RESEARCH ARTICLE

Augmented Reality for Campus Wayfinding: Enhancing Navigation Efficiency and Student Social Engagement — A Case Study of Leeds University Union

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Abstract: This study designed and evaluated a user-centered augmented reality (AR) wayfinding prototype for Leeds University Union (LUU), aiming to improve student wayfinding efficiency and encourage social exploration within a particular campus environment. A site-specific field study involving photographic documentation of existing wayfinding aids, such as signage and maps, was conducted to investigate the current design. Five semi-structured interviews were carried out to gain students' experiences and opinions, complemented by behavioral observations of three participants navigating the LUU with existing wayfinding aids to explore common challenges and dilemmas. Results showed that the existing design did not consistently support effective navigation, with participants relying on assistance from others. Furthermore, all of the students reported using the LUU mainly for social and recreational purposes, indicating that integrating navigation with real-time event information could enhance campus community engagement. In response, a prototype mobile navigation application named LUU MATE was developed that integrated AR with social exploration features to enhance both wayfinding and engagement in campus life. The iterative optimization of the prototype was based on usability tests conducted by four participants. Subsequently, a second behavioral observation was conducted with three participants using LUU MATE to assess its navigation effectiveness and potential to foster social engagement. Comparative analysis with earlier observations showed that LUU MATE reduced the time required to complete the navigation tasks and stimulate participants' interest in campus life. This study indicates that both navigation efficiency and social engagement are essential considerations in campus wayfinding design. Future research should involve larger and more diverse participant groups and apply the design across varied campus sites to validate its broader applicability.

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1. Introduction

This study aims to design an augmented reality (AR) campus indoor navigation solution to solve the wayfinding challenges encountered by students in Leeds University Union (LUU) and evaluate whether the AR navigation system can affect indoor wayfinding efficiency. Most importantly, the study seeks to use AR navigation as a means of encouraging exploration, engagement, and connection with the rich social lives of the students.

To achieve these aims, it is essential to consider the role of user interface (UI) design in AR environments. UI design is particularly crucial in AR scenarios, as AR interfaces must operate within a hybrid environment, effectively overlaying digital content onto real-world scenes in real time, enhancing users' intuitive understanding of information and ease of interaction (Chen, 2024). These unique requirements impact the application's visual design, interaction patterns, and user understanding and perception. Effective AR interface design needs to be able to adapt flexibly to different environments and not obstruct the view of the real world. This requires consideration of how digital information is presented in different scenarios (Cao et al., 2023).

As universities expand, the working environment of university campuses has become more and more complex. Currently, most campuses rely on global positioning system (GPS) technology, such as Google Maps, for outdoor navigation, but this often has difficulty covering the interior of buildings, resulting in a disconnect between indoor and outdoor campus navigation (Rajagopal et al., 2025; Tahir & Krogstie, 2023). Indoor wayfinding relies heavily on traditional wayfinding methods (such as paper maps and mounted signs) that have been shown to be inefficient (Rajagopal et al., 2025). These traditional methods are usually limited by the finite guidance that can be displayed, requiring users to actively discover navigation cues (Iftikhar & Luximon, 2022). In addition, many of these methods rely on a single language which may cause wayfinding difficulties for international students (Iftikhar & Luximon, 2022). In complex, multi-level spaces with diverse functional areas, wayfinding is not merely about reaching a destination, it is also about discovering what the space offers along the way. This is particularly relevant in environments centered on student life, where navigation naturally overlaps with opportunities for social interaction, discovery of new activities, and engagement with community resources.

LUU exemplifies this challenge. As the main hub of student activity and interaction at the University of Leeds, it houses a variety of services, catering facilities, and event spaces that support both academic and professional development while also fostering students' personal growth and sense of belonging. Beyond dining and relaxation, it serves as a venue for organizational activities, club engagement, and informal social encounters. Its design potentially facilitates opportunities for social discovery, as students navigating the space may come across events or societies they had not originally known or planned to explore. Here, navigation and social exploration are intertwined, and a system that supports both can improve spatial accessibility, accelerate students' integration, and strengthen engagement with campus resources.

This study, therefore, aims to explore how the designed AR navigation prototype can improve students' wayfinding efficiency while promoting social exploration and participation among students within the LUU. The research question of this study is:

> How can an AR navigation mobile application be designed to improve wayfinding experience for students within the LUU?

The sub-questions are:

1. What wayfinding challenges do students experience within the LUU, and how do they interact with existing wayfinding aids when navigating the building?
2. In what ways does the AR wayfinding prototype influence users' navigation behaviors and their engagement with the LUU resources?
3. What roles do AR interface design features play in enhancing the wayfinding experience and supporting social exploration?

2. Contextual Foundations

2.1. Complexity of Modern Campus Wayfinding

Wayfinding is a process in which personal attributes (such as cognitive, perceptual, and spatial abilities) interact with the characteristics of the surrounding environment (Farr et al., 2012). Wayfinding is mainly divided into three steps: confirming the destination, finding the correct route, and using auxiliary navigation tools (Farr et al., 2012). People use the surrounding natural environment or navigation tools to find their destination (Zolkefil & Talib, 2022).

Wayfinding presents particular challenges in higher education settings. University campuses are often composed of multiple buildings spread over large, open areas and organized in complex spatial configurations (Iftikhar et al., 2020). Students, staff and visitors often need to move between libraries, cafeterias, and administrative offices, requiring them to interpret a wide range of navigation cues. These cues play a key role in the wayfinding process and include external environmental cues — such as building facades, outdoor signs, and trails — as well as internal navigational instructions — such as corridor signs, room numbers, and floor guides (Jamshidi et al., 2020). New students or first-time visitors are more likely to experience this complexity because they have limited familiarity with the building layout and signage system. The frequent need to transition between indoor and outdoor environments further increases the complexity of campus navigation (Tahir & Krogstie, 2023).

Although GPS technology (such as Google Maps) is widely used for outdoor campus navigation, it cannot provide accurate positioning support indoors (Torres-Sospedra et al, 2015). GPS signals are often weakened or blocked by building structures, leading to reduced positioning accuracy or signal loss. Many studies have explored various ways to address indoor wayfinding difficulties, including using Bluetooth Low Energy (BLE) beacons, Wi-Fi fingerprinting, and radio-frequency identification (RFID) systems (Kunhoth et al., 2020; Saradha et al., 2025). However, the cost of implementing these technologies is often relatively high, and they are heavily dependent on personalized configurations, making them difficult to scale and apply across wider contexts (Tomažič, 2021).

The spatial characteristics of facilities inside university buildings often exacerbate these difficulties. Academic buildings typically feature repetitive architectural layouts, such as long corridors, uniform doors, and similar room numbering schemes, which can make it difficult for users to differentiate one location from another (Major et al., 2020). In addition, these buildings often span multiple floors connected by complex networks of staircases, lifts, and transitional spaces, which are not always well-integrated into signage systems (Li et al., 2023). These networks lack visual coherence. If building signage systems are not displayed in the appropriate location or sequence, it can make people feel uneasy (Kim et al., 2015). Academic building navigating can be further complicated by the absence of multilingual support, and a lack of intuitive wayfinding cues for first-time visitors or international students (Zolkefil & Talib, 2022; Bridgeman, 2023). Unlike outdoor environments, where landmarks and open sightlines can provide orientation, indoor environments often lack prominent reference points, making spatial awareness harder to maintain (Kim et al., 2015). In addition, there are individual differences in humans' abilities to process visual spatial information, which may involve factors such as gender, spatial cognition level, and cultural background (Verghote et al., 2019). Students' wayfinding decisions may also be influenced by their individual understanding of wayfinding aids and spatial information (Iftikhar et al., 2020).

Furthermore, academic buildings are not only important places for learning, but also important student exchange communities with important social and cultural exchange values (Cheng, 2004). Students generally desire a sense of belonging and identity on campus. This is a basic psychological need, the satisfaction of which affects students' behavior patterns, motivation, and school participation (Osterman, 2000; Cheng, 2004). In educational settings, a sense of belonging is not only supported by building positive social connections with classmates and faculty, but is also fostered through active interactions with friends, participation in clubs, and informal extracurricular activities (Kelly et al., 2024). Research has shown that in higher education, students' sense of belonging is positively correlated with their learning motivation, academic confidence, and overall learning satisfaction, and that students with a stronger sense of belonging are less likely to drop out (Pedler et al., 2022).

In academic environments, navigation is not solely a functional activity aimed at reaching a destination. Dalton et al. proposed the concept of "social wayfinding", which states that the process of wayfinding, while seemingly an individual decision-making act, is often influenced by the presence and behavior of others (2019, p.2). In other words, wayfinding can be considered a form of exploration, not only related to getting from a starting point to a destination, but also a form of social exploration (Willis, 2009). While moving through space, people may discover new people, activities, or opportunities out of curiosity or serendipity, such as encountering club recruitment, attending impromptu gatherings, or other recreational activities at school (Willis, 2009). These serendipitous encounters increase the likelihood of spontaneous participation in campus life.

