Development of a Mobile Application for Building Maintenance by Implementing Augmented Reality Technology

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Article Info

Abstract

Building maintenance procedures are currently inefficient, which emphasizes the need for more creative and efficient solutions. In order to improve maintenance operations, the present study aims to develop a functional testing of a mobile application that combines Building Information Modelling (BIM) and Augmented Reality (AR). The development process was tested using Autodesk Revit to produce 3D models that included comprehensive equipment and building material specifications. Subsequently, the AR component of the application was developed using Unity Hub in conjunction with the Vuforia Software Development Kit (SDK). Alpha and Beta testing were deployed and tested in Android devices comprising two key phases. The application showed 100% operational stability with all features functioning as intended throughout alpha testing, which comprised internal evaluations to confirm functionality, stability, and usability. The System Usability Scale (SUS), which consists of 10 Likert-scale questions assessing user confidence, ease of interaction, and perceived usefulness, was used in beta testing to gather end-user input. Beta testing confirmed the system's effectiveness, with an average SUS score of 72.5 and 90% of users reporting that the application is easy to learn

and use. The study demonstrates that integrating AR with BIM in a mobile application fundamentally enhances building maintenance by streamlining processes. This study offers a solid foundation for further research and development and shows how combining AR and BIM might enhance conventional building maintenance.

1. Introduction

Building maintenance is a crucial part of ensuring the longevity and efficiency of buildings, whether they are residential, commercial, or industrial. The rapid growth of infrastructure worldwide, especially in urban areas, has highlighted the importance of efficient and effective maintenance strategies. Studies have shown that maintaining a building's operational integrity can significantly reduce costs and downtime while enhancing the overall safety and comfort of its occupants [1]. To date, the integration of advanced technologies like AR and BIM has gained significant attention as a potential solution for improving the building maintenance process. The application of AR in building maintenance enhances visualization and real-time decision-making by overlaying digital content onto physical environments and delivering immediate, actionable information to maintenance staff [2]. Research on the application of AR in building maintenance has gained significant momentum in recent years. Traditional methods, such as manual inspections and paper-based maintenance logs, are still widely used. However, they often suffer from inefficiencies and errors, which can lead to increased costs and delays [3]. When integrated with BIM, AR not only enhances visualization but also offers an interactive digital representation of building structures, thereby streamlining maintenance operations [4].

The integration of AR and BIM for building maintenance has been explored by several researchers. Haiqal et al. [5] proposed an AR-based mobile application for visualizing maintenance tasks, which provided a real-time overlay of maintenance information on physical components. This application aimed to improve the workflow of maintenance operations and reduce the time needed for task completion. However, while these advancements have shown promising results, several challenges remain in terms of system interoperability, user interface design, and real-time data synchronization. Zhang et al. [6] emphasizes although BIM and AR have the potential to enhance maintenance processes, their adoption is still limited due to high implementation costs and technological barriers. Despite their promise, significant gaps remain in our understanding of how AR and BIM can be effectively integrated into diverse building maintenance workflows particularly in complex, large-scale facilities and varied scenarios such as emergency repairs and routine inspections [7]. This study focuses on developing and testing an AR-based mobile application that utilizes real-time issue reporting, asset management, and augmented visualization of building components. The research question of the present article is: How can augmented reality technology be effectively utilized to improve maintenance operations in building facilities?

The hypothesize that integrating AR with BIM in a mobile application can enhance the efficiency and effectiveness of maintenance tasks by providing real-time, context-aware information. This approach is expected to help maintenance personnel make faster, more accurate decisions. We predict that using this technology will reduce the time and errors associated with traditional maintenance methods, leading to improved operational performance. To validate this hypothesis, three main phases were carried out: 1) A prototype of a mobile application was created to show how AR and BIM features combined, 2) several functional tests were conducted to assess the performance, stability, and usefulness of the application, 3) user input was gathered to evaluate the app's performance in real-world building maintenance situations.

2. Methodology

This section describes the methodology used to address the research question of utilizing AR technology for building maintenance via mobile applications. The methodology involves several key steps by designing a project flowchart and identifying the design process for AR technology. Next, development of mobile applications and conducted functional alpha and beta tests.

