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Augmented Reality and NavMesh-Based Indoor Navigation for Book Retrieval in a School Library

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Abstract

Unfamiliar shelf locations can delay students' access to learning resources in school libraries. This study developed and evaluated an Android application that integrates augmented reality (AR) visualization and NavMesh pathfinding to help students retrieve books in a vocational school library. Development followed the Multimedia Development Life Cycle. Thirty students completed a conventional search followed by an application-assisted search for the same book. Evaluation included black-box testing, the System Usability Scale, and paired comparisons of search time. All five documented functional tests passed. Mean search time was 98.40 seconds in the conventional condition and 43.27 seconds in the application-assisted condition, yielding a mean paired difference of 55.13 seconds. The paired-samples t-test indicated a difference between conditions, $t(29) = 18.72$, $p < .001$, with Cohen's $d_z = 3.42$. However, the fixed sequence and repeated target may have allowed prior knowledge of the destination to contribute to the difference. The study provides preliminary evidence that navigation assistance can serve as an educational support service. Its contribution concerns access to physical learning resources; it did not assess effects on learning achievement and literacy.

Keywords: Android application; Augmented reality; Book retrieval; Indoor navigation; School library.

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Introduction

School libraries provide students with access to books and reference materials that support classroom activities and independent study. Access involves both identifying a relevant resource and locating the physical item within the collection. A catalog may help students identify a title, but finding its shelf location can remain difficult when the collection arrangement is unfamiliar. Research on technology-supported education includes AR applications in environmental education and multimodal educational products for children with visual impairments, illustrating different approaches to presenting and accessing educational content (Safitri et al., 2025; Wu et al., 2025). In school libraries, a related service concern is how students reach the physical resources they intend to use.

The digitalization of education extends beyond instructional materials to the services through which students access information and resources (Nadrljanski et al., 2022). Within library services, (Khan et al., 2023) examined technological modernization and management capabilities in relation to user satisfaction and trust. Research on participation in public-library programs also highlights users' engagement with library services in the digital age (S. S. Lu et al., 2024). Although these settings differ from a school library, they provide a basis for considering technology alongside service organization and user needs. The broader discussion of digital innovation in Industry 4.0 offers an additional organizational perspective, rather than direct evidence about school-library navigation (Gupta & Jauhar, 2023).

Augmented reality (AR) overlays digital content on a view of the physical environment. Its applications vary according to the information presented and the tasks users perform. (Hamzah et al., 2025), examined informal learning and affective design in an AR tourism context, while (Ismail et al., 2025) discussed AR and artificial intelligence in digital advertising design. In an instructional setting, (Ciloglu & Ustun, 2023; Le et al., 2022) investigated motivation, self-efficacy, and attitudes in mobile AR-based biology learning. These studies address different applications and outcomes, so their findings should be considered within their respective contexts.

Students' familiarity with digital technology also requires careful consideration. (Le et al., 2022) examined perceived digital literacy and interaction with learning resources in STEM blended learning environments. Their study offers a relevant perspective on users' engagement with technology, but it does not show that AR necessarily improves learning. For a school-library application, therefore, distinguish the ability to operate a smartphone from familiarity with the library layout and successful completion of a book-search task. These differences inform participant selection, the instructions provided, and how performance is interpreted. Indoor navigation is another setting in which AR can present

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information within the physical environment. (Pereira et al., 2024) addressed indoor navigation using AR, while (Alfakhori et al., 2023) examined occlusion handling in mobile AR applications. These topics concern different aspects of navigation and visual presentation. Displaying a route through a smartphone camera may help users relate directional cues to the surrounding space, but useful guidance also depends on localization, alignment, and the visibility of virtual content. A mobile interface alone does not determine navigation accuracy, affordability, or suitability for every user.

The broader wayfinding literature includes a systematic review of AR use in human navigation (Qiu et al., 2025) and a mixed reality system for navigation and rescue in complex multi-floor buildings (Manfredi et al., 2025). These studies situate the present application within an existing field of spatial guidance research. In the application developed here, ARCore and AR Foundation support camera-based AR functionality, while a navigation mesh, or NavMesh, represents walkable areas in the digital library model. NavMesh calculates a route between mapped positions, and the AR interface displays that route. This arrangement requires the device's position and orientation to be aligned with the mapped environment; surface detection alone does not establish the user's absolute location within the library.