2.2. AR Wayfinding

Following Apple's release of AR support for third-party developers through the iPhone 3GS in 2009, which introduced a digital compass and improved motion sensing enabling early forms of mobile AR, the Yelp app became one of the first AR-enabled applications to debut on the iPhone (Manjoo, 2009). Its Monocle feature allowed users to point their phones toward nearby restaurants and instantly view star ratings overlaid on the live camera feed. This demonstrates one of the earliest mainstream applications of mobile AR. Since then, advancements in mobile AR have substantially expanded its capabilities for wayfinding and spatial understanding. AR navigation systems overlay guidance information, such as arrows, paths, and points of interest, onto a user's real-world view. For example, Google Maps launched the Live View feature in 2019, offering real-time AR-enhanced walking guidance through spatially aligned arrows and directional cues. This approach has been shown to support more efficient and accurate wayfinding (Khairy et al., 2022) and create more intuitive navigation experiences (Dong et al., 2021; Qiu et al., 2025). Additionally, AR has demonstrated benefits in helping users visualize spatial relationships and dimensions (Ahsani et al., 2025; Shamsuddin & Din, 2016).

Recent advancements in AR navigation technologies are prioritizing markerless AR navigation systems. For example, Placenote tracking combined with the A* algorithm (Shewail et al., 2022) enables users to navigate without GPS and the QR-code-based approach (Santi et al., 2023). HUDs project information directly into the user's line of sight, enabling continuous access to guidance cues without requiring the user to look down or shift attention away from the primary field of view. Recent studies demonstrate that AR-HUDs can enhance navigation performance and reduce user errors (Chauvin et al., 2023), while also lowering cognitive load during driving tasks (Xu et al., 2025). In addition, AR is increasingly being used not only for functional guidance but also to enrich the overall user experience. In tourism, Akbar et al. (2024) developed GWIDO, a mobile app that blends AR navigation with multilingual historical storytelling, helping users explore cultural sites more meaningfully through real-world object tracking and bilingual instructions.

Table 1. Comparative Analysis of Different AR Campus Navigation Systems

Study	Design goals	AR Solution	Remaining Challenges
Dirin and Laine (2018)	To assess user familiarize themselves with environment.	Using a virtual tour achieved through floor function descriptions (rather than pathfinding guidance).	Lack of navigation details (e.g., maps, place names). Insufficient support for spatial learning and wayfinding.
Kuwahara et al. (2019)	To help campus visitors understand paths more easily.	Using AR avatars (cartoon style) to lead users along real-life path and present directions in real time.	Possible confusion due to lack of sync between the character's movement and the actual path. Absence of usability testing.
Golestanha and Satter-field (2022)	Help students and faculty, especially those with navigation difficulties, get to their destinations more easily and quickly.	It provides two modes: 2D map and AR naviga-tion, based on landmark guidance.	Absence of usability testing.
Divya et al. (2024)	Improve the efficiency with which students or visitors navigate buildings, facilities, and pathways around campus.	Use AR technology to overlay virtual path guidance, building labels and 3D campus feature virtual elements on the user's mobile phone camera view to achieve an immersive navigation experience.	No detailed prototype and usability testing were provided; the accuracy of the position of virtual elements in the interface; there is room for expansion of the interac-tion form.
Saradha et al. (2025)	Help students understand the facili-ties both inside and outside the campus.	Create an AR campus map system to provide students with seamless indoor and outdoor path guidance and point-of-interest displays.	Lack of exploration of UI design and user experience.

However, despite these expanding technological possibilities, such advancements have not yet been widely applied or validated within campus environments. Table 1 lists several studies that examined the use of AR navigation within the specific campus context for varying purposes. Table 1 indicates that most reviewed studies focus primarily on technical implementation and navigation performance, with limited attention to AR interface design and its impact on usability and user experience. Existing research has mainly examined methods of route guidance and information presentation, but studies specifically addressing design and validation in complex indoor academic settings remain limited. Only a small number of studies report usability testing to validate their solutions. Therefore, based on the literature reviewed in this study, aligning AR interface design with user needs in complex indoor campus environments and validating its effectiveness through systematic usability testing represents an area that warrants further investigation.

AR interface in mobile navigation applications. The user interface (UI), the point of interaction between a computer system and its user, enables the completion of tasks and achievement of goals (Stone et al., 2005). Effective UI design aims to provide a seamless and engaging user experience, and its quality is closely linked to the success of an application (Ayada & Hammad, 2023). A well-designed UI should ensure ease of use, practical functionality, and efficiency, which in turn influences user experience and loyalty (Chen et al., 2021). While UI design has been extensively studied across various digital applications, research focused on AR interfaces is still quite limited.

AR interface design is recognized as a key factor affecting the effectiveness of AR wayfinding (Xu et al., 2024). Even with accurate navigation technology, poorly designed interface can reduce usability and user experience. Incorporating usability and learnability into the design process is therefore essential to ensure effectiveness in real use (Granic, 2017). However, the absence of unified AR design standards, coupled with the limited applicability of existing UI theories, makes AR interface design a unique and underexplored area of research (Börsting et al., 2022). For example, the Google Maps AR deployed at Zurich Airport provides only localized, turn-by-turn prompts rather than a continuous path overview. In the real navigation scenarios, this lack of path continuity has been shown to increase the likelihood of users becoming disoriented (Hölscher et al., 2006). This issue could become even more pronounced on university campuses, which spatial layout are more irregular, destinations are dispersed, and movement patterns are social driven. These challenges collectively underscore why focusing on AR interface design is crucial for developing wayfinding solutions that genuinely support users in navigating dynamic settings.

In summary, integrating indoor navigation with social interaction, while simultaneously improving wayfinding efficiency and campus engagement, remains an emerging area of research, particularly in understanding the role the AR interface in this process. Using the LUU at the University of Leeds, as a case study, this study proposes and evaluates a solution that integrates AR navigation with social exploration features to validate the impact on wayfinding efficiency, user engagement, and overall user experience.

3. Methodology

This study aims to develop and evaluate LUU MATE, an indoor augmented reality (AR) navigation mobile application prototype for the University of Leeds as a Masters student project. The system was designed with the dual objectives of improving students' wayfinding efficiency and fostering social exploration to enhance campus community integration.

The methodology of the entire design research comprises three key phases, each guiding the development and evaluation of the LUU MATE. Figure 1 summarizes the methods and activities of each phase.

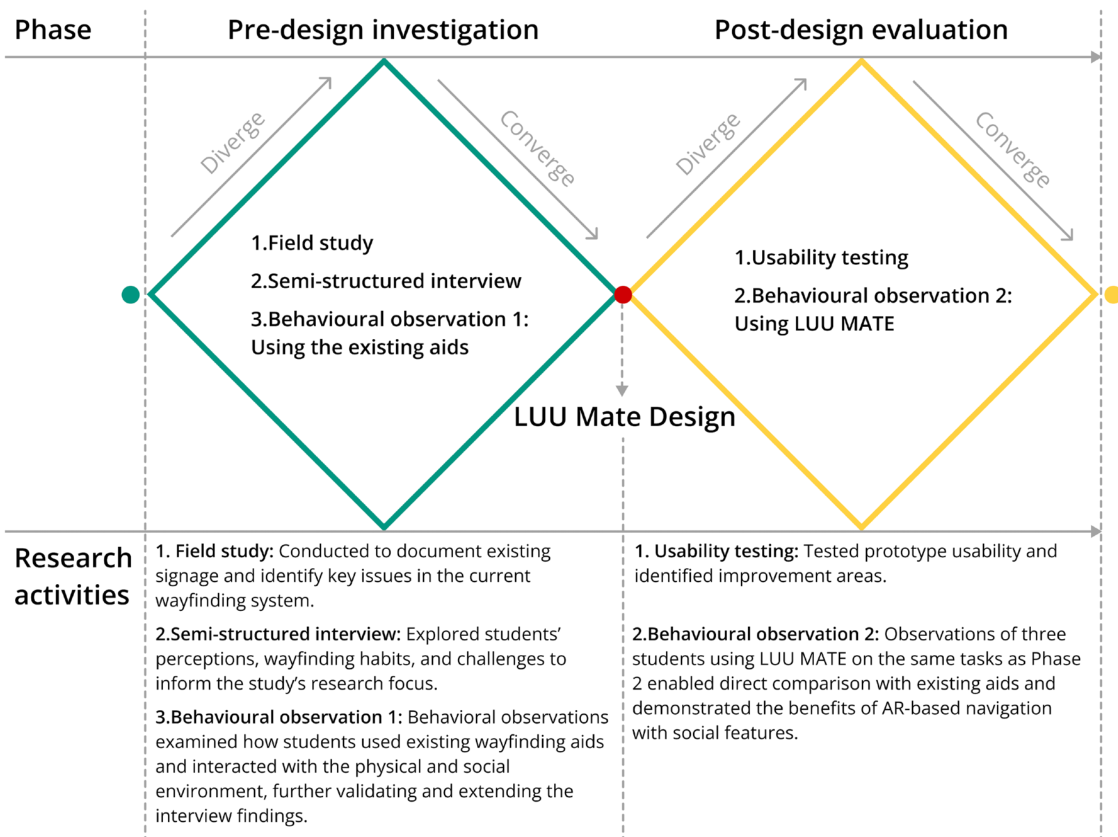

Figure 1. Methodology summary. Designed by the first author.

All participants were current students at the University of Leeds, recruited on a voluntary basis. Different groups of students were involved in the interviews, usability testing, and the two rounds of behavioral observations to avoid familiarity effects and ensure that findings reflected a range of authentic user perspectives. This study was conducted in accordance with the University of Leeds Research Ethics Framework and received ethical approval prior to data collection.

