

AUGMENTED REALITY WAYFINDING FOR SMART CAMPUSES: A CONCEPTUAL INFORMATION SYSTEM ARCHITECTURE

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Abstract:

This paper proposes an information system architecture for augmented reality (AR)-based wayfinding in smart campuses. It addresses a practical problem in university environments: users navigate between buildings, floors, rooms, services, and temporary event locations, while relevant institutional data remain distributed across separate systems and disconnected from spatial guidance. Using a conceptual design approach, the study integrates AR guidance with campus spatial data, routing services, accessibility constraints, dynamic institutional information, and anonymized operational indicators. The architecture comprises a mobile AR client, application and integration services, institutional data sources, a simplified data model, a constraint-aware route-computation procedure, a navigation workflow, data-governance rules, and an evaluation framework. It is derived from requirements identified in the literature on smart campuses, indoor positioning, AR interaction, and information systems design. The paper treats AR wayfinding as an institutional information system rather than a stand-alone mobile interface. Its operation depends on data quality, interoperability, privacy safeguards, maintenance procedures, and organizational responsibility. The proposed model can support indoor-outdoor navigation, accessible route selection, route maintenance, spatial planning, and service-quality analysis, provided that location data are minimized, anonymized, and used mainly in aggregated form. The paper does not report empirical user-testing results; systematic evaluation is reserved for future implementation.

Key words: augmented reality; smart campus; wayfinding; indoor-outdoor navigation; information system architecture; campus management.

JEL classification: C88; I23; L86; O33

Received 30 March 2026; Accepted 16 June 2026

1. INTRODUCTION

Universities use digital platforms to manage teaching, administrative processes, communication, and infrastructure. The Smart Campus concept extends this digitalization by connecting physical spaces, digital services, sensors, applications, and user-oriented processes within a coordinated institutional environment (Chourabi et al., 2012; Giffinger et al., 2007; Silva-da-Nobrega et al., 2022).

Campus navigation is a concrete problem in this environment. A student or visitor may know the name of an activity and the scheduled time, but still lack practical information about the building entrance, floor, room, accessible route, or walking time. Static signs and printed maps are useful, but they cannot respond to frequent room changes, temporary restrictions, or accessibility needs.

Augmented reality (AR) can support this task by placing route cues and labels over the real environment. The value of AR, however, depends on more than the visual overlay. A reliable service also needs localization, route computation, spatial data maintenance, interoperability with institutional systems, fallback mechanisms, and privacy rules (Azuma, 1997; Billingham et al., 2015; Schmalstieg and Hollerer, 2016).

The purpose of this article is to define an information system architecture for AR-based wayfinding in smart campuses. The paper does not report empirical user-testing results. It proposes a conceptual design that can guide implementation and subsequent evaluation. The system is therefore analyzed as a combination of software services, institutional data, operational processes, and management indicators.

2. RELATED WORK AND PROBLEM POSITIONING

Smart campus research is related to the smart-city literature, but the university campus has a narrower operational scale and a specific educational mission. Smart-campus services must support learning, administration, mobility, accessibility, resource use, and user experience within spaces that change by semester, event, and institutional schedule (Chourabi et al., 2012; Giffinger et al., 2007; Huang et al., 2019; Silva-da-Nobrega et al., 2022).

Several enabling technologies can be involved. Internet of Things (IoT) systems collect environmental or occupancy data, cloud and edge services provide processing capacity, and mobile applications create direct interaction points for students and staff (Perera et al., 2015; Siriwardhana et al., 2021). In navigation, the technical difficulty is the transition between outdoor areas, building entrances, corridors, floors, and rooms.

Indoor positioning remains a limitation for campus-scale services. Bluetooth Low Energy (BLE), Wi-Fi, pedestrian dead reckoning, map matching, visual markers, visual-inertial localization, and simultaneous localization and mapping (SLAM)-based methods can support different parts of the task, but their performance depends on infrastructure density, device variability, signal quality, lighting conditions, and map quality (Faragher and Harle, 2014; Khoshelham and Zlatanova, 2016; Lowe, 2004; Lynen et al., 2015; Tian et al., 2015; Zafari et al., 2019).