In the library of SMKS Muhammadiyah 3 Makassar, initial observations indicated that students searched for books manually without interactive indoor guidance. Students unfamiliar with shelf locations could need to inspect several shelves before finding the intended resource. This local problem motivated the development of an application that links book selection to guidance to the corresponding bookshelf. These observations establish the study's practical setting, rather than the prevalence of navigation difficulties across school libraries. Library familiarity, shelf labeling, and staff assistance may also influence search performance.

Previous navigation studies have addressed users with different needs and navigation tasks. (Messi et al., 2025) described an audio AR navigation assistant that combines satellite positioning and computer vision for people who are blind or have visual impairments. (Theodorou et al., 2024) examined usability and user experience in an indoor navigation application for users with blindness and visual impairments, incorporating training sessions into the evaluation. Their relevance lies in the attention given to navigation assistance, user characteristics, and evaluation procedures. (Xu et al., 2024) investigated AR-enabled egocentric cues for indoor wayfinding, offering another perspective on how to present directional information.

Localization and environmental representation are also central to indoor AR guidance. (M. Lu et al., 2024) investigated a navigation framework using geofencing, image tracking, and accumulated error correction. That study focuses on indoor navigation rather than book recognition or information visualization alone. (Saradha et al., 2025) addressed AR-based campus wayfinding, while (Putra et al., 2025) examined adaptive indoor AR navigation using node placement and marker localization. These approaches offer relevant comparisons for designing a mapped navigation environment. The present study focuses on a narrower service task: helping students locate physical books in a vocational school library. The literature reviewed above shows that researchers are already investigating AR navigation through different interfaces, localization approaches, and evaluation designs. This study asks how to implement and evaluate an AR and NavMesh application for book search in the participating school. Functional testing, perceived usability, and search time address separate aspects of that question. Functional testing examines documented system behavior, usability captures users' appraisal of the application, and search time describes performance during the retrieval task.

The application's educational relevance lies in supporting access to physical learning resources. It does not deliver instruction, and the evaluation does not measure learning achievement or literacy. A shorter search may help during a library visit, but further investigation is needed to determine whether students use any saved time for reading or learning. Keeping the evaluation tied to the access task lets the study examine an educational support service without assuming benefits beyond the recorded outcomes. This study aimed to develop an Android-based indoor library navigation application that integrates AR visualization and NavMesh pathfinding, and to evaluate its documented functionality, perceived usability, and book-search time. Development followed the Multimedia Development Life Cycle, using Unity, ARCore, and AR Foundation. Three questions guided the evaluation: whether the documented functions operated as expected, how students assessed the application's usability, and how search times differed between conventional and application-assisted conditions. Because the conventional search preceded the application-assisted search for the same book, interpreting the time comparison must account for prior exposure to the target location.

This work contributes an integrated implementation and a local evaluation of navigation assistance for a school-library resource-access task. The combination of AR and NavMesh is not presented as a new navigation principle or proof of technical superiority. Instead, the study examines its use in a defined educational service context involving student participants. The findings may inform further development and evaluation of school-library navigation, subject to the study design's limitations and the conditions under which the application was tested.

Method

Research Design

This study used a research and development approach to develop an Android-based indoor library navigation application that integrates augmented reality (AR) and NavMesh pathfinding. The application's development relates to the broader field of AR navigation research reviewed by (Cheliotis et al., 2023). Development followed the Multimedia Development Life Cycle (MDLC), which comprises concept, design, material collection, assembly, testing, and distribution. Published MDLC applications provide relevant methodological context for developing interactive applications (Rahmadi et al., 2026; Roedavan et al., 2025; Solehatin et al., 2023). Following development, a one-group, fixed-order repeated-measures evaluation compared conventional and application-assisted book-search times. Each participant completed the conventional search first and then used the application to search for the same book. The sequence was not randomized or counterbalanced. The comparison therefore assessed differences between the observed conditions without separating the application's contribution from possible practice and order effects. The study was conducted from January to March 2025 at the library of SMKS Muhammadiyah 3 Makassar. Thirty student library users were selected through purposive sampling based on library-use experience and basic ability to operate an Android smartphone. Search times were recorded for both conditions and analyzed as paired observations.

