monoxide (CO)</td>
<td></td>
<td>heart issues</td>
<td>CO</td>
</tr>
<tr>
<td></td>
<td>Methane (CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ammonia (NH3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquefied Petroleum Gasses (Ethanol, Isobutene, H2, CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Pollutants 1 (C4H10, CH3CHO2H, H2, CO, CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Pollutants 2 (C8H16CH3, H2S, CH3CHO2H, NH3, H2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alcohol Derivatives (CH3CHO2H, H2, C4H10, CO, CH4)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: Equipment Inventory

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
<th>Required</th>
<th>Bin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Environment Module</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Smart Cities Module</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Smart Agriculture Module</td>
<td>4</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Air Pressure Sensor</td>
<td>4</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Carbon Monoxide (CO) Sensor</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Carbon Dioxide (CO2) Sensor</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Nitrogen Dioxide (NO2) Sensor</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Methane (CH4) Sensor</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Dust Sensors</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Oxygen Sensors</td>
<td>4</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Humidity and Temperature Sensor</td>
<td>4</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Solar Radiation</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Soil Temp</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Luminosity LDR</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Soil / Water temp</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Leaf Wetness</td>
<td>4</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Ozone</td>
<td>0</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
PPM: Parts Per Million. The number of particles of a substance in a mixture out of one million particles of the mixture. All values in the chart are in ppm.

OSHA: Occupational Safety and Health Administration. US Government agency that sets workplace regulations.

NIOSH: National Institute for Occupational Safety and Health. US Government agency run by the Centers for Disease Control and Prevention that researches and recommends exposure limits to various chemicals.

ACGIH: American Conference of Governmental Industrial Hygienists. US based non-government group of industrial hygienists which tries to advance worker protections.

HSE: Health and Safety Executive. UK Government agency similar to OSHA.

TWA: Time Weighted Average. Maximum average exposure over a given timeframe. Eight hours unless otherwise stated.

STEL: Short Term Exposure Limit. TWA using a 15 minute timeframe.

Ceiling: Concentration that should not be exceeded.

Note: PM_{2.5} is not listed specifically by any of the regulators in the chart. OSHA limits “Particulates Not Otherwise Regulated (Respirable Fraction)” to 5 mg/m$^3$ of air TWA. Data in chart taken from both OSHA Chemical Sampling Information website and the HSE document EH40/2005, updated in 2013.

Note: PM_{2.5} is not listed specifically by any of the regulators in the chart. OSHA limits “Particulates Not Otherwise Regulated (Respirable Fraction)” to 5 mg/m$^3$ of air TWA. Data in chart taken from both OSHA Chemical Sampling Information website and the HSE document EH40/2005, updated in 2013.
Appendix D: Debugging the Plug & Sense

Sleep and Deep Sleep Power Modes

After working with the Plug & Senses along with the online code generator we noticed that the modules would only run their code once and would then get stuck. Using print statements to the USB we determined that the modules would not wake up after being placed into a low power mode to conserve charge. The only way around this would be to not put it to sleep and use a delay function instead. There were two problems with approaching the problem in this way: The module would use more battery power putting it at risk of running out of power which would reset the clock and the installed source code. The other problem would be that the delay function cannot delay until a chosen time, it can only wait the amount of seconds that it was told, which is not ideal because the modules would take slightly different amounts of time to take the measurements which would cause the modules to go out of sync.

The first problem was unfixable so we had to take some tests to determine the severity of the issue. This was accomplished by using our final source code, but instead of using the sleep function, we used delay for about as long as the modules would take to wait an hour. We determined that by finding the time it took to take all ten readings it took in an hour (about ten and a half minutes) and subtracting that from 60 minutes. We then ran the module from full charge until it was dead and found out that the module runs for about a day and a half without charge. With that in mind we determined that the odds of the module ever running out of power was small enough to ignore because odds were that the module’s solar panel would not be in the dark, unable to generate power for more than a day and a half.

Our solution to the second problem was to just write a function that used the internal clock’s time to set a variable that would express how long the module would delay. This allowed the module to start taking measurements always at the top of the hour so that it would always take measurements every hour.

Identifying Working Sensors

When taking measurements while testing the modules we found that some sensors were taking either the same measurement over and over again, or their measurement was completely out of believable scope. The active life of these sensors, especially the gas sensors are fairly short: three months to two years, so not all of the sensors were working properly or calibrated because of prior use of the modules. In order to find all of the malfunctioning sensors we switched them out and tested them on the Plug & Sense.