2.1 Project Flowchart

The methodology began with the development of a project flowchart, which illustrated the overall process of creating an AR-based mobile application for building maintenance. The flowchart outlined each step involved in the system's development, from the initial planning phase through to testing and deployment. This structured approach allowed the research team to visualize the sequence of actions required and help ensure that no critical steps were overlooked. The project flowchart is shown in Fig. 1.
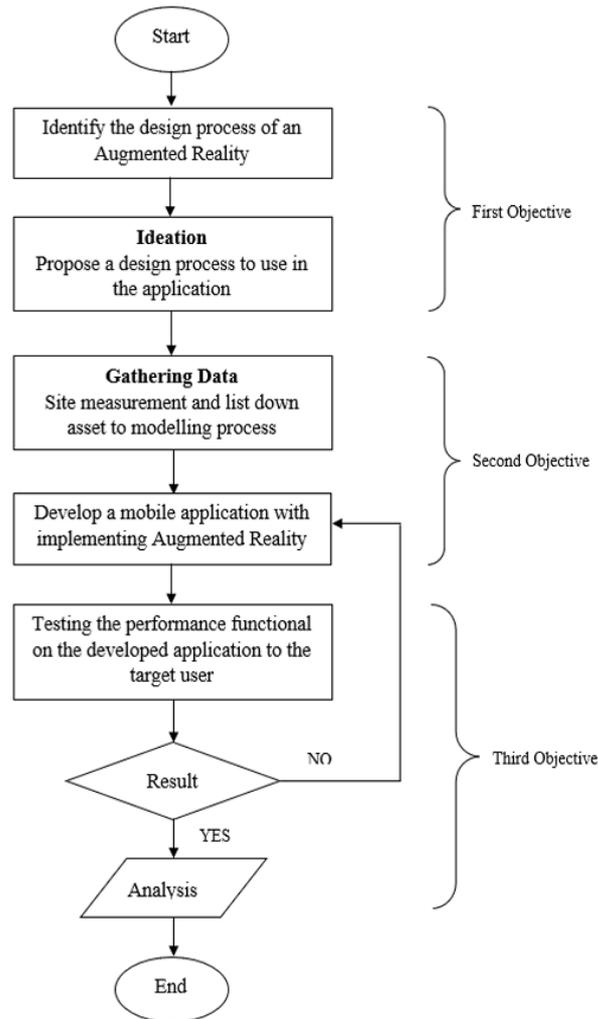
Fig. 1 *The overview of the project flowchart*

2.2 Design Process of AR Features

The design process of the augmented reality system was crucial to ensure the application met the needs of building maintenance. The initial step in this process was identifying the features necessary for the maintenance tasks. A review of existing AR-based maintenance applications revealed that most systems focused on visualization and remote assistance [8]. However, there was a clear gap in the integration of AR with real-time maintenance tracking, which prompted the need for an application that combined AR visualization with maintenance workflows.

The ideation process involved brainstorming features that would enhance user interaction with the AR system. Several key functionalities were considered, including real-time issue reporting, asset management, and AR-based visualization of 3D. The goal was to design a mobile application that could support maintenance personnel by providing them with immediate access to digital information overlaid onto physical assets, thereby improving operational efficiency [9]. This process was informed by findings from previous studies on AR in maintenance [10], which emphasized the need for intuitive user interfaces and real-time data integration.

2.3 Development of Mobile Application

The development of the mobile application followed an incremental approach, focusing on the integration of the identified features and functionalities. The application was designed for Android devices to ensure accessibility to a wide range of users. A critical aspect of the development process was the implementation of AR capabilities, which involved overlaying digital models onto real-world environments. This was done using Vuforia, a development platform for building AR experiences on Android devices. The app's architecture was built with modularity in mind, allowing easy updates and improvements in future versions [11].

2.3.1 AR App Development Process and Tools

The flowchart outlines the development process for integrating 3D modeling and augmented reality functionalities for your thesis. It begins with the importation of 3D models created in Revit into Unity software, a platform widely used for interactive development. Once the models are imported, the next step is to script the augmented reality functionalities. This scripting enables the interactive features essential for AR applications. Following this, the AR scenes are reviewed to ensure functionality, accuracy, and user experience quality. If the review indicates the need for additional models or adjustments, the process loops back to the initial import step. If no additional models are required, the process concludes. This iterative approach ensures a robust and functional AR development cycle.

