A Facility Management System with Complaint Processing Using AR and BIM Integration

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***Abstract*—Effective management of a facility is arguably one of the most pressing maintenance challenges leading to unpleasant experience and squandered resources worldwide. General issues, complaints, or feedback reported by occupants often lack a common structure and are devoid of the spatial data and digital records necessary for effective analysis and solution provision. In this study, we propose the use of Building Information Models (BIM) integrated with Augmented Reality (AR) for both occupants and Facility Management (FM) personnel to visualize their environment and access component information in order to improve complaint processing capabilities. The developed system enables users to create informed complaints directly linked with the elements in Building Information Models, all while maintaining a digital record of the process. Usability assessments demonstrate the effectiveness of this approach, showing enhanced information exchange, spatial awareness, and efficiency compared to traditional complaint processing techniques.**

Keywords- Facility Management; Building Information Models; Augmented Reality; Occupant Feedback.

I. Introduction

Facility Management (FM) is the collection of services and processes which plays a vital role in enhancing the quality of life, productivity and efficiency within a facility. The term “facility” is used for many diverse building types, such as homes, schools, hospitals, factories, etc.

Effective FM requires skilled professionals who oversee various aspects, including maintenance, repairs, inspections, and service provisions. With proper and efficient FM, systems facilities can save considerable monetary costs. Integrating smart technologies into FM systems can improve efficiency, save time while doing regular tasks, accelerate new worker training, and enhance work force distribution.

As indicated by Lewis et al. [1], it is estimated that 85% of a facility’s lifecycle costs are incurred after the completion of the construction phase. One strategy to significantly mitigate the unnecessary expenditures is the implementation of Building Information Models (BIM) throughout the lifecycle of a facility. Frontczak et al. claim that occupant feedback can be a more reliable source of information than physical measurements, such as data from sensors, other mechanical sources, or default standards for assessing a building’s performance [2]. Therefore, accurate evaluation and consideration of occupant feedback can enable a facility to operate with greater efficiency and create a more comfortable environment for its occupants.

Occupant feedback can serve as a diagnostic tool to aid facility managers in making more informed decisions regarding the planning, programming, and management of the facility. However, current FM systems often fall short in collecting this high-quality information in conjunction with contextual information. This includes details related to the specific building elements causing inconvenience, or spatial data related to the complaint.

Augmented Reality (AR) can be employed to visualize BIM within a real-world context, thereby enhancing spatial comprehension for both facility occupants and management personnel. This technology has the potential to improve the accuracy of on-site decision-making by decreasing the reliance on two-dimensional plans, thereby fostering a more interactive and immersive understanding of the facility’s spatial layout and operational needs.

In our research, we advocate for the integration of existing BIM with AR frameworks, specifically designed for mobile devices, to ensure optimal user accessibility. By scanning real-world markers, users can visualize their environment in AR using the facility’s BIM. This allows them to access all available information on the BIM, offering an interactive experience with BIM elements. This system lays the foundation for incorporating a digital history log into FM operations. Utilizing this system, occupants can report complaints or provide feedback directly linked to the relevant BIM elements, accompanied by precise spatial data. This enables FM personnel to conduct a prompt and assured analysis of the complaint, leveraging system capabilities, such as accurate AR visualizations and access to technical component information directly sourced from the BIM. Finally, this study evaluates the system’s usability through three distinct usability test scenarios performed on the developed version of the system, in comparison to a traditional form-based 2D system.

This paper is structured as follows: Section II provides a literature review, Section III outlines the design of the proposed system, Section IV presents conducted experiments, Section V discusses results, and Section VI concludes with final remarks and future work.

II. Literature Review

El Ammari et al. propose a remote collaboration tool that utilizes a BIM based approach, enhanced with Mixed

Reality (MR) technologies, to automate specific aspects of a construction project [3]. Initially, they underscore similar potential advantages, such as increased efficiency and decreased analysis time, that can be achieved through the use of a similar application. Raimbaud et al. posit that AR communication methods can be effectively implemented within a supervisory context [4]. Given that each new employee's tasks should be supervised, either throughout or at the end of the process, by a more experienced colleague, transitioning this process to a remote and digital format can result in significant time savings for experienced workers. In their paper, Chalhoub et al. focus on the use of MR methods to enhance the assembly of electrical elements in construction [5]. To evaluate the effectiveness of this approach, they utilized a usability questionnaire. Similarly, Irizarry et al. [6] created MR test environments using AR and Virtual Reality (VR). They tasked participants with locating elements within the environment and accessing attached information, such as the latest inspection date. Following the tests, they measured the time taken by the participants to complete the tasks and conducted a questionnaire to gather quantifiable data.

