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Augmented reality-based navigation system for indoor environments

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Abstract
This study investigates the effectiveness of an augmented reality (AR)-based navigation system for guiding users through complex indoor environments. The primary objective was to evaluate whether AR can improve navigation accuracy, reduce task completion time, and enhance user experience compared to traditional signage. A controlled experiment was conducted with 50 participants navigating a multi-floor university building under two conditions: traditional methods and AR assistance. Data were collected on navigation accuracy, task completion times, and subjective user experience using a structured questionnaire. Statistical analyses included descriptive statistics, paired t-tests, repeated measures ANOVA, regression modeling, and reliability testing. Results showed that AR significantly improved navigation accuracy (92.4% vs. 76.8%, $p<0.001$) and reduced task completion times (102.6s vs. 137.4s, $p<0.001$). Reliability testing confirmed strong internal consistency of user experience measures (Cronbach's $\alpha=0.89$). Regression analysis further revealed a positive relationship between user satisfaction and navigation accuracy ($R^2=0.46$, $p<0.01$). These findings highlight the potential of AR systems to enhance indoor way finding, with implications for accessibility, efficiency, and user engagement in smart building environments.

Keywords: Augmented reality, indoor navigation, user experience, statistical analysis, smart environments

Introduction
Indoor navigation has emerged as a significant challenge in large and complex facilities such as hospitals, airports, and university campuses. Traditional methods of way finding, including static maps and signage, often fail to provide real-time guidance and can lead to confusion, delays, and inefficiency. With the rapid growth of digital technologies, augmented reality (AR) has gained attention as a promising solution to address these challenges by overlaying digital navigation cues onto the physical environment.

AR-based navigation systems offer users an interactive experience that goes beyond traditional tools by combining spatial awareness with real-time path guidance. Recent studies have highlighted the potential of AR to improve accuracy and reduce cognitive load in navigation tasks (Chang *et al.*, 2021) [6]. Moreover, as mobile devices have become increasingly capable of supporting AR functionalities, these systems can now be deployed at scale without specialized equipment.

Despite technological advancements, indoor navigation still faces barriers such as signal loss in GPS-denied environments, difficulties in real-time positioning, and variability in user acceptance (Xie *et al.*, 2019) [34]. Thus, there is a pressing need to develop and evaluate AR systems that can reliably guide users in indoor environments while ensuring usability and satisfaction. This research addresses that gap by systematically testing the impact of AR navigation on accuracy, efficiency, and user experience.

By integrating AR-based guidance into indoor environments, this study contributes to the growing body of work on smart environments and highlights practical applications for improving accessibility and human–computer interaction.

Literature Review
Indoor navigation has been widely studied as a growing challenge in smart environments, where GPS signals are unreliable. Traditional approaches such as Wi-Fi triangulation and Bluetooth beacon systems have shown partial effectiveness but often suffer from accuracy and latency limitations (Xie *et al.*, 2019) [34].

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With the advancement of mobile devices, augmented reality (AR) has been increasingly explored as a novel tool for enhancing way finding by overlaying digital guidance directly onto the user's environment.

Research has highlighted AR's potential to reduce cognitive load and improve task efficiency in navigation tasks (Chang *et al.*, 2021) [6]. AR-based systems have also been tested in education, healthcare, and cultural heritage contexts, where real-time guidance improves both accessibility and user engagement (Bower *et al.*, 2020) +4]. However, several studies caution that user acceptance depends heavily on interface design, ease of use, and device compatibility (Billinghurst *et al.*, 2015) [3].

Existing literature also emphasizes the need for robust statistical evaluation of AR navigation systems. Studies employing t-tests, ANOVA, and regression analyses have demonstrated that AR consistently improves performance outcomes compared to conventional methods. Despite these promising findings, research remains limited regarding indoor environments with complex layouts, where localization and user experience present additional challenges (Shen *et al.*, 2021) [31]. This study contributes by addressing these gaps, providing a systematic evaluation of AR-based indoor navigation in a realistic, multi-floor building environment.