Internal Clock and Looping

One problem that most of the sensors had was that they could not run the complete code and would get stuck. This was believed to be some sort of hardware failure and we determined that we could not fix it ourselves. We identified each malfunctioning module by running test code provided by Libelium and seeing if it would do what Libelium described it would do. After running it on all of the tested modules we determined that only one of the modules could
correctly execute the source code which inhibited our ability to gather more data from this network.

**Identifying the Range of the Network**

A final issue we encountered before setting up the sensors in their respective places was that in preliminary tests the Meshlium received no frames from the Plug & Sense modules when we took them to the other side of the building than it. We determined it was a broadcast range error because the modules were still outputting frames through USB to the laptop. To test the distance we had the Plug & Senses send a frame every ten seconds to the Meshlium and we walked with the modules until the Meshlium did not receive the frame. Indoors the range of the module’s transmission was limited to about 150 feet, while outdoors it hit about 200 feet. We discovered that at a higher elevation and with clear line of sight, the modules broadcasted the most consistently. This diminished the range that we could set up the modules from the Meshlium. The Meshlium could still get data from farther away than that because of the module’s “daisy-chaining” ability to use each other to relay frames back to the Meshlium.

**Database Debugging**

The MySQL database needed to be able to take the data from the router. We had to set up a single table in the database to hold all of the entries from the modules. In order to do that we had to develop a user for the database unique to the Meshlium router so that it could log in with ease because Meshlium does not handle special characters e.g. (@, #, $, %, &,*). After allowing the Meshlium to put all of the data into the database, we had to pull it out to display on the website. To do this we used PHP to extract the data from the database and sort it because of PHP’s easy integration into HTML. The Meshlium stores all of its data as a character string and that is how it was stored on the Meshlium, therefore in the PHP program we had to also convert it to numbers by extracting the information out of the string. From there the raw data could be used in the website.
Appendix E: EPA Air Quality Index

<table>
<thead>
<tr>
<th>O₃ ppb</th>
<th>O₃ ppb</th>
<th>PM₁₀ µg/m³</th>
<th>PM₂⋅₅ µg/m³</th>
<th>CO ppm</th>
<th>SO₂ ppb</th>
<th>NO₂ ppb</th>
<th>AQI</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cᵢₜₐₜ - Cᵢₚₜₐₜ (avg)</td>
<td>Cᵢₜₐₜ - Cᵢₚₜₐₜ (avg)</td>
<td>Cᵢₜₐₜ - Cᵢₚₜₐₜ (avg)</td>
<td>Cᵢₜₐₜ - Cᵢₚₜₐₜ (avg)</td>
<td>Cᵢₜₐₜ - Cᵢₚₜₐₜ (avg)</td>
<td>Cᵢₜₐₜ - Cᵢₚₜₐₜ (avg)</td>
<td>Cᵢₜₐₜ - Cᵢₚₜₐₜ (avg)</td>
<td>Iᵢₜₐₜ - Iᵢₚₜₐₜ</td>
<td>Category</td>
</tr>
<tr>
<td>0-54 (8-hr)</td>
<td>-</td>
<td>0.0-12.0 (24-hr)</td>
<td>0-54 (24-hr)</td>
<td>0.0-4.4 (8-hr)</td>
<td>0-35 (1-hr)</td>
<td>0-53 (1-hr)</td>
<td>0-50</td>
<td>Good</td>
</tr>
<tr>
<td>55-70 (8-hr)</td>
<td>-</td>
<td>12.1-35.4 (24-hr)</td>
<td>55-154 (24-hr)</td>
<td>4.5-9.4 (8-hr)</td>
<td>36-75 (1-hr)</td>
<td>54-100 (1-hr)</td>
<td>51-100</td>
<td>Moderate</td>
</tr>
<tr>
<td>71-85 (8-hr)</td>
<td>125-164 (1-hr)</td>
<td>35.5-55.4 (24-hr)</td>
<td>155-254 (24-hr)</td>
<td>9.5-12.4 (8-hr)</td>
<td>76-185 (1-hr)</td>
<td>101-360 (1-hr)</td>
<td>101-150</td>
<td>Unhealthy for Sensitive Groups</td>
</tr>
<tr>
<td>86-105 (8-hr)</td>
<td>165-204 (1-hr)</td>
<td>55.5-150.4 (24-hr)</td>
<td>255-354 (24-hr)</td>
<td>12.5-15.4 (8-hr)</td>
<td>186-304 (1-hr)</td>
<td>361-649 (1-hr)</td>
<td>151-200</td>
<td>Unhealthy</td>
</tr>
<tr>
<td>106-200 (8-hr)</td>
<td>205-404 (1-hr)</td>
<td>150.5-250.4 (24-hr)</td>
<td>355-424 (24-hr)</td>
<td>15.5-30.4 (8-hr)</td>
<td>305-604 (24-hr)</td>
<td>650-1249 (1-hr)</td>
<td>201-300</td>
<td>Very Unhealthy</td>
</tr>
<tr>
<td>-</td>
<td>405-504 (1-hr)</td>
<td>250.5-350.4 (24-hr)</td>
<td>425-504 (24-hr)</td>
<td>30.5-40.4 (8-hr)</td>
<td>605-804 (24-hr)</td>
<td>1250-1649 (1-hr)</td>
<td>301-400</td>
<td>Hazardous</td>
</tr>
<tr>
<td>-</td>
<td>505-604 (1-hr)</td>
<td>350.5-500.4 (24-hr)</td>
<td>505-604 (24-hr)</td>
<td>40.5-50.4 (8-hr)</td>
<td>805-1004 (24-hr)</td>
<td>1650-2049 (1-hr)</td>
<td>401-500</td>
<td></td>
</tr>
</tbody>
</table>
\[
I = \frac{I_{\text{high}} - I_{\text{low}}}{C_{\text{high}} - C_{\text{low}}} (C - C_{\text{low}}) + I_{\text{low}}
\]

