Introduction
The concept of sustainability connects economic, social and environmental concerns to influence decisions that have the potential to improve the quality of life for all generations. In recent years, many cities and universities have become proactive proponents of sustainability and have developed plans and goals to incorporate the concepts of sustainability into their operations, planning, and management practices. In order to track progress toward achieving sustainability goals, many of these institutions employ metrics and indicators.

Challenges within many programs, however, arise from the complexity of collecting, monitoring, and reporting performance information of institutions. Another major challenge is connecting individual behavior to overall campus performance. Therefore, performance information should be collected at spatial and temporal scales fine enough to reflect individual behavior, can also be aggregated to coarser scales to show overall campus performance.

The most sophisticated system currently used to track indicators is Itron, a centralized, web-based system that tracks energy and water usage for campus buildings. Although the Itron system has helped reduce campus energy use and associated costs, many buildings are not currently connected to the system. In addition, the campus uses Itron primarily for managing energy use on campus, not for reporting purposes.

Goals and Approach
Our research and analysis outlines the design, testing, and use of a data organization system that links the flow of energy, water, and materials through campus using sustainability indicators at more detailed spatial and temporal scales than previously available. We present a prototype of a campus-based Environmental Sustainability Management System (ESMS). The project’s client and the ultimate user of the ESMS is the Sustainability Program at UCSB.

Figure 1: UCSB Campus Map and Building Types

The University of California, Santa Barbara (UCSB) recently created a Sustainability Program; the University is also developing a Campus Sustainability Plan (CSP) consisting of goals and related indicators to track sustainability in nine sectors: Built Environment, Sustainable Energy and Water, Academic and Research, Communications, Grounds, Procurement, Food, Transportation, and Waste. The CSP identifies a total of 41 sustainability indicators.

Due to the recent creation of the CSP, many of the CSP indicators are not currently monitored and tracked. Current UCSB sustainability reporting only includes campus-wide annual totals relating to only a few sustainability performance indicators. This reporting does not provide data for specific buildings, or for smaller time intervals.
Our project’s scope was limited to the main UCSB campus, outlined in Figure 1. In addition, we limited much of our analysis to the performance of campus buildings. Figure 1 also reveals the current building classification scheme used by Facilities Management, which we followed in our analysis and in the testing of the ESMS. We adhere to the use of English units to conform to the indicators as defined in the CSP.

To design the prototype ESMS, we:
• Investigated the campus monitoring needs and available data;
• Gathered and formatted relevant sustainability indicator data at smaller spatial and temporal scales;
• Organized the data in a Microsoft Access database and Geographic Information System shapefiles;
• Tested the ESMS by analyzing 3 specific environmental indicators.

Data Collection and Database Design
The data gathering process revealed that sustainability performance information on campus is inconsistent, decentralized, and often incomplete. We began by collecting campus object data to create a map of the campus. The relevant data included both spatial and non-spatial campus information, with a focus on campus building information, such as building types (Admin, Heavy Research, and Light Research), square footage, and space usage.

In order to prove the usefulness of the ESMS, we chose a subset of indicators to include in the ESMS prototype. Indicators were normalized by square footage on the assumption that flows are proportional to building size. The chosen indicators were:
• Electricity usage per square foot
• Potable water usage per square foot
• Solid Waste (trash and recycling) generated per square foot

With input from the Client, these indicators were chosen based on the priorities of the Sustainability Program at UCSB. They are limited to environmental performance of campus buildings. However, additional sustainability indicators may be added to the ESMS prototype in the future.

Gathering relevant data revealed the following technical and political barriers:
• Data were decentralized, with sources ranging from the Campus Planning Office to Facilities Management to specific academic departments.
• Data were inconsistent in their temporal and spatial scales creating discrepancies in interpreting and analyzing the data.
• Electricity and water data are based on measurements from analog meters, which may create inaccuracies and large variability among data.

Figure 2 below shows the data categories that were incorporated into the database, based on the information we collected about campus buildings and the three indicators chosen for this project.

Indicator Analysis
The authors utilized the database to analyze the three indicators.