System Development

System development followed the six MDLC stages: concept, design, material collection, assembly, testing, and distribution (Roedavan et al., 2025; Solehatin et al., 2023). During the concept stage, observations and interviews with library managers helped identify book-search problems and application requirements. The design stage covered the system architecture, user interface, library map, bookshelf destinations, and navigation workflow. Material collection included the floor plan, shelf positions, and multimedia assets. The team assembled the application in Unity, using C# for programming and ARCore and AR Foundation for camera-based AR functionality. NavMesh supported route calculation within the mapped walkable area. The application was developed for Android devices supporting ARCore. Testing examined the implemented functions, followed by distribution for local evaluation. Figure 1 presents the application architecture. Users select a book, and the application displays a route toward the assigned bookshelf destination. ARCore and AR Foundation support camera-based tracking, while NavMesh calculates the route within the mapped environment. Guidance to a stored destination requires the device position and orientation to correspond to the library map.



Figure 1. Architecture of the AR and NavMesh-Based Indoor Navigation Application

System Evaluation

Evaluation comprised black-box testing, perceived usability assessment, and paired comparisons of book-search time. Black-box testing compared observed application outputs with expected behavior. The five documented scenarios

covered the main menu, navigation, AR camera, surface detection, and mini-map. Functional conclusions were limited to the scenarios for which test results were available.

We assessed perceived usability using the 10-item System Usability Scale (Higgins et al., 2023). (Aripiyanto et al., 2024) provide an example of SUS use in evaluating a student-facing mobile application. Participants recorded responses on a five-point agreement scale. For each participant, odd-numbered responses were adjusted by subtracting one, while even-numbered responses were adjusted by subtracting the response from five. The ten adjusted contributions were summed and multiplied by 2.5, as shown in Equation (1).

$$SUS = \left(\sum_{i=1}^{10} S_i\right) x\ 2.5 \quad (1)$$

Where S_i is the adjusted contribution of item i for a participant. Individual SUS scores range from 0 to 100. We calculated the mean score by summing participant-level scores and dividing by the number of complete questionnaires included in the analysis. SUS measures perceived usability rather than the percentage of successful tasks.

Book-search performance was assessed using completion time in seconds. Each participant first searched conventionally, then completed the application-assisted search for the same book. The search condition was the within-participant comparison factor, and recorded search time was the outcome. Because the target was repeated, participants could use information acquired during the first search when completing the second.

Data analysis

We analyzed the data using descriptive and inferential statistics in IBM SPSS Statistics version 26. Descriptive statistics summarized the mean, standard deviation, minimum, and maximum book-search time in the conventional and AR NavMesh-assisted conditions. For each participant, the paired difference was calculated as conventional search time minus application-assisted search time. Positive differences indicated shorter search times in the application-assisted condition. Before hypothesis testing, we used the Shapiro–Wilk test to assess the normality of the paired differences.

We interpreted a p-value greater than .05 as no departure from normality, not confirmation of a normal distribution (Li et al., 2025; Yao et al., 2025). A two-sided paired-samples t-test assessed whether the mean paired difference differed from zero at a significance level of .05. The standardized paired difference was calculated as Cohen's $\boldsymbol{d_z}$, using the standard deviation of the paired differences as the denominator (Lakens, 2013; Lee et al., 2025; Y. Lu et al., 2023), as shown in Equation (2).

$$dz = \frac{\overline{D}}{S_{\mathrm{D}}} \quad (2)$$

Here, $\overline{D}$ is the mean difference between conventional and application-assisted book-search times, and S_D is the sample standard deviation of those differences. The standardized difference was interpreted alongside the mean difference in seconds and the limitations of the study design (Gignac & Szodorai, 2016). Because the conventional search always preceded the application-assisted search for the same book, we did not interpret either statistical significance or effect size as evidence that the application alone caused the observed difference.