where:

- \(I\) = the (Air Quality) index,
- \(C\) = the pollutant concentration,
- \(C_{\text{low}}\) = the concentration breakpoint that is \(\leq C\),
- \(C_{\text{high}}\) = the concentration breakpoint that is \(\geq C\),
- \(I_{\text{low}}\) = the index breakpoint corresponding to \(C_{\text{low}}\),
- \(I_{\text{high}}\) = the index breakpoint corresponding to \(C_{\text{high}}\).
Appendix F: Maintenance Manual

UTP Libelium Network Technical Manual

Setting up the Network

The network was made with Libelium’s weatherproof Plug & Sense modules that connect to a Meshlium router, which is configured to send data to UTP’s MySQL database. This manual was made to aid in further expanding the network, making it easy to set up and run the modules so they are compatible with the existing network.

Equipment and Software

A couple items that need order to expand the network.

If the network is expanded within the range of a pre-existing network area (about 100 meters from meshlium router or Plug & Sense module), these items must be acquired.

- A Plug & Sense Module from Libelium
- The Libelium IDE compatible with the model of Plug & Sense acquired
- Mounting equipment (usually supplied with Plug & Sense)
- Solar panel or other power source
- Temperature, CO, NO, and CO sensors
- Zigbee 2.4Ghz communication module

If the network is to be expanded in a new area not in range of another network, then a meshlium router must also be purchased.

Choosing Appropriate Software

The IDE required depends on what model of Plug & Sense will be used. At the time of writing, different versions of the Wasp mote API exist for v12 and v15 hardware revisions. If the version is unknown it can be determined by the sticker at the bottom of the module, as shown below.
After the hardware version is identified the IDE can be downloaded from the development websites be found here:


Plug & Sense IDE

Code can be uploaded into the modules once the IDE is downloaded. The IDE is based on the Arduino IDE which makes it simple for people who have used Arduino or C++ to code these modules. No C++ or Arduino knowledge is necessary to implement these into the pre-existing network though, all code necessary is provided at the end of this manual.

The basic functions of the IDE can be seen in the image below. It is important to know how to upload and see test results in order to make sure the module is operating correctly.
To upload code you must first put the code in the IDE text space. Then you have to compile and upload; the upload button will do both. If the code prints anything out of the USB it will appear in the serial window which is opened with the button in the top right. All system information and errors from the module appear in the bottom output window; common errors and their fixes will be explained later.

The module must be adequately charged and on to properly upload code. The button next to the USB and power sockets is the power button; if the button is pushed in it is on, and if it is not, then it is off. The LED around the button is software controlled and does not always indicate the state of the module.
Connecting to the Network
In order to add modules to the current network they must be set up exactly as the rest of the modules, including placing the correct sensors in the appropriate sockets.

Sensor Placement
Libelium’s sensors are only designed for some sockets so proper placement is key to have the modules perform correctly. There are 6 sockets for sensors on the module, sockets A to F. The image below shows the respective sockets.