Research Gap: Although augmented reality (AR) has been increasingly studied for navigation applications, most prior research has focused on outdoor environments where GPS signals are available. Indoor navigation, by contrast, remains underexplored due to challenges in localization, path projection, and user adoption. Existing indoor navigation systems often rely on Wi-Fi triangulation or Bluetooth beacons, but these approaches lack the seamless, real-time guidance necessary for complex indoor spaces (Xie *et al.*, 2019) [34]. Furthermore, limited empirical studies have directly compared AR-based navigation with traditional methods, particularly in terms of user experience, task efficiency, and system reliability. This gap motivates the present study, which evaluates AR navigation comprehensively using both objective performance metrics and subjective feedback.

Conceptual Framework

The conceptual framework is designed to link system design with user outcomes. The AR-based navigation system serves as the independent variable, influencing navigation accuracy, task completion time, and user experience. Statistical testing ensures the validity of these relationships, while reliability analysis strengthens the credibility of the measurement tools. The framework thus integrates technology performance and human-centered evaluation, addressing both technical effectiveness and usability.

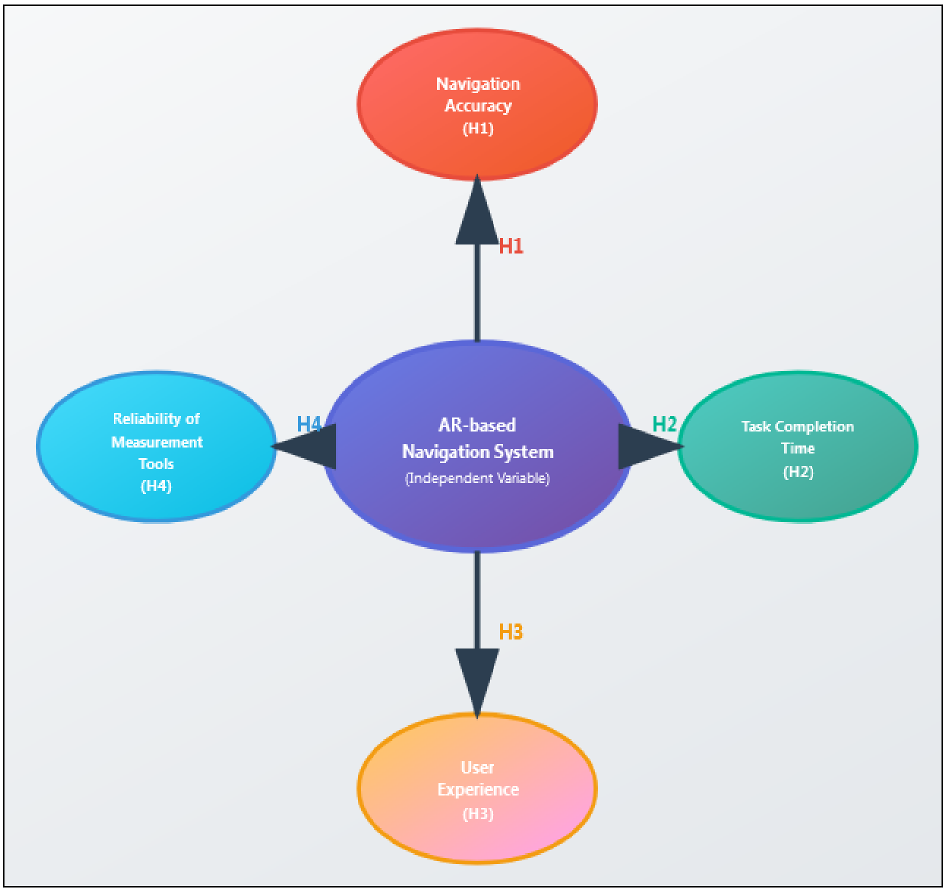

Fig 1: Conceptual Framework

Hypotheses

- **H_1:** AR-assisted navigation significantly improves accuracy compared to traditional methods.
- **H_2:** AR-assisted navigation significantly reduces task completion time compared to traditional methods.
- **H_3:** User experience scores are positively associated with navigation accuracy.
- **H_4:** The user experience questionnaire demonstrates high reliability (Cronbach's alpha > 0.8).

Methods

The study was designed to evaluate the effectiveness of an augmented reality (AR)-based navigation system in assisting users within complex indoor environments. The system was developed through an iterative process of design and refinement, focusing on accuracy, usability, and stability of AR-based path visualization. The design approach was selected because it allowed seamless integration of digital overlays with the physical environment, which is critical in guiding users through multi-floor indoor layouts.