Results and Discussion

Results

We developed an Android application that integrates AR visualization and NavMesh pathfinding for book retrieval at the SMKS Muhammadiyah 3 Makassar library. We implemented the application in Unity using ARCore and AR Foundation. Its features included book selection, camera-based route visualization, a mini-map, user guidance, and application information. Users select a book from the collection list, and the application displays a route toward its assigned bookshelf destination through the smartphone camera. NavMesh calculates the route within the mapped walkable area. Figure 2 presents the main interface.

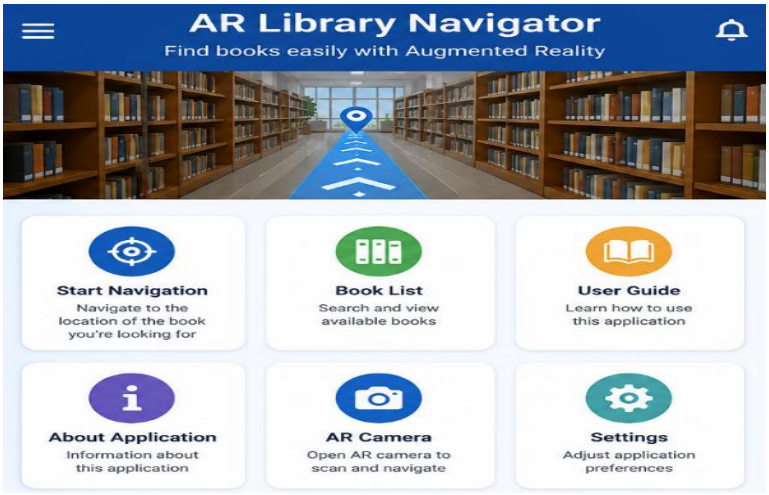


Figure 2. Main Menu Interface of AR Library Navigation Application

Figure 2 presents the controls for accessing navigation, the book list, user guidance, application information, and the AR camera. The navigation workflow begins with selecting a target book. The application then displays guidance toward the assigned bookshelf destination in the camera view. Figure 3 illustrates book selection and route visualization.

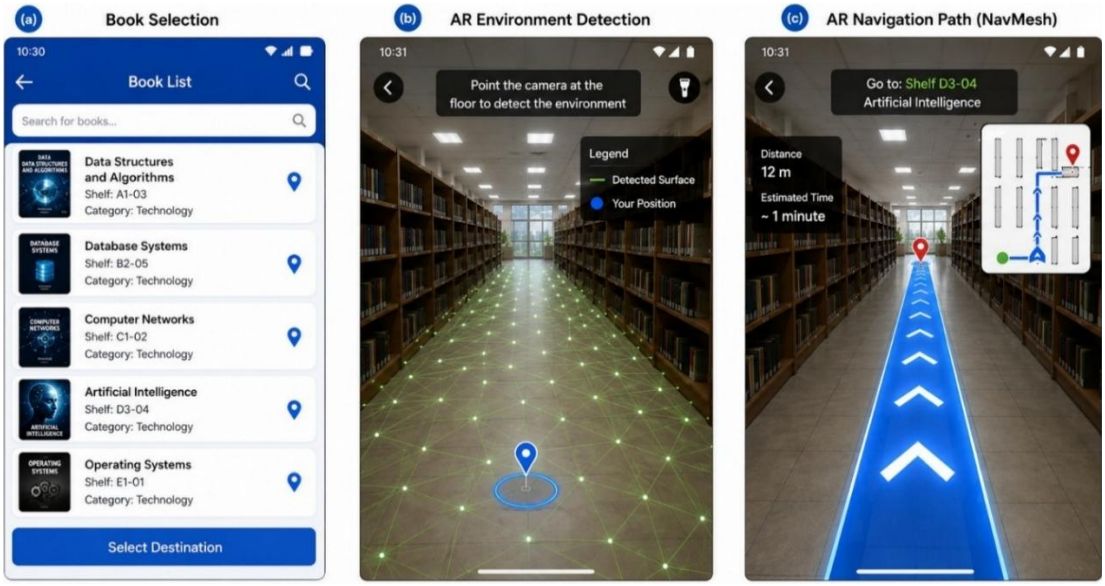


Figure 3. Implementation of Indoor Navigation Using Augmented Reality and NavMesh

Figure 3 illustrates the application workflow from book selection to route visualization. Functional evaluation used black-box testing. Table 1 reports five documented scenarios: the main menu, navigation, AR camera, surface detection, and mini-map. All five scenarios passed under the tested conditions.