Occupant feedback has various collection methods, such as calls, messages, emails, or surveys. Pritoni et al. [7] explored the use of a mobile application for collecting occupant feedback, while Barrios et al. [8] emphasized the use of wearable devices equipped with sensors. However, both these studies primarily focus on a single aspect, such as thermal comfort. In contrast, real-world feedback is typically more multifaceted and complex, necessitating extensive filtering and manual processing by FM teams, which can be labor-intensive and time-consuming, confirmed by Shalabi et al. [9].

Post-Occupancy Evaluation (POE) surveys enable facility managers to continuously implement improvements in their facilities by accurately identifying both short-term and long-term inconveniences and problems. However, given that most POE tools are not designed to record problems, they often fail to gather crucial details, such as the contextual information necessary for problem-solving. This limitation was reaffirmed by Li et al. [10], with particular emphasis on the inability to provide contextual information continuously in real-time.

Furthermore, as seen in Ilter et al. [11], most POE tools lack an extensive inquiry about the degree of occupant satisfaction. While POE tools do measure occupant satisfaction for certain parameters, they often fail to identify the reasons behind low satisfaction rates or the root causes of the complaints. Another significant limitation of POE tools is their failure to collect necessary location information related to an occupant's complaint or feedback. Despite evidence suggesting that linking feedback data with location information can increase system efficiency, confirmed by Hua et al. [12], many POE systems still do not collect location information. This lack of spatial context can hinder the effective resolution of complaints and the overall management of the facility.

Our research proposes the integration of BIM with AR, emphasizing the user experience and practicality for complaint processing operations for occupants. This integration allows the FM team to collect structured feedback enriched with precise spatial data. The enhanced access to information through our system enables swift complaint analysis and the simultaneous creation of digital records for the process, thus offering a practical and efficient solution for day-to-day FM operations.

III. Methodology

A. Problem Definition and Design Issues

According to the research of Ilter et al. [13], current POE tools are lacking in functionality in terms of gathering comprehensive information about occupant satisfaction rates within a facility. Our system plans to address this issue by offering an intuitive interface where occupants can provide detailed textual feedback about various aspects of a facility. By facilitating easy reporting options and providing users with a way to effortlessly track the status of their feedback, our systems aims to enhance communication between the occupants and the facility managers.

Current Post-Occupancy Evaluation (POE) tools exhibit lack of spatial occupant feedback. This issue can be addressed by integrating BIM with AR. AR enables occupants to identify their location and incorporate this spatial information into their feedback. This enhanced feedback, complete with spatial information, aids in identifying specific building elements related to the feedback.

As confirmed by Hua et al. [12], linking occupant location to evaluation data has been proven to enhance process efficiency. This integration of spatial data not only enriches the feedback but also aids facility managers in swiftly identifying and addressing issues, thereby improving overall FM operations. By visualizing occupant feedback within the BIM model with the aid of AR visualization, our proposed system aims to provide a refined and easily consumable information report to decision-makers. This visual representation of data can facilitate a more intuitive understanding of the feedback, thereby enabling more informed and effective decision-making in FM.

B. Proposed Complaint Processing System with the Integration of AR and BIM

The application consists of two interfaces, one tailored for the facility occupants and the other designed for the FM team. The former interface enables facility occupants to utilize the system for delivering feedback or lodging complaints, leveraging the visualizations offered by the system. Conversely, the latter interface allows the FM team to scrutinize and analyze the issues reported by the occupants. The ensuing discussion will commence with a description of the application from the perspective of the facility occupants.