The development process provides a clear visual representation of the systematic phases of creating the proposed mobile application. The flow begins with the Draft Phase, encompassing data collection, design interface, and 3D modeling. Tools such as Canva and Autodesk Revit are highlighted as essential components for designing user-friendly interfaces and creating BIM-based 3D models. These steps ensure the application's foundation aligns with user needs and enhances the overall user experience. The move to the Development Phase also captures sophisticated tools such as Vuforia and Unity. Vuforia supports the powerful functionality required for AR, while Unity simplifies app development and integration with the Android SDK. Additionally, implementing Visual Studio reinforces structured coding practices. This multi-tool approach is common in industry, as experts like Kamaruzzaman and his team [12] emphasize the necessity of specialized tools and techniques in practical application development. The flowchart process is available in Fig.2.
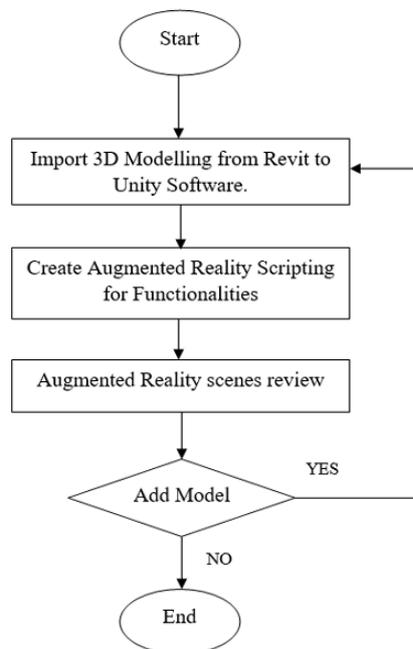

Fig. 2 *The overview of the development process*

2.4 Functional Testing and User Evaluation

Once the application was developed, extensive functional testing was conducted to evaluate its performance, usability, and overall effectiveness in real-world maintenance scenarios. This process involved alpha and beta testing stages, allowing for continuous improvements and refinement based on user feedback.

Alpha was tested internally by the development team to identify bugs, glitches, or design flaws that could affect the user experience. The application was evaluated under various conditions, including varying lighting levels and object recognition scenarios. The feedback from the development team was used to refine the system's core functionalities and user interface. The results confirmed that the system could effectively overlay AR content on physical building assets [13].

Beta testing was conducted with a select group of external users, including maintenance personnel who were the intended end-users of the application. This phase involved gathering qualitative and quantitative feedback on the usability and practicality of the application. The beta testers used the app in real-world environments to report issues, manage assets, and visualize 3D Model using AR. Feedback was collected using structured surveys, which assessed user satisfaction, ease of use, and perceived benefits of the AR features. These findings showed high user

satisfaction, particularly with the real-time issue reporting and AR visualization features, confirming the effectiveness of the application in improving maintenance operations [14]. After the respondent has answered all the questions, the evaluation will be made following the Standard version of the System Usability Scale and the interpretation. Fig. 3 shows the Standard version of the System Usability Scale and the interpretation.
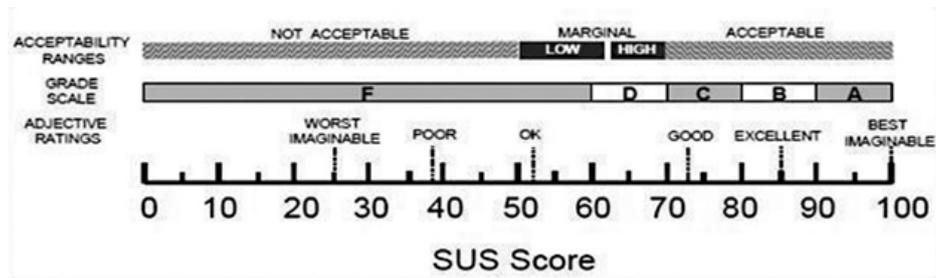