Table 1. Black-Box Testing Results

Test Case	Expected Result	Actual Result	Status
Main Menu	The main page appears	In accordance	Passed
Navigation	The navigation path appears	In accordance	Passed
AR Camera	AR camera active	In accordance	Passed
Surface Detection	Field detected	In accordance	Passed
Mini Map	Mini-map appears	In accordance	Passed
Total Success Rate	**5 features**	**5 Passed**	**100%**

All five documented functional scenarios passed, yielding a success rate of 100% for the scenarios listed in Table 1. This result supports functional operation under the tested conditions but does not establish reliability across all devices or library environments. Perceived usability was assessed using SUS with 30 student participants. Table 2 shows the usability evaluation results.

Table 2. System Usability Scale Evaluation Results

Evaluation Aspects	Mark
Number of Respondents	30
SUS Score	83.21
Category	Excellent
Grade	A

We evaluated book-search performance using paired observations from 30 students. Each participant completed the conventional search first and then searched for the same book using the application. Table 3 presents the descriptive statistics for both conditions.

Table 3. Descriptive Statistics of Book Search Time

Variables	N	Mean	Standard Deviation	Minimum	Maximum
Conventional	30	98.40	14.27	72	128
AR NavMesh	30	43.27	8.91	29	61

Mean search time was 98.40 seconds in the conventional condition and 43.27 seconds in the application-assisted condition, giving a mean paired difference of 55.13 seconds. Participants performed the application-assisted search after they had already searched for the same book conventionally. The observed difference may therefore reflect both navigation assistance and prior knowledge of the destination. Table 4 presents the normality test results for the paired differences.

Table 4. Results of the Shapiro-Wilk Normality Test

Variables	Statistics	Sig.
Difference Score (Conventional − AR NavMesh)	0.968	0.462

The Shapiro-Wilk test did not detect a departure from normality in the paired differences, W = 0.968, p = .462. The paired-samples t-test indicated a difference between conditions, t(29) = 18.72, p < .001. These results describe the difference within the observed testing sequence and do not isolate the application's contribution from practice or order effects. Table 5 presents the paired-samples t-test results.

Table 5. Paired Sample t-Test Results

Variables	Mean Difference	SD Difference	Std. Error Mean	t	df	Sig. (2-tailed)
Conventional – AR NavMesh	55.13	16.13	2.94	18.72	29	<0.001

Using the reported rounded summary values, Cohen's D_z was calculated as 55.13/16.13 = 3.42. This represents a large standardized paired difference in the observed sequence. Because students had already located the same book during the conventional search, prior familiarity may have contributed to the difference. The estimate should therefore not be interpreted as the isolated causal effect of the application.

Discussion

The application-assisted search took less time on average than the preceding conventional search. This finding supports the application's intended task of helping students locate library resources. Route guidance plausibly explains part of the difference, but participants also knew more about the target after completing the first search. The present design cannot distinguish the contribution of guidance from that of prior familiarity. AR navigation research includes systems developed for different environments and user needs (Arokiaraj et al., 2025; Qiu et al., 2025). Work on AR interfaces and situated visualization also provides perspectives on presenting information within a physical setting (Martins et al., 2022; Szentirmai, 2024). In the present application, the route appears in the camera view while students move toward a bookshelf. This arrangement may assist the task, but it did not measure spatial understanding or cognitive workload and cannot be presented as a demonstrated mechanism.

The findings should also be considered alongside research on indoor navigation and the usability of AR applications (Alluhaidan et al., 2025; Qiu et al., 2025; Zanjani & Askarinejadamiri, 2024). Comparisons across studies require attention to differences in participants, navigation tasks, interfaces, and evaluation procedures. The time difference reported here is not a benchmark establishing superiority over those systems. NavMesh provides route calculation within the mapped library environment. Related applications have addressed navigation to other destinations and used mapping and localization procedures (KG et al., 2023; Putra et al., 2025). However, this study did not compare routing algorithms or measure route optimality. It therefore cannot attribute the observed time difference specifically to NavMesh or establish that the application produced the shortest physical route.

