Supporting Post-Occupant Evaluation through Work Order Evaluation and Visualization in FM-BIM

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Abstract –

The application of BIM and data analytics in facility management is an area of growing interest and research. The ability to mine data from occupant complaints in real-time and visualize this at the building and building cluster scale provides new opportunities for facility managers to more effectively respond to occupant complaints and optimize the performance of the building. A project is currently underway at Ryerson University in collaboration with the facility management team to mine data from work orders and develop a comprehensive visualization strategy for FM-BIM integration. This paper presents the development of mapping and data visualization strategies to support the identification of priority areas and extraction of key occupant satisfaction trends. Key visualizations and BIM integration protocols from the campus deployment are presented and discussed to identify applicability of this data to support post-occupancy evaluation, limitations, and opportunities for further expansion and refinement.

Keywords –

Post-Occupant Evaluation, Work Order, BIM, Facility Management, Visualization, Operations & Maintenance

1 Introduction

People spend 80% of their lives indoors, where indoor environmental quality has significant effects on occupant comfort, productivity, and well-being. At the same time, buildings use approximately 40% of total energy globally, with the majority of this use – and associated cost - associated with day-to-day operations [1]. Within this context, Post-Occupancy Evaluations (POEs) are increasingly recognized as providing significant value to both increase occupant comfort and decrease energy and operations costs. Studies have found that buildings rarely perform as expected during occupancy, requiring intervention [2]. Despite this, POE is rarely effectively used in practice [3] and adoption rates remain low [4]. The motivation for this research is to develop strategies to support POE through the evaluation of already-collected data (work orders) to increase this adoption rate.

While there is little consensus regarding the definition of POE [4], several elements are commonly considered within the scope of such studies: indoor air quality (IAQ), indoor environmental (thermal, acoustic, visual & spatial) quality, space functionality, asset condition, cleanliness, aesthetics, sound privacy, workspace & building features, occupant behaviour, occupant health & safety, and user satisfaction/comfort [5-10]. User surveys are the most common source of information for POEs [5], and are often combined with in-situ measurements to contextualize user responses [3, 7].

The increasing adoption of Building Information Modelling (BIM) within the Facility Management (FM) context provides a significant opportunity to integrate a multitude of building information of value to POE studies. There have been several significant studies, for example [11-13] exploring the benefit of BIM within the FM context, and this body of research is well-summarized in recent literature reviews [14, 15]. A number of case studies [16-20] demonstrate the development of such models. Of specific relevance to this paper, Akcamete *et al.* [21] linked work order information with BIM in spaces to allow spatio-temporal analysis of maintenance history to support operations; this work focused primarily on maintenance costs and issue frequency but did not consider occupant experience directly. Motawa and Almarshad [22] developed a case-based reasoning system to create knowledge from work order information. Shoolestani *et al.* [6] developed SocioBIM to enable user comments and feedback on building condition and occupant concerns, which could be read by other users and the FM team. Gerrish *et al.* [23] integrated building management systems (BMS) with BIM to develop a dashboard but found unstructured data very difficult to integrate. To overcome this unstructured data issue, machine learning was used by Raghubar *et al.* [14] to automatically classify work orders by complaint type and map these to an FM-BIM using techniques developed by Khaja *et al.* [24].

Few studies have linked BIM with POE, notably the work of Göçer *et al.* [3, 9] who created a GIS and BIM-enabled platform to support bi-directional communication between FM teams and users and created a series of supporting BIM visualizations of POE survey results. This paper responds to existing research gap of POE integration within BIM [5] and presents strategies for leveraging maintenance work orders to enhance and complement POEs. An FM-BIM integration approach is integral to implementation, providing an information management framework and visualization capacity. A set of sample visualizations from a current case study demonstrates the application of these strategies.

2 Methodology

The development of the POE-BIM integration for the case study (a university campus) consisted of six steps: (1) documentation of POE information requirements; (2) review of work order content and alignment with POE inputs; (3) storyboarding of potential visualizations; (4) development of the necessary data structure to support FM-BIM integration; (5) data mapping; and (6) visualization creation.