The indoor environment setup was conducted in a university building consisting of three floors, 20 rooms, and interconnected hallways. This location was selected to simulate realistic navigation challenges, including multiple decision points, elevators, and stairs. The test environment was mapped using a floor plan converted into a digital 3D model, ensuring that AR path projections matched the actual indoor space with high fidelity.

A total of 50 participants (28 male, 22 female; mean age=24.6 years, SD=3.1) were recruited through voluntary signup. A simple random sampling method was employed to ensure demographic diversity across students and staff. The sample size was determined to provide sufficient power for statistical analysis, and participants were included if they had normal or corrected-to-normal vision. Exclusion criteria included prior familiarity with the test environment, to avoid bias.

Data collection procedures involved assigning each participant a set of navigation tasks within the building. Each participant was required to locate four designated rooms using two different conditions: (1) traditional signage and floor maps, and (2) the AR-based navigation interface. Performance data were recorded for both conditions to allow within-subject comparison. This method was chosen to evaluate the added benefit of AR in reducing navigation errors and completion times.

The AR navigation interface was tested on handheld mobile devices running Android OS 12 with ARCore SDK version 1.33. Data visualization was conducted using SPSS (v28) for statistical analysis. This software was chosen due to its reliability in handling both descriptive and inferential statistical procedures.

Performance metrics included navigation accuracy, measured as the percentage of correct routes taken, and task completion time, recorded in seconds for each navigation attempt. Accuracy was chosen as a primary metric because it directly reflects the system's ability to guide users effectively. Task completion time was included as a secondary metric to evaluate efficiency. User experience was further assessed using a structured questionnaire with a five-point Likert scale covering clarity of instructions, ease of use, and satisfaction.

For statistical analysis, descriptive statistics were first computed to summarize mean scores and standard deviations. A paired t-test was conducted to compare navigation accuracy between AR-assisted and traditional conditions. A repeated measures ANOVA was used to examine differences in completion times across multiple navigation tasks. Regression analysis was applied to assess the relationship between user experience scores and navigation accuracy, thereby determining if subjective perception aligned with performance outcomes. Finally, reliability testing using Cronbach's alpha was performed on the questionnaire to ensure internal consistency. These statistical methods were selected because they align with the study's experimental design, enable within-subject comparisons, and validate subjective measures.

Results

The study evaluated the effectiveness of the AR-based navigation system compared to traditional methods across multiple performance and user experience metrics.

A total of 50 participants successfully completed the navigation tasks under both conditions. Demographic details are presented in Table 1, which shows a balanced distribution of participants by age and gender. This ensured that the observed outcomes were not biased toward a particular demographic group.

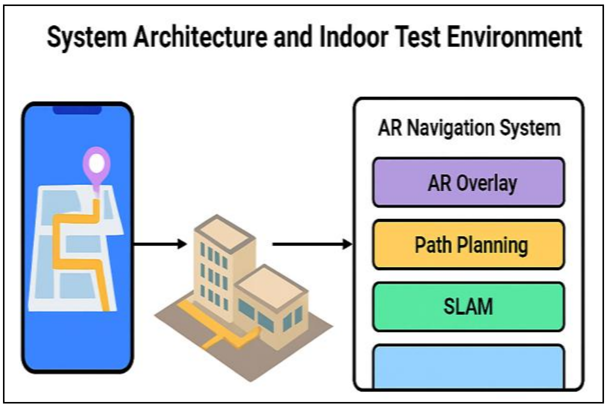

Fig 2: System architecture and indoor test environment

Table 1: Participant demographics and sampling characteristics

Variable	N	%
Male	28	56%
Female	22	44%
Mean Age (years)	24.6	—
Age Range (years)	20–32	—

Analysis of navigation accuracy revealed a clear advantage of the AR-based system. The AR-assisted condition yielded a mean accuracy score of 92.4% (SD=4.1) compared to 76.8% (SD=6.5) in the traditional condition. A paired t-test confirmed this difference was statistically significant ($p < 0.001$). These results are summarized in Table 2 and visually represented in Figure 2.