3.1. Pre-Design Investigation

Current wayfinding design in the LUU at the University of Leeds. At the initial stage of this study, a field investigation was conducted in the LUU at the University of Leeds to document the existing wayfinding system and identify key issues within the current system. Photographs were taken to document signage, spatial cues, and key decision points. These photographs were gathered through walkthroughs of major circulation routes during the field investigation.

The LUU's spatial layout includes multiple entrances and interconnected floors, encompassing functional areas such as dining, social, and administrative spaces. However, the similar facilities are scattered across different floors, resulting in an

Figure 2. The floor plan posted near the ground floor entrance in the LUU. Among five entrances, this is the only one that provides a posted floor plan to aid navigation. Photographed by the first author in Nov 2024.

irregular and complex spatial layout that makes it difficult for new visitors to form a coherent mental map. Of the five entrances, only one has a posted floor plan to aid navigation (Figure 2). As a result, new visitors may struggle to form an immediate mental map of the building and often rely on asking for help.

LUU employs geometric shapes on the signage, such as prisms, stars, and circles, to distinguish functional areas (Figure 3). Despite maintaining visual consistency, the lack of explanatory background information makes the system less intuitive, especially for first-time visitors. The map's layout uses horizontally divided floors, requiring visitors to match the list of destinations at the top with corresponding symbols on a simplified floor plan below. This increases cognitive load and hinders rapid spatial understanding. Furthermore, the floor plans are small and have low color contrast, potentially reducing readability. Information about ongoing activities is only available on a single digital screen at the information desk, potentially limiting users' understanding of the union's broader social activities.

These limitations highlight the need for more effective and socially connected wayfinding solutions, for which AR offers a promising direction. AR applications have gradually been widely recognized for its potential in indoor navigation (Dong et al., 2021; Pence,

Figure 3. The floor plan of the LUU using geometric shapes to differ functional areas. The content in the upper row shows the locations of each corresponding shape on each floor, and the lower row is the floor plan corresponding to each floor. Photographed by the first author in Nov 2024.

2011). By overlaying digital guidance directly onto the user's view of the real world, AR can make spatial relationships and dimensions easier to interpret (Ahsani et al., 2025; Shamsuddin & Din, 2016). Recent developments suggest that AR can prompt exploration, highlight social opportunities, and create contextual touchpoints that invite users to engage with events, activities, and peers as they navigate (Wadne et al., 2024). This opens up possibilities for a more integrated approach, where functional navigation seamlessly incorporates social discovery cues into the wayfinding process.

Semi-structured interview and behavioral observation 1. To understand students' wayfinding experiences within the LUU and identify key navigational challenges, five semi-structured interviews were conducted with current students familiar with the building, each lasting approximately 20–30 minutes. Students discussed their daily activities within the building, their wayfinding habits, and the challenges they encountered in finding their way.

To validate and expand these insights, three behavioral observations were subsequently conducted with three additional participants, who used existing wayfinding aids to complete a pre-defined navigation task (Table 2). A 'think-aloud' method was employed to record participants' decision-making processes and moments of confusion as they navigated between floors. Their path selection, key decision points, and moments of confusion were the primary parameters noted during the analysis. These activities collectively provided a better understanding of existing navigational barriers within the LUU and its social interactions.

Table 2. Instructions for three behavioral observation tasks.

Task	Scenario
1. Find a study area	You need to join a group discussion, and your team leader has reserved Meeting Room 1 in the LUU for the discussion. Navigate from the LUU entrance on the Ground Floor to Meeting Room 1 on the Second Floor.
1. Find a public facility	You have just finished class and are going to the LUU to rest. You are very thirsty and ready to look for the water dispenser first. Navigate from the LUU entrance on the Ground Floor to the student kitchen on the Basement Floor.
1. Find the Student Service Center	You want to volunteer at a school. You've learned that Essentials is a support department for students in the LUU and are looking for volunteer opportunities. Navigate from the LUU entrance on the Ground Floor to the Student Services (Essentials) on the M Floor (the mezzanine between the Ground Floor and Level 1).

Overall, the pre-design tasks identified key challenges students are facing using the existing wayfinding system, including complex spatial structures, unclear visual hierarchy of signage, lack of certain location information, and insufficient integration with social activities. These findings (Section 4.1) provided the basis for the develop of the LUU MATE prototype, which aimed to assist spatial understanding through AR-based cues and promote community engagement by embedding information about ongoing activities into the navigation interface.

3.2. Design and Prototype Development

The LUU MATE prototype was developed to integrate core wayfinding and social engagement functions within a single mobile application. The Home page (Figure 4) featured two functions: 'Find a place' and 'Explore' reflecting the app's dual focus on wayfinding effectiveness and social engagement. The 'Find a place' was designed to help students quickly locate specific locations within the LUU and receive AR route guidance. This feature addressed challenges identified from interviews and observations, where many students reported difficulty locating their destinations upon entering the LUU.

The AR wayfinding interface (Figure 5) provided linear, continuous route guidance using virtual green arrows. A white panel at the bottom displayed navigation-related information (such as distance and an 'Exit' button), ensuring that users could easily track their progress. In addition, floating icons were superimposed near relevant functional areas along the route, enabling students to access information about events or services encountered in route.

The 'Explore' feature (Figure 6) provided themed guided tours to help students systematically understand the building's functional areas and facilities. This feature was partic-

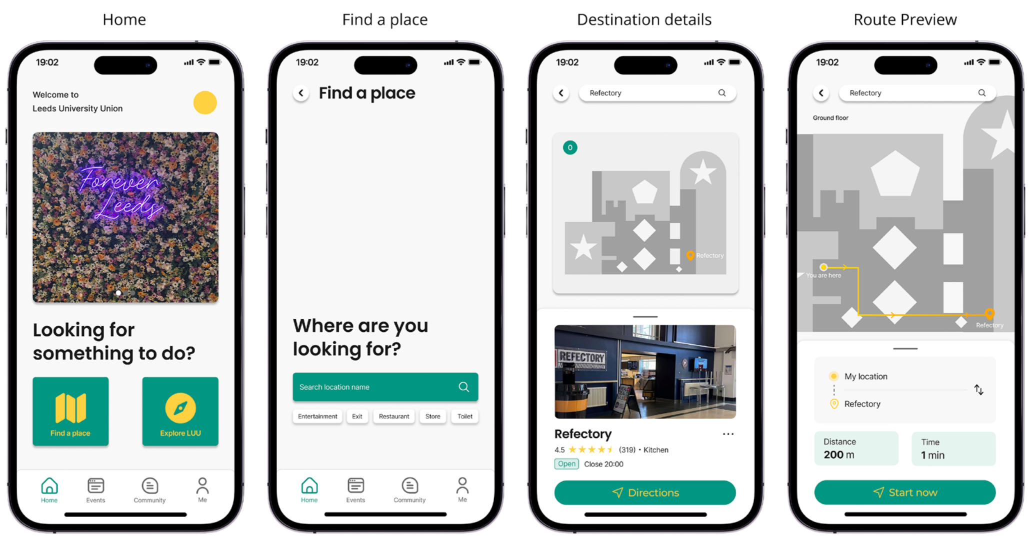

Figure 4. LUU MATE 'Find a place' function flow. The first screen displays LUU MATE's home page, offering two navigation methods: entering your destination for directions and viewing specific guided routes. The second screen shows the 'Find a place' interface. The third screen displays information about the destination after entering it on the previous screen. The fourth screen displays the route to the destination. Designed by the first author.

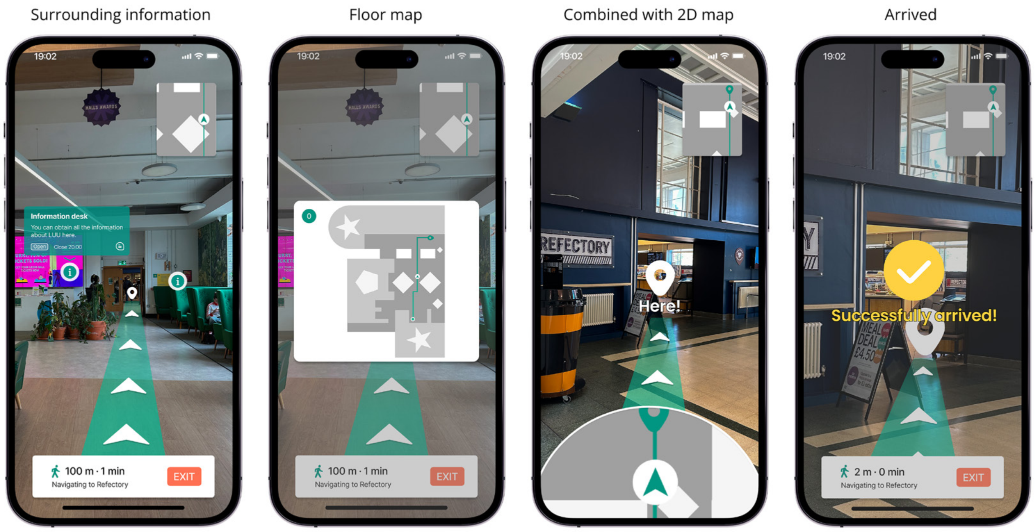

Figure 5. LUU MATE AR interfaces for route guidance. The first screen displays nearby activities and facilities, encouraging students to learn about campus facilities or ongoing campus events during navigation. The second screen displays an overview of the current floor map, providing users with route presets. The third screen shows an AR navigation path overlay combined with a mini 2D map approach when the user reaches a corner, aiding spatial awareness. The fourth screen confirms successful arrival at the destination. Designed by the first author.

