Development of a Building Occupant Survey System with 3D Spatial Information

Jong-Won Lee [1,2] , **Deuk-Woo Kim [2]** , **Seung-Eon Lee [2]** and **Jae-Weon Jeong [3,*]**

[1] Department of Architectural Engineering, College of Engineering, Hanyang University, Seoul 04763, Korea; jongwonlee@kict.re.kr

[2] Korea Institute of Civil Engineering and Building Technology, 283 Goyang-daero, Daehwa-dong, Ilsanseo-gu, Goyang-si 10223, Gyeonggi-do, Korea; deukwookim@kict.re.kr (D.-W.K.); selee2@kict.re.kr (S.-E.L.)

[3] Department of Architectural Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul 04763, Korea

[*] Correspondence: jjwarc@hanyang.ac.kr; Tel.: +82-2-2291-9609

check for updates

Abstract: This paper summarizes the recent post-occupancy evaluation (POE) method studies and latest literature reviews. According to the research trends, data visualization of an occupant's feedback is an important perspective and surveys through POE methods have provided a quick and cost-effective approach for gathering and analyzing an occupant's feedback. Therefore, the objective of this study is to establish a web-based building occupant survey system that incorporates new approaches based on a geographic information system (GIS) tool and open-source spatial information. This paper reports the following to provide the detailed system framework: (1) development requirements from literature reviews; (2) integration of collected data and 3D (three dimensional) spatial information; (3) system processes and user-friendly functions; and (4) pilot test and data visualization. The difference between the proposed platform and existing online survey systems is that in the former the survey responses are linked to the 3D spatial information of the buildings on a map. Thus, the results provide more intuitive insights for building managers and occupants to identify specific performance issues related to the building.

Keywords: building occupant survey system; post-occupancy evaluation (POE); indoor environmental quality (IEQ); occupant satisfaction; data visualization; geographic information system (GIS); open data; information integration

1. Introduction

Post-occupancy evaluation (POE) is a comprehensive method of assessing buildings that have been occupied for some time in order to evaluate the building's actual performance and help resolve operational issues, eventually enabling the building to attain a higher level of efficiency [1,2]. POE helps obtain a building user's feedback on the operational performance of the building, including the energy performance, indoor environmental quality (IEQ), occupant satisfaction, and productivity [3–8]. Pinder et al. (2003) emphasized that building occupants, as the end users of buildings, can provide insights into the building performance. Effective POE methods must be equipped with practices that include interrelated responses of occupants who reside in the buildings [9–12].

There are diverse POE methods to gain detailed and specific user feedback. Specifically, surveys and interviews of occupants are typically incorporated into a POE framework [7,13]. Interviews are a good method for in-depth discussions and insights into an occupant's perception of the environment; however, these approaches tend to be labor-intensive and difficult to examine. Although an in-depth

review is not feasible, surveys provide a quick and cost-effective method for gathering and analyzing occupants' feedback [14].

Therefore, in POEs, building occupant surveys have generally been conducted as an important evaluation tool to evaluate occupant satisfaction [7,15–17].

The distribution of surveys conventionally involves labor-intensive delivery of paper-based materials. As the conventional paper-based survey method requires researchers or surveyors to directly visit the occupants of a building, the investigation time and costs are significant, particularly when there are many occupants. In other words, paper-based surveys can be conducted only in a limited number of buildings, which restricts the generalization and distribution of POE studies [7]. Furthermore, in the event of a pandemic, such as COVID-19 (referring to the coronavirus disease that originated in 2019), field surveys would need to be suspended, and alternative survey approaches would be required.

To overcome the drawbacks of a paper-based survey, computer software for web-based surveys has been developed since the 2000s [18,19]. For example, the Center for the Built Environment (CBE) of the University of California, Berkeley has developed an occupant satisfaction survey, which is the most widely used web-based questionnaire and reporting tool [14,19–21]. Other internationally used survey tools include the Building Use Studies Ltd.'s PROBE (Post-occupancy Review of Buildings and their Engineering) in the UK, Overall Liking Score, and Building Occupants Survey System Australia [7,22–26]. New digital web-based tools, such as SurveyMonkey™, Qualtrics™, and Google Forms™, have alleviated the technological obstacles related to the use of online surveys in obtaining and analyzing occupant feedback [27–29]. In addition, optimized mobile devices are gradually being deployed to evaluate occupant responses [30–34]. Today, researchers only need to send an invitation email, and participants can complete the survey on smartphones [35–37].

In recent POE studies, visualizing the data aggregated from surveys has gained attention. In particular, geographic information system (GIS) technology has been employed in POE studies as a powerful visualization tool [38–42]. GIS applications provide intuitive survey results with a large array of statistical graphs on the map. In other words, a GIS-based spatial analysis in POE studies can help better understand and identify patterns of the spatial distributions of occupant satisfaction and dissatisfaction [43]. However, the GIS is specifically oriented to 2D (two dimensional) systems (mapping, optimal routing), whereas architectures, such as buildings, are mainly three dimensional [44–46].

Building information modeling (BIM) has been employed alongside GIS technology as a spatial information tool using a 3D computer-aided design (3D CAD). Ning and London (2010) and Porwal and Hewage (2013) reported that the use of BIM will only increase in the near future, particularly for POE, given the current state of BIM and its contribution to architecture, engineering, and construction (AEC) industries [47,48]. However, BIM adoption in POE studies is still insufficient and has faced significant drawbacks [49–51]. First, it is difficult to apply it to old and small buildings that do not possess CAD floor plan files that are based on the BIM model. Second, the considerable time required to generate a BIM model and the high cost of BIM software and high processing requirements significantly limit the speed and cost-effectiveness of the survey. Thus, in this context, simple combined open-source 3D spatial information is preferred over the BIM approach. Open sources are cost-effective and customizable [52,53]. Therefore, it is necessary to base the framework development research of the occupant survey system on open sources.

Furthermore, in this study, two significant new literature reviews on POE have been analyzed to find the directions for a future POE system and for a data visualization perspective. Li et al. (2018) conducted a comprehensive and critical review of 146 POE projects published since 2010. Five directions for future POE studies were reported:

1.　From one-off to continuing;
2.　From high-level to detailed;
3.　From researchers-oriented to owners/occupants-oriented;
4.　From academia to industry;

5. From independent to integrated.

Leitner et al. (2020) also established a systematic literature review of 55 papers published from 2013 to 2017 [54]. They concluded that there cannot be a single response or a perfect solution in the elaboration of POEs. Thus, a single-size-fits-all POE approach may not be sufficient or even feasible [55]. In other words, it is necessary to design a flexible survey system that can be developed and customized by users and developers.

Solving the issues reported in the two literature reviews on POE is important to provide directions for developing new systems. However, in contrast to the development of a global POE web-based tool, POE studies in Korea have conducted one-off surveys without an occupant survey system model that shows a comprehensive understanding of occupant' responses [56–58]. A more advanced, new, online survey system that can reflect the insights gained from many studies is required to gather and analyze occupant responses cost-effectively. To be specific, a framework for building occupant survey system that reflects these considerations, as well as connected to a comprehensive academic perspective and the point of view of practitioners, needs to be developed.