Fig. 3 *The standard version of the System Usability Scale and the interpretation*

The respondents for beta testing were selected through purposive sampling, targeting professionals in the building maintenance field. The sampling process ensured the users were familiar with building maintenance procedures and could provide valuable insights into the application's utility. The sample size of 10 respondents is relatively small but can be justified in the context of beta testing, where the goal is to gather in-depth, qualitative feedback rather than generalize findings to a larger population. Small sample sizes are common in usability testing and beta phases, as they allow for detailed analysis of user interactions and feedback [19]. Nielsen's research on usability testing suggests that even 5 to 10 participants are sufficient to identify significant usability issues. In most cases, the majority of problems are detected within the first few tests [19]. The feedback from these respondents was crucial for the final refinements of the application, ensuring that it met the needs and expectations of real-world maintenance teams [19].

3. Results

The present study focuses on the results obtained during the application design stage, the development of the interface, and usability tests. It goes deeper into the graphical design of the application and particularly illustrates various working interfaces, including the home page, complaint page, staff login, and assets. Additionally, it defines testing activities such as alpha testing and beta testing as a way of determining the efficiency, ease of use, and success of the application. The study concludes with the findings from the SUS, where detailed information about the level of satisfaction among the user respondents, along with the list of possible areas for improvement, is explained.

3.1 Ideation

This topic will discuss the features that want to be applied to the application that will be developed based on the discussion made in the case study of an existing related system.

3.1.1 Login Features

The login features serve as a critical security and access control mechanism, ensuring that only authorized personnel can access the system. These features typically include user authentication through usernames and passwords and may also incorporate multi factor authentication for enhanced security.

3.1.2 Works Order

The work order feature allows reporters to create maintenance requests for technicians, streamlining the process of addressing equipment issues. When a reporter submits a work order, it includes details about the problem, location, and any relevant observations or symptoms. This information is then used to generate a task for technicians. This feature ensures that maintenance tasks are clearly documented, prioritized, and systematically managed, leading to efficient workflow, timely responses, and effective resolution of maintenance issues.

3.1.3 Asset Management

The asset management feature enables organizations to comprehensively track, monitor, and manage their physical assets throughout their lifecycle. This functionality allows users to record detailed information about each asset, including specifications, location, and maintenance history.

3.1.4 3D View from Augmented Reality

The function of the 3D model in the application is to improve maintenance work by enabling technicians to easily identify the location of damaged components and read building plans more effectively. These features enhance spatial awareness and understanding, making maintenance tasks more precise and efficient.

3.2 Application

The design of the application focuses on increasing its acceptance and usability among building maintenance personnel, particularly technicians, by leveraging AR technology, which has seen widespread adoption in maintenance management internationally. The application prioritizes user-friendliness to ensure accessibility for first-time users, with a straightforward and intuitive interface. Key features of the application include a homepage with four main buttons 'Complaint,' Staff,' 'About Us,' and 'Exit'—providing essential navigation points for users. Fig. 4 (a) shows the Application Interface of homepages. Upon accessing the 'Complaint' section, users can report damage by completing the required fields, such as Name, Room Name, Broken Equipment, and Details, ensuring comprehensive issue documentation before submission.

The application integrates an authentication mechanism in the 'Staff' section to allow only authorized personnel to access advanced functionalities. Staff members must log in using their credentials, ensuring system security and credibility. Upon successful login, staff members are provided with an interface featuring five core functionalities: 'New Complaint,' 'Asset Management,' 'AR Technology,' '3D Model,' and 'Sign Out.' Each section enhances operational efficiency, such as viewing submitted complaints, managing assets, and visualizing system details.

The application's standout feature, however, is AR Technology, which introduces a highly interactive and immersive tool for maintenance management. When users select the AR Technology option, the application activates the device's camera to support AR functionalities. By aiming the camera at specific program markers within the application, users can access and manipulate 3D models of building systems, such as HVAC and electrical systems. This feature enhances technicians' ability to visualize and interact with equipment in real-time, offering a more dynamic and detailed understanding of building components. Furthermore, AR Technology allows users to interact with the virtual environment by enabling or disabling systems directly through the 3D models. This integration of AR significantly improves troubleshooting and system analysis, reducing reliance on static documents and plans. Fig. 4 (b) shows the Application Interface of AR technology.