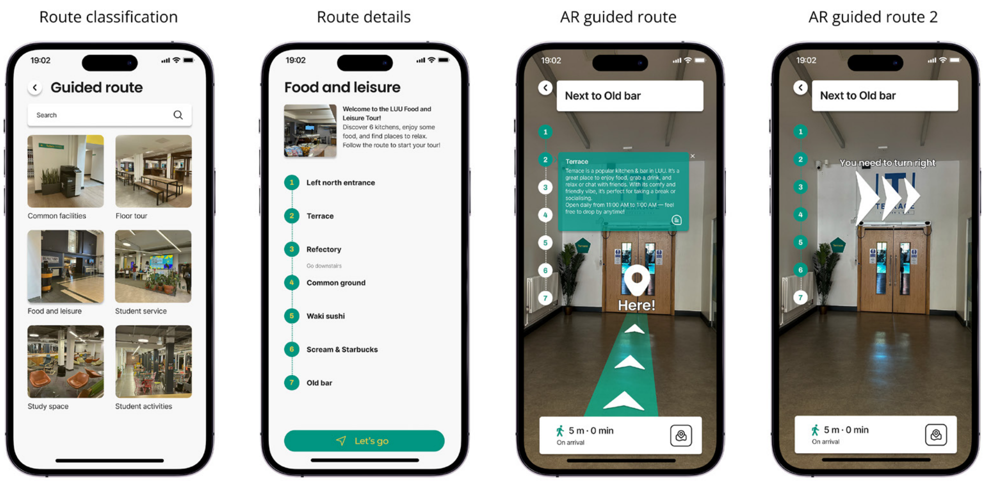

Figure 6. LUU MATE ‘Explore’ function flow. The first screen displays guided routes on different themes, primarily for new visitors. The second screen provides an introduction and route information for the theme ‘Food and leisure’. The third screen shows how to navigate to the second destination on this guided route; users can view destination information on the left side of the screen. The fourth screen demonstrates the interface when heading to the next location. Designed by the first author.

ularly useful for first-time students, providing a holistic understanding of the building layout and addressing the lack of unified functional guidance identified in earlier research (Section 4.1.1), aiming to enhance students' familiarity and confidence in finding their way. Guided tours were categorized based on common students' activities (such as socializing, resting, and dining) and distributed across floors and activity areas. The interface included a progress bar on the left to display the number of stops, track progress, and indicate visited versus unvisited locations. At each stop, a short pop-up description introduced the location's purpose, further supporting users' confidence and familiarity with the building.

The 'Event' feature (Figure 7) showcased upcoming events within the LUU, allowing students to stay updated and access events of interest more efficiently. Integrated with the 'Find a Place' function, this feature also provided route guidance to event locations, bridging wayfinding with social engagement. Complementing this, the 'Community' feature (Figure 7) provided an open communication platform where students could share posts related to daily experiences, interests, or campus activities. This design reinforced the LUU's role as a "student community", encouraging peer-to-peer interaction and strengthening social cohesion on campus.

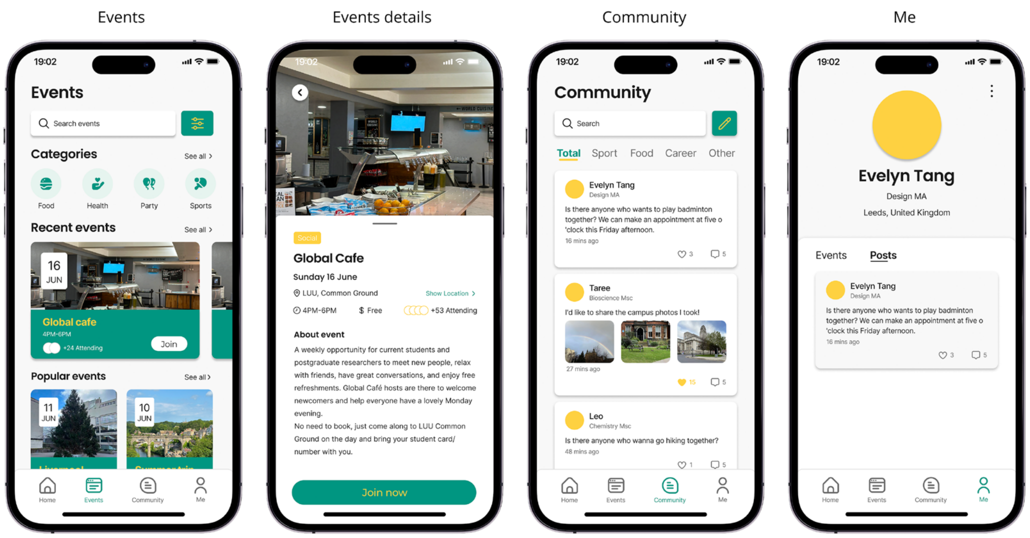

Figure 7. LUU MATE 'Events', 'Community' and 'Me' function main page display. The first screen displays the main interface of the 'Events' feature, providing event categories and push notifications of recent events. The second screen shows the event details displayed after clicking 'Global cafe' within the 'Events' interface. The third screen displays the main interface of the 'Community' feature, where users can post any information, including making friends, new community events, and dining events. The fourth screen displays the main interface of the 'Me' feature, showcasing the user's personal information. Designed by the first author.

3.3. Post-Design Evaluation

Usability testing. After developing the first high-fidelity version of LUU MATE, four students from the university were recruited to participate in usability testing. With participants' consent, all sessions were screen-recorded. A 'think-aloud' method was employed. To gain users' impressions of first-time engaging the prototype, participants first spent five minutes freely browsing LUU MATE without assigned tasks. They then completed three structured tasks corresponding to the app's main functions:

1. Find a place: Use LUU MATE to search for and navigate to 'Refectory'.
2. Explore: Imagine visiting the LUU for the first time and want to explore dining and leisure areas using the 'Food and Leisure' themed tours under 'Explore' feature.
3. Events: Locate details about the 'Global Cafe' and attempt to make a reservation.

Following the task, each participant completed a post session to comment on their experiences about how the prototype might impact their social engagement.

Since the LUU MATE prototype did not implement actual AR navigation, the usability test evaluated a simulated AR experience created entirely in Figma (Figure 8). The

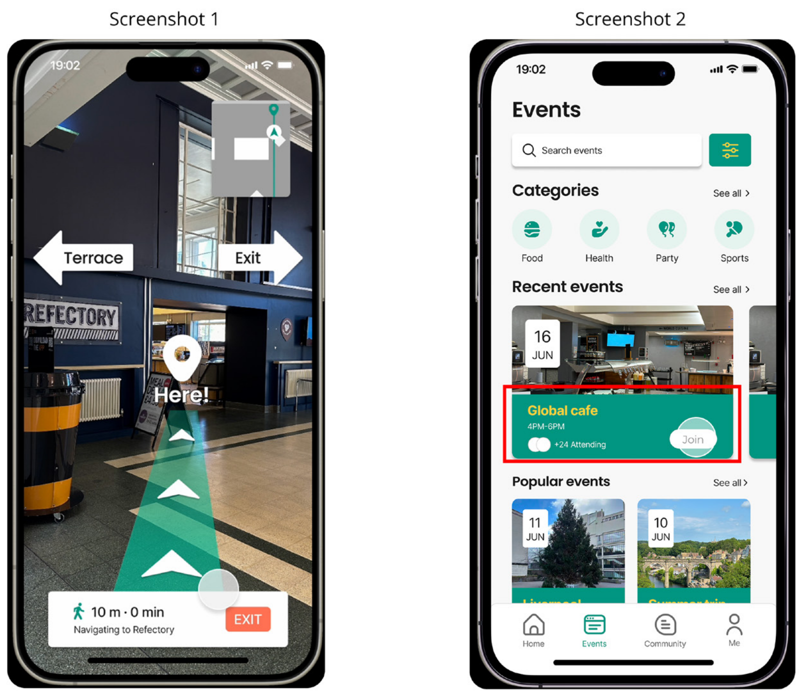

Figure 8. Screenshot of the usability testing materials. Participants used a Figma prototype to complete test tasks, which were conducted face-to-face with the first author. Screenshot 1 shows that the user has successfully reached the destination using AR navigation and is about to exit the navigation. Screenshot 2 shows that the user is searching for and joining the 'Global café'. Provided by the first author.

prototype used pre-recorded environment images and screen-based overlays to represent how AR cues would appear during navigation. The first author conducted all usability tests in individual, face-to-face sessions with each participant. During the test, screen recording software was used to record the process, which allowed the participants to interact with the Figma prototype while automatically capturing task completion time, click paths, mis-clicks, and success rates. After each task, participants provided subjective feedback to assess their perception of interface clarity, ease of use, and overall user experience.

The findings (Section 4.2.1) of the usability testing were used for iterative refinement of the prototype and the final design is presented in Figure 13.

Behavioral observation 2. The second behavioral observation mirrored the first in both tasks and methods to enable a controlled comparison of wayfinding behaviors with and without the support of LUU MATE. Participants were asked to complete the same tasks (Section 3.1.2, Table 2), with the aim of evaluating whether the AR prototype improved wayfinding efficiency and reduced navigation challenges.

