Developing an Energy Spatial Map for the University of Virginia's Living Link Lab

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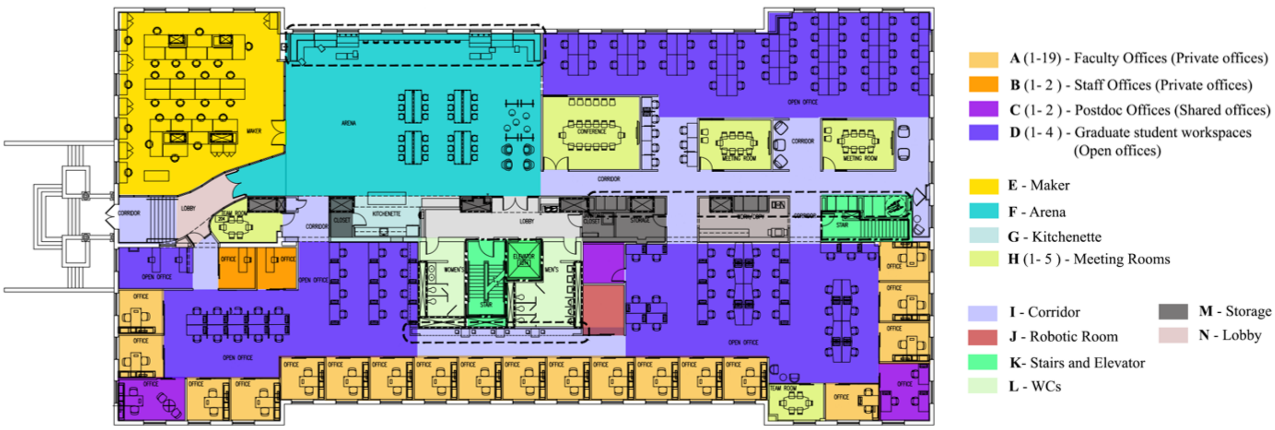

Figure 1: Floor plan of the Link Lab with labeled occupant spaces [2]

Abstract

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Keywords

Insert, In, This, Format

1 Introduction

The Link Lab is a University of Virginia (UVA) multidisciplinary, cyber-physical systems research lab that opened in January 2018. Since its opening, the lab has supported novel research ranging from robotics and autonomous vehicles to smart and connected health [1]. Moreover, the lab space has been utilized in a research platform called the Living Link Lab (LLL). The LLL is a cyber-physical system that enables sensing of occupants and the environment, allows reproducible studies on human-building interaction, and aims to promote sustainability [4]. The laboratory is a 17,000-square-foot area equipped with a multitude of sensors that monitor environmental characteristics, including temperature, humidity, noise level, electricity consumption, and air quality. The sensors are spread across the entire lab to collect data in shared work areas and single occupancy spaces used by more than 100 occupants. A diagram of the Link Lab is shown above in Figure 1. The LLL's sensing infrastructure allows for the monitoring of occupants' states, along with human behavior. It can be used for energy optimization and sustainability studies or to gain insights into occupant health, comfort, and productivity. A main goal of the Living Link Lab was to collect longitudinal data of the space over time. This allows connections to be made between how people interact with the environment and vice versa over different time frames and during different events. To make this kind of analysis possible, all of the data gathered is stored on InfluxDB, an open-source database platform that specializes in the storage and retrieval of time series data [3].

2 Problem Statement

Despite the availability of large amounts of building energy data, there lacks an approachable method to interact with the data. Data is often gathered from meters or individual sensors and stored as complex time-series values with the potential for multiple readings every second. The vast amount of data, combined with the presence of outliers and the lack of intuitive visualization tools, makes it challenging for non-technical users to meaningfully draw any conclusions from the data. Consequently, there is a need for an

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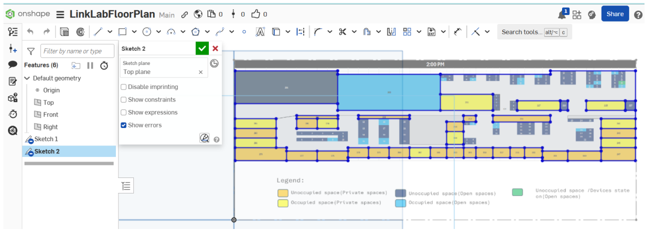

Figure 2: Process of creating the CAD drawing file of the floor plan given an uploaded background image

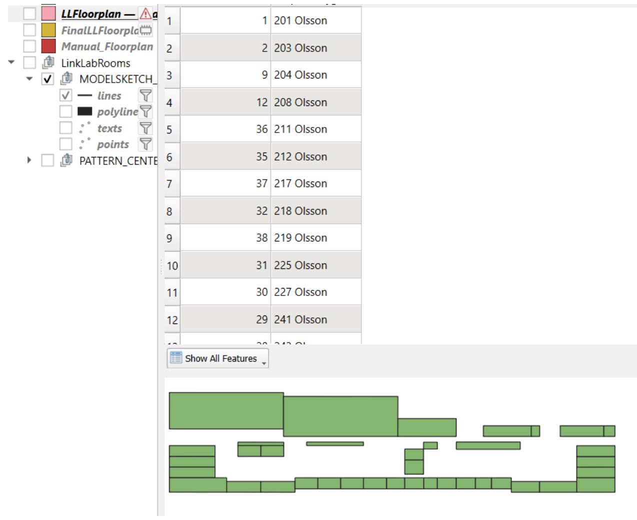

Figure 3: This image demonstrates how QGIS was used to define each closed shape from the CAD drawing as a polygon, which was then labeled with its corresponding Room ID

interactive system that can map and visualize this energy data in a way that integrates spatial, temporal, and behavioral dimensions (i.e. how the space is used).