In addition, the application provides a separate '3D Model' section, allowing technicians to access pre-defined 3D models without activating the AR functionality. This feature complements the AR capabilities by offering a detailed visualization of equipment and systems, categorized by rooms such as Bilik Kuliah 1 to 8. Technicians can retrieve comprehensive details about item names, sizes, quantities, classifications, and maintenance logs, further supporting efficient management and decision-making processes.

The combination of AR technology and a user-friendly interface makes this application a valuable tool for modern maintenance management, streamlining operations, enhancing system visualization, and providing an interactive platform for technicians to engage with building systems effectively. The detailed figures accompanying this explanation illustrate the application's interface and its various functionalities, with particular emphasis on the AR Technology, showcasing its practicality and innovative approach in building maintenance.

(a)   **(b)**

Fig. 4 *Application interface (a) Home pages; (b) The AR technology*

3.3 Function Testing

The testing stage involves putting the system through its paces to discover if there are any elements that are not functioning properly before releasing them to the public. Alpha testing is the term used to describe this type of testing. It will be possible to identify and uncover any errors that may exist in the developed application because of the testing that has been carried out, and if any errors are discovered, an improvement will be implemented. After alpha testing is carried out, beta testing is also performed by real users in a real environment. The application is demonstrated, and the feedback from the user is collected.

3.3.1 Alpha Testing

Testing is a critical phase in system development to ensure that all functionalities operate as intended. All system features were tested and found to perform according to the specified objectives. The results indicate that the system successfully met its intended goals. Table 1 presents the system testing forms used to evaluate the individual system modules. The test confirmed that all application features functioned as required, demonstrating the system's overall utility and efficiency. The login module successfully authenticated users with registered IDs and passwords. In addition, the work order module allowed detailed navigation of individual records and successfully exported reports to Excel. The asset management module displayed a comprehensive asset list with accurate information. The 3D view feature proved highly functional, enabling users to navigate through 3D visualizations of building components, HVAC systems, and electrical systems, highlighting the effectiveness of the integrated 3D rendering tools. These results collectively validate the application's efficiency and reliability in supporting maintenance management tasks.

Table 1 *List of test cases*

No.	Test Cases	Expected Outcome	Actual Outcome
1	Login Features		
	Login to system using ID and password that have been registered into the database.	Able to login into system using registered ID and password.	**Success**
2	Work Order Features		
	The Excel listed all work orders that were reported by a reporter.	A list of work orders that were reported to the user (Technician) in Excel.	**Success**
	Work Order Details	The screen shows all the work order details	**Success**
	Users can update the work order	The work order was updated using Excel	**Success**
3	Asset Management Features		
	List of assets	Users can view asset lists on asset list pages	**Success**
	Details of assets	The screen shows all the asset management details	**Success**
4	3D View Features		
	3D view of the building	Users can see a 3D view of the building	**Success**
	3D view of HVAC system	Users can see a 3D view of the HVAC system	**Success**
	3D view of Electrical system	Users can see a 3D view of the Electrical system	**Success**

3.3.2 Beta Testing

Once the application is fully developed, the beta testing is performed. This test is done by choosing a few technicians, a Facility Manager, a Facility Executive, and a BIM Specialist from UTHM Pagoh, Sime Darby Property, and IAQ Solutions, involving users with different levels of expertise and roles helps identify a wider range of usability issues, as each user group may interact with the application differently. The sample size of 10

respondents is appropriate for beta testing, as it aligns with established usability testing practices. Nielsen (2000) argues that 5 to 10 users are sufficient to identify the majority of usability issues in a system, as the law of diminishing returns applies to usability testing [19].