Three students who had not participated in the first observation were recruited to avoid familiarity effects. Following each session, a semi-structured post-test interview was conducted to gain their impressions of LUU MATE and obtain suggestions for improvement.

A consistent 'think-aloud' method was employed throughout the observations, with participants' sessions video-and audio-recorded. The researcher followed them to document their verbalized thoughts and wayfinding behaviors. The same observation metrics were used to ensure data comparability across the two behavioral observations. Key metrics included: wayfinding time, decision points, and moments of confusion, which were used to assess the effectiveness of LUU MATE.

4. Findings

4.1. Pre-Design Investigation

Semi-structured interviews. The purpose of the semi-structured interviews was to explore the wayfinding challenges and to understand how navigation impacts students' social interactions, activity participation and overall experience in the LUU.

A total of five participants took part in semi-structured interviews. Three reported themselves as relatively familiar with the LUU, while two considered themselves less familiar. The most common activities participants engaged in within the LUU included socializing, dining, and studying — underscoring the LUU's dual role as both a functional and social hub. For navigation, they primarily relied on memory or existing signage, though some admitted seeking help from staff or passersby when disoriented.

All participants reported difficulties finding their way around the LUU, and the overall impression was that the building felt complex and confusing. As Participant 1 noted:

> I think the LUU has many floors, and the structure of each floor is different. There are many forked intersections, and the wayfinding signages [sic.] are incomplete, which can easily cause people to feel anxious when trying to find their way.

All participants noted that the building lacked clear information about the functions of each floor, making it difficult to determine the correct floor for their destination. Furthermore, existing wayfinding signage lacked comprehensive location information, with some destinations omitted. Icons on the signs were ambiguous and required extra time to interpret. Many participants described feeling confused and anxious when unable to find their destination, especially when under time pressure. Finally, all participants stated that they were unaware of the availability of the LUU's floor plans, which they agreed could have helped alleviate some of these difficulties.

In addition to navigational challenges, participants also mentioned how the difficulty in finding the destination would affect their willingness to explore the buildings or participate in activities. For many students, attending club activities or informal gatherings is an important part of their student council experience. However, several participants described situations where uncertainty about locations prevented them from participating. Participant 2 noted: "I missed an event because I failed to find the correct floor and room in time, and later rarely participated in activities within the LUU".

Participant 3 said:

> I happened to find an event poster in the LUU, but the poster did not provide the corresponding floor information, only the location of the event, and there was a lack of relevant activity indications around, making it impossible for me to participate in the event.

These experiences demonstrate the close relationship between social engagement and navigation. Importantly, participants expressed a desire for more readily accessible information about activities within the space. This insight directly influenced the design of LUU MATE's social engagement features, combining social exploration with navigation functionality.

Behavioral observation 1: Using existing wayfinding aids. The purpose of this observation was to evaluate how students navigate the LUU using only existing wayfinding aids, in order to identify key wayfinding challenges.

Table 3 shows the task completion times (in minutes) for each participant. Overall, navigation tines were long, with an average completion time of 4:03 for Task 1, 3:04 for Task 2, and 5:18 for Task 3.

Table 3. Behavioral observation using existing wayfinding aids. Completion times of each participant (minutes: seconds).

Time	P1	P2	P3
Task 1: Meeting room 1	3:12	3:42	5:16
Task 2: Student kitchen	2:05	3:49	3:18
Task 3: Essentials	6:55	5:58	3:03

A user journey was mapped to visualize participants' navigation experiences (Figure 9). It presents four stages: Start, Explore, Error, and Arrival, which represent the progression from orientation, through active searching, to moments of disorientation, and finally reaching the destination. Analysis of participants' emoji selection data indicated that their perceived emotional state was initially stable, declined during the Explore and Error stages, and recovered once they reached their destination.

Figures 10-12 depict the paths participants took for each task. The three colored lines represent the routes taken by participants. Decision points and confusion points were annotated along these paths.

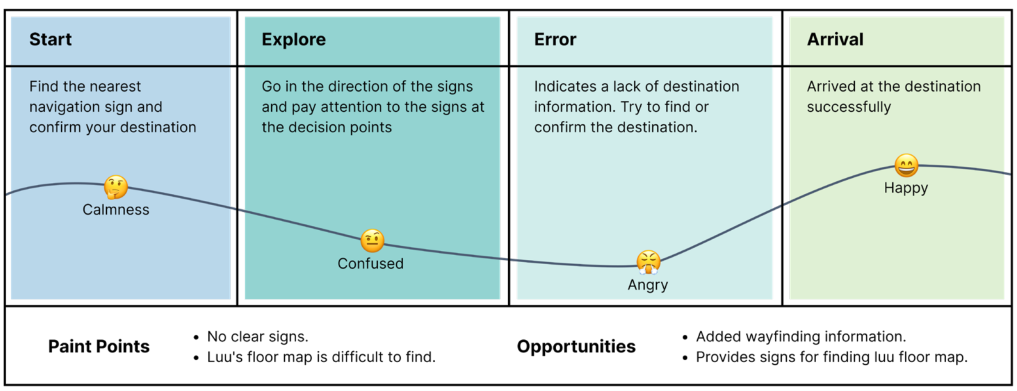

Figure 9. Participants' wayfinding journey map across the three given tasks, showing the four stages of Start (orientation), Explore (active searching), Error (disorientation), and Arrival (reach destination). Drawn by the first author.

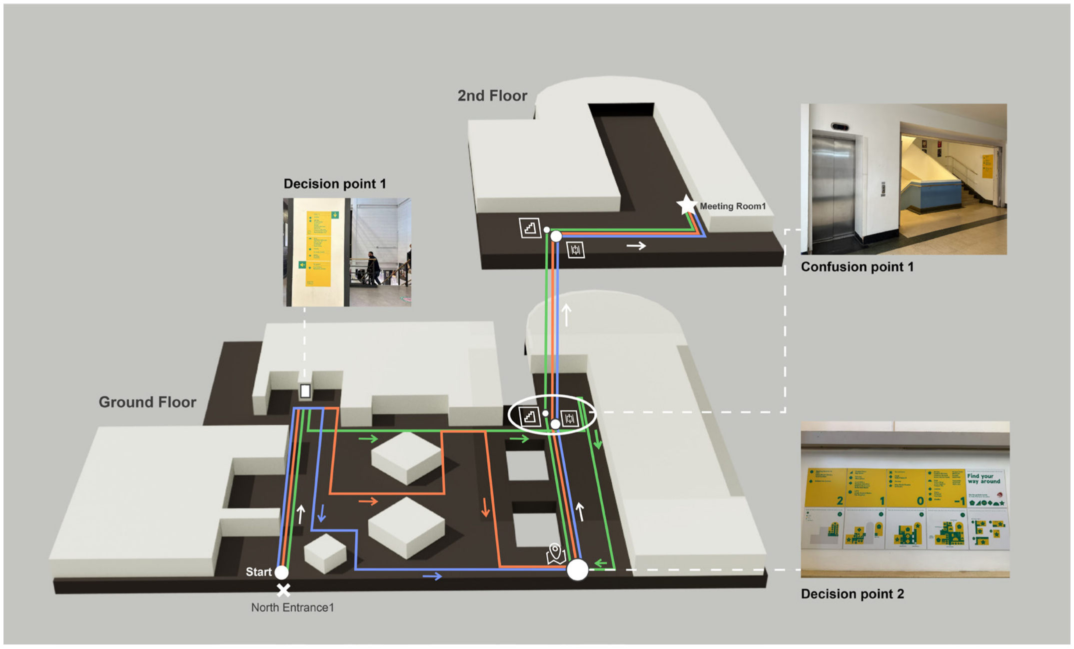

Figure 10. Routes taken by the three participants during Task 1 (Find the Meeting Room 1), shown in three colors. A white square marks Decision Point 1, where participants checked for destination information on labels. A white circle marks Decision Point 2, which shows the LUU floor plans. A white spot marks Confusion Point 1, where participants were uncertain whether to go upstairs or downstairs. Drawn by the first author.

Figure 10 represents the routes taken by participants when tasked with locating Meeting Room 1 from the North Entrance (Task 1). While all participants ultimately reached the destination, their paths diverged significantly on the Ground Floor, indicating uncertainty in interpreting the signage. All three paused at Decision Point 1, the first major signage location, highlighting its role as an initial reference but also its inadequacy in providing clear directions. Decision Point 2, where the floor plan was located, was also consulted, though its limited visibility and small text contributed to hesitation. A major area of difficulty emerged at Confusion Point 1 near the stairwell and elevator, where participants struggled to determine the correct vertical circulation option. This clustering of hesitation at key junctions, which is suggestive of heightened cognitive load, was attributable to insufficient guidance for vertical movement and led to unnecessary detours and longer completion times.