When analyzed and organized correctly, work orders provide a large database that enables increasing evolution of Computer-aided FM (CAFM). Generally, previous research has described three approaches to POE: indicative, investigative, and diagnostic. A work order system that is intrinsically diagnostic and lends itself to supporting diagnostic POEs, has the potential to permit targeting of investigative POE toolkits in problem areas and provide justification for such future investment.

Work orders intrinsically provide strictly negative feedback as users are motivated by dissatisfaction to report issues. As a result, work orders must be understood as first indicating those areas where dissatisfaction exceeds a threshold for the user, thus only identifying priority areas; areas without significant issues will be indicated only by a lack of comment. Because of this nature of the input data, dissatisfaction was developed as the primary metric for such diagnostics.

Prior to defining a data structure for the POE information, the visualization concept was storyboarded to determine how this information could be most effectively integrated and presented for FM use. This strategy is central to user-centered design practice of Human-Machine Interfaces (HMIs) [25] to allow end-users to provide feedback on potential visualizations.

Once the information requirements and visualization concepts were developed, the supporting data structure was created to host the required information. Because all occupant-reported work orders are logged by room by the CAFM system, rooms were deemed the most appropriate hosts. Data mapping was achieved using Python coding in Dynamo, similar to the approach presented in previous studies [23, 24]. Visualizations were then developed using HMI design best practices from industry [26, 27] and academic literature [28, 29, 30]. The data source used for test deployment are the campus work orders from 07/2015 through 12/2017.

3 Work Order and POE Alignment

3.1 Information Required to Support POEs

The ‘essence’ of POE has been discussed using terms such as health, safety, security, functionality, cleanliness, asset condition, satisfaction, and comfort. The first three are best defined by the presence of alarms, incident reports, and security system information, which can all be integrated in an FM-BIM, but this is beyond the scope of this initial study. Acoustic, thermal, visual, and indoor air quality [5] define the indoor environmental quality (IEQ) of a space and address the latter two categories while reports of broken fixtures, furniture and equipment (FFE) and custodial and groundskeeping requests indicate compromised functionality and condition issues (covering both maintenance and cleanliness) of specific elements within the space.

3.2 Information Generated by Work Orders

A machine-learning enabled work order reporting system is being deployed that automatically classifies work order types [31] and prompts building occupants with follow-up questions during issue reporting. These questions, developed by the FM team, provide the necessary input to both enable engineers to quickly identify problem causes and deploy the necessary personnel to resolve the issue. A sample of these categories and associated questions is shown in Figure 1.

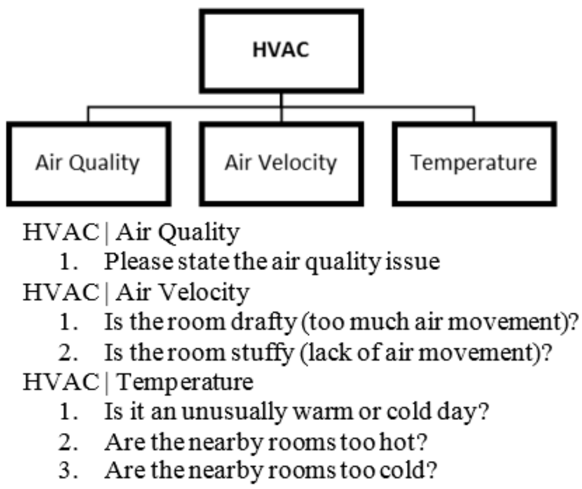

Figure 1. Work order classification structure and selected follow-up questions

This enhanced work order reporting system will allow a greater structure of information regarding occupant complaints to be obtained. Alignment with POE requirements is defined by six dissatisfaction subcategories: thermal, acoustic, IAQ, visual, condition, and functionality. These are presented alongside relevant work order categories and the information that can be gleaned from the enhanced system in Table 1. The sum of the dissatisfaction category scores is defined as the *Occupant Dissatisfaction* (OD), which serves as an overall metric and provides a basis for prioritization.