Therefore, this paper aims to fill this knowledge gap by developing a new system on the basis of the country's context as a general framework for use in other countries. It provides a better understanding of the open source development for an occupant survey system. To be specific, the objective of this study is to establish a web-based building occupant survey system that incorporates these characteristics and is based on a GIS tool and open-source spatial information. The proposed system in this study aims to include significant design characteristics as follows:

1. The ability to conduct replicable and repeated occupant surveys in the same building. A sustainable POE with aggregated data could help identify the reasons for dissatisfaction that otherwise cannot be fully explained the first time. In this regard, a new system is required to design an integrated database.
2. The ability to decipher the meaning of survey responses from broad aspects to in-depth details. For instance, the average satisfaction level of the occupants can be analyzed from the entire building level to detailed end-user patterns.
3. The ability to practically develop the actual system to reflect the owner/occupant-oriented perspectives as well as the researcher-oriented perspective.
4. The findings of the POE are often displayed in the form of technical figures and charts in a report or paper. Nonprofessionals, such as building owners and occupants, should be able to understand the building's performance from the figures and charts. Multidimensional displays can improve the understanding of spatial distributions [42]. In this regard, GIS tools could be a great solution to visualize the occupant feedback and display the spatial analysis of the building on maps. Thus, it makes it easier to link diverse stakeholders from academia to industry. In other words, the industry as well as academic researchers can play an important role in driving the development and implementation of POE through data visualization.
5. The new comprehensive system, involving related stakeholders, helps POE activity to be integrated into a cost-efficient building performance evaluation scheme.
6. To enhance the flexibility of survey options, such as criteria, items, and categories, an easily changeable survey module with various open sources should be developed and integrated into the survey tool.

This paper reports the following aspects: (1) integration of open data; (2) visualization of collected data and 3D spatial information; and (3) pilot test.

2. Development of an Open-Source-Based Online Platform, K-BOSS

We call the proposed system the Korean Building Occupant Survey System (K-BOSS). In Korea, surveys for POE research are limited to temporary measurements and evaluations [58]. Therefore, it is

necessary to discuss a new system that can systematically link, accumulate, and manage the data collected from the occupants of each building. In this paper, we introduce the K-BOSS, including data, added functions, survey process, and visualization.

2.1. Integration of Open Data from the Korean Government

The primary reason for utilizing open-source libraries and public data (open data) from the Korean government was to reduce the costs of development and data collection. Furthermore, public data from government agencies provide high reliability and availability with annual updates. The road name address building application programming interface (API) provided by the Spatial Information Industry Promotion Institute's V-World website and the GIS building-integrated information provided by the National Spatial Data Infrastructure Portal both represent building information. For each building address, if a bonding box is sent as a parameter in the latitude and longitude coordinates, the information related to the buildings belonging to the corresponding area is returned to the system. However, we checked which building information was more accurate and stable with the related government agencies and decided to use the GIS building-integrated information only. The open data used in the system are as follows in Table 1.

Table 1. Used open data list in the system.

Organization	Data	Description
Spatial Information Industry Promotion Institute's V-World website	Address and Location searching APIs	When a user enters and searches an address in the system, a list of addresses corresponding to the search term is displayed on the screen.
	Background Map	The background map image is in the form of a tile map
	Road Name Address Building API	Building information provided by V-World; The system searches for the building information selected by the user.
National Spatial Data Infrastructure Portal	GIS building-integrated information	The polygon shape of each building is obtained, so it is displayed on the map.

The map program used in the system was built using an open source library called Leaflet. When developing a map function in a web system, it is possible to use other map services, such as Google Maps; however, the purpose of the system is to achieve a low cost and high-efficiency development using an open source map library. Leaflet [59] and Openlayers [60] are the most commonly used open source map libraries. Leaflet was chosen due to the larger open source community and expandability for additional functions.

To represent buildings on a map in a polygonal form, it is necessary to use a function to draw lines on the map in this Leaflet library with a list of latitude and longitude coordinates in the EPSG (European Petroleum Survey Group): 4326 coordinate system. However, the GIS building-integrated information API provided by the National Spatial Data Infrastructure Portal offers polygon data of buildings with a list of latitude and longitude coordinates in the EPSG:5174 coordinate system. Therefore, it is necessary to convert the list of latitude and longitude coordinates provided in the EPSG:5174 coordinate system to the EPSG:4326 coordinate system to be adopted in the Leaflet library. An open-source library called Proj4js [61] is used for this coordinate conversion, and the code for the coordinate conversion is as follows.

2.2. Spatial Information Collection

The difference between this platform and existing online survey systems is that the survey information is linked to the shape and spatial information of the buildings. Thus, the collected data can be visualized in three dimensions to determine any problems in the space (x, y, z), as shown in Figure 1. To perform a 3D visualization, we collected the latitude (x), longitude (y), and height (z) information, and mapped the survey results. A user can directly click the [x, y] latitude and

longitude points on the map to record a 2D location, after which the user can directly enter the height [z] information. The interior of the building was visualized using the Indoor3D API open source. The feedback provided by the occupants is displayed in multilevel colors such as red, yellow, and green. For example, occupant satisfaction is displayed in red if the occupants are not satisfied, yellow if the satisfaction is normal, and green if the occupants are satisfied. While other existing studies conventionally display information through primary methods (mainly graphs or floor plans), this study displays results in a 3D space to enhance the spatial intuitiveness for the user, as shown in Figure 2.
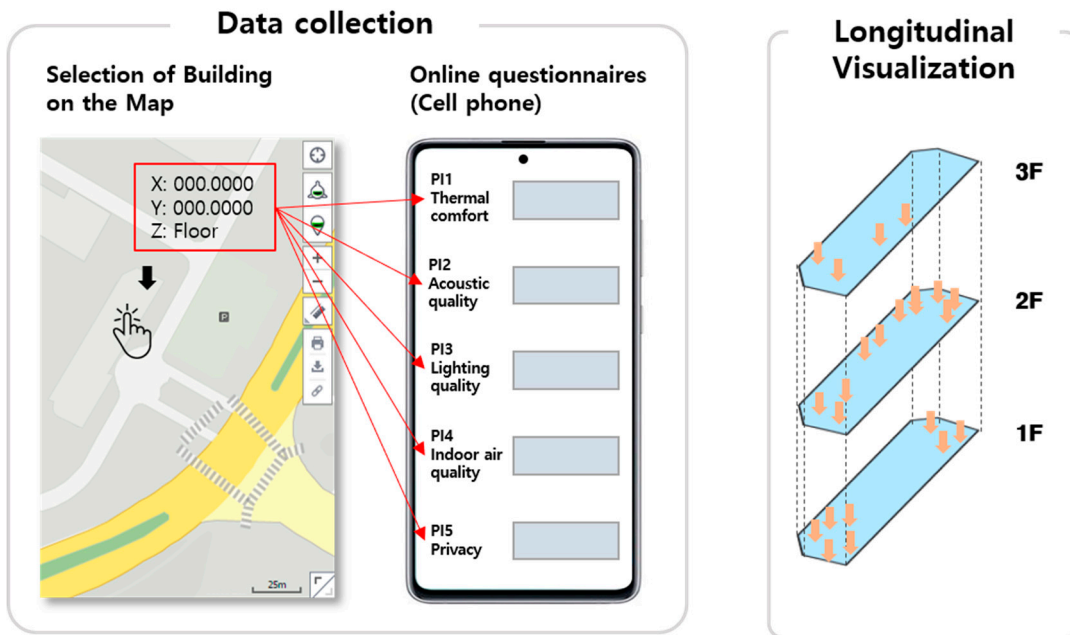
Figure 1. Conceptual model: data collection in the latitude [x], longitude [y], and height [z] coordinates with online questionnaire [S] (left). Visualization of the collected information (right).
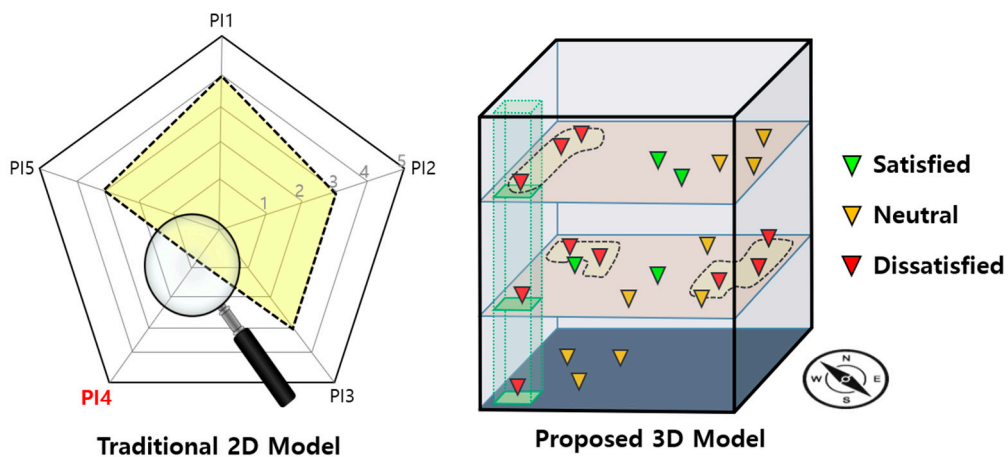