Figure 11 represents the routes taken by participants when tasked with locating Student Kitchen from the North Entrance (Task 2). All participants eventually reached their destination. Initially, they all found the correct direction at Decision Point 1 (the first major signage location) and chose the same path. However, when they reached Confusion Point 2 on the first floor below ground, lacking information about the destination, they hesitated and began to choose different directions. One participant chose a different route from the other two and subsequently encountered Confusion

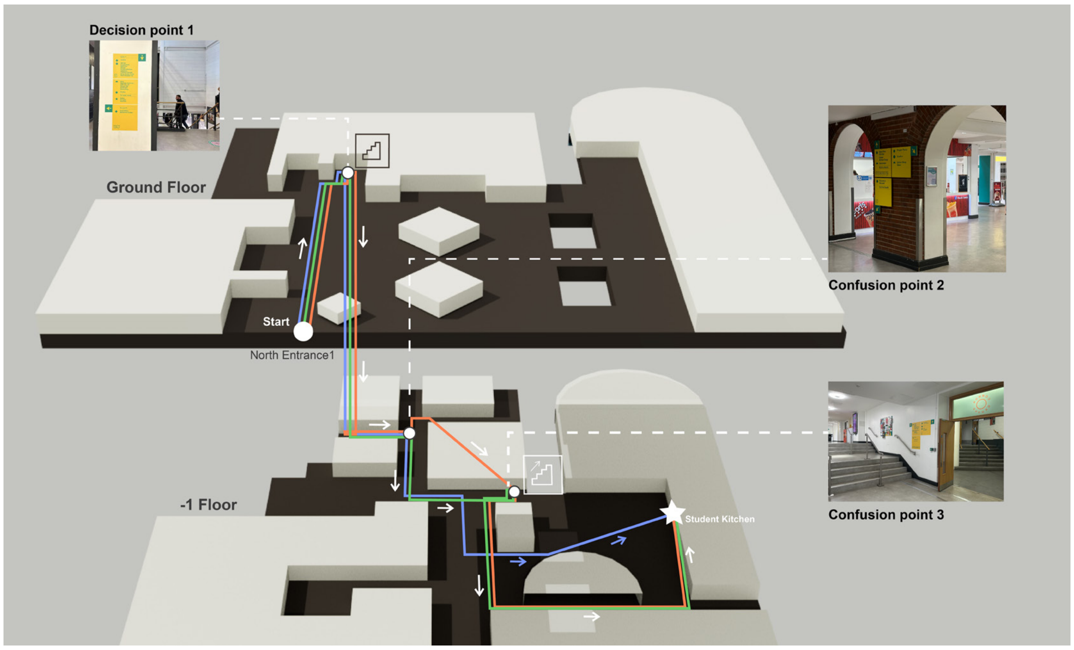

Figure 11. Routes taken by the three participants during Task 2 (Find the Student Kitchen), shown in three colors. Decision Point 1: participants checked destination information on labels. Confusion Points 2 & 3: destination information was lacking. Drawn by the first author.

Point 3. Since no relevant information was provided here, they had to choose a random direction and continue. This demonstrates that when faced with a multi-directional fork in the road, the lack of correct cues can easily lead to incorrect decisions.

Figure 12 represents the routes taken by participants when tasked with locating Essentials from the North Entrance (Task 3). All participants ultimately reached their destination. Initially, two participants attempted to search for destination information at decision point 1 (the first major signage location) but received no guidance. They then randomly chose a direction and continued on, searching for a way up the stairs. Another participant opted to simply search for a way up the stairs. Subsequently, two participants searched for location information at confusion point 4, where the floor plan was located, but received no clues. Because the task only provided information about the floor level of the destination, participants had to reach the designated floor before continuing to explore the target location. The results indicate that the lack of explicit information about essentials within the LUU caused participants to spend more time finding their way.

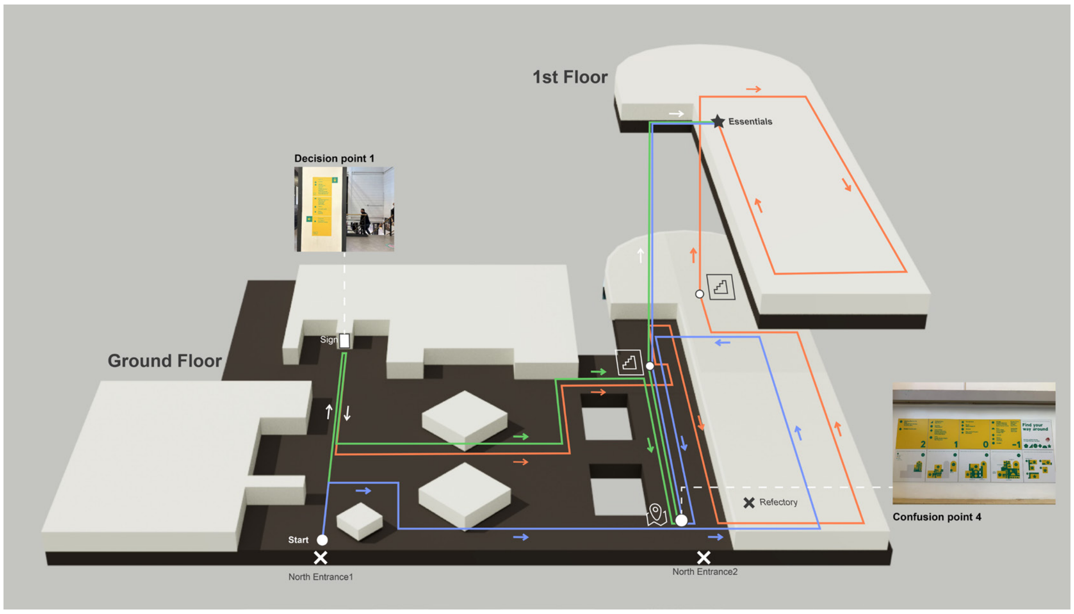

Figure 12. Routes taken by the three participants during Task 3 (Find the Essentials), shown in three colors. The white square indicates decision points 1 where participants needed to check if there is any destination information in the label, while the white circle highlights the confusion point 4 where lack the destination information. Drawn by the first author.

4.2. Post-Design Investigation

Usability testing. The purpose of this usability testing was to evaluate the usability of LUU MATE in the interaction process and the rationality of its interface design, thereby verifying its design effectiveness and provide a reference for subsequent optimization.

Participants were first invited to explore the application freely to form initial impressions. They generally perceived LUU MATE as an app focused on navigation and engagement with activities (e.g., “I thought the app’s functions were mainly for finding directions and selecting events of interest”). The overall interface was described as comfortable and clear, with the green and yellow color scheme evoking the interior atmosphere of the LUU and fostering a sense of community cohesion (e.g., User 1: “I found LUU MATE’s color scheme reminded me of the LUU and was similar to it”). In particular, the Events page was noted as a space where information could be quickly accessed (e.g., User 3: “I really like the Events interface because it allows me to quickly access information about different types of events”).

Following the initial exploration, participants were asked to complete three given tasks (Section 3.3.1). All four participants successfully completed the tasks, achieving a 100% success rate. Table 4 shows the task completion times, which were broadly consistent across participants, with only User 2 requiring slightly more time than the others.

Table 4. Time completion times of each user (in seconds).

Time	User 1	User 2	User 3	User 4
Task 1	50s	80s	63s	77s
Task 2	75s	87s	80s	76s
Task 3	20s	37s	23s	21s

After completing all tasks, participants offered positive reviews of LUU MATE*'s* interface and user experience but also identified areas for improvement. Most participants noted that the app's color scheme felt clear and comfortable, evoking the atmosphere of the LUU and enhancing the sense of relevance. They found the app's layout and functionality easy to understand, and information quickly accessible. Some participants emphasized that "The flat icon design makes it easy to understand what the icons mean", effectively improving readability. When using the AR interface, participants reported that the green virtual path provided clear guidance, enabling them to complete navigation tasks efficiently and with greater confidence. In addition, some participants also considered how LUU MATE could support their social participation in the LUU. User 4 noted:

> Integrating event information into the navigation process could help me discover activities I would not have noticed otherwise, and might encourage me to stop and explore during my journey to a certain destination.

Most of the participants believed that if a social exploration function was provided during the navigation process, they would be able to understand the functions of each area in the LUU more quickly, and they would be more willing to explore the LUU.

The main issues and corresponding suggestions are summarized in Table 5, and the revised prototype incorporating these improvements is shown in Figure 13.

Table 5. Identified usability and interface issues and suggested improvements.

No.	Problems	Severity	Solution
1	There is no confirmation interface after the navigation is completed.	High	Add an end interface.
2	'Find a place' is too deeply embedded in the hierarchy.	High	Place 'Find a place' and 'Explore' separately in the navigation bar.
3	Exit location inconsistent between 'Explore' and 'Find a place'.	Medium	Add a consistent exit button in 'Explore'.
4	Bottom navigation bar icons unevenly spaced.	Low	Modify icon and text size and refine spacing.