AR research provides the interaction model for overlaying digital information on the physical environment. Foundational studies clarify the role of registration, tracking, display, and interaction in AR systems (Azuma, 1997; Billinghurst et al., 2015; Kato and Billinghurst, 1999; Milgram and Kishino, 1994; Schmalstieg and Hollerer, 2016). For campus wayfinding, these principles must be connected to institutional information systems, not used only as a visual interface.

3. RESEARCH CONTRIBUTION AND CONCEPTUAL DESIGN METHOD

The article follows a conceptual design method. The architecture is developed by translating requirements from smart campus studies, AR interaction, indoor positioning, and information-system design into a coherent artefact. The method includes six steps: identifying the campus mobility problem, defining system requirements, structuring the architecture, specifying the core data entities, describing the navigation workflow, and proposing an evaluation framework.

The contribution is limited but explicit. The paper proposes: (1) a layered architecture for AR-based wayfinding in smart campuses; (2) a simplified data model for indoor-outdoor route guidance; (3) a navigation workflow and a constraint-aware route-computation procedure; (4) a controlled management feedback cycle; (5) data-governance principles for navigation sessions; and (6) indicators for future technical, usability, accessibility, and managerial evaluation.

The model is deliberately conservative. It does not assume perfect localization, automatic user adoption, or complete institutional data. It treats AR wayfinding as a service whose quality depends on spatial data, service integration, fallback procedures, user trust, and continuous maintenance. The resulting functional requirements are summarized below (table no. 1).

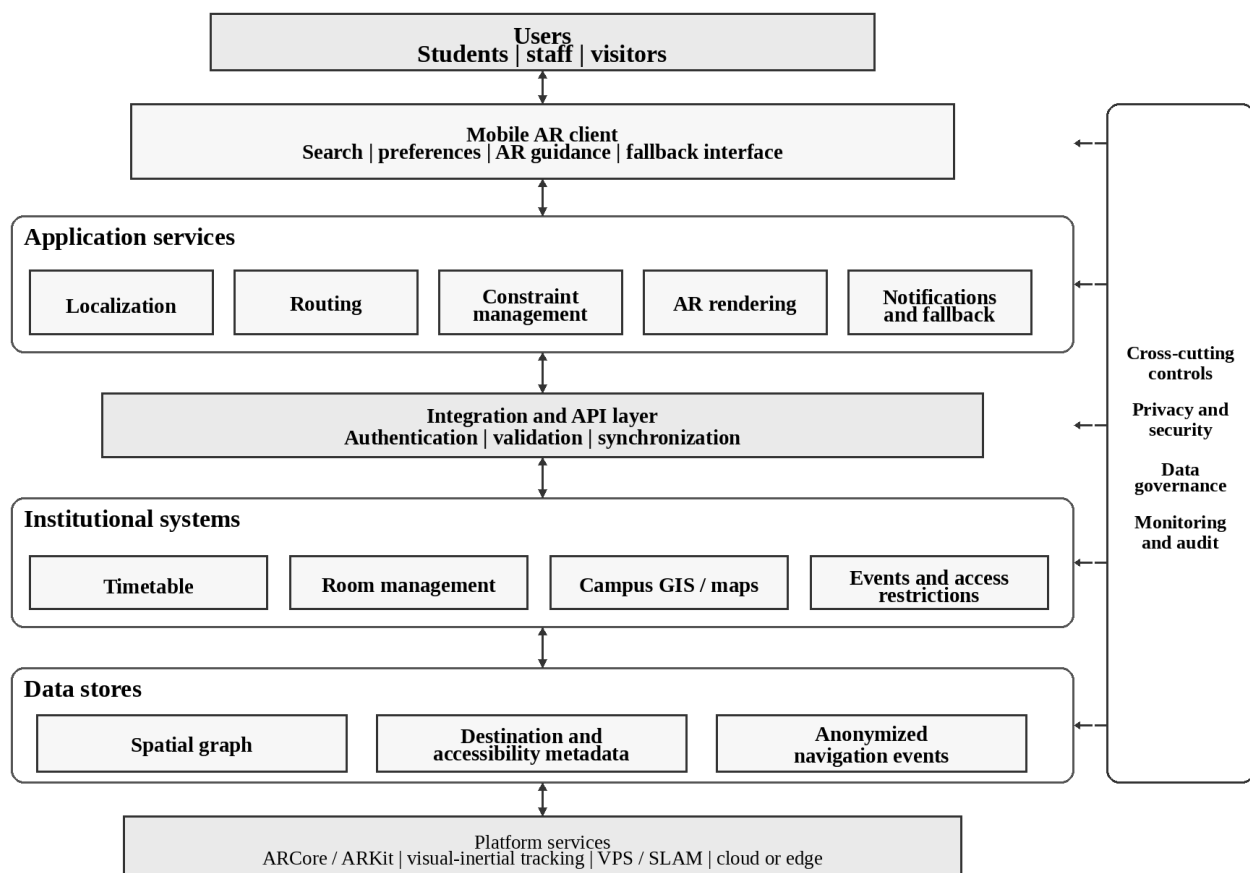
Table no. 1. Functional requirements for AR wayfinding as an information system