1) Occupant Interface: Upon initial engagement with the application, the occupant is prompted to scan a pre-established marker image in the physical environment. This marker image serves as an anchor to precisely overlay the BIM within the AR framework. These markers are assumed to be placed in predefined static locations in the real world. Following the accurate positioning of the AR visualization over the real-world environment, participants are at liberty to navigate and interact with the BIM elements. Selection of a component within the BIM presents the information panel, which furnishes comprehensive details about the component, sourced directly from the BIM. Figure 1 illustrates the selection of a "Glass Door" component by tapping on its corresponding BIM image superimposed onto the camera view of the physical glass door. It is noteworthy to mention that a mock BIM is used due to the difficulty of acquiring a BIM of a real building.

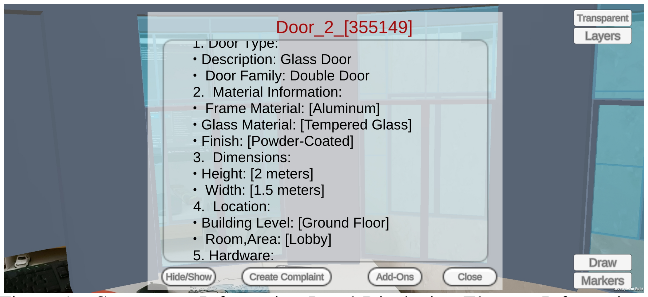

Figure 1. Component Information Panel Displaying Element Information.

By employing the "Hide/Show" button, users have the ability to activate or deactivate the rendering of the selected element. The "Create Complaint" button facilitates occupants in formulating informed complaints or delivering feedback, capitalizing on the information of the presented BIM element and directly associating them with the element in the BIM. This provides precise spatial data for the complaint and highlights the implicated element. All component and complaint correlations are established utilizing the component's unique ID sourced from Revit, a commercial BIM software, which guarantees precise tracking and identification of each component. The "Add-Ons" button is planned to be used for third-party API integration for applicable elements, such as sensor data, user manuals, etc. Using the "Close" button, users can close the open panels. Occupants also have the option to utilize the "Transparent" feature, which renders the BIM model transparent, thereby permitting them to see through the elements. The "Layers" button enables occupants to alternate between the rendering of various component groups, such as walls, doors, plumbing, etc., thereby offering a more lucid view of the BIM. This feature also allows occupants to view and interact with BIM elements that would typically be invisible. The "Draw" function allows occupants to sketch anchored shapes within the AR view, as depicted in Figure 2. Furthermore, the "Markers" function enables the placement of markers of varying colors and shapes. Both the "Draw" and "Markers" features empower users to articulate their thoughts within the 3D space, adding further detail to their complaints or feedback and facilitating more efficient communication of their concerns. If the occupant's issue is not directly associated with a BIM element, but rather pertains to a specific area, these features can be employed to mark an arbitrary area and attach their complaint to the markers. These features are designed to augment the occupant's interaction with the BIM model, fostering a more interactive and personalized view of the facility's components.

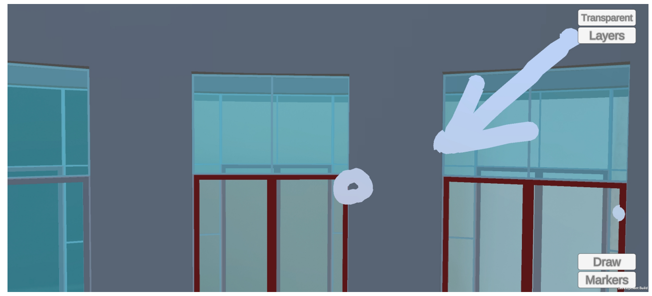

Figure 2. Anchored Drawings in AR View.

2) FM Personnel Interface: In addition to having access to all of the aforementioned functionalities, the FM team is provided with a few additional features intended to facilitate their tasks. The FM personnel can utilize "Filters" feature to filter the highlights of BIM elements associated with complaints, as in Figure 2. This functionality can be used to filter high-priority complaints and prioritize them accordingly. The "My Tasks" button allows FM team members to view a list of issues or complaints assigned to them, which have been submitted by facility occupants. Selecting an individual task reveals the details of that specific complaint and highlights the corresponding element within the BIM model so that FM personnel can initiate their analysis.