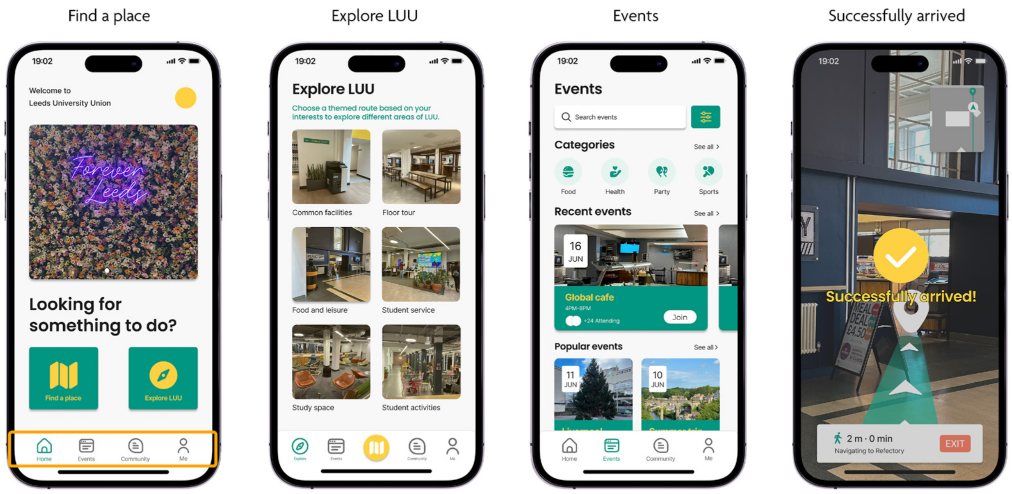

Figure 13. Revised LUU MATE interface informed from usability testing. Key improvements included separating ‘Find a Place’ and ‘Explore’ for more direct navigation, adjusting navigation bar spacing for readability, and adding a confirmation screen at the end of navigation to clarify task completion. Designed by the first author.

Behavioral observation 2: Using LUU MATE. The purpose of behavioral observation 2 was to evaluate whether LUU MATE could effectively improve students’ wayfinding efficiency within the LUU. Table 6 presents the task completion time for the three participants in behavioral observation 2, while Table 7 compares the average times from both observations to highlight the efficiency gains achieved through the use of LUU MATE. Figures 14-16 compare the paths of each task in the second behavioral observation with the most complex path in the first behavioral observation, to visually demonstrate the changes in participants’ navigation efficiency.

Table 6. Behavioral observation using LUU MATE. Completion times of each participant (minutes: seconds).

Time	U1	U2	U3
Observation task1	1:39	1:49	1:53
Observation task2	1:26	1:23	2:12
Observation task3	1:20	1:32	1:14

Overall, navigation with LUU MATE was considerably faster than with existing wayfinding aids, with task times reduced by approximately 46% to 74% (Table 7). During the post-interviews, participants described the AR wayfinding process as clear and intuitive. They particularly valued the path visualization and directional arrows, which they felt improved navigation accuracy and efficiency compared with static signage. In

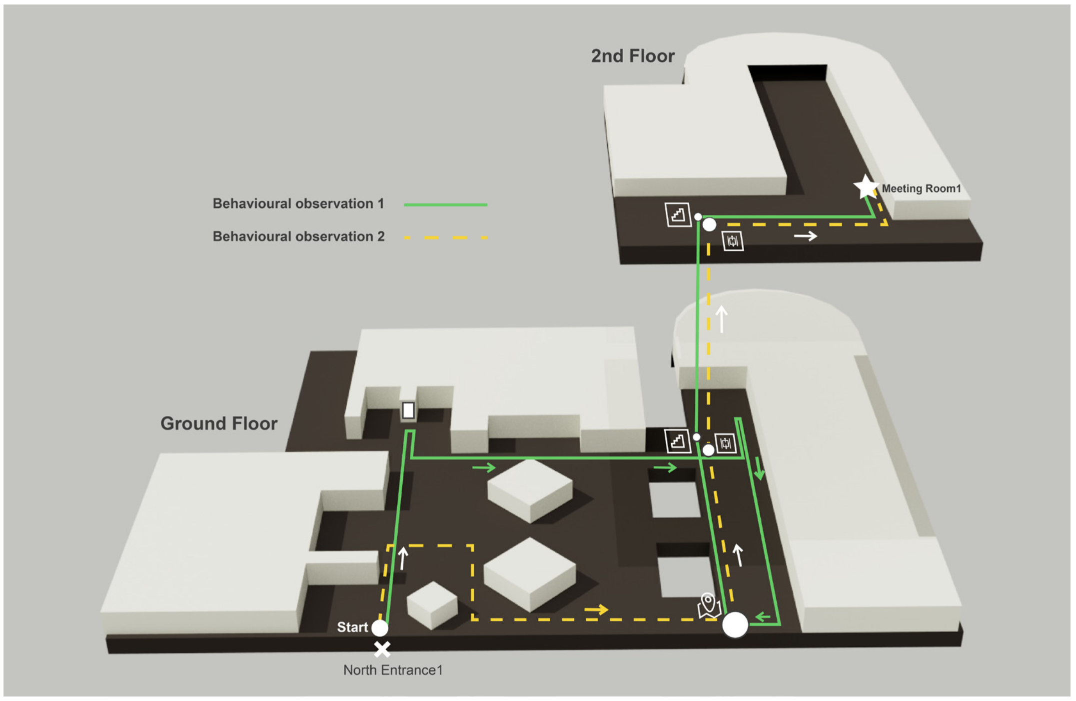

Figure 14. Comparison of the path in Behavioral Observation 2 with the most complex path in Behavioral Observation 1 (Task 1: Meeting Room 1). The yellow dashed line represents the path of behavior observation 2. Drawn by the first author.

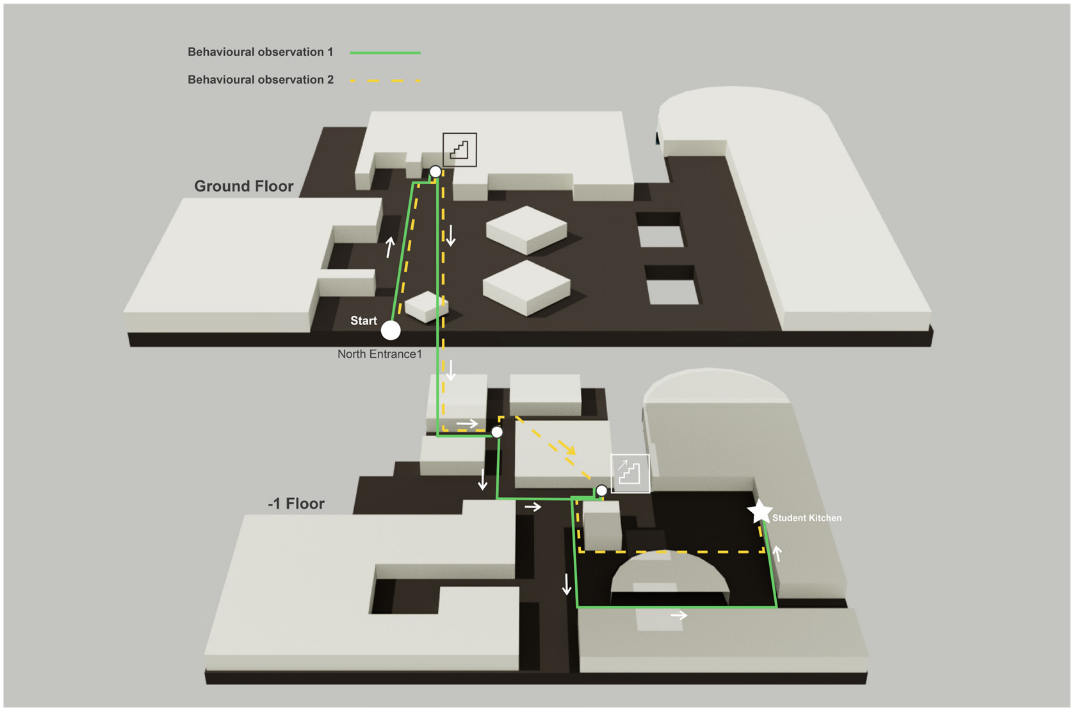

Figure 15. Comparison of the path in Behavioral Observation 2 with the most complex path in Behavioral Observation 1 (Task 2: Student Kitchen). The yellow dashed line represents the path of behavior observation 2. Drawn by the first author.

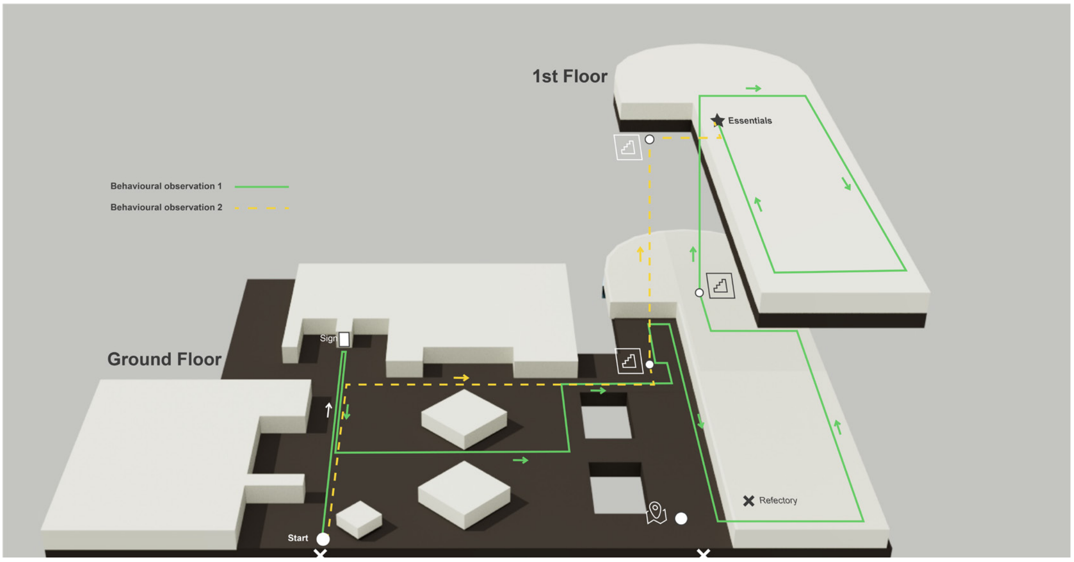

Figure 16. Comparison of the path in Behavioral Observation 2 with the most complex path in Behavioral Observation 1 (Task 3: Essentials). The yellow dashed line represents the path of behavior observation 2. Drawn by the first author.

addition, the surrounding environment guide was seen as a useful feature for promoting awareness of nearby facilities and ongoing activities. However, some participants noted shortcomings in the handling of vertical circulation. Specifically, the lack of explicit floor information during floor transitions caused anxiety. To address this, participants suggested that the system should display indicators of the floor they were heading to.