Requirement	Operational description	Information-system role	Risk if ignored
Accurate spatial data	Consistent representation of buildings, floors, rooms, entrances, nodes, and edges.	Provides the routing and integration base.	Directions may be incorrect or incomplete.
Dynamic constraints	Updates restrictions, maintenance work, events, and access rules.	Links navigation to campus operations.	Unavailable routes may be recommended.
Accessibility metadata	Stores stairs, ramps, elevators, slopes, doors, and accessible entrances.	Enables inclusive route selection.	Routes may not meet specific user needs.
Localization and fallback	Uses positioning, with map or text guidance when tracking fails.	Maintains service continuity.	Tracking errors reduce user trust.
Analytics governance	Minimizes and anonymizes logs; retains them only when needed.	Supports planning while limiting privacy risks.	Operational value may be lost or privacy risk may increase.

Source: Own elaboration.

4. SYSTEM ARCHITECTURE AND INTEROPERABILITY

The proposed architecture separates the mobile AR client from the application services, institutional systems, data stores, and platform services that support it. This separation is necessary because a visually clear interface cannot compensate for missing destination metadata, an inconsistent route graph, or delayed institutional updates. The main components and the interfaces between them are represented below (figure no. 1).

**Figure no. 1. Component architecture of the proposed AR campus wayfinding information system**

Source: Own elaboration.

The mobile client manages destination search, route preferences, AR guidance, and map or text fallback. The application-services group contains localization, routing, constraint management, AR rendering, and notification functions. These services exchange validated data through an integration layer and application programming interfaces (APIs) with institutional systems such as timetable management, room management, the campus geographic information system (GIS), and registers of events or access restrictions. Spatial graphs, destination metadata, accessibility metadata, and anonymized navigation events are maintained as distinct data stores.

Interoperability is treated as an explicit architectural component rather than an informal exchange of files. Each interface should define data ownership, identifiers, validation rules, update frequency, error handling, and synchronization responsibilities. The platform layer may include visual-inertial tracking, visual positioning systems (VPS), simultaneous localization and mapping (SLAM), and cloud or edge services. Privacy, security, data governance, monitoring, and audit apply across all components.

Privacy and security are also cross-cutting controls. Access to route data, administrative updates, and analytics dashboards must be restricted according to institutional roles. Navigation-session data should not be used for individual monitoring unless there is a specific, lawful, and transparent basis for doing so.

5. DATA MODEL, DATA GOVERNANCE AND INFORMATION REQUIREMENTS

Figure no. 2 presents the platform-independent entities, attributes, and cardinalities required for spatial structure, dynamic institutional data, routing, and management.

Buildings, floors, spaces, nodes, and edges form the stable spatial layer; schedules, restrictions, and accessibility constraints form the dynamic layer. Navigation sessions and minimized events form the operational layer, from which aggregated indicators are derived. This separation allows frequent updates without rebuilding the spatial graph.

Constraints and restrictions are linked to route edges so invalid segments can be excluded before path computation. Separating navigation events from user identity supports privacy-preserving analysis. Tables no. 2 and 3 summarize entity roles and governance rules.