The sensors used are temperature, CO₂, NO₂, and CO which go in sockets A, C, D, and F respectively. If not all sensors are available the code provided for the network will have to be altered to handle the lack of sensors.
Connection Range

An important aspect of placing these sensors is transmission range. Unfortunately, it is not as long as advertised by Libelium. Prior tests at UTP showed the Zigbee communication only reaches about 100 meters with clear line of sight. The modules can use each other to relay messages, so chaining the modules together is a possible way to reach the Meshlium router. If the area that you want to set modules up in is too far from the pre-existing Meshlium position, then another Meshlium will have to be set up within range of the module area to communicate to the database (see Meshlium Section).

Source Code

The source code was made for this specific network. There are some options that you can change in the Plug & Sense code that will still allow for data to be sent and processed correctly in the database and website. Parts of this code are a workaround to the sleep function, because the modules used had hardware malfunctions that prevented leaving a sleep state. To use the sleep function to decrease power usage, remove comments towards the very end of the code. Remember to change the name of each module; they must all have a unique node ID to be processed properly by the database and website. The MAC address needs to be changed if connecting to a different Meshlium than the original one located in UTP’s main campus Edificio 1. The most important thing to keep in mind if editing the code is that the string that it sends to the Meshlium must not be modified, because the website uses a string parser to gather the data from the database which may not work with a different string format. The code can be found at the end of the manual.

Meshlium

This section is only important if setting up a new Meshlium. The set-up is easy, but important things to note before messing around with it are:

- The only way to turn the Meshlium off is by logging into it and shutting down
  - If unplugged without shutting down properly the Meshlium can be damaged
- The default username and password is “root” and “Libelium”
- Data can be seen in Sensor Network->Capturer
- It must be connected to the internet to send data to the database

To setup the connection to the database you must first get the username and password to the database from UTP’s network administrators; there is one unique to the Meshlium network. All data to connect to the database is found in Sensor Network->Capturer->External Database. The database and table used is “dbgitts” and “zigbeeData” respectively.

Regular Maintenance

There is very little to do after the sensors are setup, but some situations will need attention after the sensors are set up. They are not very difficult and only two real possibilities will need attention after setup.

Sensor Maintenance
The sensors on the modules have a short lifespan and may need to be replaced every three months to two years depending on their level of use. The air quality sensors (e.g. CO₂, NO₂, CO) have the shortest lifespan. The temperature sensor lasts longer than the others but still may need to be replaced eventually. To determine if a sensor is not working properly examine the data that it takes and look for outlier readings, or if it reports the same value repeatedly with no change. The sensors commonly reported 3.29 as their value repeatedly when they weren’t working. Upkeep on these sensors is important to report accurate data.

Handling Low Power

The modules are programmed to make it through the night, but cloudy days and poor placement can cause shut-down due to power failures. The problem with the modules running out of power is that they will not report their data after they turn back on, so the only way to get them to run again is to manually upload the code over USB.

Network Deployment

For full deployment of the sensor network for a potential heatmap, sensor placement is important. With the modules’ difficulty in communicating farther than one hundred meters the suggested placement is a three by seven grid across campus so that each module covers a 10000m² area for measurement. Some areas can be omitted because of a lack of sunlight due to tree cover or difficulty placing the module. The school should try to cover at least one of each of the local environments of their campus (e.g. road area, tree area, building area etc.) Some specific places to try to measure would be the rotunda in the front of campus where all school traffic crosses through, and the archaeology site. Full deployment of a heatmap like this may get expensive as well so an alternative module system may have to be used to allow for this.

Figure 5: Possible heat map of campus
The Source Code:

```c
#include <WaspSensorGas_v20.h>
#include <WaspXBeeZB.h>

//This is the frequency, default is set to 5
//***********************************************************************
#define iterator 5
//***********************************************************************

char CONNECTOR_A[3] = "CA";
char CONNECTOR_B[3] = "CB";
char CONNECTOR_C[3] = "CC";
char CONNECTOR_D[3] = "CD";
char CONNECTOR_E[3] = "CE";
char CONNECTOR_F[3] = "CF";

long sequenceNumber = 0;

//NEED TO INPUT UNIQUE ID FOR EACH MODULE
//********************************************************************************
char nodeID[10] = "ENV1";
//********************************************************************************

//MUST CHANGE MACADDRESS IF NOT ORIGINAL MESHLIUM
//********************************************************************************
char* macAddress = "0013a20040900478";
//********************************************************************************

long waitTime;

int alarmHour = 1;
int alarmDay = 0;
char* sleepTime = "00:01:00:00";

char data[100];

unsigned long epoch;
```
float connectorAFloatValue[iterator];
float connectorCFloatValue[iterator];
float connectorDFloatValue[iterator];
float connectorFFloatValue[iterator];
float connectorAMeanValue;
float connectorCMeanValue;
float connectorDMeanValue;
float connectorFMeanValue;
char connectorAString[10];
char connectorCString[10];
char connectorDString[10];
char connectorFString[10];
packetXBee* packet;