Figure 2. Visualization of results: conventional vs. proposed method (illustrative view).

2.3. System Working Process and Functions

The developed system consists of three functions: a survey creation function, a survey conduction function, and a visualization function. Figure 3 shows a schematic of the main components.
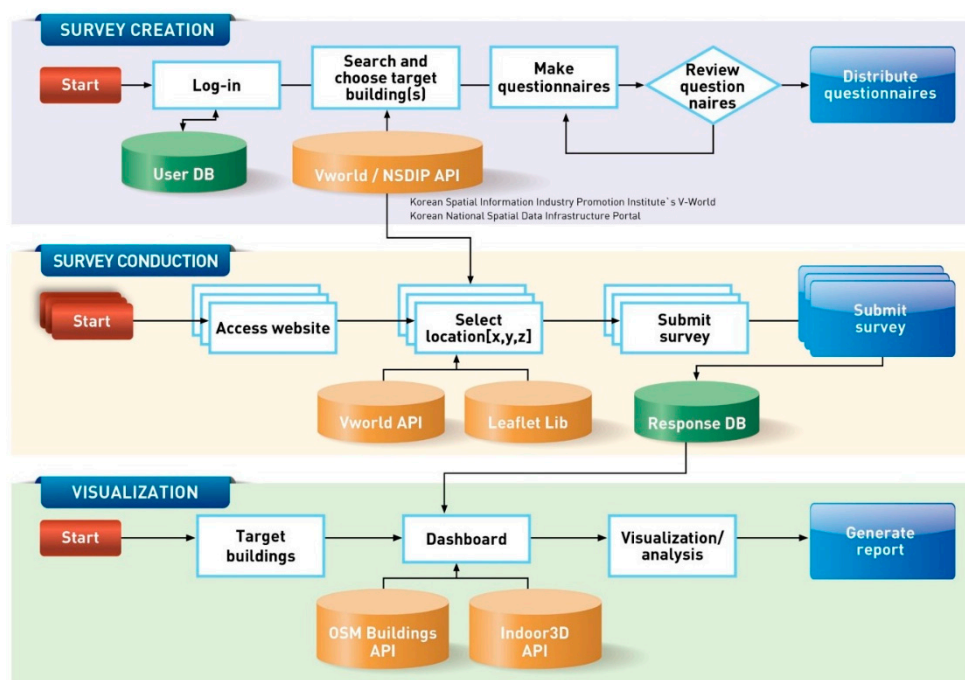
Figure 3. Operational process of the system: survey creation, conduction, and visualization.

- Survey creation function. This function is accessed by survey designers (researchers, facility managers, building owners, etc.). After logging in, the surveyor selects the building to be surveyed and then creates and distributes the questionnaires. The building to be surveyed is selected from the GIS building-integrated information provided by the National Spatial Data Infrastructure Portal. The process of creating the questionnaires is similar to other survey schemes; the main difference is that this system requires the respondents to choose their location in the building in terms of geospatial information (latitude [x], longitude [y], and height [z]). Furthermore, the survey can be customized for various purposes using open-source libraries.

- Survey conduction function. This function is accessed by the survey respondents. A respondent accesses the distributed survey on the webpage and confirms the location and shape polygon of the building to be surveyed. First, the respondents type and choose the address of the building that they have occupied. Second, they choose their occupied location in the building by inputting the 3D spatial information [x, y, z] in the shape polygon of the building. After this process, the occupant satisfaction survey of their location commences. The final responses and location information completed and submitted by the respondents are saved in the database.

- Visualization function. This function is accessed by the surveyor and respondents. To create a 3D visualization of the collected dataset, a free editable map, OpenStreetMap (OSM), and OSM Buildings (3D building geometry data based on OSM), and API are used for the online map. In addition, the Indoor3D API is used for the 3D space. OSM Buildings and Indoor3D are open sources that provide a form that can be viewed directly in a web browser without having to install any program to express 3D visualization. The data from the response database are displayed in the dashboard, as shown in Figure 4. The dashboard service shows a building from a list of buildings on which the survey was conducted and detailed information on the buildings. In this figure, "User ID" means the K-BOSS's user's ID. "Survey ID means unique identification number in the survey and "Building ID" means the number of the state, city, and town and unique building number. Additionally, "Responses No" means the number of responses and "Details" shows the details of survey results. Furthermore, the dashboard displays the state of the surveyed buildings nationwide on a web-based GIS map and allows the entire list of buildings to

be downloaded to Excel. Building ID on the dashboard means building register code in the GIS building-integrated information.
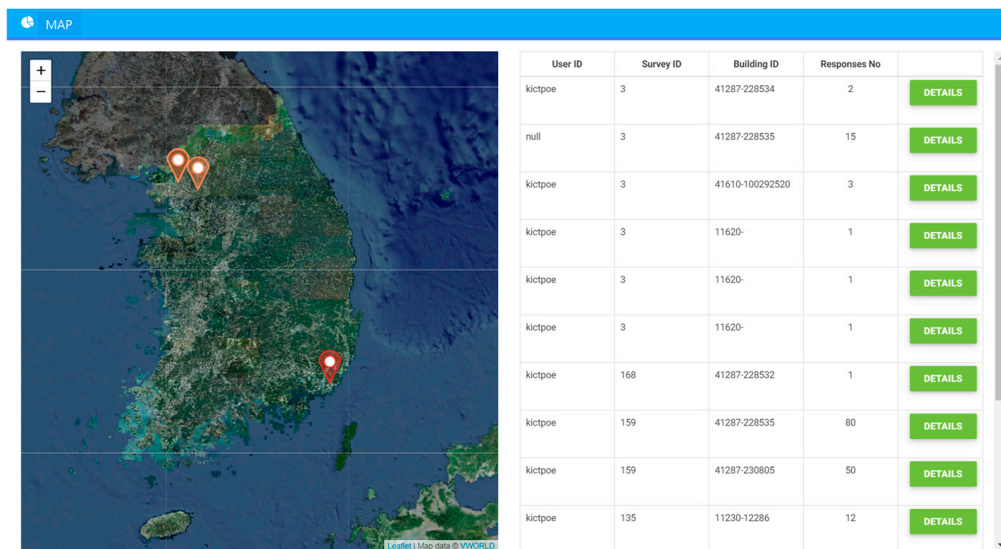

Figure 4. Dashboard screen.

