Prospectus

Deep Learning Based Predictions for Smart Buildings
(Technical Topic)

Actor-network Theory analysis of the Amsterdam Smart City
(STS Topic)

By

Danny Nguyen

11/1/20

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: Danny Nguyen

Approved: ______________________________________ Date ________________________
Ben Laugelli, Department of Engineering and Society

Approved: ______________________________________ Date ________________________
Haiying Shen, Department of Computer Science

Introduction

Smart buildings, buildings equipped with the physical and software infrastructure to control the building's HVAC (heating, ventilation, and air conditioning) system and other systems automatically, have become increasingly popular due to the improved working environment provided to the occupants and the associated energy efficiency benefits ("What is a Smart Building?", 2011). These buildings can alter the physical aspects (temperature, lighting, ventilation, humidity) of the building to meet the comfort needs of the individual automatically. Smart buildings do this by using data from sensors, actuators, and external data like weather as inputs to machine learning models in order to predict the desired physical settings based on the individual and organization. The physical aspects in office buildings mentioned above have long been recognized as the key ambient work features that affect human comfort and health conditions (Allen et al., 2015). Optimizing indoor building environments can not only provide benefits to human health but also significantly reduce energy usage by reducing facility usage intelligently i.e. turning off heat and lights when no one is there. This is significant as buildings account for about 30% to 40% of the total energy consumption and carbon dioxide emissions worldwide (Dean, Dulac, Petrichenko, & Graham, 2016). Smart enabled buildings can improve occupant comfortability and energy efficiency as long as the underlying smart building system can accurately adjust indoor-environment settings; although this can prove to be quite difficult due to data quality and quantity restrictions.

Rice Hall, the computer science department facility at the University of Virginia, is a smart enabled building. However, currently Rice Hall does not fully utilize its hardware and software infrastructure to take advantage of the smart building benefits. Additionally, current smart building prediction systems cannot accurately predict the desired settings for an individual due to the lack of high-quality personalized data available for each individual. The technical project aims to address these issues by using a deep learning approach and feature engineering techniques along with sensor data and external data sources like historical weather data, individual calendar data, and personal preferences in order to accurately predict and set an individual's ideal physical settings using Rice Hall to implement and test the process.

However, implementing this approach does not fully resolve the overall problem because it does not address the social factors needed to make building smart cities successful. Smart cities are comprised of a network of smart buildings/systems and use the same underlying technical model to make intelligent decisions; Amsterdam is an example of a successful smart city. This means that the technical machine learning algorithms are needed for the Amsterdam smart technologies, however, creating a collaborative "startup" culture in the city is also integral to the success of Amsterdam since many projects can be completed faster this way. Looking past this social factor would prevent other projects to build smart cities effectively, thus preventing the benefits of smart technology from reaching millions of people.

To effectively improve the prediction accuracy for an individual's office/room in a smart building and thus improve the overall occupant's working experience and reduce energy consumption, both technological and social factors must be considered. Below I outline a technical system to better predict what physical features to set using various data collection techniques and a comprehensive deep learning model that utilizes feature engineering approaches. I also use the STS framework of actor-network theory to analyze how the "startup" culture of the Amsterdam smart city, as well as other human and non-human actors, lead to the success of the socio-technical system that is Amsterdam.

Technical Problem

Smart building infrastructures are equipped with hundreds of sensors to monitor physical building aspects and provide smart solutions for occupant comfortability and energy efficiency. Ideally, an automated system can predict and adjust the physical features (e.g., lighting, air quality, temperature, etc.) in a person's office based on his/her personalized preferences and activities. Most smart buildings use machine learning algorithms to predict events, which depend on a lot of input data to statistical models to make educated guesses (Hao, 2018). The underlying reasons for the preferred environmental settings can be quite complicated, including personal preference, scheduled activities, weather, and so on, so machine learning techniques are a practical approach for predicting preferred settings. Though, since the data is from one person, there may not be sufficient data for the machine learning model training to be accurate, and the data's quality may be low. Then, it is a challenge to conduct accurate predictions to provide personalized environment adjustment. Furthermore, current smart building implementations and research deal with the building and its occupants as a whole, for example, using predicted occupancy to control temperature and lighting (Mao & Huang, 2017). These approaches, however, do not automatically consider the individual occupants' environmental preference based on his/her different indoor activities. They also do not deal with low quality and quantity data particularly well, as they use traditional machine learning techniques. By not providing a personalized service to each individual accurately, the benefits of smart buildings cannot be obtained due to the wide range of preferences among people and the unpredictable environment variables that can occur (meetings/events).