4 FM-BIM Integration

There are two key benefits to integrating POE diagnostic information into an FM-BIM. First, the multi-dimensional (nD) nature of BIM intrinsically supports data management and visualization necessary for spatio-temporal analysis of semantics. Second, complementary use cases executed in FM-BIMs such as space management, equipment characteristics and repair histories, and building automation system (controls and sensors) information, provide additional information on users, equipment, and measured space conditions, respectively, contextualizing complaints.

The FM-BIM integration consists of two key steps: pre-processing work orders to calculate dissatisfaction scores for each space over time, and mapping algorithms to integrate these score histories into the FM-BIM.

The pre-processing first uses a series of logical relationships based on the Table 1 alignment to assign a score of 1 (aligns) or 0 (does not align) for each dissatisfaction metric. Work orders are then sorted by metric. Since user complaints are reported by location, rooms are the most appropriate hosts for dissatisfaction data. Input arrays for the BIM are created such that each column includes data for the room while rows provide time series data in reverse chronological order. Each array is then saved as a comma-separated value (csv) file named for the metric type, e.g. thermal.csv. The monthly average based on two years of historical data is also calculated for each metric to provide a historical baseline for FM team reference and is saved as a separate baseline file.

FM-BIM mapping requires that a set of parameters for both monthly counts ({Thermal, Visual, IAQ, and Acoustic Dissatisfaction, Functionality, Condition} as integers), and baseline values ({same set} as numbers) to be created and mapped to rooms, levels, and buildings. Using a modification to the technique developed in [24], Dynamo is used to populate these parameters. For a given time selected, the appropriate row is identified and the mapping algorithm creates a vector of parameter values for each room. This data structure supports the integration of customized slider in the visualizations to permits navigation through time. The Dynamo script and code blocks (developed in Python) support this functionality and are presented in Figure 2.

Table 1. Work Order and POE Alignment

POE Category	POE Information Required	Work Order Category	Information generated by work order system
Acoustic Comfort	Type of Disturbance Disturbance Frequency	NOISE (all)	Description of noise Extent of complaint (spatial, temporal)
Thermal Comfort	Thermal Complaint, Draftiness	HVAC | Temperature HVAC | Air Velocity	Too hot or too cold Extent of complaint (spatial, temporal) Too much/not enough air movement
Indoor Air Quality (IAQ)	Air Quality, Freshness/Stuffiness	HVAC | Air Quality	Too much air movement (Drafty) Lack of air movement (Stuffy) Air quality description
	Olfactory Discomfort	ODOR (all)	Odor description, source (if known), Duration of complaint
Visual Comfort	Lighting Quality; Glare	LIGHTING (all) FFE | Coverings GRAFFITI	Lights burned out or flickering; Glare from non-functioning blinds or missing lens; Graffiti
Functionality	Broken Equipment	FFE | Fixture PLUMBING | Fixture	Details of broken or malfunctioning fixture(s) and equipment
Condition	Indications of spaces requiring cleaning, indications of wear, or poor asset condition	CUSTODIAL (all); PLUMBING | Leak; FFE | Paint	Reports of stains, graffiti, spills, etc. as well as leaks and other condition-related issues