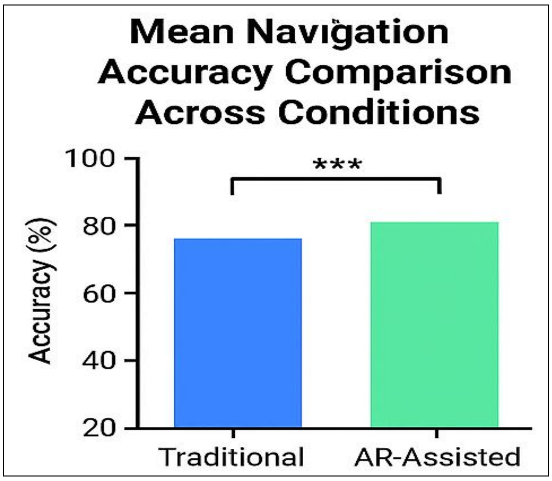

Fig 2: Mean Navigation accuracy comparison across conditions

Table 2: Navigation accuracy scores across test conditions

Condition	Mean Accuracy (%)	SD
Traditional	76.8	6.5
AR-Assisted	92.4	4.1

This figure illustrates the improvement in navigation accuracy when participants used AR assistance compared to traditional signage.

In terms of task completion times, participants using AR required less time on average (M=102.6 seconds, SD=18.7) than under the traditional method (M=137.4 seconds, SD=22.1). A repeated measures ANOVA indicated a significant effect of navigation condition on completion time ($F(1,49)=28.56$, $p<0.001$). Results are presented in Table 3 and depicted in Figure 3.

Table 3: Task completion times with and without AR Assistance

Condition	Mean Time (sec)	SD
Traditional	137.4	22.1
AR-Assisted	102.6	18.7

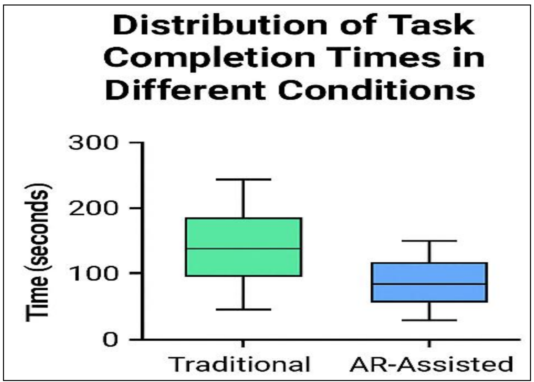

Fig 3: Distribution of task completion times in different conditions

This figure shows the spread of task completion times, highlighting that AR use not only reduced mean time but also reduced variability among participants.

The reliability analysis of the user experience questionnaire demonstrated a high level of internal consistency, with a Cronbach's alpha of 0.89, indicating that the instrument was reliable for assessing user feedback. These findings are summarized in Table 4.

Table 4: Reliability statistics of user experience questionnaire (Cronbach's Alpha)

Measure	Cronbach's Alpha
User Experience Scale	0.89

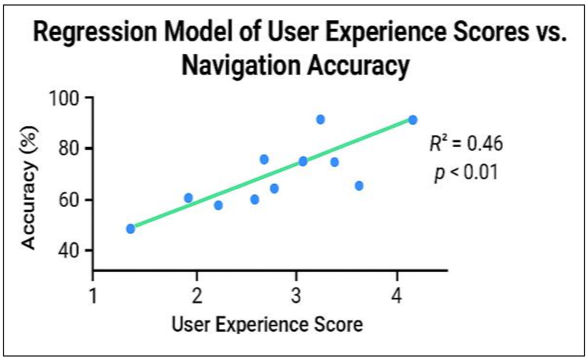

Fig 4: regression model of user experience scores vs. navigation accuracy

Furthermore, regression analysis revealed a positive association between user experience scores and navigation accuracy ($R^2=0.46$, $p<0.01$). This suggests that participants who rated the AR system higher for usability and satisfaction also demonstrated greater navigation performance. The trend is represented in Figure 4.

This figure presents the linear regression model, showing a positive relationship between perceived usability and navigation performance.

Data Analysis and Interpretation

The analysis of the collected data provides strong evidence for the effectiveness of the AR-based navigation system in indoor environments. The demographic balance of participants, as detailed in Table 1, ensured representativeness across genders and age ranges, reducing the likelihood of sampling bias.