To handle this problem, I will propose a smart building assistance system that automatically controls an office's environment settings to increase its occupant's comfort and energy-efficiency. The proposed system predicts the physical features preferred by the occupant based on his/her previous activities and the corresponding physical features they set by preference. It can then proactively adjust the physical features so that the occupant's desire for comfortability and energy efficiency is satisfied. For the technical project, we will deploy sensors in a faculty member's office in Rice Hall and collect data. The person can adjust the temperature, humidity, lighting, and air quality based on his/her preference for comfortability and energy efficiency. The dataset consists of different physical features (e.g., lighting, temperature, air quality) of the office environment, calendar events, everyday office activities, public holidays, and weather information. The physical feature settings are the occupant's preferred settings set by him/her. We then utilize the dataset for physical feature prediction to realize the person's preferred office environment. To predict different physical features more accurately, we will use various data analysis techniques and feature selection procedures to maximize the expressiveness of the collected dataset. The project will use feature engineering, which are techniques to prepare features (measurable properties of observed phenomena) for machine learning inputs, in order to increase machine learning accuracy. More specifically, we will perform feature discretization, feature combination, and regularization to enhance the expressive nature of the dataset (Rencberoglu, 2019). Deep learning is then used, which is a subset of machine learning that utilizes neural networks to predict patterns more effectively. Neural networks use many computational nodes in tandem to process data and detect patterns (Brownlee, 2019). A deep neural network (DNN) model will be used that leverages a mixture of a feed-forward DNN blocks and several recurrent neural network (RNN) blocks to achieve higher prediction accuracy. Finally, we will conduct experimental studies using the collected datasets and compare them to the experimental results to show that our proposed prediction methods for the occupant's preferred physical factors achieve higher accuracy.

STS problem

In 2009, the Dutch Capital city of Amsterdam launched the Amsterdam Smart City Initiative; this project aimed to fight against global warming and implement innovative technology into the city infrastructure. Smart cities essentially use the same technology and techniques smart buildings use to make intelligent decisions at a city scale. Using the various data sources available across a city, smart cities help monitor, manage and control systems across its communities including, traffic, transportation systems, utilities, waste, crime detection, schools, libraries, hospitals, and other community services ("Smart Building Technologies", 2019). An example of a smart technology in Amsterdam can be seen with the dimmable LED lights that automatically light up and dim when bikers pass over it. Amsterdam is also on track to have no CO2 emissions by 2040 (Bosch, 2018). Amsterdam's success in building a smart city led to it being ranked as the third smartest city by the IESE Cities in Motion Index. The co-author of that report, Joan Ricart, said, "A truly smart city is one that has as its goal improving the quality of life of its residents, which means ensuring economic, social and environmental sustainability." when addressing the criteria of the ranking (Smith, 2017).

Some scholars have pointed towards the initial political backing of the City of Amsterdam and its association with major private partners as a major reason for its success. These associations were crucial in initiating the implementation of the first projects and getting the necessary seed funding; 40% of the proposed €4 million budget came from these partners (Smith, 2017). Another scholar uses the excellent planning, logistical implementation, and monitoring tactics of the smart projects by Amsterdam to be key actions needed for a successful smart city (Mora & Bolici, 2016). While both of these reasons indubitably led to the wide success of the Amsterdam smart city, it was the collaborative "startup" culture of Amsterdam that propelled the innovative development of smart technologies. This "startup" culture manifested due to the fact that city data sets are open source, meaning anyone can access/add to the database. The Amsterdam Smart City online platform, an organized partnership of twelve public, private and university partners that acts as a centralized forum for the communication and coordination of smart city projects between partners, also contributes to the "startup" culture. Those partners could be anyone, with startups being the most prominent. An open and collaborative mindset coupled with favorable government regulations all contributed to the success of the smart city initiative. If we continue to think that the initial Government execution and funding was solely responsible for the success of the city, then we lose understanding of how the open "startup" culture greatly contributed to the project's success and will thus be less effective in building other smart cities that benefits millions of people.