2.4. User-Friendly Functions of K-BOSS

The first screen of this system on the website, as shown in Figure 5, contains the following user-friendly functions: Q&A bulletin board, live chat, document and video clip manual, mobile application link, interactive user guide design.
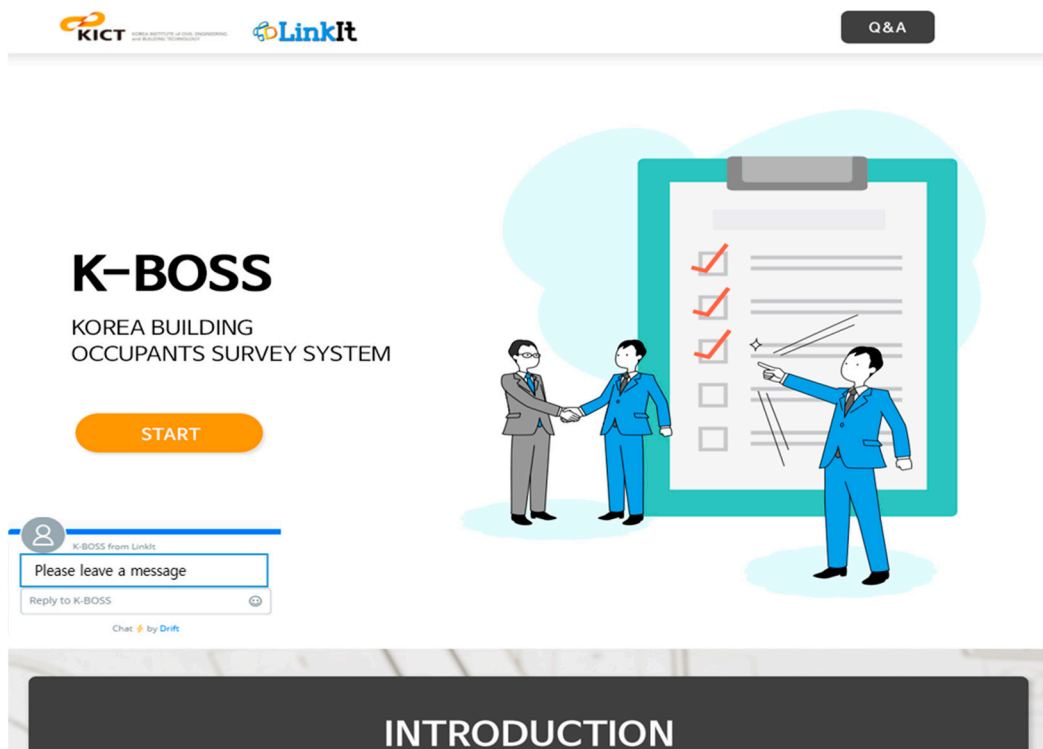

Figure 5. First page of Korean Building Occupant Survey System (K-BOSS).

The functions mentioned above are intended to provide a guide for various stakeholders who can easily use the system as well as for researchers from an academic perspective. The details are as follows:

- Q&A: the Q&A bulletin board is for questions and answers on how to use the system between different users and between users and administrators. Anyone can register inquiries and answers regardless of membership registration. There is a button on the top right of the system. Questions and answers are documented through the Q&A bulletin board for other mid-term users and long-term users.
- Live chat: although the Q&A bulletin board has a history management function in the long term, a live chat function is also applied to respond to immediate questions. Clicking the button at the lower-right corner of the site opens the chat window and allows users to chat with the administrator in real time. Through the live chat, a user can have a one-on-one conversation with the administrator in the system. If users leave inquiries in the chat window, administrators can view and respond to the chats not only on the web page but also on the mobile app. Anyone can enter a live chat without membership. This live chat function is developed as an open source.
- User manual: an instruction video and a document manual have been added to the first main page of the system. The function of selecting the location in a building based on the GIS map provided by K-BOSS is a new concept, so users may find it initially difficult to use this function. Therefore, three video manuals are provided: "Selecting the location and number of floors in my building", "Checking my building on a GIS satellite map", and "Registering photo information" so that users can conveniently use the system. In addition, the system is used by the building managers as well as the occupants, so a manual for the administrators is added.
- Mobile accessibility: the web-based survey system is not only used on the web but is also linked to a mobile application in order to have the expandability to conveniently participate in the survey anytime, anywhere. By clicking the messenger icon at the bottom right of the first webpage, a user can share the page via a messenger application. Users with whom it is shared can access K-BOSS and conduct surveys by clicking on the shared link in the messenger application.
- Interactive user guide design: the system has an interactive user guide design based on Intro.js, an open source that allows web and mobile developers to easily build a step-by-step introduction. This open source is small, which is suitable for cost-effective systems. When clicking on the question mark in each description, it highlights parts of the system as a guide.

2.5. Survey System Open Source and API Interaction Function

The K-BOSS was developed on the basis of WordPress, which has the most users in the world as an open-source content management system. A system for administrators to create, edit, distribute surveys, and for users to participate in the surveys was developed using WordPress' plugin. The plugin is an extension that allows the use of features that WordPress does not provide by default. The plugin can be developed by the developer and installed on WordPress. The modified source code of the plugin provides the survey function to search for an address, and then to select an occupant's location in the building through a map.

In addition, the system can provide its own data through API services to other survey systems. Other survey systems can access the API from K-BOSS and retrieve data from our system. Three types of data can be provided: user API, building API, and response API. The user API is the information provided by the respondents who log in to use and respond to the survey, and response API represents the detailed responses of the occupants who have participated in the surveys. Table 2 lists the details.

Table 2. User application programming interface (API) and response API information.

USER API		RESPONSE API	
Column Name	Description	Column Name	Description
(ID)	**(Table Primary Key)**	**(ID)**	**(Table Primary Key)**
user_login	User ID	m_id	Survey ID (ID of survey table)
user_pass	User Password	m_type	Survey form (form of survey table)
user_name	Username	ip	Survey respondent's IP address
user_email	User Email Address	details	Survey response history-questions and answers
user_url	User Homepage Address	info	Survey respondent's web browser UserAgent information
user_registered	User Registration Time	created_date	Survey participation time

Building API represents the building data retrieved through the Open API from the National Spatial Data Infrastructure Portal, which is a hub for the spatial information published by the Korean government. This Open API uses a GIS building-integrated identification number as the primary key. Among them, the following list in Table 3 is provided through the K-BOSS:

Table 3. Building API information.

BUILDING API	
Column Name	Description
GIS_IDNTFC_NO	GIS building-integrated identification number
SHAPE	Vector file structure used to store the location and attribute information of the points, lines, and faces
SRC_OBJECTID	Raw Figure ID of the continuous cadastral map defined in open DB
PNU	Parcel Serial Number
LD_CPSG_CODE	Administrative district code where the land is located
MNNM	Identification value of the land (first section number)
SLNO	Identification value of the land (second section number)
REGSTR_SE_CODE	Special land code
BULD_PRPOS_CODE	Building use code
STRCT_CODE	Building structure code
AR	Building area
USE_CONFM_DE	Building use approval date
TOTAR	Total floor area
PLOT_AR	Land area
HG	Height
BTL_RT	Building-to-land ratio
MEASRMT_RT	Floor area ratio
BULD_IDNTFC_NO	Unique Building Identification number
VIOLT_BILD	Violation of the building
REFRN_SYSTM_CNTC_NO	Reference system linkage key
LAST_UPDT_DT	Database date

3. Pilot Test

To evaluate the visualization in K-BOSS, pilot tests were conducted with developers and researchers. Diverse and flexible parameters and questionnaires were created for K-BOSS. Specifically, we focused on the fact that "occupant satisfaction" refers to an occupant's subjective evaluation of the residential conditions of a living space. Thus, the evaluations of occupant satisfaction must consider residential environment factors. Many previous studies have classified residential environment factors in terms of physical (climate, temperature, humidity), socio-cultural (geography, ethnicity, psychology), and economic (costs) characteristics [62]. Among these parameters, IEQ, which requires a substantial amount of energy, was found to have the greatest impact on residential satisfaction [63–66]. Thus, this pilot test prioritizes the IEQ survey. Regarding the factors affecting the indoor residential environment studied in existing literature, we identified thermal quality, acoustic quality, lighting quality, and indoor air quality as universal factors affecting the indoor environment quality for evaluating the building's performance [2,67–69]. Thus, this pilot test was performed with K-BOSS to collect information on four indoor environment quality factors. The pilot test was conducted on a seven-point rating scale.