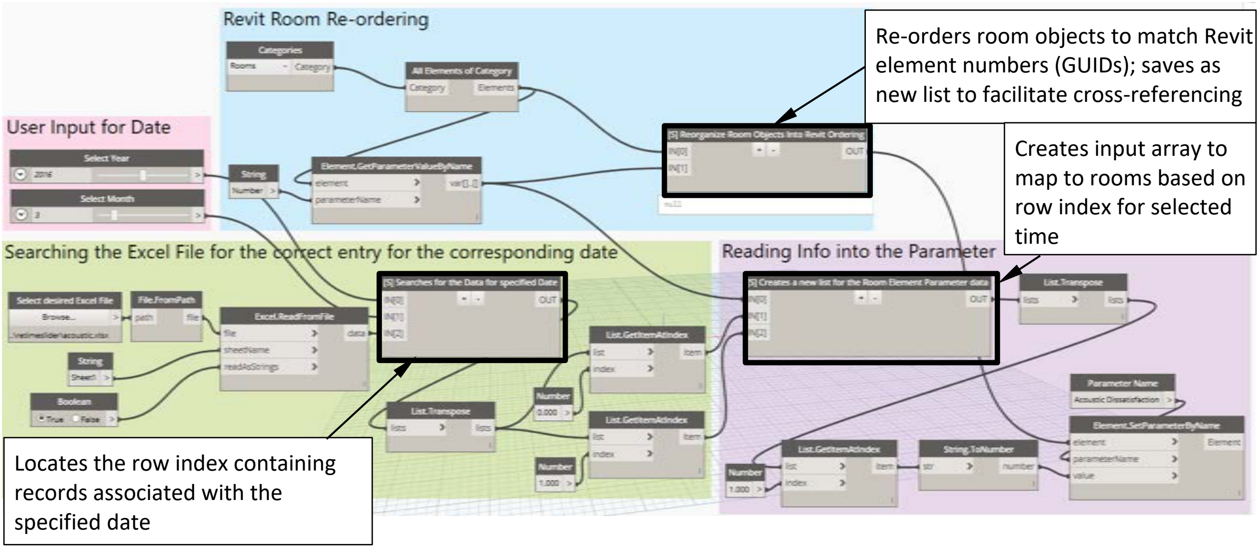

Figure 2. Dynamo script to execute time navigation and supporting code functions

5 Visualization Strategy

There has been significant research within the process control domain to developing effective human machine interfaces (HMIs). To develop the visualization strategy, HMI best practice from both academic literature [25, 29, 30] and industry guidelines [26, 27], including principles of user-centered design, were considered.

5.1 Priority Identification

In order to improve the AAG ability of CAFM systems, the proposed visualization strategy will incorporate a priority identification chart that will map, 1) worst buildings, 2) worst building levels, 3) number of open POE-related complaints for the selected time, and 4) top complaint data categories. The first two comparisons in the priority identification chart use OD (total complaints) metrics to develop these ranks, but individual dissatisfaction metrics can be selected using a toggle function.

5.2 Temporal Analysis

The dashboard will allow the user to select the desired timeframe to show OD and the associated category metrics for the area under consideration. By displaying the current (rolling window) value of these metrics along with average values from a three-year period as illustrated in Figure 3, it is readily apparent to the FM team whether the current frequency of complaints is (a) consistent (b) noticeably above, or (c) noticeably below historic values.

5.3 Spatial Analysis

Where full 3D geometry exists for FM-BIMs, 3D visualizations of the building(s) under consideration provide insight on potential causes. For example, a high window-to-wall ratio could explain significant thermal comfort issues within a particular space. Providing level totals for each of the POE dissatisfaction metrics allows the priority level(s) in a building to be identified quickly.

In all cases, 2D representation (floorplans), color-coded by semantic parameter (nD) data providing POE information are used as the primary navigation interface. Following published guidance [26, 29] a neutral (white) background is used for all floorplans and increasing color saturation – associated with each individual metric – indicates a higher dissatisfaction value.

5.4 Spatio-temporal Representation

Visualization of issue clustering in both space and time provides benefit to the FM team by simultaneously showing clusters of rooms with common issues as well as complaint clusters at individual points in time. The time navigation slider described previously permits near-real-time navigation of historical data. This functionality draws from a data consolidation and mapping architecture developed under a related project [32] to create the necessary time-series arrays for FM-BIM integration.