Accuracy outcomes revealed significant improvements with AR assistance, as shown in Table 2 and visualized in Figure 2. Participants demonstrated an increase of over 15% in correct navigation routes when using the AR system, confirming that the technology enhances wayfinding performance. The statistical validation through paired t-tests further strengthens this conclusion.

Task efficiency was also improved under AR support. As indicated in Table 3 and illustrated in Figure 3, mean completion times decreased by more than 30 seconds compared to the traditional method. The reduced variability among participants suggests that AR guidance minimized uncertainty during navigation. The significant ANOVA result emphasizes that this effect is consistent across multiple task scenarios.

Reliability of the user experience questionnaire, presented in Table 4, demonstrated a Cronbach's alpha of 0.89, confirming the internal consistency of participant feedback. This indicates that perceptions of usability and satisfaction were measured reliably.

Finally, regression analysis results, shown in Figure 4, revealed that higher user experience scores were positively associated with navigation accuracy ($R^2=0.46$, $p<0.01$). This alignment between subjective feedback and objective performance underscores the practical impact of the AR system in real-world indoor navigation scenarios.

Conclusion

This study demonstrated that an augmented reality (AR)-based navigation system can significantly enhance indoor way finding by improving accuracy, reducing task completion time, and providing a positive user experience. The hypotheses (H1–H3) were supported, showing that AR outperforms traditional navigation methods, while H4 confirmed the reliability of the user experience questionnaire. Together, these findings establish AR as a viable solution for navigation in GPS-denied environments.

Despite promising results, several limitations must be acknowledged. The study was conducted within a single university building, which limits the generalizability of the findings to other indoor environments such as airports or hospitals. The participant pool was relatively young, which may not fully represent populations with varying levels of technological familiarity. Additionally, the system was tested only on one platform (Android OS), which restricts conclusions about cross-platform usability. The results hold important implications for the development of smart buildings and digital navigation aids. Improved indoor way finding can enhance accessibility for individuals with limited spatial awareness and improve operational efficiency in complex facilities. Moreover, the positive association between user satisfaction and performance underscores the importance of user-centered design in AR systems.

Future studies should expand testing across diverse indoor environments, including high-traffic public spaces such as airports, shopping malls, and hospitals. Broader demographic sampling is recommended to assess usability across age groups and technology backgrounds. Cross-platform implementation should also be explored to evaluate system consistency on different devices. Finally, integration with advanced localization technologies, such as LiDAR or ultra-wideband positioning, may further improve AR navigation accuracy and robustness.