Perceived usability and task time address different aspects of application use. SUS summarizes participants' appraisal of the system, whereas the timed search records performance under the specified conditions. An overall usability score does not independently demonstrate memorability, low error rates, or successful use without training. Research on AR-

supported learning experiences provides relevant context for user interaction, but instructional outcomes should not be inferred from a navigation task (Ramli et al., 2024).

The educational contribution concerns access to physical learning resources. Students may identify a required title yet remain unfamiliar with its shelf location. Navigation assistance addresses that service problem. Broader work on digital transformation in education situates such services within institutional change (Kaputa et al., 2022; Mohamed Hashim et al., 2022). Nevertheless, the study did not measure whether shorter searches increased reading, improved assignment completion, or strengthened literacy. Those outcomes remain questions for further investigation.

Implementation also depends on conditions beyond the route display. Research on AR services, smartphone-based applications, and AR technologies provides a broader context for considering deployment support (Alimamy & Jung, 2025; Ariano et al., 2023; Mendoza-Ramírez et al., 2023). In this library application, device compatibility, shelf-coordinate maintenance, and tracking conditions require attention. No cost comparison was conducted, so the present evaluation cannot describe the system as more economical than alternative navigation solutions. The fixed sequence and repeated target are central limitations. Students searched for the same book twice, and they always used the application second. Remembering the destination or route could shorten the second search independently of the application. Pairing observations accounts for measurements from the same students but does not remove this carryover effect.

The evaluation was also limited to one school library and a purposively selected sample of 30 students. Applicability to other libraries, shelving arrangements, or users requires further testing. Functional results cover five documented scenarios. Those tests alone did not establish localization accuracy, tracking interruptions, or performance under changes in lighting or shelf positions. Further evaluation should use randomized or counterbalanced conditions with equivalent target books and routes. Recording retrieval success, wrong turns, assistance requests, and tracking interruptions alongside time would clarify when guidance is useful. The present findings provide a basis for that evaluation rather than a definitive estimate of the application’s effectiveness.

Conclusions and Suggestions

Conclusions

We developed an Android application that integrates augmented reality (AR) visualization and NavMesh pathfinding for book retrieval at the library of SMKS Muhammadiyah 3 Makassar. All five documented functional tests passed. Mean search time was 98.40 seconds in the conventional condition and 43.27 seconds in the application-assisted condition. The shorter search time suggests potential for supporting students’ access to school-library resources. However, the conventional search always preceded the application-assisted search for the same book, so prior knowledge of the destination may have contributed to the difference. The study provides a local implementation and preliminary evaluation of an educational support service, while further controlled testing is needed to establish the application’s contribution to search performance.

Suggestions

Further research should use randomized or counterbalanced search conditions with equivalent target books and routes to reduce practice and order effects. Evaluation should record retrieval success, wrong turns, assistance requests, and tracking interruptions alongside search time. Studies with more participants, additional school libraries, and different devices would help assess the findings' applicability. Further system development should be guided by observed navigation problems and user needs.

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Author Contributions

Akbar Iskandar and Riska Kherani contributed to the conceptualization, methodology, software development, data collection, data analysis, and manuscript preparation. Saltanat Meiramova contributed to language editing and

manuscript review. Richard K. Lomotey contributed to scientific review, quality assessment, and manuscript improvement. All authors have read and approved the final version of the manuscript.

Research Ethics and Informed Consent

The Ethics Committee of Universitas Teknologi Akba Makassar reviewed and approved this study under Protocol No. 003/UNITAMA/LP2M/B.2/II/2025. The school principal granted permission to conduct the study. All study procedures followed the committee's ethical standards and recommendations.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

Requests for access to the data supporting this study, including book-search times and System Usability Scale responses, should be directed to the corresponding author. Access is subject to participant confidentiality and applicable consent or institutional restrictions.

Declaration of Generative AI Use

The authors used generative AI to refine wording and improve sentence structure in the manuscript. The authors reviewed the revised text and remain responsible for its accuracy, originality, and integrity.

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