Table 7. Comparison of average task completion times between Behavioural Observation 1 (existing wayfinding aids) and Behavioural Observation 2 (LUU MATE).

Task	Existing Wayfinding Aids (avg. time)	LUU MATE (avg. time)	Improvement
Task 1: Meeting Room 1	4:03	1:47	-56%
Task 2: Student Kitchen	3:04	1:40	-45.7%
Task 3: Essentials	5:18	1:22	-74.2%

5. Discussion

While much of the existing research on AR navigation in campus settings has explored the technical implementation and performance (e.g., positioning accuracy, tracking algorithms), limited research has examined interface design usability, and the integration of social exploration functions. Moreover, no prior published studies seem to have examined navigation in the context of a Student Union building, a space characterized by multifunctionality, complex vertical circulation, and high levels of social activity. This study therefore contributes by demonstrating AR interface design can be leveraged not only to improve wayfinding efficiency but also to foster student community engagement with campus life.

5.1. Wayfinding Effectiveness

Combined with the analysis of wayfinding paths (Figure 10-12), it was found that without effective navigation assistance, participants took detours or stopped, increasing their time spent on wayfinding. In summary, the main wayfinding challenges for the LUU were the incompleteness of existing wayfinding signage and the hidden and difficult-to-access location of floor plans, which made it difficult for participants to obtain effective navigation information in a timely manner.

The findings show that LUU MATE achieved high levels of usability: all participants successfully completed the given tasks in both usability testing and the observation 2, indicating that the application was intuitive and easy to use.

The comparative analysis of the two rounds of behavioral observations (Table 7) provides quantitative evidence of efficiency gains. Across all tasks, participants completed wayfinding with LUU MATE in substantially less time than with existing wayfinding aids, reducing average task times by 59% in some cases. For example, locating the Student Kitchen decreased from 5:19 minutes (Observation 1) to just 1:40 minutes (Observation 2). These results align with prior studies (e.g., Diao & Shih, 2018, who demonstrated AR's advantages for pathfinding in dark, unfamiliar indoor settings) that highlight AR's advantages over traditional signage-based navigation. They also confirm that the observed improvements were not only subjective (ease of use, confidence) but also objectively measurable in terms of reduced task completion time.

Beyond speed, participants also reported greater confidence when following the green AR path, describing it as clear, continuous, and well-integrated into the physical environment. This reduced hesitation and cognitive load at decision points, enabling smoother navigation. However, challenges remained in vertical circulation: participants expressed anxiety during floor changes due to the lack of explicit floor-level indicators. This highlights a limitation of AR overlays — they provide strong local guidance but insufficient global orientation. Future AR navigation systems should therefore combine micro-level cues (e.g. step-by-step arrows) with macro-level orientation tools (e.g. mini-maps, floor indicators) to enhance user trust and support wayfinding in complex, multi-level environments.

5.2. Integration with Social Exploration

Another key contribution of this study is its integration of wayfinding with opportunities for social engagement, highlighting the significance of this connection within the campus context. Existing AR navigation research has largely prioritised technical performance or route guidance (e.g., Xu et al., 2024), while overlooking how navigation systems might also facilitate community integration. LUU MATE addresses this gap by embedding contextual information, such as dynamic prompts about functional spaces and community events during the navigation process. Participants noted that these features encouraged awareness of their surroundings and piqued interest in activities they might not otherwise have considered.

This demonstrates that navigation and social exploration are mutually reinforcing: by guiding students to destinations, the system simultaneously exposes them to new opportunities for participation. From a design perspective, this integration transforms navigation from a purely functional activity into a socially engaging experience. It also reflects the role of the LUU as not only a physical hub but also a social ecosystem. The implications extend beyond the LUU: campus navigation tools that incorporate real-time social and event information could strengthen student belonging and participation across higher education settings.

5.3. AR Interface for Wayfinding Applications

Finally, this study underscores the importance of interface design in shaping the usability and effectiveness of AR navigation systems. Usability testing revealed high levels of task success and satisfaction, with participants praising the clarity of the layout, intuitive organisation of functions, and visual consistency of the green-and-yellow colour scheme, which echoed the atmosphere of the LUU and reinforced a sense of place. The flat iconography improved readability, and the Events page was especially valued for its quick access to information. These findings highlight that interface design directly influences learnability and acceptance of AR tools.

At the same time, feedback pointed to areas requiring refinement. Participants found the ‘Find a Place’ function buried too deeply in the navigation hierarchy, and the absence of a confirmation screen after completing navigation reduced clarity. These issues were addressed in the revised prototype (Figure 13), illustrating how iterative user feedback can guide design improvements. More broadly, the results point to a wider research gap: while UI and interaction design theories are well established for 2D applications, their applicability to 3D AR environments remains limited (Börsting et al., 2022). This study therefore contributes by demonstrating how interface principles, such as clarity, consistency, and contextual relevance, must be reinterpreted in the AR context to ensure both usability and engagement.

5.4. Limitations

This study has limitations that open avenues for future research. As this research was conducted within the scope of a master's-level study and under time constraints, the sample size in each phase was small. This limits the reliability and generalizability of the findings. Nevertheless, the study was designed with clear, sequential objectives across all phases, allowing each stage to build cumulatively on the previous one. As a result, the study still generated meaningful insights into students' wayfinding behaviors and their interactions with AR-based navigation concepts. Future research should employ a larger, more diverse participant pool and longer-term field deployment to validate the findings and examine how AR navigation tools perform across varied user groups, scenarios, and environmental conditions.

Although this study emphasized the importance of social engagement within AR-supported campus navigation, its ability to methodically evaluate this dimension was limited. The pre-design investigation revealed a recurring user need for greater awareness of student life and highlighted the unique character of the LUU as a socially vibrant environment, insights that strongly informed the prototype's emphasis on exploration and helping students discover what is happening around them. However, the empirical evaluation focused primarily on navigation efficiency, and the study design did not allow for a rigorous assessment of social engagement outcomes. Only short, qualitative usability testing post-session reflections were collected, which provide suggestive but not robust evidence of social engagement. Future research should therefore adopt a longer-term deployment approach, enabling students to use the system over an extended period and allowing researchers to examine how AR navigation tools influence actual patterns of social participation, event discovery, and informal campus interactions over time.

This study focused primarily on interface design and the optimization of information hierarchy and did not address the technical implementation of AR functionalities. Consequently, potential issues that may arise in real-world deployment, such as insufficient positioning accuracy, device constrains, or AR recognition issues were not evaluated. These technical issues could affect the reliability and overall user experience of the system. Future research could incorporate these aspects, allowing for a more holistic understanding of how technical and interaction components jointly affect usability in the campus environments.

Additionally, only one round of interface design was completed and evaluated, which restricted opportunities to explore alternative interaction methods and visual styles. Nevertheless, the design at this stage still offers insights, revealing how interface clarity and cues influence the user's interactive experience.

Finally, the 'Community' feature designed to promote student social interaction was only partially implemented and not fully tested. While this limitation means its effectiveness remains to be evaluated, initial feedback indicates user interest in the feature, suggesting its potential value for future designs.

5.5. Design Insights and Criteria

The design insights and criteria presented in Table 8 are derived from field research, interviews, behavioral observations, and prototype evaluations. These insights reflect the navigational challenges and social interaction patterns students encountered in the study, and the corresponding criteria provide practical guidance for the design of future AR campus navigation systems.

Table 8. Design insights and criteria.

Design insights	Design criteria
1. When signs are unclear, students will rely on following others or seeking help.	AR navigation should integrate social and contextual information, such as nearby activities or the activities of companions, to assist navigation and promote community interaction.
2. Existing geometric symbols lack semantic clarity, causing confusion for first-time visitors.	Using intuitive icons, labels, and color coding, spatial meaning is clearly conveyed, allowing for quick understanding without prior knowledge.
3. Users experience anxiety when switching floors due to a lack of clear floor instructions.	Synchronize AR navigation with floor information, visualize vertical connections and spatial transitions, and help users maintain their sense of direction.
4. Participants expressed interest in discovering campus activities during the browsing process.	AR navigation incorporates social discovery features, connecting destinations with real-time activities and opportunities, encouraging exploration and a stronger sense of belonging.

The above demonstrates that AR campus navigation can serve not only as a spatial guidance tool but also as a medium for fostering social connections within the student environment. By combining spatial clarity, contextual information, and social interaction, future systems can transform campus navigation into a more interactive and community-oriented experience.

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