3.3.3 System Usability Scale (SUS) Based Assessment

The SUS is a Likert scale that measures the usability of a system through a ten-item questionnaire that requires the respondent to express their degree of agreement or disagreement with the question [15]. The ten-item questionnaire is constructed with five positive-toned questions on odd numbers, namely the first, third, and so on, and five negative-toned questions on even numbers, such as the second, fourth, and continuing even-numbered questions. The analysis of the result for positive-toned questions from the SUS questionnaire is shown in Fig. 5 (a) while the analysis of negative-toned questions is illustrated in Fig. 5 (b).
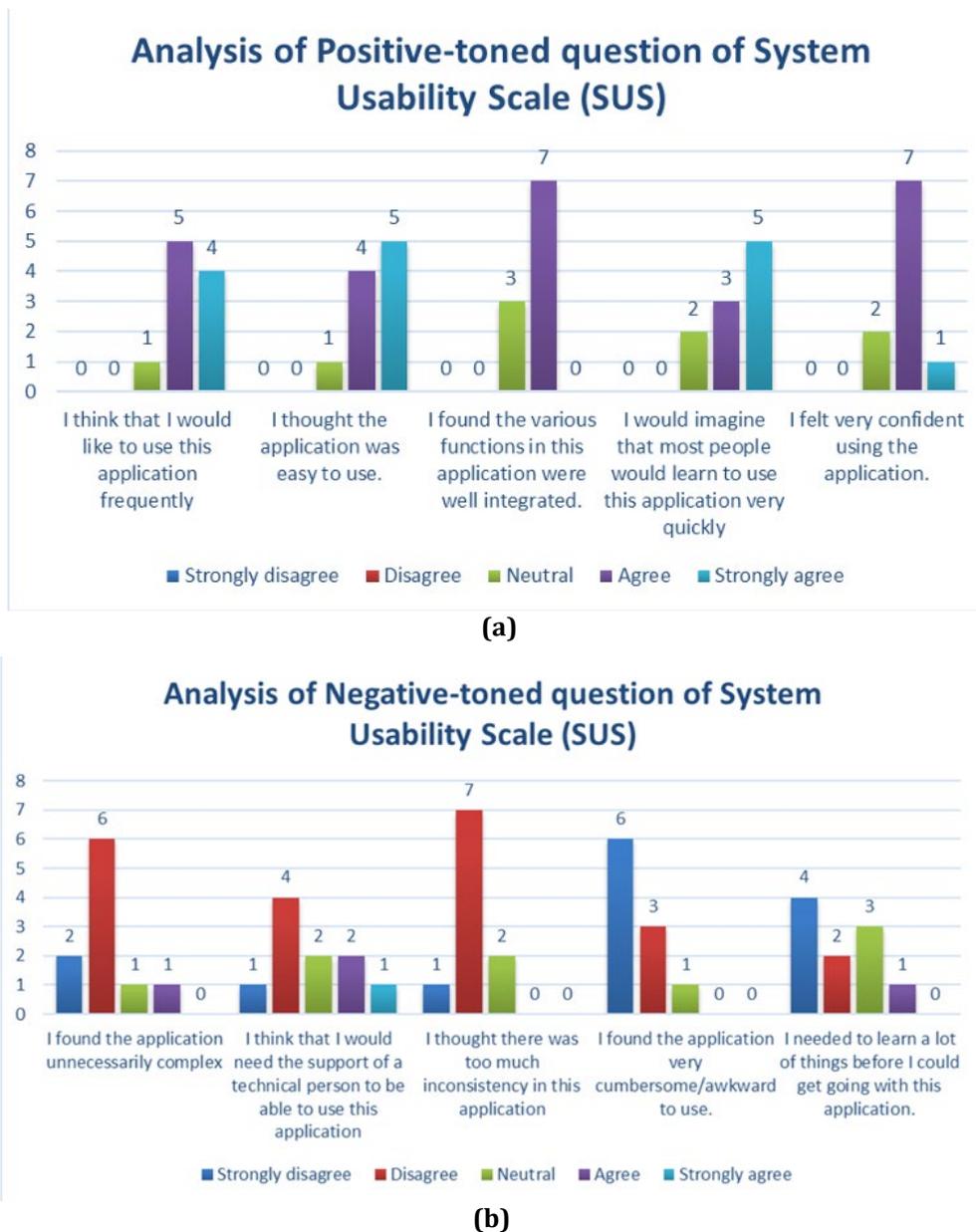

(a)

(b)

Fig. 5 *The analysis of SUS questionnaire (a) The result for positive-toned questions; (b) The result of negative-toned questions*

The analysis of the SUS questionnaire indicates a high level of user satisfaction with the application. Strong approval is indicated by responses to statements that are positively 90% of users imply that they would like to use the application frequently, find it straightforward to use, and are well-integrated. Notably, 90% of respondents agreed that the application was easy to learn and felt confident when using it.