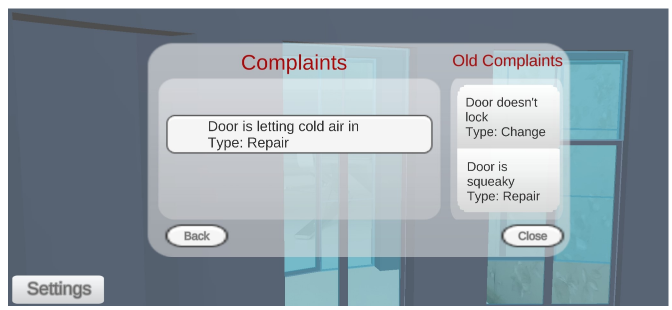

Figure 3. Complaints Panel.

If a FM worker selects a highlighted BIM element in the AR view, they can also access the complaints linked to the element using the "Complaints" button, as in Figure 3. This action opens the "Complaints" panel for the selected element. Within this section, FM workers can view both current and past complaints pertaining to the selected component, as illustrated in Figure 3. Selecting a specific complaint opens a detailed complaint panel with comprehensive data, including the individual who lodged the complaint, the time of creation, problem details, classification, etc. For past complaints, FM workers can view details about any inspection measures that were implemented as a result of the complaints, thereby providing a comprehensive history of each component's issues and the measures taken to resolve them.

In Figure 4, we can see an FM worker using the "Transparent" and "Filters" functionality to view BIM elements associated with complaints. Facility management workers can conduct inspections on the complaints using the "Inspection" button. The "Inspection" button is reachable by clicking on a

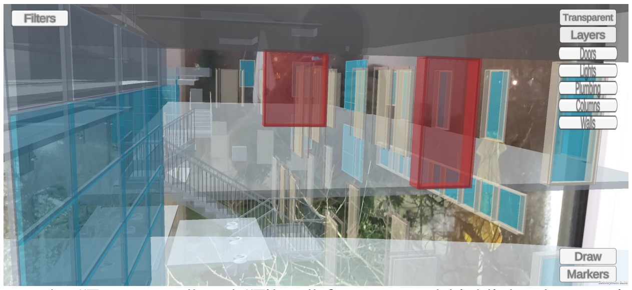

Figure 4. "Transparent" and "Filters" features used highlight elements in a mock BIM.

complaint and opening its details panel. This action opens the inspection panel for the workers, facilitating the inspection of the complaint related to the component. During the inspection, the worker can provide details about the analysis of the complaint, such as the root cause, desired action, required action, priority, status, performed action, assignee, required materials, additional information, etc. They have the option to resolve the complaint immediately if feasible, or reject the complaint if it is deemed irrelevant. If a complaint is beyond the worker's capacity to resolve, they can add their findings to the complaint details and assign the complaint to another facility management worker. For instance, an electrical complaint would necessitate the involvement of an electrical engineer.

IV. Experiments

A. Hardware and Software

The experiments were conducted using a Samsung Galaxy A70 mobile device. It is equipped with a Qualcomm Snapdragon 675 processor and 6GB of RAM. This device ensures that the application's performance and functionality can be evaluated on a rather low-cost device.

The application was developed using Unity game engine due to its cross-platform support for iOS and Android from a single codebase. Unity's AR Foundation framework was selected because of its superior tracking accuracy and performance against similar AR frameworks. The application launches with importing BIM, developed and sustained in Revit. The BIM model and its associated properties were exported independently, with a connection established through specific Revit IDs. To ensure the accurate rendering of materials, a customized pipeline in Blender was utilized.

In order to assess the performance of the proposed framework of AR and BIM integration, a conventional form-based 2D mobile application was developed that enables occupants to lodge complaints or offer feedback regarding their environment. This 2D application without AR also facilitates the scanning of markers and provides corresponding 2D floor layouts, allowing users to incorporate spatial data into their feedback by placing markers on the layout plan.

B. Participants

The study was conducted involving a total of 11 participants (10 males, 1 female), with an average age of 27 ± 2.69. The selection of participants was predicated on a composite metric encompassing their familiarity with AR frameworks, BIM, mobile device usage, and their respective professions. The intention was to engage participants possessing prior knowledge in the pertinent domains, thereby mitigating the learning curve. Participants' previous encounters with AR frameworks were primarily through gaming and simulation platforms as well as mobile applications. Six participants had previous exposure to BIM, attributable to their academic pursuits or professional engagements. The participants boasted diverse academic backgrounds and professional affiliations, spanning civil, manufacturing, computer, and support engineering. The entirety of the participant pool comprised prospective or current professionals in the respective fields.