3 Motivation

Understanding how energy is consumed within indoor spaces is essential for promoting sustainable practices, optimizing building function and operation, and enhancing occupant comfort. However, there remains a lack of *accessible and meaningful* energy data for general building occupants to make informed decisions about their spaces. A floor-plan-based visualization tool could give autonomy to occupants, managers, and owners to make these decisions, bridging the gap between raw sensor output and intuitive human understanding. For example, a tool could help users visualize lighting and HVAC energy use patterns, see how the outdoor environment impacts energy use, and preemptively estimate daily energy use to best prepare the system. The development of a visualization tool furthers the LLL's goal of being a testbed for cyber-physical systems research with a particular focus on fostering human-building interaction and contributing towards sustainable development.

4 Methodology

First, the InfluxDB for the Link Learning Lab was connected to VS Code (Python) using a secure connection. Only sensors that collected kWh energy data in the Link Lab were selected for analysis. A list of relevant room numbers was compiled so that a 2D floor map could be produced accurately and appropriately labeled.

When collecting data, it was decided to aggregate sensor data by location (room number) and not by device ID. An initial sum of data by room number produced a result with a 400% faster runtime and produced results equal to those obtained when sensor data was summed based on device ID. Data was aggregated weekly from 01/01/2022 until 09/31/2025. Data exploration was conducted on all available data which ranged back to September 2020. However, too many null values existed to make energy mapping meaningful. 2022 was chosen as the start date since data availability was much greater; missing values will be imputed, which will be discussed in a later section. A temporal resolution of a week was chosen as it would produce enough data points to show meaningful trends over time while also not producing so many that analysis is slow. Any increase in the temporal resolution would cause the resultant CSV to require exponentially more storage.

Based on the parameters chosen above, the total energy usage of the room was found per week. A CSV file was created to organize the data and allow for future integration into a 2D floor plan of the space. A CSV file type was chosen as its universality would allow for seamless integration between the data set and the floor plan. CSV files can be constantly written over, which eliminates the need to rewrite code whenever an updated analysis is desired. Next, a Computer-Aided Design (CAD) software was used to make a diagram of the floor plan that could be exported to a .dxf file. This was done by importing an image of the Link Lab floor plan [2], and drafting the perimeter of the lab and rooms that were equipped to track energy use (kWh). Figure 2 shows the process of outlining the necessary room features for the CAD drawing file.

While the drawing file was a crucial step to create a format that Python would be able to understand and map, the floor plan had to be converted to a GeoPackage (.gpkg) file. The spatial map is ultimately created using a geospatial library called GeoPandas, which is not built to read drawing file formats. Instead, the file must be changed into a more structured format that can define the spatial relationships between different objects, or in this case, rooms. To convert the .dxf into a .gpkg file, a free and open-source application called Quantum GIS (QGIS) that specializes in spatial visualization was used [5]. Using QGIS, the drawing file can be imported, and the lines that were used to define the various rooms of the lab in CAD can be labeled as different polygons with a corresponding Room ID (Figure 3). It is critical to note that the name assigned to each closed polygon in QGIS must match the variable name used to identify the rooms in the CSV file. If these names do not match up, the code will not be able to correlate the energy value from the CSV file to the correct spatial location on the visual map.

Once an accurate floor plan was created, and could be read by GeoPandas it was able to be referenced alongside the CSV file. The spatial map and CSV file could be cross-referenced based on the shared parameter, room number, and the final spatial map was created using the GeoPandas function in Python. Data values were represented by the use of a continuous color gradient with low

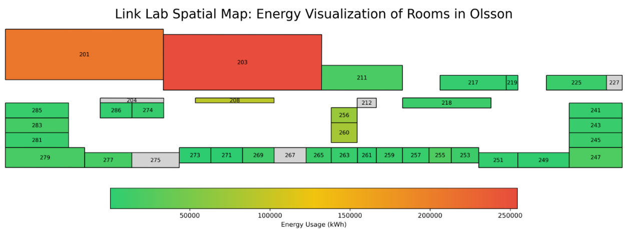

Figure 4: Spatial Map of Energy Usage in the Link Learning Lab

energy values (kWh) being represented in green and high energy values (kWh) being represented in red (Figure 4). Currently, the sensor data is being summed over a specified week, but in future iterations, an average value over a given time period will be more appropriate. These changes will be shown in the results sections, but all of the necessary code automating the data visualization from a CSV file is functioning.

5 Results

INSERT LATER

6 Discussion

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Acknowledgments

INSERT ACKNOWLEDGMENTS

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