/**
 * @brief A function used to find the mean of an array
 * @param array the array that holds the data to be averaged
 * @return the mean of the array
 */
float mean(float* array){
    int i;
    float sum = 0;
    for(i = 0; i < iterator; i++){
        sum += array[i];
    }
    return sum/iterator;
}

/**
 * @brief A function that increments a string used for the alarm in the RTC
 */
void incrementAlarm(){
    //Always increments the hour
    alarmHour++;
    //If it has gone through an entire day
if(alarmHour == 24){
  alarmDay++;
  alarmHour = 0;
}

//String formatting
if(alarmDay<10){
  if(alarmHour<10){
    sprintf(sleepTime, "0%i:0%i:00:00", alarmDay, alarmHour);
  }else{
    sprintf(sleepTime, "0%i:%i:00:00", alarmDay, alarmHour);
  }
}else{
  if(alarmHour<10){
    sprintf(sleepTime, "%i:0%i:00:00", alarmDay, alarmHour);
  }else{
    sprintf(sleepTime, "%i:%i:00:00", alarmDay, alarmHour);
  }
}
}

/**
 * @brief autoregulates the delay time based on the internal RTC
 * this is just if the PWR.sleep still messes up the clock
 */

void getDelay(){
  int currentSecond, currentMinute, currentHour, currentDay;
  int seconds = 60 - RTC.second;
  int minutes = 60 - RTC.minute;
  waitTime = seconds*1000 + minutes*60000;
}

void setup() {
  USB.ON();
  USB.println(F("ENV1 Initialized...\n"));
  //Turning on Zigbee 3g
  xbeeZB.ON();
  USB.println(F("ZB On"));
  //Allocating memory for transmission message
  packet=(packetXBee*) calloc(1,sizeof(packetXBee));
USB.println(F("assigning message memory"));

//Sending message
packet->mode = UNICAST;
USB.println(F("Setting mode to Unicast"));
xbeeZB.setDestinationParams( packet, macAddress, "ENV1 connected to Meshlium\n\r\n");
USB.println(F("setting destination"));
xbeeZB.sendXBee(packet);
USB.println(F("Sent frame"));

//Clearing memory
free(packet);
packet=NULL;
USB.println(F("freeing memory"));
xbeeZB.OFF();
USB.println(F("ZB Off"));

//Starting the clock
RTC.ON();//ENV3 stops working here
USB.println(F("RTC on"));
delay(1000);
USB.println(F("End Setup"));
USB.OFF();

}

void loop() {

  //Turn sensors on
  SensorGasv20.ON();
delay(10000);
  //The loop to take multiple readings and find the mean
  //Takes ~1 minute per reading
  int i;
  for(i = 0; i < iterator; i++){
    //Turning on NO2 Sensor
    SensorGasv20.setSensorMode(SENS_ON, SENS_SOCKET3B);
delay(300000);
    SensorGasv20.configureSensor(SENS_SOCKET4CO, 1, 100);
    //First dummy reading for analog-to-digital converter channel selection
    SensorGasv20.readValue(SENS_TEMPERATURE);
    //Sensor temperature reading
    connectorAFloatValue[i] = SensorGasv20.readValue(SENS_TEMPERATURE);
    //First dummy reading for analog-to-digital converter channel selection