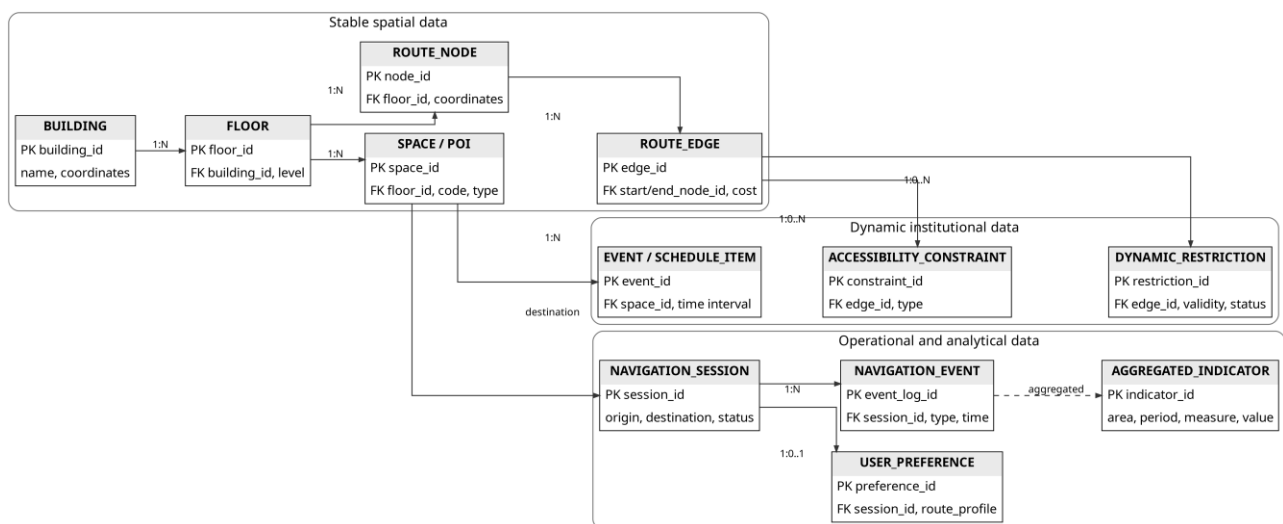


Figure no. 2. Simplified entity-relationship model for campus navigation data

Source: Own elaboration.

Table no. 2. Main data entities and their operational relevance

Entity	Examples of attributes	Operational relevance
Building and floor	ID, name, coordinates, entrances, level number	Defines the campus spatial structure.
Room and point of interest	Code, function, capacity, opening hours	Links destinations to academic and administrative services.
Route node and edge	Coordinates, length, cost, direction, floor transition	Supports path computation and recalculation.
Accessibility constraint	Elevator, ramp, stairs, slope, restricted segment	Supports personalized and accessible routes.
Schedule item	Time, room, activity, responsible unit	Connects navigation to current academic data.
Navigation session	Origin, destination, time, route status	Supports aggregate analysis without direct identification.

Source: Own elaboration.

Table no. 3. Data-governance rules for navigation services

Rule	Practical meaning	Expected effect
Data minimization	Store only what is needed for route quality, service diagnosis and aggregated analysis.	Reduces privacy exposure.
Separation of identity and movement data	Avoid linking navigation sessions to named users unless strictly necessary.	Limits behavioural profiling.
Aggregation by default	Use corridor, building, interval or route-level indicators instead of individual traces.	Supports management analysis without personal monitoring.
Retention limits	Delete raw logs after a short, predefined period and keep only aggregated indicators.	Reduces long-term risk.
Transparent use	Explain what is collected, why it is collected and how users can avoid optional tracking.	Supports trust and responsible adoption.

Source: Own elaboration.

6. NAVIGATION WORKFLOW AND ROUTE COMPUTATION

The navigation process is presented separately from the management feedback cycle. During a navigation session, the user selects a destination and, where relevant, specifies route or accessibility preferences. The mobile client requests an estimated position, while the navigation services validate the destination, retrieve the current route graph and institutional constraints, and compute a valid route. The allocation of responsibilities is shown below (figure no. 3).

The workflow includes two explicit fallback conditions. If localization confidence is insufficient, the client displays map or text instructions instead of placing potentially inaccurate AR cues. If the routing procedure cannot identify a valid path after restrictions and accessibility requirements are applied, the service returns an unavailable-route status rather than an incomplete route. Route computation is triggered again when the user deviates from the selected path or when a new restriction affects the current route.