6 Case Study Implementation

The central theme of user-centered design is to actively engage the end-user, focusing on understanding their needs and priorities, and developing prototypes and mock-ups to gain input at each iteration [25], similar to the Agile [33] process used to develop the FM-BIM at the case study campus [34]. The following priorities were communicated by the Facility Engineers related to prioritization: (1) immediate identification of the most problematic areas; (2) visualization of clusters of issues within buildings and an understanding of these issues over time; and (3) the ability to differentiate between types of issues and their distributions. The support of root cause analysis of these complaints is a long-term goal but is beyond the scope of this study; at this time, this analysis is related to seasonal and other temporal effects.

To address the need to identify priority areas, a hierarchy of views [26] are required: 1) room, 2) level, 3) building, and 4) multi-building comparison (where applicable). Along the top of the screen is the navigation bar to indicate the current scale and permit navigation to other scales. A common conceptual layout is used for each scale. The HMI (Figures 3-5) displays the highest priority areas in the leftmost pane, with a visual of the worst areas based on *OD* (top left), tables listing the OD scores and top complaint types (middle left) and graph indicating breakdown by type of issue (bottom left). The top right pane indicate the current scores by dissatisfaction metric on a gradient metric where the center of the metric (grey) is the baseline value, increasing to red for higher scores and to green for lower scores. The bottom right quadrant shows the navigation through time and permits the user to select a value type (current value, total over range, average over range) and metric for the area selected using the time slider described previously and displays values for each subspace. Increasing color saturation and consistent colors indicate increasing metric scores [26]. At the building cluster level (Fig 3), this is a map showing each building total.

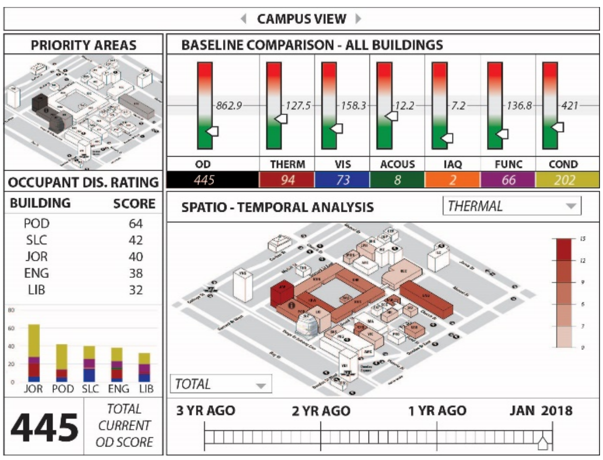

Figure 3. Sample campus-level navigation

This campus-level navigation could support several FM tasks. The top bar provides a real-time summary of campus issues compared to the baseline, allowing the FM team to quickly contextualize the individual results. From the leftmost pane, the FM team can readily identify buildings of concern for further investigation. For example, POEs are being planned for selected buildings across the campus. The campus map illustrated quickly provides a visual indication of the most critical buildings requiring further investigation due to high levels of occupant dissatisfaction. The integration of the time slider extends this visualization into four dimensions, providing insight into seasonal issues and facilitating identification of regular patterns of complaint. Key areas of improvement such as necessary HVAC plant upgrades serving multiple buildings would be informed by patterns of summer overheating and winter undercooling.

Navigating to the building level (Fig 4), the visualization format is retained, however the 2D representation of multiple levels in the building is not immediately user legible, and thus a column graph replaces this visualization. The user can select which metric to display, or whether to display the total OD using a stacked column graph made up of the individual dissatisfaction metrics.