The 3D screens, shown in Figure 6a,b, are visualizations obtained through the pilot test. An M-shaped building in Goyang-si, Korea is shown on a background map and on a satellite map. This building is a five-story building, and information regarding the number of floors is automatically linked from the GIS building-integrated information. As it is difficult to identify the exact floor height, it was assumed that each floor is three meters tall, and the building height is automatically expressed on the map. In Figure 6c, the occupant satisfaction is expressed using small cubic colors by responding to a survey on the IEQ for each floor of the building. The color red indicates that the resident is extremely dissatisfied with the IEQ factors, orange color indicates somewhat dissatisfied satisfaction, and yellow indicates moderate satisfaction. Since the color of the occupant satisfaction level for each floor may not be visible, the building is highlighted in translucent gray.
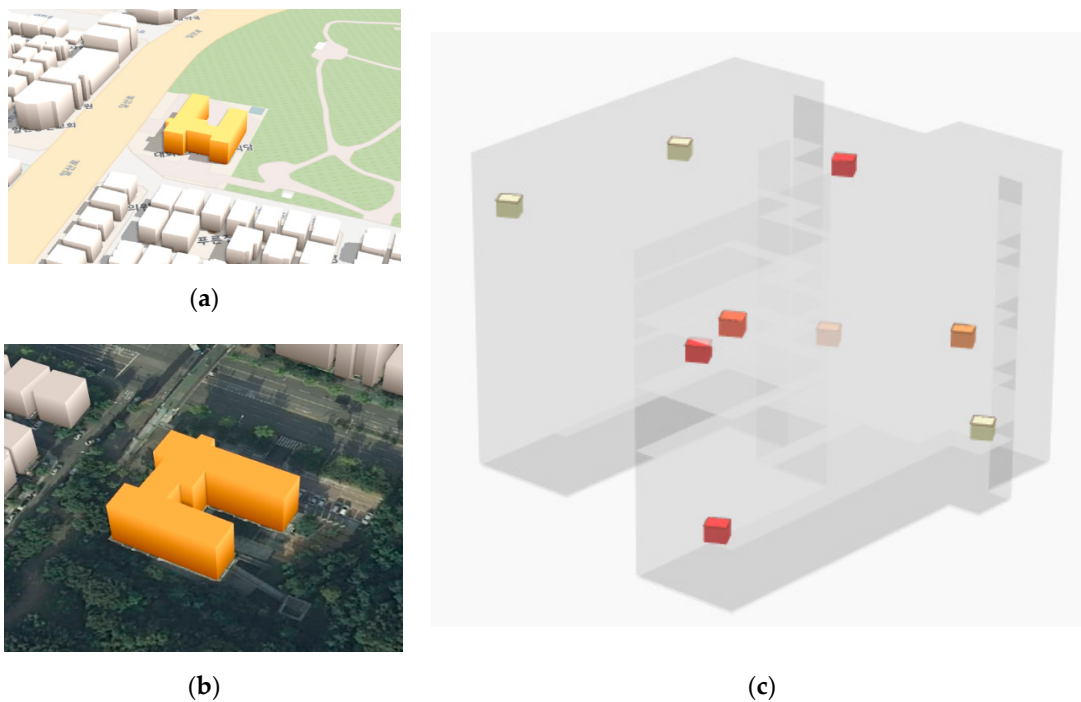

(**a**)

(**b**)

(**c**)

Figure 6. Three-dimensional spatial visualization (**a**) on a background map; (**b**) on a satellite map; (**c**) on an indoor map.

Another pilot test was performed at the International Finance Center Seoul in Seoul city, Korea, with 51 responses for the IEQ factors as shown in Figure 7. All the buildings in the map show the average occupant satisfaction for the IEQ factors. The height of each building was automatically visualized from Open API as described above. Regarding the IEQ factors, buildings with a high occupant satisfaction are colored closer to green, whereas buildings with a low IEQ satisfaction are indicated in red. In addition, a selection box under the map was added to show the average of all IEQ factors and of each of the four factors. For instance, when clicking on the International Finance Center Seoul building, the number of responses, 51, appears in a blue box. The average value of the IEQ factors is expressed as total, and the average value of each of the four IEQ factors is displayed.
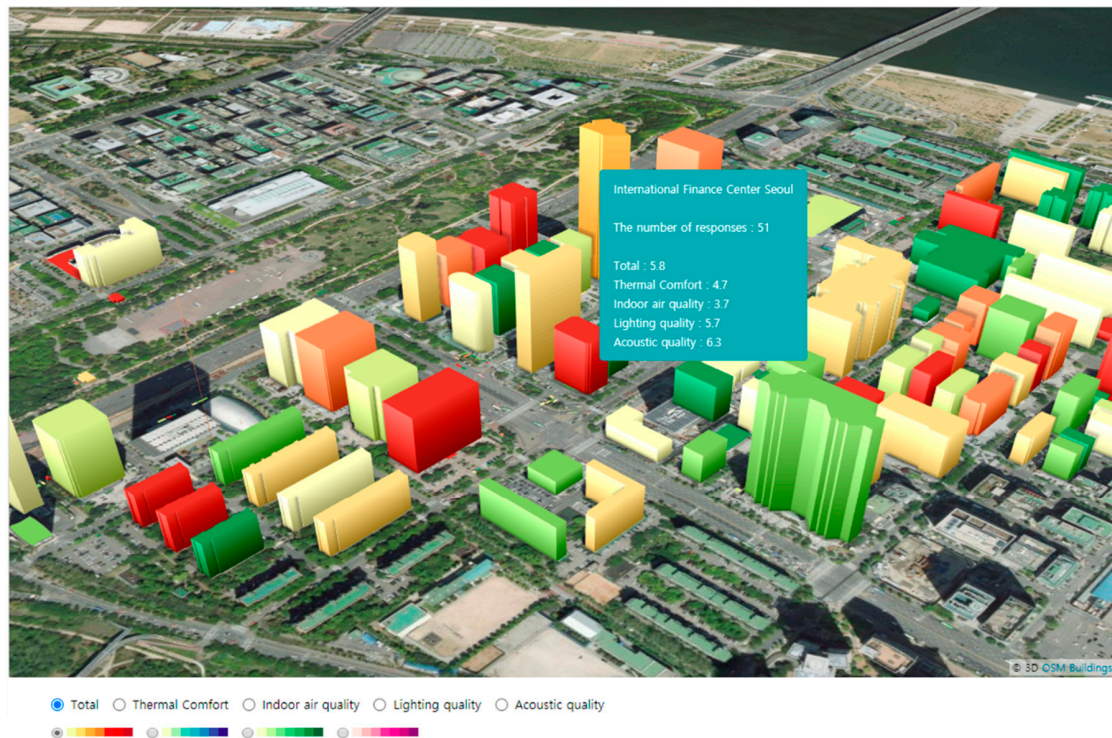
Figure 7. Colorful building 3D visualization.