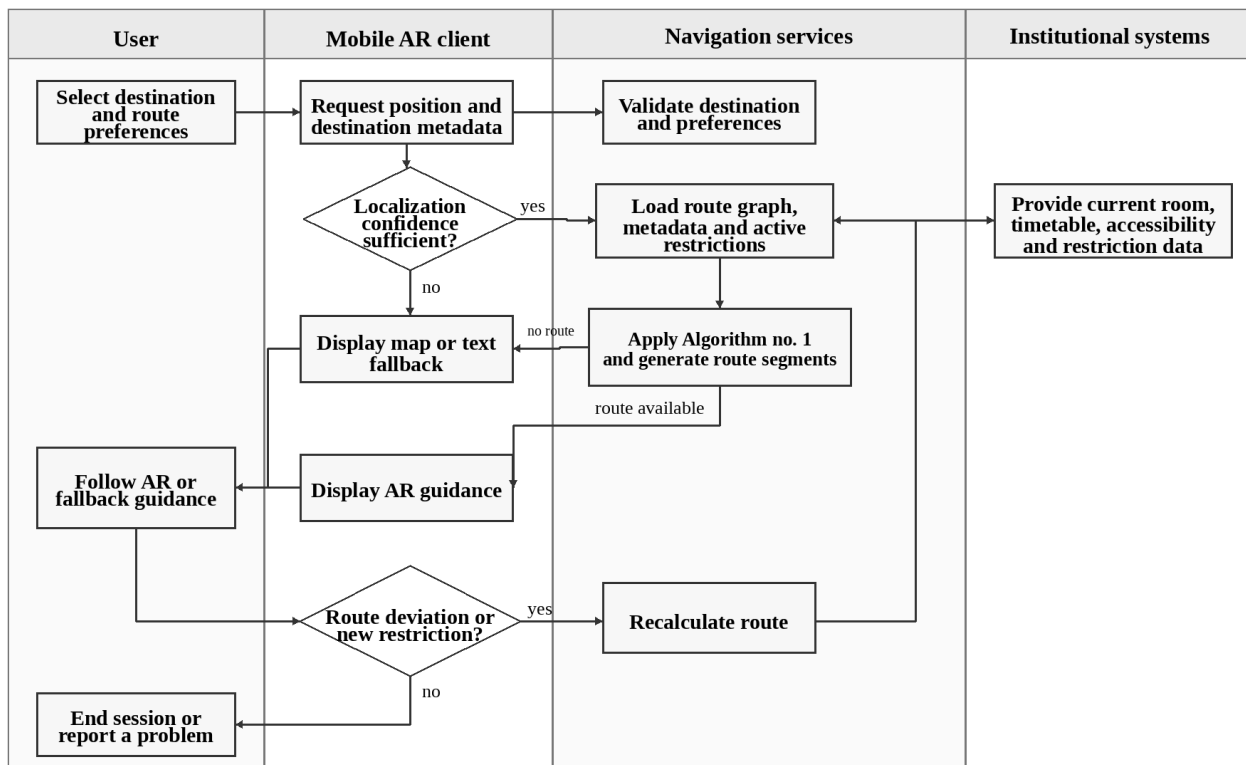


Figure no. 3. Navigation-session workflow and allocation of system responsibilities

Source: Own elaboration.

The routing component operates on a graph representation of the campus. Route nodes represent entrances, corridor intersections, floor transitions, decision points, and destinations. Route edges represent traversable segments such as corridors, stairs, ramps, elevators, doors, and outdoor paths. The localization service is outside the routing procedure: it provides an estimated position, which is mapped to a valid graph node before route computation. Similarly, AR rendering is performed after a route has been returned.

The procedure presented below (algorithm no. 1) specifies the constraint-processing logic used by the routing service. It is not proposed as a new shortest-path algorithm. A conventional graph-search method, such as Dijkstra's algorithm (Dijkstra, 1959), can be used after unavailable or incompatible edges have been removed. The procedure therefore defines how campus restrictions and user preferences are applied before path computation and how route availability is reported to the navigation workflow (figure no. 3).

