HalO
[Indoor Positioning Mobile Platform]
A Data-Driven, Indoor-Positioning System With Bluetooth Low Energy Technology To Datafy Indoor Circulation And Classify Social Gathering Patterns For Assisting Post Occupancy Evaluation

ABSTRACT
Post-Occupancy Evaluation (POE) as an integrated field between architecture and sociology has created practical guidelines for evaluating indoor human behavior within a built environment. This research builds on recent attempts to integrate datafication and machine learning into POE practices that may one day assist Building Information Modeling (BIM) and multi-agent modeling. This research is based on two premises: 1) that the proliferation of Bluetooth Low Energy (BLE) technology allows us to collect a building user’s data cost-effectively and 2) that the growing application of machine learning algorithms allows us to process, analyze and synthesize data efficiently. This study illustrates that the mobile platform HalO can serve as a generic tool for datafication and automation of data analysis of the movement of a building user. In this research, the iOS mobile application HalO, combined with BLE beacons enable building providers (architects, developers, engineers and facility managers etc.) to collect the user’s indoor location data. Triangulation was used to pinpoint the user’s indoor positions, and k-means clustering was applied to classify users into different gathering groups. Through four research procedures—Design Intention Analysis, Data Collection, Data Storage and Data Analysis—the visualized and classified data helps building providers to better evaluate building performance, optimize building operations and improve the accuracy of simulations.
INTRODUCTION
The increasing penetration rate of smartphones has laid the foundation for the emerging self-tracking trend while machine learning algorithms provide a promising solution for synthesizing and analyzing the ever-exponentially-growing data. This research builds upon the increasing datafication of human behaviors. It takes a social as well as a spatial analytical approach to explore the feasibility of 1) using a mobile application to collect building users’ position data and 2) using a machine learning algorithm to analyze social gathering patterns inside buildings.

Background
An architect’s interest in sociology is rooted in the impossibility to conceive buildings or communities apart from the human activities they serve (Gutman 1975). However the knowledge and opinions that building users have about spaces rarely find their way back to the providers (Kernohan 1992). To learn from their buildings, architects started to seek support from behavioral science to better understand the users’ needs. Figure 2 shows the current field integration of social science and environment design.

POE allows us to consider real-time issues in problem solving and thus is changing the literature on state-of-the-art design criteria (Preiser et al. 1980). Despite providing time-based feedback, current POE is static, labor intensive, expensive and only covers a short period of a building’s life span. Similar to most traditional social sciences, it is prone to examiners’ biases and observer effects. Also, most POE is designed for specific groups in specific buildings and regions, and cannot be adopted as general practice guidelines for all building providers (Cheung 2007). A more cost-effective and broad-based approach to POE is explored in this research by taking advantage of the booming self-tracking trend.

The proliferation of smartphones has led to a significant increase in digital traces of humans, which raises new opportunities for the practice of behavioral science (Neff 2016). Self-tracking as an emerging social phenomenon offers building providers meaningful insights into building user behavior. Complexity theory—the belief that the nature of social interaction and human behavior is a nonlinear, dynamic system—provides social scientists a theoretical framework to effectively synthesize and analyze this data (Roy 2009). User behavior in building environments is a series of dynamic movements, inherently decentralized and complex (Koutamanis 2001). It often requires the use of bottom-up models for analytical and generative purposes (Puusepp 2011). Therefore, virtually all environmental problems are dynamic system problems and the architectural solution to these problems is an aggregation of various sub-systems.

2 A brief look at the field and some current environment behavior and society research (Moore 2004).
3 Diagram of the beacon grid.
4 Diagram of how do beacons detect smartphone.
For this study, machine learning algorithms are essential to deepen our understanding of these complex phenomena.

Precedents
Several studies have been conducted that integrate one or two of the above aspects, but none of them provided a complete understanding of the social-spatial relationship of the building users and the building itself. Many researchers have applied Global Positioning Systems (GPS) to explore how people perceive spaces and navigate through urban fabrics. Some studied dynamic navigation of city spaces with the aid of mobile devices (Goel 2001). Others have explored the possibilities of GIS on landscape design (Carlsson 2013).

However, little investigation has been done on indoor environments due to privacy concerns, security, accuracy and building complexity. Even if they are carried out, they are usually politically or financially motivated. Organizations such as the Disney Corporation and the World Bank both have linked POE data to their geographic information systems for future planning and design purposes (Washington DC 2001). Walmart’s bold plan for changing the state of its supply chain by employing radio-frequency identification (RFID) tags made RFID the global provider of in-store merchandise-availability solutions. Despite numerous RFID studies on customer shopping behavior (Shangguan et al. 2015), RFID has limited accessibility when compared with Bluetooth Low Energy (BLE) technology. BLE’s ability to adapt to mobile devices has made it a better solution for tracking an indoor environment. Unfortunately, the current application of BLE is primarily used to track customers’ shopping behaviors. Generally speaking, this type of data has not been collected with the intention of promoting better architectural design, and rarely has it been accessible to the general public or the building providers. The potential of adding circulation path and social gathering information to BIM systems to make better design solutions is promising. This research has been geared towards the development of a more cost-effective data collection method, which can be scaled up and adopted globally. Through the synthesis, analysis and classification of building users position data, combined with the self-tracking industries’ database and a multi-agent modeling system (Puusepp 2011), a universal self-generative modeling tool for assisting architecture design becomes possible.