Based on Fig.5, all users think it is easy to learn, and 90% feel confident using it. Negative-toned questions further support these findings. 80% of users do not find the application complex, and half do not need technical support to use it. Most users (90%) do not see any inconsistencies, do not find it cumbersome, and 60% do not need to learn much before using it. The SUS analysis revealed that the application achieved an average score of 72.5, indicating above-average usability and user satisfaction. The SUS scores ranged from 57.5 to 92.5, with the lowest score close to average and the highest significantly above average, demonstrating the application's user-friendliness and overall positive reception. The results confirm that the application effectively meets most usability needs while allowing room for further refinement to enhance the user experience. Additionally, the SUS score corresponds to a 'C' grade with a good adjective rating, affirming the application's high acceptability based on the SUS grading and acceptability range. These findings validate the application as a functional and user-friendly tool for its intended purpose. Figure 3 shows the standard version of the SUS and its interpretation.

3.4 Discussion

The development process provides a clear visual representation of the systematic phases of creating the proposed mobile application. The flow begins with the Draft Phase, encompassing data collection, design interface, and 3D modeling. Tools such as Canva and Autodesk Revit are highlighted as essential components for designing user-friendly interfaces and creating BIM-based 3D models. These steps ensure that the application's foundation aligns with user needs and enhances the overall user experience.

In the Development Phase, the use of Vuforia and Unity streamlined AR integration and app development, while Visual Studio reinforced structured coding practices—together ensuring efficient app functionality. This approach is prevalent in industry practices where different practices and approaches related to practical application development stress on the necessity to utilize different specialized tools and techniques as +mentioned in the works of Kamaruzzaman and his team [12]. Both alpha and beta testing validated the application's functionality and usability—alpha tests detected critical issues subsequently refined, and beta tests confirmed user acceptance through iterative improvements, aligning well with established mobile testing practices [16].

The integration between BIM and AR used in this thesis brings potential benefits for building maintenance management with several improvements. BIM acts as the primary, centralized source for managing building information—covering details such as geometry, spatial arrangements, and asset records. In contrast, AR serves as a middle layer by projecting real-time visual content onto physical spaces, allowing maintenance teams to access necessary data in a natural and intuitive manner. Consequently, BIM and AR enhance the levels of accuracy in problem solving, quick identification of problems and duration of maintenance activities. This makes it less cumbersome to verify the information through the checking process since a maintenance personnel member can engage in the augmented reality enhanced building information modeling for information on the same. Such integration not only guarantees real-time visualization but also allows relatively inexperienced personnel to perform sophisticated tasks by providing step-by-step instructions. This can be further supported by recent research conducted by Khaja and Husain (2022) who investigated the effect of integrating BIM and AR and identified that the integration of BIM and AR enhances task performance, user satisfaction and error rate reduction in maintenance tasks [17]. Also, it helps in reducing costs since organization processes can be made more efficient, and resource misuse could be eliminated, as described by Azhar et al. (2021), who pointed to the importance of driving the building lifecycle management through AR-enhanced BIM [18].