Specifically, the indoor visualization of the International Finance Center Seoul is as follows: for each floor, when the respondents selected occupant satisfaction for the IEQ factors as an example, the satisfaction level of the IEQ factors was expressed in color up to the 17th floor. Figure 8 shows the average value of the IEQ factors for each floor. Figure 9 shows the satisfaction level on the first and 17th floors in color and the average value of each IEQ factor for each floor in the small box on the right.
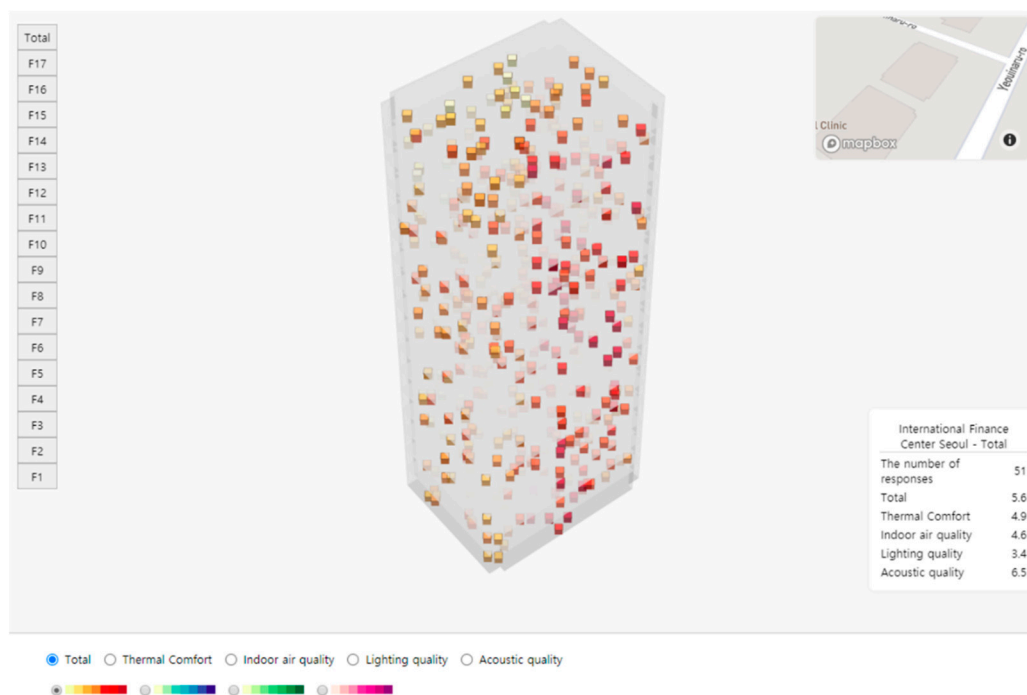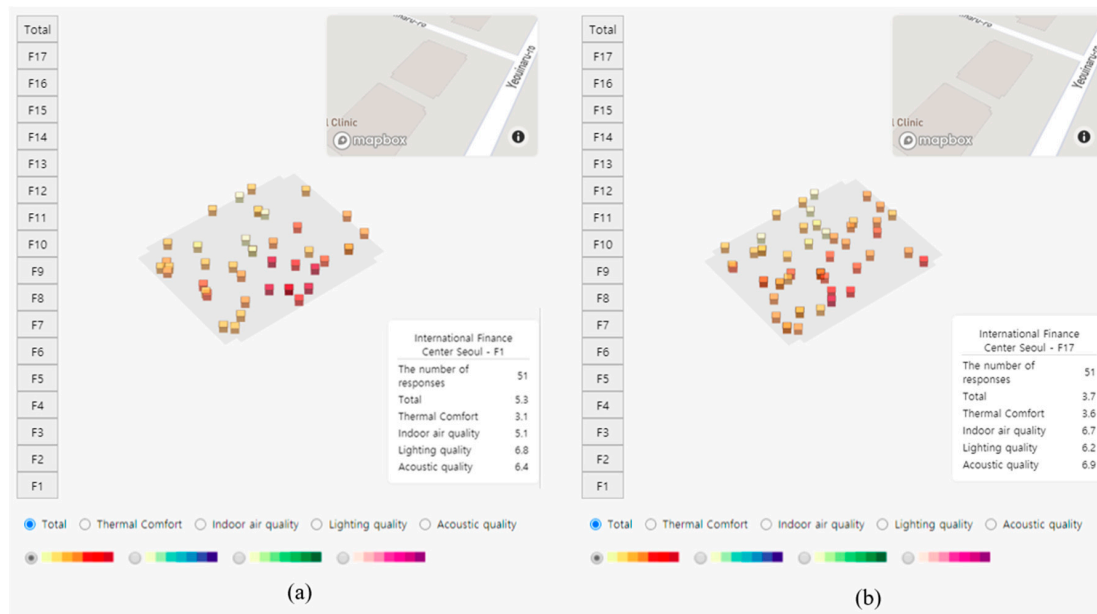

Figure 8. Building indoor visualization.

Figure 9. International Finance Center Seoul indoor visualization: (**a**) first floor, (**b**) 17th floor.

4. Discussion

The difference between this platform and the existing online survey systems is that the survey information is linked to the shapes on the map and the spatial information of the buildings provided by the government. Since the system is linked in the API format, the map and building information of the system are automatically updated when the data provided by the government are periodically updated. This is different from other survey systems that only have a database of occupant feedback. In addition, since this system emphasizes data visualization using GIS and 3D spatial information, it helps to intuitively view information on occupant satisfaction in the buildings and on the map. Specifically, while only the overall occupant satisfaction could be known for each building or floor in other existing systems, this system provides a service that helps analyze specific satisfaction levels for each occupied location by identifying the occupant's x- and y-coordinate information. Furthermore, while other systems with a 2D-based planar maps provide 2D information, our system provides 3D information, so that both horizontal and vertical information of the building can be intuitively known. For example, if an occupant is dissatisfied with the noise problem on the northwest side of the building in each floor, it helps to conclude that there is a noise problem in the northwest direction.

This study also conducted a pilot test and showed cost-effective data visualization. Light open-source libraries can help quickly load diverse functions such as rotation and zoom. Since this system is flexible and changeable regarding the creation of new questionnaires of occupant satisfaction, the IEQ factors can be customized on a 5-point or 7-point scale along with colors. A 3D building was created with latitude and longitude coordinates similar to the polygon coordinate data of the building. Accordingly, it is possible to provide the user with various types of visualization results that can be switched between two dimensions and three dimensions. In other words, a building can be automatically created with only polygonal latitude and longitude coordinates.

5. Conclusions

The paper summarized and analyzed the recent POE studies in view of the importance and capabilities of a new occupant survey system based on GIS tools and open-source spatial information. Furthermore, directions for future POE research reported in recent literature reviews were incorporated in the occupant survey system with the following six categories: (1) from one-off to continuing, (2) from

high-level to detailed, (3) from researchers-oriented to owners/occupants-oriented, (4) from academia to industry, (5) from independent to integrated, (6) design of a flexible survey system.

It is important to develop the Korean Building Occupant Survey System. Compared to the heavy visualization system using BIM [40–43], this quick and cost-effective building occupant survey system is expected to significantly reduce time and costs associated with similar systems. Most importantly, this paper provides detailed used data and a framework development process on how to connect 3D spatial information, so that other developers can follow and use open sources such as OSM and Indoor3D that are available in other countries.

In addition, the collected survey responses provide more intuitive insights for the owner and occupants of the building with data visualization through a web-based survey system. In this study, pilot tests were performed to confirm how 3D data visualization can be well displayed and how well it can assist visual inspection intuitively. Therefore, with the 3D visualization function, building managers and owners can check the building's environmental performance in a short time. Similarly, human resources personnel who wish to conduct a survey on the indoor environment satisfaction of employees can check the employees' feedback for their IEQ. From a long-term perspective, it is expected that policymakers and planners can compare low and high building performance by comparing neighborhoods, as shown in Figure 7, and thus the results of the system can be evidence for helping propose regulations on building performance improvement [70].