//Configure and turn on the CO2 sensor
SensorGasv20.configureSensor(SENS_CO2, 7);
SensorGasv20.setSensorMode(SENS_ON, SENS_CO2);
delay(30000);
//First dummy reading to set analog-to-digital channel
SensorGasv20.readValue(SENS_CO2);
connectorCFloatValue[i] = SensorGasv20.readValue(SENS_CO2);
SensorGasv20.setSensorMode(SENS_OFF, SENS_CO2);
// Configuring NO2 sensor
SensorGasv20.configureSensor(SENS_SOCKET3B, 1, 2);
delay(10);
//First dummy reading to set analog-to-digital channel
SensorGasv20.readValue(SENS_SOCKET3B);
connectorDFloatValue[i] = SensorGasv20.readValue(SENS_SOCKET3B);
//First dummy reading to set analog-to-digital channel
SensorGasv20.readValue(SENS_SOCKET4A);
connectorFFloatValue[i] = SensorGasv20.readValue(SENS_SOCKET4CO);
// Step 11. Turn off the sensors
SensorGasv20.setSensorMode(SENS_OFF, SENS_SOCKET3B);
//USB Debugging
USB.ON();
USB.print(RTC.getTime());
USB.print(F("", Reading#: "));
USB.println(i+1);
Utils.float2String(connectorAFloatValue[i], connectorAString, 2);
Utils.float2String(connectorCFloatValue[i], connectorCString, 2);
Utils.float2String(connectorDFloatValue[i], connectorDString, 2);
Utils.float2String(connectorFFloatValue[i], connectorFString, 2);
sprintf(data,"I:%s#N:%li#%s:%s#%s:%s#%s:%s#%s:\n", 
    nodeID ,
    sequenceNumber, 
    CONNECTOR_A , connectorAString, 
    CONNECTOR_C , connectorCString, 
    CONNECTOR_D , connectorDString, 
    CONNECTOR_F , connectorFString);
USB.println(data);
USB.OFF();
}

connectorAMeanValue = mean(connectorAFloatValue);
connectorCMeanValue = mean(connectorCFloatValue);
connectorDMeanValue = mean(connectorDFloatValue);
connectorFMeanValue = mean(connectorFFloatValue);

Utils.float2String(connectorAMeanValue, connectorAString, 2);
Utils.float2String(connectorCMeanValue, connectorCString, 2);
Utils.float2String(connectorDMeanValue, connectorDString, 2);
Utils.float2String(connectorFMeanValue, connectorFString, 2);

// Step 12. Message composition
// Data payload composition
sprintf(data, "I:%s#N:%li#%s:%s#%s:%s#%s:%s\n\n",
    nodeID ,
    sequenceNumber,
    CONNECTOR_A , connectorAString,
    CONNECTOR_C , connectorCString,
    CONNECTOR_D , connectorDString,
    CONNECTOR_F , connectorFString);

// Memory allocation
packet=(packetXBee*) calloc(1,sizeof(packetXBee));
// Choose transmission mode: UNICAST or BROADCAST
packet->mode=UNICAST;
// Set destination XBee parameters to packet
xbeeZB.setDestinationParams(packet, macAddress, data);
// Communication module to ON
xbeeZB.ON();
delay(10000);
// Message transmission
xbeeZB.sendXBee(packet);
USB.ON();
USB.println(RTC.getTime());
USB.println(data);
USB.OFF();
// Free variables
free(packet);
packet=NULL;
// Communication module to OFF
xbeeZB.OFF();
sequenceNumber++;
// This is used if it's sleep mode works
/*RTC.setAlarm1(sleepTime, RTC_ABSOLUTE, RTC_ALM1_MODE2);
// Entering Sleep Mode
PWR.sleep(ALL_OFF);
// Alarm handling
if(intFlag & RTC_INT ){
    intFlag &= ~(RTC_INT);
    USB.ON();
    USB.println(RTC.getTime());
    USB.OFF();
    incrementAlarm();
}*/

// This is the workaround to the sleep mode
getDelay();
delay(waitTime);
Appendix G: GreenMetric Questionnaire