Recent studies by Khaja and Husain (2022) confirmed that integrating BIM and AR enhances task performance, user satisfaction, and reduces errors [17], while Azhar et al. (2021) emphasized its potential to streamline processes and reduce costs by minimizing resource misuse [18]. This is especially applicable in areas where traditional maintenance processes are known to experience some challenges and high costs of operations. By showcasing the practical implementation of BIM and AR, this thesis demonstrates how digital technologies can revolutionize building maintenance processes, ensuring precision, efficiency, and cost-effectiveness. These contributions reflect the study's objectives and highlight its potential as a benchmark for future research and applications in the field. Fig.6 shows the development process flow chart.
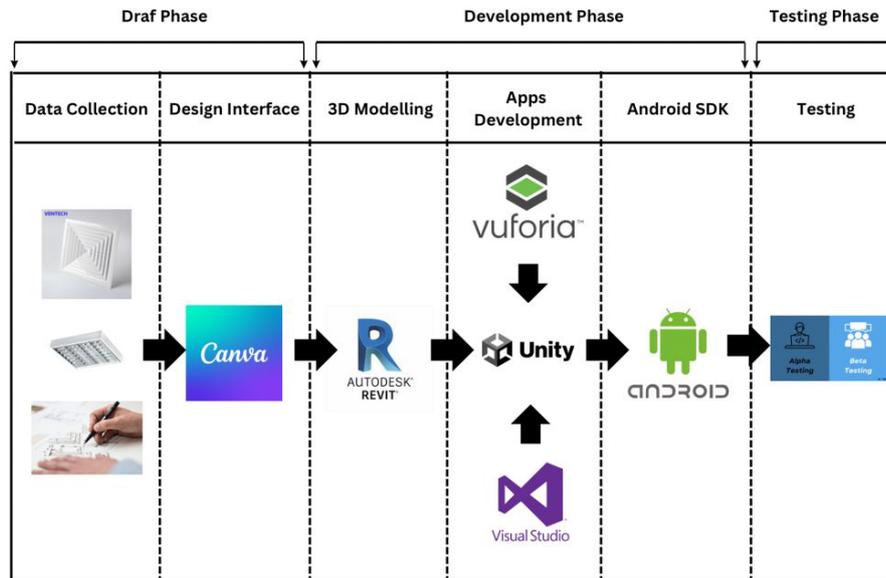
Fig. 6 *The development process flowchart*

4. Conclusion

This study has demonstrated the capability of AR as an innovative tool for enhancing building maintenance processes. The first research question, which focuses on designing AR for building maintenance applications. , was achieved through the systematization of existing systems and methodologies. The study examined various AR design strategies and integrated BIM with AR to enhance maintenance processes. These findings contributed to identifying the most suitable design strategy for the proposed application, ensuring it aligns with practical maintenance requirements. This process ensures that the mobile application for building maintenance leverages AR technology effectively, providing a robust foundation for intuitive and efficient maintenance workflows. The integration of BIM and AR not only enhances visualization but also bridges the gap between digital models and real-world maintenance tasks, making the application a valuable tool for professionals in the field.

The second objective, which focused on developing a mobile application for building maintenance using AR technology on Android devices, was achieved through the incremental development approach. The application incorporates essential components such as Real-Time Issue Reporting, Asset Management, and Augmented Reality-Based Visualization. These features were specifically designed for Android platforms to facilitate user-friendly and efficient maintenance tasks. By leveraging AR technology, the application provides an innovative solution for visualizing and interacting with maintenance tasks, demonstrating its potential to revolutionize traditional maintenance practices.

The third objective involved conducting a functional test of the developed application with target users. This objective was addressed through comprehensive alpha and beta testing phases. Quantitative and qualitative feedback from the SUS indicated a positive reception among users. High satisfaction levels were reported, and analysis of flowcharts and error rate reductions confirmed that the application significantly improved maintenance operations. The augmented reality functionalities proved to be particularly effective in providing intuitive visualization and interaction for maintenance tasks, showcasing the potential of AR technology in enhancing building maintenance workflows. The reduction in error rates and streamlined workflows, as evidenced by flowcharts and user feedback, confirm that the application effectively enhances building maintenance processes. Overall, the findings demonstrate that AR-based mobile applications have a great potential to transform the building maintenance industry by making complex tasks more accessible and efficient.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm sole responsibility for the following: **Conceptualization:** *A.I. Mohamed & M.S.S Mustafa;
Methodology, A.I. Mohamed and M.S.S Mustafa;* **Data Collection:** *A.I. Mohamed & M.F.M. Yunus; Formal Analysis, A.I.
Muhammed & M.S.S Mustafa;* **Writing – Original Draft:** *A.I. Muhammed;* **Writing – Review & Editing:** *N.M. Apandi,
M.S.S. Mustafa & M. Wijayaningtyas;* **Supervision:** *M.S.S. Mustafa & A. R. Jumat. All authors have read and approved
the final manuscript.*

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