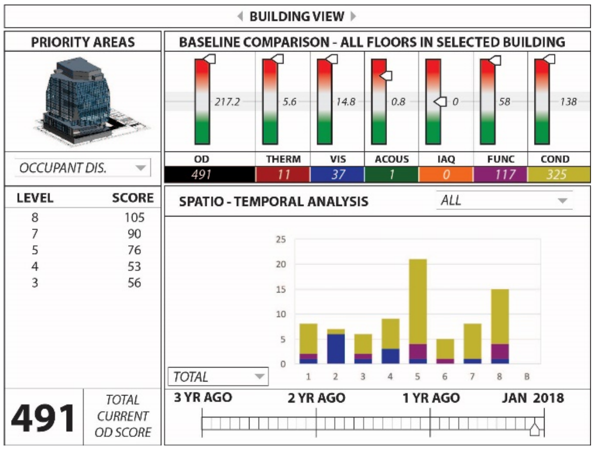

Figure 4. Sample building-level navigation

This view provides the FM team with insight on potential floor-level clustering of complaints. If one floor has a much higher level of dissatisfaction than others, it permits further POE prioritization within a building of concern identified from the campus visualization, and thus enable specific targeting of problem areas. This view also begins to provide insight on large-scale issues causing widespread discomfort or dissatisfaction. For example, high levels of visual discomfort could be caused either by problems with a lighting panel, as these typically serve an entire floor, or due to high levels of solar glare (or low levels of available daylight) in different locations within the building. Thermal and IAQ issues clustered on floors could indicate poor control of zoned equipment, while functionality issues could signal water pressure challenges. Finally, a high condition dissatisfaction score could inform either a custodial services audit to ensure that those floors are being adequately cleaned, or a targeted building condition assessment, depending on the underlying work orders. Given that each work order is flagged to any associated dissatisfaction score(s), queries using these terms would help narrow down underlying causes of clustered complaints.

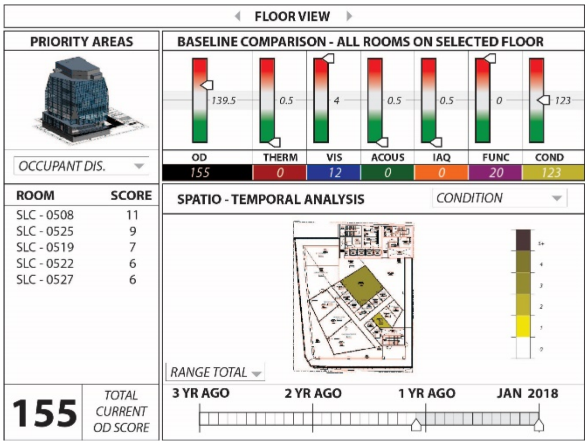

Figure 5. Sample floor-level navigation

The dashboard floor view (Fig. 5) returns to the map view, using the floor plan and colouring data by room, permitting Facility Managers to quickly identify problematic rooms or room clusters within the building. A room-level display has not been created; rather, the FM could refer to the FM-BIM for specific room and local equipment information at this scale. The latter is illustrated in Figure 6, which overlays truncated room and space views for the highlighted room in a real FM-BIM model.

The floorplan view supports similar functionality as the preceding views but with increased granularity. Specific rooms can be identified at this level, permitting a targeted response through reactive maintenance or interaction with the room occupant. The effectiveness of building retrofits or equipment replacement could be assessed by determining whether such action has resulted in a decrease in complaints, or vice versa. Similar conclusions can be drawn regarding the effectiveness of changes in control strategies or maintenance practices. Within the floor, clustering of problems within an area – for example the southwest corner of a building – could indicate faulty equipment, poor building condition in that area, zoning issues, or other underlying causes not evident without this graphical display. Seasonal patterns also become much more visible to FM team with this approach.