### Setting and Infrastructure

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Año 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Type of higher education institution</td>
<td>2 (Specialized higher education institution)</td>
</tr>
<tr>
<td>1.2</td>
<td>Climate</td>
<td>1 (Tropical)</td>
</tr>
<tr>
<td>1.3</td>
<td>Number of campus sites</td>
<td>6 (Campus)</td>
</tr>
<tr>
<td>1.4</td>
<td>Main campus setting</td>
<td>6 (Urban)</td>
</tr>
<tr>
<td>1.5</td>
<td>Total campus area (m²)</td>
<td>649,801</td>
</tr>
<tr>
<td>1.6</td>
<td>Total main campus ground floor area of building (meter square)</td>
<td>14,393,29</td>
</tr>
<tr>
<td>1.7</td>
<td>Total main campus buildings area (m²)</td>
<td>45,574,20</td>
</tr>
<tr>
<td>1.8</td>
<td>Total main campus smart building area (m²)</td>
<td>0</td>
</tr>
<tr>
<td>1.9</td>
<td>Total parking area (m²)</td>
<td>16,000</td>
</tr>
<tr>
<td>1.10</td>
<td>Total area on campus covered in vegetation in the form of forest (percentage)</td>
<td>37.9%</td>
</tr>
<tr>
<td>1.11</td>
<td>Total area on campus covered in planted vegetation</td>
<td>25%</td>
</tr>
<tr>
<td>1.12</td>
<td>Total area on retentive surfaces on campus for water absorption besides forest and planted vegetation</td>
<td>33%</td>
</tr>
<tr>
<td>1.13</td>
<td>Total number of students</td>
<td>22,273</td>
</tr>
<tr>
<td>1.14</td>
<td>Total number of academic and administrative staff</td>
<td>3,524</td>
</tr>
<tr>
<td>1.15</td>
<td>University budget for sustainability efforts</td>
<td>0,51%</td>
</tr>
</tbody>
</table>

### Energy and Climate Change

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Año 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Energy efficient appliance usage are replacing conventional appliances</td>
<td>6 (80%-100%)</td>
</tr>
<tr>
<td>2.2</td>
<td>Smart building implementation</td>
<td>1 (None)</td>
</tr>
<tr>
<td>2.3</td>
<td>Renewable energy produce inside campus</td>
<td>1 (None)</td>
</tr>
<tr>
<td>2.4</td>
<td>Energy intensity per year / (kWh per square meter)</td>
<td>16,023,399</td>
</tr>
<tr>
<td>2.5</td>
<td>Ratio of renewable energy produce/production towards total energy usage per year</td>
<td>1 (None)</td>
</tr>
<tr>
<td>2.6</td>
<td>Elements of green building implementation as reflected in all construction and renovation policy</td>
<td>2 (None)</td>
</tr>
<tr>
<td>2.7</td>
<td>Green house gas emissions reduction program</td>
<td>0 (None)</td>
</tr>
<tr>
<td>2.8</td>
<td>Percent of total buildings carbon footprint (CO2 emissions in the last 12 months in metric tons)</td>
<td>6,192</td>
</tr>
</tbody>
</table>

### Waste

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Progam to reduce the use of paper and plastic on campus</td>
</tr>
<tr>
<td>3.2</td>
<td>Recycling program for university waste</td>
</tr>
<tr>
<td>3.3</td>
<td>Toxic waste handling</td>
</tr>
<tr>
<td>3.4</td>
<td>Organic waste treatment</td>
</tr>
<tr>
<td>3.5</td>
<td>Inorganic waste treatment</td>
</tr>
<tr>
<td>3.6</td>
<td>Sewage disposal</td>
</tr>
</tbody>
</table>

### Water

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Water conservation programs implementation</td>
</tr>
<tr>
<td>4.2</td>
<td>Water reusing program implementation</td>
</tr>
<tr>
<td>4.3</td>
<td>The use of water efficient appliances (water tap, toilet flush, etc)</td>
</tr>
<tr>
<td>4.4</td>
<td>Treated water consumed</td>
</tr>
</tbody>
</table>

### Transportation

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Number of cars owned by your university</td>
</tr>
<tr>
<td>5.2</td>
<td>Number of cars entering university daily</td>
</tr>
<tr>
<td>5.3</td>
<td>Number of motorcycles entering the university daily</td>
</tr>
<tr>
<td>5.4</td>
<td>Number of campus bus operated in your university</td>
</tr>
<tr>
<td>5.5</td>
<td>Average passengers of each shuttle bus</td>
</tr>
<tr>
<td>5.6</td>
<td>Total trips for shuttle bus service each day</td>
</tr>
<tr>
<td>5.7</td>
<td>Number of bicycles that are found on campus on an average day</td>
</tr>
<tr>
<td>5.8</td>
<td>Parking area type</td>
</tr>
<tr>
<td>5.9</td>
<td>Parking area reduction for private vehicles within 3 years</td>
</tr>
<tr>
<td>5.10</td>
<td>Initiatives to decrease private vehicles on campus</td>
</tr>
<tr>
<td>5.11</td>
<td>Campus shuttle service</td>
</tr>
<tr>
<td>5.12</td>
<td>Bicycle and pedestrian policy on campus</td>
</tr>
<tr>
<td>5.13</td>
<td>The approximate travel distance of a vehicle each day inside campus only (in kilometers)</td>
</tr>
</tbody>
</table>