However, studies on specific literature analysis and factor selection for the IEQ were not conducted. Thus, it is necessary to conduct research on IEQ factors. In addition, we were unable to suggest a direction for analyzing occupant satisfaction and the visualization displayed vertically. Thus, future studies are needed to conduct a case study of occupants in an actual building to suggest a direction for statistical analysis with 3D visualization.

Author Contributions: Conceptualization, formal analysis, writing—original draft preparation, J.-W.L.; project administration, funding acquisition, S.-E.L.; conceptualization, writing—review and editing, D.-W.K.; writing—review and editing, supervision, J.-W.J. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Corgnati, S.; da Silva, M.G.; Ansaldi, R.; Asadi, E.; Costa, J.; Filippi, M.; Kaczmarcczyk, J.; Melikov, A.; Olesen, B.; Popiolek, Z. *REHVA-Indoor Climate Quality Assessment*; Guidebook No.14; REHVA: Brussels, Belgium, 2011.
2. Frontczak, M.; Schiavon, S.; Goins, J.; Arens, E.A.; Zhang, H.; Wargocki, P. Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. *Indoor Air* **2012**, *22*, 119–131. [CrossRef] [PubMed]
3. Hay, R.; Samuel, F.; Watson, K.J.; Bradbury, S. Post-occupancy evaluation in architecture: Experiences and perspectives from UK practice. *Build. Res. Inf.* **2018**, *46*, 698–710. [CrossRef]
4. Bordass, B.; Cohen, R.; Standeven, M.; Leaman, A. Assessing building performance in use 2: Technical performance of the Probe buildings. *Build. Res. Inf.* **2001**, *29*, 103–113. [CrossRef]
5. Bordass, B.; Cohen, R.; Standeven, M.; Leaman, A. Assessing building performance in use 3: Energy performance of the Probe buildings. *Build. Res. Inf.* **2001**, *29*, 114–128. [CrossRef]
6. Bordass, B.; Leaman, A. Making feedback and post-occupancy evaluation routine 1: A portfolio of feedback techniques. *Build. Res. Inf.* **2005**, *33*, 347–352. [CrossRef]
7. Li, P.; Froese, T.M.; Brager, G. Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. *Build. Environ.* **2018**, *133*, 187–202. [CrossRef]

8.   Duarte Roa, C.; Schiavon, S.; Parkinson, T. Targeted Occupant Surveys: A Novel Method to Effectively Relate Occupant Feedback with Environmental Conditions. CBE Report. June 2020. Available online: https://escholarship.org/uc/item/9sj1c34p (accessed on 25 November 2020).

9.   Pinder, J.; Price, I.F.; Wilkinson, S.J.; Demack, S. A method for evaluating workplace utility. *Prop. Manag.* **2003**, *21*, 218–229. [CrossRef]

10.   Cole, R.J.; Robinson, J.; Brown, Z.; Shea, M. Re-contextualizing the notion of comfort. *Build. Res. Inf.* **2008**, *36*, 323–336. [CrossRef]

11.   Janda, K.B. Buildings don't use energy: People do. *Archit. Sci. Rev.* **2011**, *54*, 15–22. [CrossRef]

12.   Lowe, R.; Chiu, L.F.; Oreszczyn, T. Socio-technical case study method in building performance evaluation. *Build. Res. Inf.* **2018**, *46*, 469–484. [CrossRef]

13.   Preiser, W.F.; Hardy, A.E.; Schramm, U. From linear delivery process to life cycle phases: The validity of the concept of building performance evaluation. In *Building Performance Evaluation*; Springer: Berlin, Germany, 2018; pp. 3–18.

14.   Graham, L.T.; Parkinson, T.; Schiavon, S. Where Do We Go Now? Lessons Learned Form 20 Years of CBE's Occupants Survey. 2020. Available online: https://escholarship.org/uc/item/8k20v82j (accessed on 25 November 2020).

15.   Clements-Croome, D. (Ed.) Post-occupancy evaluation. In *Intelligent Buildings: An Introduction*; Routledge: Abingdon, UK, 2014.

16.   Humphreys, M.A. Field studies of thermal comfort compared and applied. *Build. Serv. Eng.* **1976**, *44*, 5–27.

17.   Tang, H.; Ding, Y.; Singer, B.C. Post-occupancy evaluation of indoor environmental quality in ten nonresidential buildings in Chongqing, China. *J. Build. Eng.* **2020**. [CrossRef]

18.   Newsham, G.R.; Tiller, D.K. A field study of office thermal comfort using questionnaire software. *ASHRAE Trans.* **1997**, *103*, 3–17.

19.   Zagreus, L.; Huizenga, C.; Arens, E.; Lehrer, D. Listening to the occupants: A web-based indoor environmental quality survey. *Indoor Air* **2004**, *14*, 65–74. [CrossRef] [PubMed]

20.   CBE. Occupant Indoor Environmental Quality (IEQ) Survey and Building Benchmarking. 2020. Available online: https://cbe.berkeley.edu/research/occupant-survey-and-building-benchmarking/ (accessed on 25 November 2020).

21.   CBE. Occupant Survey Toolkit. Berkeley, CA: Center for the Built Environment. 2020. Available online: https://cbe.berkeley.edu/resources/occupant-survey/ (accessed on 25 November 2020).

22.   Cohen, R.; Standeven, M.; Bordass, B.; Leaman, A. Assessing building performance in use 1: The Probe process. *Build. Res. Inf.* **2001**, *29*, 85–102. [CrossRef]

23.   Levermore, G.J. Occupants' assessments of indoor environments: Questionnaire and rating score method. *Build. Serv. Eng. Res. Technol.* **1994**, *15*, 113–118. [CrossRef]

24.   Candido, C.; Kim, J.; De Dear, R.; Thomas, L. BOSSA: A multidimensional post-occupancy evaluation tool. *Build. Res. Inf.* **2016**, *44*, 214–228. [CrossRef]

25.   Dykes, C.; Baird, G. A review of questionnaire-based methods used for assessing and benchmarking indoor environmental quality. *Intell. Build. Int.* **2013**, *5*, 135–149. [CrossRef]

26.   Candido, C.; Dear, R.; Thomas, L.; Kim, J.; Parkinson, T. *Introducing BOSSA: The Building Occupants Survey System Australia'*; Ecolibrium: Melbourne, Australia, 2013.

27.   Finley, R. *SurveyMonkey*; SurveyMonkey: San Mateo, CA, USA, 2019.

28.   Qualtrics, L.L.C. *Qualtrics: Online Survey Software & Insight Platform*; Qualtrics Labs, Inc.: Provo, UT, USA, 2014.

29.   Google. *Google Forms: Free Online Surveys for Personal Use*; Google: Mountain View, CA, USA, 2019. Available online: https://www.google.com/forms/about/ (accessed on 25 November 2020).

30.   Parkinson, T.; Candido, C.; de Dear, R. 'Comfort Chimp': A MultiPlatform IEQ Questionnaire Development Environment. In Proceedings of the 11th REHVA World Congress and 8th International Conference on IAQVEC, Prague, Czech Republic, 16–19 June 2013.

31.   Parkinson, T.; Parkinson, A.; de Dear, R. Continuous IEQ monitoring system: Performance specifications and thermal comfort classification. *Build. Environ.* **2019**, *149*, 241–252. [CrossRef]

32.   Parkinson, T.; Parkinson, A.; de Dear, R. Introducing the SAMBA indoor environmental quality monitoring system. *Living Learn* **2015**, 1139–1148.