C. Experimental Framework

Participants were assigned tasks in a step-by-step manner, which not only delineated the primary objective but also allowed a degree of flexibility for participants to explore their own approaches to task completion. Initially, the participants performed the first three tasks in the role of a facility occupant submitting a complaint or providing feedback, and the next three tasks in the role of an FM personnel member. For each task, participants first performed the task on the 2D application, then on the AR application.

Task 1: Participants were assigned the task of reporting a complaint regarding a window in an office space infiltrating cold air even when closed. They were expected to utilize the AR application, scan a marker to visualize the BIM model and select the problematic window element by clicking within the AR view. Participants were given the freedom to place markers, for instance, to indicate where the cold air was seeping in. Subsequently, they completed the remaining complaint details, such as type, additional information, etc., and finalized the complaint submission. In contrast, within the 2D application, the scanned marker presented the 2D floor layout plan, and participants were required to place a marker on the floor plan to incorporate spatial information. They then filled out the identical complaint details, with the addition of extra location information to accurately identify the problematic window among all windows in the space, thereby concluding the scenario.

Task 2: Participants were instructed to report an unpleasant odor in the workspace. Identifying the source of such odors can be complex due to the potential for various origins and sporadic occurrences. Therefore, providing detailed location information and the time of occurrence is crucial. Participants proceeded to fill out the complaint details and provide spatial information using the features of both applications.

Task 3: Participants were tasked with reporting a faulty light fixture in a conference space where all light fixtures are identical. Identifying the correct fixture can be challenging, often necessitating manual filtering and detailed descriptions in the absence of spatial data.

For **Task 4, Task 5** and **Task 6**, participants assumed the role of an FM employee. They were given three pre-constructed scenes mimicking the complaints similar to the

 ISBN: 978-1-68558-163-3

ones in **Tasks 1-3**. For example, **Task 4**'s scene already had the complaint created about the problematic window described in **Task 1**. Participants utilized the application to locate the source of the complaint, identify related BIM elements, view attached complaints, and analyze the issue.

Upon completion of all six tasks, participants were asked to complete the System Usability Scale (SUS) and a Post Evaluation Questionnaire (PEQ). SUS is a commonly used usability questionnaire developed by Brooke et al. [13] which consist of questions designed for responses on a 1 to 5 scale, ranging from "Strongly Disagree" to "Strongly Agree" summing to 100. The PEQ drew upon previous research conducted in this field by Yilmaz et al. [14], with additional customized questions and current and future design recommendations for the application regarding User Interface design and elements, evaluation of possible feature implementations and push notifications for gathering feedback. Based on the outcomes of these tests and the observations made throughout the experiments, the ensuing findings have been formulated.

V. Results

A. Average Task Time Results

The results of **Tasks 1-3** can be seen in Table 1. The examination of the table reveals a marginal disparity in the time required to accomplish tasks between the AR application and the 2D counterpart. Nonetheless, participants attested that the AR application, featuring direct integration of BIM data, significantly heightened their spatial awareness. Consequently, this enhancement facilitated a more confident articulation of complaints and related elements. Users engaging with the 2D application faced challenges in locating some elements, necessitating a reliance on detailed verbal descriptions. In contrast, the AR application, leveraging BIM, enabled participants to effortlessly identify these elements, empowering them with a visual reference.

TABLE I
AVERAGE TASK COMPLETION TIME

Evaluation Metric	Tasks		
	Task 1	*Task 2*	*Task 3*
AR Application Avg. Task Completion Time (sec.)	72.10 ($\pm$14.46)	89.91 ($\pm$24.93)	67.82 ($\pm$16.97)
2D Application Avg. Task Completion Time (sec.)	88.73 ($\pm$18.71)	86.12 ($\pm$33.39)	75.46 ($\pm$22.82)

Being able to see technical information about the components allowed users to create more informed complaints with confidence indicated by participant's comments. How these informed complaints effect the process for FM personnel is much harder to measure. The genuine impact of complaints enriched with component information through the utilization of BIM for FM personnel proves challenging to discern within these basic artificial test scenarios. The true ramifications can be evaluated when the application is deployed in real-world settings, addressing authentic issues routinely encountered by FM personnel.