### Education

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Number of courses relative to environment and sustainability offered</td>
</tr>
<tr>
<td>6.2</td>
<td>Total number of courses offered</td>
</tr>
<tr>
<td>6.3</td>
<td>Total research funds dedicated to environment and sustainability offered</td>
</tr>
<tr>
<td>6.4</td>
<td>Total number of courses offered</td>
</tr>
<tr>
<td>6.5</td>
<td>Number of scholarship programs on an environment and sustainability published</td>
</tr>
<tr>
<td>6.6</td>
<td>Number of scholarly events related to environment and sustainability</td>
</tr>
<tr>
<td>6.7</td>
<td>Number of student organizations related to environment and sustainability</td>
</tr>
<tr>
<td>6.8</td>
<td>Existence of university-run sustainability website</td>
</tr>
</tbody>
</table>
Appendix H: UTP Campus Body Survey (English)

Thoughts on Campus Sustainability
Questions about the impact of air quality on health

Xx User id
1. Are you a student or faculty member of UTP?
   ☐ Student
   ☐ Faculty
   ☐ Other

Survey Eligibility Check
2. How old are you?
   ☐ Less than 18
   ☐ 18 to 24
   ☐ 25 to 34
   ☐ 35 or more

Student Information
3. Year of study?
   ☐ 1
   ☐ 2
   ☐ 3
   ☐ 4
   ☐ 5 or more

4. Form of study?
   ☐ Full time
   ☐ Part time
   ☐ Distance learning

Thoughts on Campus Sustainability (Student)
As a part of UTP, what are your thoughts on air quality sustainability?

Thoughts on Campus Sustainability (Faculty)
As a part of UTP, what are your thoughts on a campus with sustainability effect?

10. In which area do you think UTP is the most sustainable?
   ☐ Electricity usage
   ☐ Water usage
   ☐ Food waste usage
   ☐ Waste management
   ☐ Environmental pollutants
   ☐ I don’t know

11. How interested would you be in taking courses on environmental sustainability at UTP?
   ☐ Not interested
   ☐ Somewhat interested
   ☐ Very interested

12. What type of sustainability education are you most likely to participate in?
   ☐ A SUST course
   ☐ A student seminar
   ☐ A single lecture
   ☐ I am not interested in taking a course or sustainability at UTP
   ☐ Other

13. Would you be interested in seeing statistics on UTP’s sustainability?
   ☐ Yes
   ☐ No
   ☐ Maybe

14. Do you have any opinions or suggestions on improving UTP’s sustainability?

Stop filling out this form.

Faculty information
Appendix I: UTP Campus Body Survey (Spanish)

Sus reflexiones sobre la sostenibilidad de la UTP

1. ¿Es estudiante, docente o administrativo?
   - Estudiante
   - Docente
   - Administrativo
   - Otra

2. Verificación de elegibilidad de la encuesta
   - Valoración de la encuesta
   - Desplazamiento a la siguiente pregunta

3. Información del estudiante
   - Número de estudiantes
   - 1
   - 2
   - 3
   - 4
   - 5
   - Otro

Preguntas sobre sostenibilidad

8. ¿Cómo valorarías tu situación en términos de sostenibilidad? (Por ejemplo, calidad del aire, consumo de energía, desperdicio, etc.)
   - 1
   - 2
   - 3
   - 4
   - 5
   - 6
   - 7
   - 8
   - 9
   - 10

9. ¿Qué tipo de impacto tiene el campus UTP en el medio ambiente local?
   - Importante
   - Moderado
   - Menos importante

10. ¿Cómo impacta la Universidad de Producción y Tecnología de la UTP (UTP) en el medio ambiente local?
    - 1
    - 2
    - 3
    - 4
    - 5
Appendix J: Cost Analysis

The cost of the Libelium devices and sensors were based on their 2017 catalog that can only be obtained by emailing the company with interest to purchase. The prices may not be completely accurate because Libelium does offer bulk deals for their products so the entire cost for the full network may be a little bit inflated than an actual offer. The arduino sensors are just preliminary searches for them on the internet. The only definite price was from the arduino. Here are all of the parts needed for the alternate Arduino module.

- Arduino Uno (wifi)
- Shinyei PPD42 Particulate Matter Detector
- MQ-2 Gas Sensor
- MQ-9 Gas Sensor
- MiCS-2714 Gas Sensor
- Keyes DHT11 Temperature and Humidity Sensor