33.   de Dear, R.; Kim, J.; Parkinson, T. Residential adaptive comfort in a humid sub- tropical climate—Sydney Australia. *Energy Build* **2018**, *158*, 1296–1305. [CrossRef]

34. Nian, F.Z.; Wang, K.; Zhao, Q.C. Research on indoor environmental comfort based on complaints. *Int. J. Innov. Comp. Inf. Control* **2017**, *13*, 1323–1333.

35. Geng, Y.; Ji, W.; Wang, Z.; Lin, B.; Zhu, Y. A review of operating performance in green buildings: Energy use, indoor environmental quality and occupant satisfaction. *Energy Build.* **2019**, *183*, 500–514. [CrossRef]

36. O'Brien, W.; Schweiker, M.; Day, J.K. Get the picture? Lessons learned from a smartphone-based post-occupancy evaluation. *Energy Res. Soc. Sci.* **2019**, *56*, 101224. [CrossRef]

37. Day, J.K.; Ruiz, S.; O'Brien, W.; Schweiker, M. Seeing is believing: An innovative approach to post-occupancy evaluation. *Energy Effic.* **2020**. [CrossRef]

38. Xia, J. *Visualizing Occupancy of Library Study Space with GIS Maps*; New Library World: Cambridge, UK, 2005.

39. Göçer, Ö.; Hua, Y.; Göçer, K. Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance. *Build. Environ.* **2015**, *89*, 14–27. [CrossRef]

40. Göçer, Ö.; Hua, Y.; Göçer, K. A BIM-GIS integrated pre-retrofit model for building data mapping. *Build. Simul.* **2016**, *9*, 513–527. [CrossRef]

41. Göçer, Ö.; Göçer, K.; Karahan, E.E.; Oygür, I.İ. Exploring mobility & workplace choice in a flexible office through post-occupancy evaluation. *Ergonomics* **2018**, *61*, 226–242.

42. Göçer, Ö.; Göçer, K.; Başol, A.M.; Kıraç, M.F.; Özbil, A.; Bakovic, M.; Siddiqui, F.P.; Özcan, B. Introduction of a spatio-temporal mapping based POE method for outdoor spaces: Suburban university campus as a case study. *Build. Environ.* **2018**, *145*, 125–139.

43. Hua, Y.; Göçer, Ö.; Göçer, K. Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platinum campus building. *Build. Environ.* **2014**, *79*, 124–137. [CrossRef]

44. Chrisman, N.R. *Exploring Geographic Information Systems*; Wiley: New York, NY, USA, 1997.

45. Demers, M.N. *Fundamentals of Geographic Information Systems*; Wiley: New York, NY, USA, 1997.

46. Nichol, J.E. Monitoring Singapore's microclimate. *Geo-Info-System* **1993**, *3*, 51–55.

47. Ning, G.; London, K. Understanding and facilitating BIM adoption in the AEC industry. *Autom. Constr.* **2010**, *19*, 988–999.

48. Porwal, A.; Hewage, K.N. Building information modeling (BIM) partnering framework for public construction projects. *Autom. Constr.* **2013**, *31*, 204–214. [CrossRef]

49. Ozturk, Z.; Arayici, Y.; Coates, P. *Post Occupancy Evaluation (POE) in Residential Buildings Utilizing BIM and Sensing Devices: Salord Energy House Example, Tuesday 24 Jan e Thursday 26 Jan, 2012*; The Lowry: Greater Manchester, UK, 2012.

50. Motawa, I.; Corrigan, W.; Architects, W.S. *Sustainable BIM-Driven Post-Occupancy Evaluation for Buildings*; CIC Start Feasibility Study: Glasgow, Scotland, 2012; pp. 1–12.

51. Motawa, I.; Carter, K. Sustainable BIM-based evaluation of buildings. *Procedia Soc. Behav. Sci.* **2013**, *74*, 419–428. [CrossRef]

52. West, J.; Dedrick, J. Open source standardization: The rise of Linux in the network era. *Know. Technol. Policy* **2001**, *14*, 88–112.

53. West, J. How open is open enough: Melding proprietary and open source platform strategies. *Res. Policy* **2003**, *32*, 1259–1285. [CrossRef]

54. Sanchez Leitner, D.; Christine Sotsek, N.; de Paula Lacerda Santos, A. Postoccupancy evaluation in buildings: Systematic literature review. *J. Perform. Constr. Facil.* **2020**, *34*, 03119002. [CrossRef]

55. Leaman, A.; Bordass, B. Are users more tolerant of 'green' buildings? *Build. Res. Inf.* **2007**, *35*, 662–673. [CrossRef]

56. Kim, H.G.; Kim, S.S. Occupants' Awareness of and Satisfaction with Green Building Technologies in a Certified Office Building. *Sustainability* **2020**, *12*, 2109. [CrossRef]

57. Lee, J.; Shepley, M. Analysis of human factors in a building environmental assessment system in Korea: Resident perception and the G-SEED for MF scores. *Build. Environ.* **2018**, *142*, 388–397. [CrossRef]

58. Jong-Won, L.; Deuk-Woo, K.; Seung-Eon, L. Research on comparison and analysis of online occupant satisfaction survey system focusing on post-occupancy evaluation. *J. Korean Inst. Archit. Sustain. Environ. Build. Syst.* **2019**, *13*, 580–589.

59. Leaflet—A JavaScript Library for Interactive Maps. Available online: https://leafletjs.com (accessed on 21 October 2020).

60. OpenLayers—Welcome. Available online: https://openlayers.org (accessed on 21 October 2020).

61. Proj4js by proj4js. Available online: http://proj4js.org (accessed on 21 October 2020).
62. Park, J.-O.; Jung, T.-S.; Sung, M.-Y. A study on the residential environment satisfaction of apartment complex. *J. Korea Real Estate Soc.* **2009**, *27*, 223–240.
63. Kats, G.; Alevantis, L.; Berman, A.; Mills, E.; Perlman, J. *The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force*; Massachusetts Technology Collaborative: Boston, MA, USA, 2003; p. 134.
64. Pyke, C.; McMahon, S.; Dietsche, T. *Green Building & Human Experience Testing Green Building Strategies with Volunteered Geographic Information*; US Green Building Council Research Program White Paper: Washington, DC, USA, 2010.
65. Wilson, A. Productivity and Green Buildings. *Environ. Build. News EBN* **2004**, *13*, 10.
66. Wargocki, P.; Seppänen, O.; Andersson, J.; Boestra, A.; Clements-Croome, D.; Fitzner, K.; Hanssen, S.O. *Indoor Climate and Productivity in Offices: How to Integrate Productivity in Life Cycle Costs Analysis of Building Services*, Guidebook 1st ed.; REHVA: Brussels, Belgium, 2006.
67. Olesen, B.W.; Costa, J.J.; Wargocki, P.; Popiolek, Z.; Kaczmarczyk, J.; Asadi, E.; Filippi, M.; Ansaldi, R.; Melikov, A.K. *Indoor Climate Quality Assessment*; Guidebook No.14; REHVA: Brussels, Belgium, 2011.
68. Olesen, B.W. Revision of EN 15251: Indoor environmental criteria. *REHVA J.* **2012**, *4*, 6–12.
69. Webster, T.; Heinzerling, D.; Schiavon, S.; Anwar, G.; Dickerhoff, D. A Prototype Toolkit for Evaluating Indoor Environmental Quality in Commercial Buildings. 2013. Available online: https://escholarship.org/uc/item/12z3z69c (accessed on 25 November 2020).
70. Yang, T.; Zhang, X. Benchmarking the building energy consumption and solar energy trade-offs of residential neighborhoods on Chongming Eco-Island, China. *Appl. Energy* **2016**, *180*, 792–799. [CrossRef]