B. System Usability Survey Results

The AR application for the Occupant Interface garnered an average score of 71.9 ± 8.7 on the SUS scale. For the FM Personnel Interface, the AR application achieved a score of 73.2 ± 6.8. The average results for the AR application marginally fall into the "Good" category.

C. Post Evaluation Questionnaire Results

The following results are derived from participants evaluating the AR application using the PEQ. Participants indicated that the suggested AR application adequately met their daily needs, with a score of 4.46 ± 0.7. Although participants deemed the existing filtering method to be satisfactory in the AR application, with an average score of 4.2 ± 0.6, they suggested to incorporate a more detailed and customizable search system within the application. Notably, participants with experience in facility operations highlighted that a customizable search would allow management teams to create and save queries related to their responsibilities, thereby facilitating easy tracking of their work status.

Regarding the utilization of occupant feedback, participants stated that they could make more effective use of the feedback, with a score of 4.27 ± 0.5. From the perspective of a facility worker, participants suggested that this application would expedite the analysis of complaints/feedback, with an average score of 4.09 ± 0.7. Participants stated that they would find this application useful in their workspace from both a user's perspective and a facility worker's perspective, with a score of 4.64 ± 0.5. Participants expressed that they would utilize the application for the purpose of lodging complaints or offering feedback within their workplace or professional environment, with an average score of 4.36 ± 0.5. The overall satisfaction rate among users was determined to be 4.2 ± 0.6.

D. User Comments

From the FM personnel perspective, participants found being able to access history of past operations performed on a component useful, commenting that it can help save considerable time. Participants were asked how they feel about sharing their location information for the analysis of location tracking. With the exception of 3 participants, all participants indicated discomfort with sharing their location with third party applications. When queried about the use of hand gestures for navigating the application, 5 participants stated that utilizing hand gestures through camera gesture recognition could be advantageous. 8 participants posited that the incorporation of voice commands would be advantageous. Given the escalating ubiquity of AI companions, the utilization of voice commands to facilitate interaction may improve the efficiency of the system.

Finally, participants were asked whether the application can be used as a regular way of gathering occupant feedback by utilizing the push notification feature of mobile applications. Only 4 participants indicated they would opt to receive push notifications, whereas 5 participants were uncertain about this preference. Small incentives, such as rewards or points, could potentially motivate the remaining percentage of occupants to participate in these push notification programs, thereby assisting in the evaluation of subjective metrics within the facility. 3 participants deemed receiving daily push notification questions to be acceptable, with the general consensus favoring a once-a-week frequency. In this context, the push notifications could be structured more like a brief survey rather than a simple yes-or-no question to gather generic feedback. A brief survey could enable users to provide more detailed information over the period of a week. When participants were asked about, the types of subjects they would like to receive push notifications about safety and security and air quality were the most important factors for the participants, respectively, achieving a rate of 9 and 7 positive answers, as it can be seen in Table II.

TABLE II
ACCEPTANCE RATE FOR PUSH NOTIFICATION

Environmental Factor	Acceptance Rate
Safety and security	9/11
Air quality	7/11
Smell and odors	6/11
Accessibility	6/11
Humidity levels	5/11
Lighting conditions	5/11
Sensory stimuli	5/11
Temperature	4/11
Noise level	4/11

E. Discussion

Participants proposed a zoom in/pan to functionality, whereby the camera would transition from the user's current location to the location of the related BIM element associated with a complaint before slowly panning back to the user's original location. Participants also requested the implementation of a cross-section slider. The cross-section view functionality is frequently employed during construction stages, and participants indicated that it is occasionally utilized in addressing day-to-day management issues.

Participants also articulated a need for a more management-centric user interface for use in monthly or quarterly reports. They proposed the inclusion of a section for graphical analytics that encapsulates all feedback and complaints logged by the application. Participants believed that such metrics would be beneficial for frequent use in their reports and for evaluating site equipment. Furthermore, they mentioned that having easier access to the history of all these actions would provide a comprehensive overview, enabling managers to gain a better understanding of the overall condition of the facility.