I will use Michel Callon's actor-network theory to argue that it was the "startup" culture fostered in Amsterdam in conjunction with the government's excellent logistical execution that led to the initial funding and collaboration with private partners that caused the project to succeed. Actor-network theory analyzes the relationships among human and non-human actors that form a network designed to accomplish a particular goal; in this case the goal is building a successful smart city. To support my argument, I will analyze how effective the online platform is by looking at the success of smart startups in Amsterdam through financial records of public startups. I will also look at how startups use and manipulate the open data and to what degree they affect the city and its people through case studies of various startups; Wander is an example of a startup that uses map data to connect you to “hidden gems” of the city powered by GPS and tourism data.

Conclusion

The technical project outlined in this paper will deliver a novel system for processing various data inputs in a smart building in order to accurately predict the physical settings desired by the individual of the room. This smart building system uses a deep learning model in conjunction with feature engineering that considers the context of the situation using external data sources like, weather, calendar events, and user personal preferences. The process will be optimized to be accurate in situations where the amount of data available is scarce using feature engineering techniques. In addition, I will analyze the social factors integral to the success of the Amsterdam smart city using actor-network theory. This analysis helps to broaden our understanding of what human and non-human actors are required for a complex system to function.

The results of the technical report will help to resolve the broad socio-technical issue of creating a more comfortable working experience that is energy efficient by utilizing deep learning and feature engineering. The findings from the STS paper will also we strive to unveil how smart technology is made up of many actor-networks that are interrelated for a common purpose. Without this insight, ensuring the success of building other smart city projects would be very difficult leading to failures that are costly and prevent the benefits of smart technology from reaching the general population.

Word Count: 2017

References

Allen, J. G., Macnaughton, P., Laurent, J. G., Flanigan, S. S., Eitland, E. S., & Spengler, J. D. (2015). Green Buildings and Health. *Current Environmental Health Reports, 2*(3), 250-258. doi:10.1007/s40572-015-0063-y

Bosch, H. (2018, May 23). Amsterdam: Better than 'smart'. Retrieved November 22, 2020, from http://smartcityhub.com/governance-economy/amsterdam-better-than-smart/

Brownlee, J. (2019, August 16). What is Deep Learning? Retrieved November 02, 2020, from https://machinelearningmastery.com/what-is-deep-learning/

Dean, B., Dulac, J., Petrichenko, K., & Graham, P. (2016, November 17). Towards zero-emission efficient and resilient buildings – Global status report 2016. Retrieved November 01, 2020, from https://www.buildup.eu/en/practices/publications/towards-zero-emission-efficient-and-resilient-buildings-global-status-repor-0

Hao, K. (2017, November 17). What is machine learning? Retrieved November 02, 2020, from https://www.technologyreview.com/2018/11/17/103781/what-is-machine-learning-we-drew-you-another-flowchart/

Mao, C., & Huang, Q. (2017). Occupancy Estimation in Smart Building using Hybrid CO2/Light Wireless Sensor Network. *Journal of Applied Sciences and Arts, 1*. Retrieved November 1, 2020, from https://www.researchgate.net/publication/307959656_Occupancy_Estimation_in_Smart_Building_using_Hybrid_CO2Light_Wireless_Sensor_Network

Mora, L., & Bolici, R. (2016). How to Become a Smart City: Learning from Amsterdam. *Smart and Sustainable Planning for Cities and Regions Green Energy and Technology,* 251-266. doi:10.1007/978-3-319-44899-2_15

Rencberoglu, E. (2019, April 01). Fundamental Techniques of Feature Engineering for Machine Learning. Retrieved November 02, 2020, from https://towardsdatascience.com/feature-engineering-for-machine-learning-3a5e293a5114

Smart City Technologies: Role and Applications of Big Data and IoT: HERE Mobility. (2019). Retrieved November 02, 2020, from https://mobility.here.com/learn/smart-city-mobility/smart-city-technologies-role-and-applications-big-data-and-iot

Smith, L. (2017, December 10). Amsterdam Smart City: A World Leader in Smart City Development. Retrieved November 22, 2020, from https://hub.beesmart.city/city-portraits/smart-city-portrait-amsterdam

What is a Smart Building?: Building Efficiency Initiative: WRI Ross Center for Sustainable Cities. (2011, April/May). Retrieved November 01, 2020, from https://buildingefficiencyinitiative.org/articles/what-smart-building