Algorithm no. 1. Constraint-aware campus route computation

```

Input:  currentPosition, destination, campusGraph, userPreferences,
dynamicRestrictions
Output: selectedRoute, guidanceSteps, routeStatus
1. currentNode <- mapToValidNode(currentPosition, campusGraph)
2. destinationNode <- getDestinationNode(destination)
3. if currentNode is null or destinationNode is null then
4.   return emptyRoute, emptyGuidance, routeUnavailable
5. end if
6. availableGraph <- removeRestrictedEdges(campusGraph, dynamicRestrictions)
7. availableGraph <- removeIncompatibleEdges(availableGraph, userPreferences)
8. selectedRoute <- shortestValidPath(availableGraph, currentNode,
destinationNode)
9. if selectedRoute is empty then
10.  return emptyRoute, emptyGuidance, routeUnavailable
11. end if
12. guidanceSteps <- generateGuidance(selectedRoute)
13. return selectedRoute, guidanceSteps, routeAvailable
  
```

Source: Own elaboration. The shortest-path operation may use a conventional graph-search method (Dijkstra, 1959).

The procedure returns three outputs: the selected route, the corresponding guidance steps, and a route-status value. The status is used by the mobile client to decide whether AR guidance can be displayed or whether a fallback message is required. Tracking confidence is not tested inside the algorithm because it is a property of the localization service, not of graph search. Session logging is also kept outside the routing procedure so that data collection can follow the minimization and retention rules summarized earlier (table no. 3).

The management feedback cycle is asynchronous and does not alter a route automatically. Navigation events are first validated and aggregated. Service-quality indicators are then reviewed by authorized staff, and any map, sign, or service-rule modification is approved before it is returned to the operational system (figure no. 4). This separation prevents unverified user behaviour or isolated errors from producing immediate changes in institutional data.

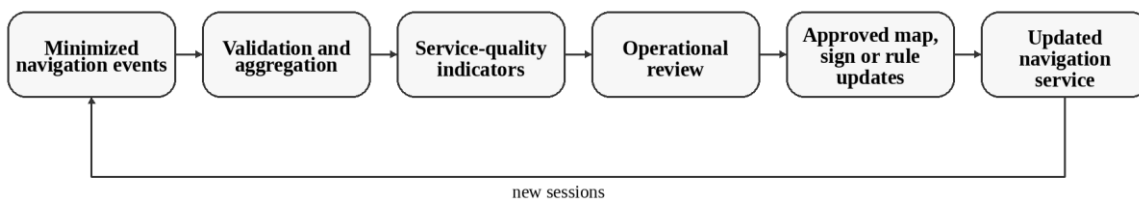


Figure no. 4. Controlled management feedback cycle based on aggregated navigation indicators

Source: Own elaboration.

7. IMPLEMENTATION CONSIDERATIONS

Implementation should begin with spatial mapping and data validation. Without reliable maps, room identifiers, entrances, floor transitions, and route constraints, the AR layer becomes a decorative interface rather than a navigation service. The mapping phase should include indoor corridors, outdoor routes, building entrances, elevators, stairs, accessible routes, restricted areas, and temporary closure procedures.

Localization can combine several methods. BLE and Wi-Fi approaches are useful in many indoor-positioning scenarios, but their accuracy depends on signal density, device type, and environmental changes (Faragher and Harle, 2014; Torres-Sospedra et al., 2015; Zafari et al., 2019). SLAM research provides general methods for mapping and loop closure, while visual-inertial localization and feature-based tracking are more directly relevant to mobile AR guidance (Hess et al., 2016; Klein and Murray, 2007; Lynen et al., 2015; Rublee et al., 2011). Their performance depends on camera input, lighting, recognizable features, map quality, and tracking stability.

Outdoor AR introduces different constraints. The Global Positioning System (GPS) can support coarse positioning, but may not be precise enough for overlays near entrances, narrow paths, or dense buildings. Geospatial APIs and VPS-based services can improve outdoor anchoring where the service is available, but they should be treated as implementation options, not as guarantees (Google Developers, 2026).