METHOD
Data collection and data analysis were the two major procedures of this research. Data was collected by using a mobile application combined with BLE devices. The application was running 30 minutes per day for 5 days during the Beta Test while the observation was taking place. After data collection, the Machine Learning Model was introduced to classify the data into “hot spot” and “non-hot spot” groups. I define a “hot spot” as a space that attracts social gathering by the building users, which means people stay or linger in this area rather than use it purely for circulation purposes. Clustering suited the research as it helps find patterns in the data without advanced knowledge of the users’ gathering styles (Park 2015).
HalO System Development

There are three major components of the HalO system architecture: a mobile application as a data collection tool, a web server to store the data and a machine learning model to synthesize and analyze the data (Figure 5). HalO channels different user information into different categories, and the web server stores those categorized data in JSON format for future processing. The machine learning model calculates the users’ position and classifies their gathering patterns accordingly.

BLE beacon devices were used to “listen” to smartphones’ Bluetooth signals to detect the distance between them. Beacons’ low energy feature and cheap replacement cost made it suitable for long period deployment. Accuracy was improved by placing beacons along the Student Activity Center’s (SAC) grid system (Figures 3 and 4). Besides passive “listening”, beacons can also send information to users who are within a certain distance range ("broadcasting"). As beacons can only detect the distance between devices rather than locate their positions, mathematic triangulation was introduced to calculate the intersection of three randomly selected beacons and smartphones to determine a user’s position.

The HalO platform development includes the front-end design, the back-end development and the machine learning model.

- The Front-end Design: HalO serves as an indoor tracking tool as well as a digital surveying tool. The first task was to recognize the existing users and navigate potential users to the registration page (Figure 6). Existing users needed to submit a series of questionnaires when they entered the SAC. (Geofencing technology was applied here). Users can skip the questionnaire and switch between Beacon mode and Tracking mode (Figure 7). Beacon mode turns smartphones into beacons to broadcast signals, and the same default UUID will be assigned to identify the site (Figures 8 and 9). Different UUIDs will be assigned to distinguish different sites when the deployment expands. Major and minor values are assigned based on users’ categories. Tracking mode displays users’ positions, but due to privacy concerns, only users who enabled the display function will be shown on the plan.

- The Backend Development: Back-end development was divided into two parts: iOS Development and the web server. The iOS Development was accomplished by using the Swift programming language through the Xcode platform. I selected Google Firebase as my web server to export data in JSON format (Figure 10).

- The Machine Learning Model: Rhinoceros was used for its visual representation and its adaptability. The data preparation, processing (Figure 11) and mathematic triangulation (Figures 12–14) were done using Grasshopper. Python was used to write the k-means clustering as a small plugin inside Grasshopper (Figure 15).

Beta Test

TestFlight, an online service for over-the-air installation and testing of mobile applications, was used to carry out the HalO Beta Test. Ten student volunteers took part in the test. First, we
configured the SAC plan with beacons. Six beacons were placed inside the Lobby and the Study Lounge, then configured with the dimensions of the space. Second, students were asked to stay at the SAC as they normally would for 30 minutes while HalO was collecting and sending their distance data to the Firebase web server. Third, distance data from the previous stage was exported as JSON data to Grasshopper for processing and triangulation. Fourth, k-means clustering was applied to datasets to classify “hot spot” and “non-hot spot”.

RESULT

To assure the validity of this research, Space Syntax was used to analyze the architects’ design intentions and compare them with HalO’s Beta Test result. Figure 16 shows the Space Syntax Connectivity Map (hereafter referred to as the Map) of the SAC. The colors indicate the intensity of the connectivity. Red regions have the highest degree of connectivity (Al-Sayed et al. 2014). Figure 17 shows the overlay of the Map and the HalO Beta Test Plots, hereafter referred to as the Plot (Figure 18). The Plot from real-time data didn’t perfectly align with the Map; the
left top of the building with the highest degree of connectivity actually has little attraction to users according to both the Plot and field observation. Also, the Plot shows that programs such as restrooms and water fountains actually have high degrees of attraction to users while the Map rendered them as "low". What's more, the Plot shows that the Retail A (at the bottom right of the Plan) attracts and serves most of the student at the SAC, but it was identified as "low" on the Map. This may have been due to program changes after construction completion. Retail A was modified as a study lounge so it now serves as a gathering place for the building users. Also, the door on the bottom left of the SAC plan was modified for emergency use only, and lots of students actually lingered in that area because the inoperative emergency entry resembles a French window (Figure 19).

The above comparisons illustrate that HalO can serve as a real-time indoor positioning and classification system to provide more accurate analysis and meaningful findings by taking advantage of smartphone and BLE technology. Over time, HalO can assist building providers in collecting and analyzing data.
more cost-effetely for understanding building users’ needs and learning from buildings. As only ten students participated at this stage, the dataset was not big enough to reflect the complete social gathering patterns at the SAC. Next steps will focus on expanding the sample group, qualitative studies and experiments. Topics to explore going forward include the relationship between furniture layout and gathering patterns, the impact of age and gender on moving patterns, and the possibility of using facial recognition technology to better understand human emotion inside buildings.

CONCLUSION
The key contribution HalO potentially makes to architecture is the optimization of building operation. HalO’s long-term benefit is to provide feedback to building providers on building performance over all building types. Building providers can customize HalO’s database with certain parameters they are looking for (such as building sizes, building types and locations etc.) to improve the efficiency of their research. This novel method of POE will accelerate the design/construction evaluation process to improve building providers’ ability to meet their design intention and learn from other buildings based on how people use the space.

There are two groups to which HalO caters. One is to the clients, who can use data as a daily planner (combining personal data and public event data). The other is to the building providers, who can link HalO with BIM systems to make better and more effective design decisions. The internet-based mobile platform proposed in this research has the potential to work with smart buildings and responsive architectural designs to form highly flexible buildings that can dynamically adapt and adjust themselves according to the needs of building users.

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