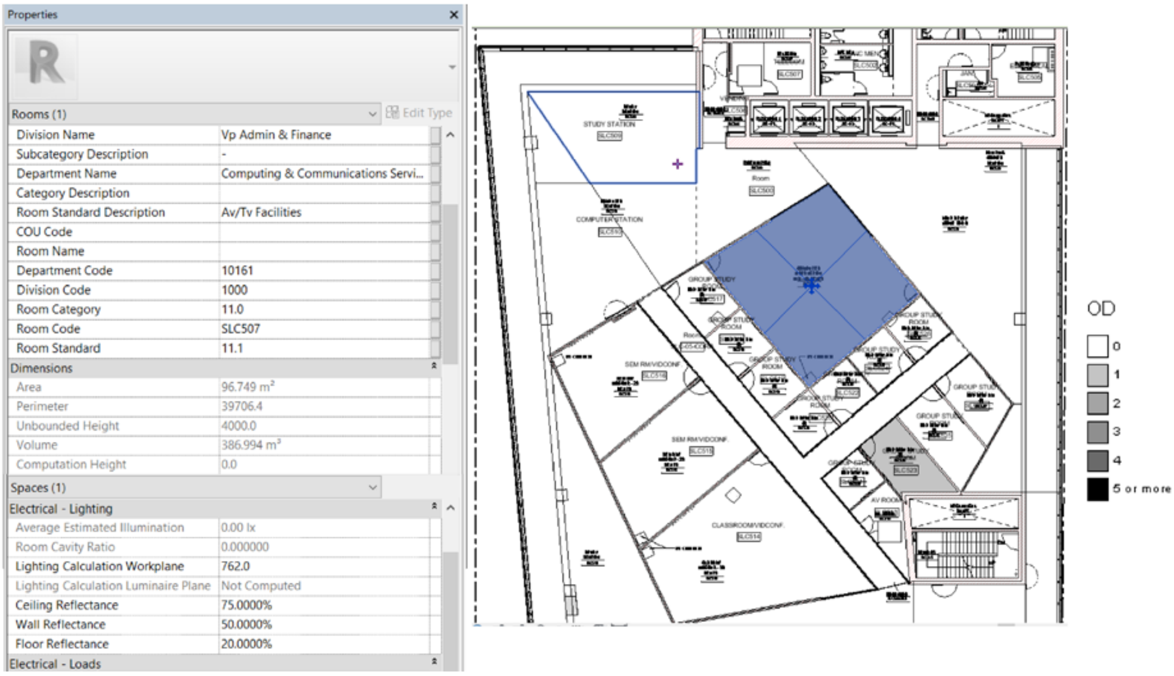

Figure 6. FM-BIM showing room-level information and integration of POE with building automation and other building data

7 Discussion and Conclusions

Given the known impact of the indoor environment on occupant health and productivity, post-occupancy evaluation is a topic of increasing significance.

The case study demonstrates that it is possible to extract relevant data from work orders of relevance to post-occupancy evaluations. Such data indicates the frequency of a high level of dissatisfaction – enough to compel a user to take action and report a complaint – which, in turn, identifies priority areas for intervention and for the deployment of a complete POE study. The data can also support POEs by providing longer-term insight on the frequency and type(s) of complaints reported by space users. By mapping this information into an FM-BIM, it can be readily overlaid with the broader building information, allowing the FM team to understand these complaints in the context of broader building operational parameters, for example current system performance (building automation system point data), equipment condition, and space management.

The conceptual visualizations presented leverage the inherent geometric, time, and semantic data management capability of BIM, and integrate best practices from HMI to provide increasingly detailed navigation through the sample campus and building through a series of dashboards (Fig 3-5).

While the pre-processing logic can be automatically applied to the work order data, this processing occurs in batches in a spreadsheet (Excel); future research will import this algorithm into Dynamo to integrate and fully automate this process. Further, the use of work order categories permits false positive classification and natural language processing algorithms to score dissatisfaction metrics of work orders automatically based on work description text is an avenue of future research to improve the specificity of this mapping and reduce misclassification. Further refinements of the visualizations informed by the test case would include more integration with the BIM and work order system to allow the text of specific work orders (lists at the building, floor, and room levels) to be readily accessed through this interface rather than simple totals. A second refinement would be to allow a side-by-side comparison of different times or ranges of time rather than the single views currently supported.

The single context demonstration is the major limitation of this study. Future research involving new case studies will permit rigorous testing and generalization, while POEs informed by resultant work order visualizations would provide further insight into visualization refinement. The resultant data would support development of a refined work order reporting strategy incorporating POE-supporting questions and mine the data generated to support root case analysis and enhance the decision-making value of this approach.

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