The development environment should be selected according to platform coverage, maintainability, and institutional capacity. Unity's AR Foundation supports multi-platform AR applications through native provider plug-ins for ARCore and ARKit, while conditional compilation can isolate platform-specific code (Unity Technologies, 2023; Unity Technologies, 2026). The final choice should consider long-term maintenance, staff expertise, licensing, and the need to update maps and institutional data.

8. EVALUATION FRAMEWORK

The model should be evaluated before institutional deployment. Evaluation must cover more than the visual quality of AR overlays. It should include technical reliability, usability, accessibility,

management value, and governance compliance. Usability can be measured with task-based indicators and standardized instruments such as the System Usability Scale and technology-acceptance constructs (Brooke, 1996; Davis, 1989). The proposed dimensions, indicators, and data sources are summarized below (table no. 4).

Table no. 4. Evaluation framework for future implementation

Evaluation dimension	Possible indicators	Data source
Technical reliability	Localization error, tracking loss, route recalculation time, fallback frequency	Application logs and controlled tests
Usability	Task completion time, wrong turns, perceived ease of use, perceived usefulness	User testing and questionnaires
Accessibility	Availability of accessible routes, clarity of multimodal instructions, satisfaction of users with specific needs	Accessibility audit and user feedback
Management value	Repeated route failures, congested areas, long detours, unclear decision points	Aggregated navigation indicators
Governance compliance	Data minimization, retention period, access control, transparency of data use	Privacy and security audit

Source: Own elaboration.

A future study should compare AR guidance with non-AR alternatives, such as static maps, mobile maps, or written directions. This comparison is necessary because AR should be adopted only if it improves navigation performance, user confidence, accessibility, or service management in a measurable way.

9. INSTITUTIONAL MANAGEMENT AND DECISION SUPPORT

The managerial relevance of the model arises from linking navigation data to institutional processes. The service should be assessed not only through interface quality, but also through its capacity to improve access to services, reveal recurrent operational problems, and support data-based planning.

As represented in the controlled feedback cycle (figure no. 4), authorized staff review aggregated indicators before any map, sign, or service-rule update is approved. Repeated disorientation, route recalculation, fallback use, or unusually long accessible routes may justify reviews of signage, room metadata, maintenance, route design, or accessibility.

These indicators are not self-explanatory and must be validated against events, physical constraints, and technical conditions. Institutional value therefore depends on accurate data, stable interfaces, user trust, clear governance, and continuing maintenance. Table no. 5 summarizes possible management uses and the cautions required when interpreting the indicators.

Table no. 5. Management uses of anonymized navigation indicators

Indicator	Management use	Required caution
Repeated route recalculation in one area	Review signs, map structure, or route logic.	Do not infer individual behaviour without consent.
High traffic on accessible routes	Plan maintenance, lighting, elevator availability, and capacity.	Consider peak periods and temporary events.
Longer accessible routes	Assess whether accessible routes are unnecessarily indirect.	Compare with feasibility and safety requirements.
Frequent destination-search failures	Correct room names, abbreviations, and search metadata.	Check whether naming, rather than user error, is the cause.
Fallback use after tracking loss	Identify areas with poor visual features, signals, or lighting.	Separate technical causes from user preference.

Source: Own elaboration.

10. LIMITATIONS AND CONCLUSIONS

The main limitation of the paper is that it proposes a conceptual and technical model without reporting empirical results. This is appropriate for the present stage, but it also defines the next research step. The model should be implemented as a prototype and tested in both indoor and outdoor campus routes.

A second limitation concerns institutional data. The model assumes that a university can provide accurate maps, room identifiers, timetables, accessibility metadata, and update procedures. In practice, these data may be incomplete, inconsistent, or stored in incompatible systems. Data preparation may therefore require more effort than AR interface development.

The paper proposed an information system architecture for AR-based wayfinding in smart campuses. Its contribution is not the claim that AR alone solves campus mobility, but the specification of the data, services, governance rules, and evaluation indicators required for AR navigation to function as a reliable institutional service.

Future work should implement and evaluate the model in a real campus environment, compare AR and non-AR guidance, test accessibility scenarios, and examine the managerial usefulness of anonymized navigation indicators. Only after such evaluation can the operational value of AR wayfinding be assessed with sufficient confidence.

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