Electricity
We gathered electricity usage data for 35 campus buildings. The median daily electricity usage was calculated from the daily electricity data for each building and multiplied by the appropriate number of days to calculate monthly electricity usages. Summing these revealed an annual electricity usage for each building. We found that Heavy Research buildings used the most electricity annually while Admin buildings used the least. Electricity usage varied within each building type with a few buildings registering far below or far above the median annual electricity usage for the building type (Figure 3).
The spatial analysis of electricity usage revealed that electricity-intensive Heavy Research buildings are concentrated in the northwestern corner of campus. Furthermore, the southern and western areas of campus generally lack buildings with electricity data available on Itron (See Figure 4.)

Specific analysis limitations for electricity include data variability due to metering type and data availability. Furthermore, the annual electricity usages of non-state-funded buildings were extrapolated from the December 2006 bill; thus, it was not possible to analyze seasonal electricity usage fluctuations for these buildings.

**Water**

The water data had the most variability and required the most alteration, including removing negative water usage values. The water data was also the most limited, with data available for only 3 buildings. Similar to the electricity analysis, we calculated a median daily water usage for each building using the daily water usage data. This median was then used to calculate an annual water usage for the 3 buildings, which conveniently reflected the three main building types. Similar to the electricity analysis, we found that Heavy Research buildings use the most water while Light Research buildings use the least. The spatial analysis of the water usage reveals a general lack of campus data.

We also formed a water usage time trend from the monthly water usage values that we calculated. This time trend revealed many large usage fluctuations (Figure 5), which could be due to imprecise water metering methods, seasonal behavioral changes, or water-intensive experiments.

The annual water usage values were also extrapolated to reveal an estimated total campus water usage and compared to the actual main campus potable water usage of 2006. The comparison revealed that we can not account for 78.9 million gallons of potable water, which is due to inadequate monitoring of water usage for campus buildings and landscape irrigation.

**Waste**

Waste data came from waste audits which measured the daily solid waste generation and included amounts (in pounds) of trash, defined as non-recyclables plus improperly sorted recyclables, and properly sorted
recyclables. Waste audit data was available for 7 campus buildings. We used the daily waste value for one Heavy Research building and the average daily waste values for Admin and Light Research buildings to calculate the estimated monthly waste value for each building type. This showed that Admin buildings create the most amount of waste while Light Research buildings have the highest amount of properly sorted recyclables.

Figure 6: Breakdown of Trash and Recycling Disposal per Square Foot

The monthly waste values were then multiplied and added to calculate a campus waste generation value, which we compared to the actual campus waste generation value from annual billing statements. The actual recycling amount is larger than the estimated recycling amount, which may be due to recycling of construction waste. Furthermore, large differences in actual and estimated campus waste and recycling amounts may be due to the omission of outdoor waste receptacles in our analysis (due to a lack of data for outdoor bins).

Conclusions and Recommendations
Campus managers and decision makers can use the database and ESMS prototype to identify buildings with poor electricity, water and/or waste performance and that may qualify for building retrofits or sustainable operations training.

Additionally, the authors of this report recommend the following actions:

Tracking and Monitoring
- Create a campus-wide data tracking system that includes methods to consistently and reliably obtain data, such as
  - Installing volume-measuring electricity and water meters
  - Connecting all major buildings to Itron
  - Creating an ongoing schedule for building waste audits and include outdoor waste receptacles
- Develop and implement a comprehensive and central data storage system, such as the ESMS.

Management
- Identify buildings that have potential to achieve higher sustainability performance based on normalized indicator data by building type.
- Reconsider the building classification scheme, especially for Administrative buildings.

Education
- Improve methods for sharing and disseminating information, including ESMS utilization, data sharing and collaboration systems, outreach programs, and possible interactive web-based kiosks.

Suggested further investigations include experiments to better understand how to foster more sustainable individual behavior. One option is the use of energy budgets based on building or department electricity usage. The campus could also establish baseline measurements related to campus indicators and could add analytical capabilities to the ESMS to evaluate policy or technological options.

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