Participants further proposed the inclusion of a tutorial or an onboarding guide to assist first-time users in comprehending and adapting to the application. By employing a simulated environment and tasks, the functionalities of the application could be effectively demonstrated to the users.

The incorporation of third-party communication platforms, such as chat and video applications, into the software represents a considerable stride towards fostering collaboration. This integration would facilitate communication with external parties who may not have direct access to the application, utilizing widely recognized tools. By capitalizing on these interactive meeting tools, users could articulate their concerns or issues to third parties with enhanced efficacy.

VI. Conclusion and Future Work

This paper proposed AR-BIM integration for FM operations. This integration has shown to offer a more interactive, user-friendly, and efficient approach to managing building data and collecting occupant feedback. The application's ability to collect spatial data with feedback provides comprehensive understanding of the user's experience, which is a significant advancement over existing feedback collection methodologies.

Future work could focus on refining the system and increasing ease of use based on the insights gathered during the usability tests, such as, a task history panel for FM personnel, improved search functionalities, etc. Moreover, conducting real-world trials to assess the application's efficacy within authentic FM operational scenarios could provide valuable insights into its effectiveness in terms of complaint comprehension and resolution time. Another promising avenue for future work could be investigating how this system could be used to facilitate other aspects of FM, such as predictive maintenance, resource management and space utilization.

References

[1] A. Lewis, D. R. Riley and A. Elmualim, "Defining High Performance Buildings for Operations and Maintenance," International Journal of Facility Management vol.1, 2010.
[2] M. Frontczak, S. Schiavon, J. Goins, E. Arens, H. Zhang and P. Wargocki, "Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design," Indoor air, vol. 22(2), pp. 119–131, 2012.
[3] K. El Ammari and A. Hammad, "Remote interactive collaboration in facilities management using BIM-based mixed reality," Automation in Construction, vol. 107, 2019.
[4] P. Raimbaud, R. Lou, F. Merienne, F. Danglade, P. Figueroa and J. T. Hernandez, "BIM-based Mixed Reality Application for Supervision of Construction," IEEE Conference on Virtual Reality and 3D User Interfaces, 2019.
[5] J. Chalhoub, S. Ayer and S. Ariaratnam, "Augmented reality for enabling un- and under-trained individuals to complete specialty construction tasks," Journal of Information Technology in Construction, vol. 26, 2021.
[6] J. Irizarry, E. Karan and F. Jalaei, "Integrating BIM and GIS to improve the visual monitoring of construction supply chain management," Automation in Construction. vol. 31, pp. 241–254, 2013.
[7] M. Pritoni, K. Salmon, A. Sanguinetti, J. Morejohn and M. Modera, "Occupant Thermal Feedback for Improved Efficiency in University Buildings," Energy and Buildings. vol. 144, pp. 241-250, 2017.
[8] L. Barrios and W. Kleiminger, "The comfstat-automatically sensing thermal comfort for smart thermostats," IEEE International Conference on Pervasive Computing and Communications, pp. 257-266, 2017.
[9] F. Shalabi and Y. Turkan, "IFC BIM-based facility management approach to optimize data collection for corrective maintenance," Journal of performance of constructed facilities, vol. 31, 2017.
[10] P. Li, T. M. Froese and G. Brager, "Post-occupancy evaluation: state-of-the-art analysis and state-of-the-practice review," Building and Environment, vol. 133, pp. 187–202, 2018.
[11] D. Ilter, E. Ergen, D. Dönmez and I. Tekce, "A Critical Review of Post-Occupancy Evaluation (POE) Tools," 5th international Project and Construction Management Conference (IPCMC2018), 2018.
[12] Y. Hua, Ö. Göçer and K. Göçer, "Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platinum campus building," Building and Environment, vol. 79, pp. 124-137, 2014.
[13] J. Brooke, "SUS: A quick and dirty usability scale," Usability Eval. Ind., vol. 189, 1995.
[14] N. Yılmaz, E. Ergen and D. Ilter, "A usability test protocol for evaluating mixed reality environments," European Conference on Computing in Construction, pp. 423-430, 2021.