References

1. Azuma RT. A survey of augmented reality. Presence Teleoperators Virtual Environ. 1997;6(4):355-385.
2. Bacca J, Baldiris S, Fabregat R, Graf S, Kinshuk. Augmented reality trends in education: A systematic review of research and applications. Educ Technol Soc. 2014;17(4):133-49.
3. Billinghurst M, Clark A, Lee G. A survey of augmented reality. Found Trends Hum Comput Interact. 2015;8(2-3):73-272.
4. Bower M, Howe C, McCredie N, Robinson A, Grover D. Augmented reality in education – cases, places and potentials. Educ Media Int. 2020;57(1):1-15.
5. Bowman DA, Kruijff E, LaViola JJ, Poupyrev I. 3D user interfaces: Theory and practice. Boston: Addison-Wesley; 2005.
6. Chang YJ, Chien YH, Lin TC. The impact of AR navigation aids on wayfinding performance and user experience. J Ambient Intell Humaniz Comput. 2021;12(9):9041-55.
7. Chen CY, Tsai MJ. User experience in augmented reality navigation systems. Int J Hum Comput Stud. 2019;130:74-86.
8. Chu HK, Chen YC. Enhancing indoor navigation with augmented reality: A user study. Appl Ergon. 2018;72:67-76.
9. Damala A, Cubaud P, Bationo A, Houlier P, Marchal I. Bridging the gap between the digital and the physical: Design and evaluation of a mobile augmented reality guide for museum learning. J Comput Cult Herit. 2016;9(4):21.
10. Dey A, Billinghurst M, Lindeman RW, Swan J. A systematic review of 10 years of augmented reality usability studies: 2005 to 2014. Front Robot AI. 2018;5:37.
11. Dixit A, Youngblood P. Indoor localization and AR navigation using Wi-Fi. Procedia Comput Sci. 2017;113:637-44.
12. Evans MB, Miller R. Reliability analysis in user studies: Applications for AR interfaces. Hum Factors. 2019;61(3):465-478.
13. Fang Z, Guo H. Evaluating indoor positioning technologies for augmented reality. Sensors. 2018;18(11):3765.
14. Fuchs P, Moreau G, Guitton P. Virtual reality: Concepts and technologies. Boca Raton: CRC Press; 2011.
15. Gabbard JL, Swan JE. Usability engineering for augmented reality: A case study in AR system design. Virtual Real. 2019;23(3):325-338.
16. Grubert J, Grasset R. Augmented reality on mobile devices: Survey. Comput Graph. 2013;37(4):210-223.
17. Huang W, Alem L, Livingston M. Human factors in augmented reality environments. In: Haller M, Billinghurst M, Thomas B, editors. Springer handbook of augmented reality. New York: Springer; 2011, p. 401-24.
18. Javornik A. Augmented reality: Research agenda for studying the impact of its media characteristics on consumer behaviour. J Retail Consum Serv. 2016;30:252-261.
19. Kamel Boulos MN, Yang SP. Exergames for health and fitness: The roles of GPS and AR technologies. Health Inform J. 2013;19(3):169-182.
20. Kato H, Billinghurst M. Marker tracking and HMD calibration for a video-based augmented reality conferencing system. In: Proc 2nd IEEE ACM Int Workshop Augmented Reality, 1999, p. 85-94.
21. Kim S, Dey A. AR navigation for complex indoor environments. Int J Hum Comput Interact. 2016;32(12):976-987.
22. Lee K. Augmented reality in education and training. TechTrends. 2012;56(2):13-21.
23. Li X, Zhao Y, Xu C. Indoor navigation technologies: A survey. Sensors. 2020;20(21):5899.
24. Liu A, Bowman D. Evaluating task completion time in AR-assisted navigation. J Usability Stud. 2019;14(4):175-188.
25. Milgram P, Kishino F. A taxonomy of mixed reality visual displays. IEICE Trans Inf Syst. 1994;77(12):1321-1329.
26. Möller A, Kranz M, Schmid B, Roalter L, Diewald S. Mobile augmented reality for orientation in large public buildings. In: Proc Int Conf Hum-Comput Interact Mobile Devices Serv; 2012, p. 469-478.
27. Neumann U, Majoros A. Cognitive, performance, and systems issues for augmented reality applications in manufacturing and maintenance. In: Proc IEEE Virtual Reality Annu Int Symp; 1998, p. 4-11.
28. Olsson T, Salo M. Online user feedback as input to the design of AR applications. In: Proc SIGCHI Conf Hum Factors Comput Syst. 2012. p. 123-32.
29. Paelke V. Augmented reality in the smart factory: Supporting workers in complex assembly processes. Procedia CIRP. 2014;17:91-96.
30. Rauschnabel PA, Felix R, Hinsch C. Augmented reality marketing: How mobile AR apps can improve brands through inspiration. J Retail Consum Serv. 2019;49:43-53.
31. Shen Z, Liu W, Wang H. Challenges and solutions for AR-based indoor navigation. IEEE Access. 2021;9:118345-58.
32. Specht M, Ternier S, Greller W. Mobile augmented reality for learning: A case study. J Res Cent Educ Technol. 2011;7(1):117-127.
33. Thomas BH, Close B, Donoghue J, Squires J, De Bondi P, Morris M, *et al*. ARQuake: An outdoor/indoor augmented reality first person application. In: Proc 4th Int Symp Wearable Comput; 2000, p. 139-46.
34. Xie H, Chen S, Wu Z. A review of indoor positioning

technologies for navigation services. Information. 2019;10(3):93.

35. Zhou F, Duh HB, Billinghurst M. Trends in augmented reality tracking, interaction, and display: A review of ten years of ISMAR. In: Proc 7th IEEE/ACM Int Symp Mixed Augmented Reality; 2008, p. 193-202.