TECHNE
Journal of Technology for Architecture and Environment
SITdA
FIRENZE UNIVERSITY PRESS

RESEARCH AND
EXPERIMENTATION

Data-driven management of usability. A platform for the national museum system

Teresa Villani[1], https://orcid.org/0000-0003-3665-1609
Gianmauro Romagna[2], https://orcid.org/0009-0008-0961-2552
Angelo Oddi[2], https://orcid.org/0000-0003-4370-7156
Federica Romagnoli[1], https://orcid.org/0000-0001-5520-3356

[1] Department of Urban Planning, Design, Architectural Technology, Sapienza University of Rome, Italy
[2] CNR ISTC - National Research Council, Institute of Cognitive Sciences and Technologies, Rome, Italy

Primary Contact: Teresa Villani, teresa.villani@uniroma1.it

Published: May 15, 2026
DOI: 10.36253/techne-19992

Abstract.
Framing digitalisation as an opportunity for heritage governance, this contribution introduces predictive usability as a paradigm for rethinking museums as dynamic and inclusive ecosystems. To this end, it presents an open-source platform that integrates spatial, behavioural, and accessibility data to support the management of sites within the National Museum System. The validation process, conducted with the Regional Directorate for Museums of Lazio and the Archaeological Museum of the Italic Peoples "Amedeo Maiuri" in Veroli, verified the platform's operational robustness with respect to the contents of the PEBA and, through simulated datasets, to patterns of spatial and content use. The results confirm its reliability as a decision-support tool and highlight its potential scalability in more complex museum contexts.

Keywords: Predictive usability; Museums; Cultural heritage; Accessibility; Data-driven Management.

Please cite this article as: Villani T., Romangna G., Oddi A., Romagnoli F. (2026) Data-driven management of usability. A platform for the national museum system. *Techne. Journal of Technology for Architecture and Environment*, Just Accepted.

Introduction

Digitalisation has become a fundamental strategic component in the management, enjoyment, and transmission of tangible and intangible cultural heritage to future generations (European Commission, 2025). Within the European framework of the Digital Decade 2030, it has emerged as a cornerstone of public policies aimed at enhancing cultural assets capable of generating cultural, social, and economic value beyond national boundaries.

Among the applications of emerging technologies designed to strengthen knowledge and promotion of cultural heritage is the creation of virtual replicas of artworks, monuments, and cultural sites. These replicas can integrate linked open data and expanding modes of access and engagement (Niccolucci *et al*., 2023), with clear benefits in terms of inclusive participation by increasingly diverse audiences.

With specific reference to museum spaces, the conversion of environments and their characteristics into digital models expands opportunities for interaction between individuals and cultural assets. It also enables analyses based on the integration of heterogeneous datasets, supporting collaborative, data-driven management processes (Hou *et al*., 2024).

Within the broad range of factors that systemically contribute to the proper functioning of museum environments, a primary concern is ensuring physical, sensory, and cognitive access and usability for all individuals, as established by the Convention on the Rights of Persons with Disabilities (United Nations, 2006). It therefore becomes essential to consider the potential offered by recent digital tools to investigate and enhance the usability of cultural buildings, with the aim of improving the overall quality of the visitor experience.

It is within this context that the paradigm of "predictive usability" (Villani *et al*., 2024) is framed. This approach seeks to assess museum usability *ex ante*, anticipating the effects of spatial configurations and exhibition layouts on different user profiles and supporting evidence-based reconfigurations. Operational approaches include configurational analyses (Hillier and Hanson, 1989; Hillier, 2007) and virtual simulations aimed at verifying in advance spatial performance in relation to accessibility requirements (Andrich *et al*., 2022), probable visitor pathways (Centorrino *et al*., 2021; Gath-Morad, 2022; Lo Turco *et al*., 2022), and perceived quality of the user experience (Ceccarelli *et al*., 2024). Such tools are valuable both in supporting the design phase and in guiding organisational and strategic decisions during the operational phase.

The need to adopt digital tools capable of enabling the information-based management of the multiple dimensions characterising cultural sites is closely linked to the evolution of the very concept of the museum. In 2022, ICOM defined the museum as an institution serving society – open, accessible, and inclusive – committed to promoting diversity and sustainability. No longer conceived solely as a place of conservation, the museum is now understood as a network of spaces for social interaction, education, and participation, interconnected with one another: an ideal testing ground for recent innovations aimed at improving facility management and broadening access to cultural content (ICOM, 2019).

In Italy, these principles are shared by the National Museum System (SMN), which aims to establish a network among nearly 5,000 museums and cultural institutions across the country to enhance usability, accessibility, and sustainable management (MIBACT, 2018). Coordinated by the Directorate-General for Museums (DGM), the SMN operates through multi-level and intersectoral cooperation and provides for the voluntary participation of museums in compliance with uniform

quality standards structured around organisation (including guarantees of physical, sensory, and cognitive accessibility), collections, communication, and relationships with local communities.
Since 2018, all Italian cultural institutions have been required to adopt a Plan for the Elimination of Architectural Barriers (PEBA), aimed at planning progressive improvement interventions (MIBACT, 2018b). Attention to this issue has been further strengthened by the National Recovery and Resilience Plan (PNRR), which has allocated dedicated funding for the removal of physical and cognitive barriers in museums [1] (Directorate-General for Museums, 2022).
Museums therefore constitute complex systems in which conservation, safety, accessibility, managerial sustainability, and quality of experience intersect. Each intervention requires balancing heterogeneous demands within a regulatory framework that is both articulated and continuously evolving. In the absence of adequate tools, there is a risk of proceeding through fragmented and misaligned interventions, with limited capacity for *ex ante* evaluation of their impacts.
Within the field of scientific research, recent studies have proposed digital environments – information frameworks – capable of integrating heterogeneous datasets to overcome data fragmentation in cultural heritage management. These include, for example, systems addressing architectural and artistic documentation (Lei *et al*., 2025), as well as the functional, structural, and energy performance of historic buildings (Massafra *et al*., 2026).
In this direction, and focusing specifically on the usability and accessibility of cultural sites, this contribution presents the development of an open-source platform that integrates spatial, behavioural, and accessibility data. The platform is conceived as an infrastructure capable of supporting and informing decisions related to usability throughout the entire life cycle of SMN sites, from the planning and design of improvement interventions to the management and long-term monitoring of usage practices.
The platform is structured according to a multi-level logic consistent with the organisation of the SMN – from the Directorate-General for Museums (DGM) and the Regional Directorates for National Museums (DRMN) to individual museum institutions – and generates a series of dashboards that correlate usability data at both territorial and building scales.
The results presented stem from an Implementing Agreement for Scientific Collaboration between the Regional Directorate for National Museums of Lazio (DRML) and the Department of Planning, Design, and Architecture Technology (PDTA) at Sapienza University of Rome. The agreement was aimed at developing tools for accessibility and environmental communication, with application to the Archaeological Museum of the Italic Peoples “Amedeo Maiuri” in Veroli (FR).

Methodology
The conception of a platform aimed at managing the dynamics related to the usability of cultural sites within a structured system such as the National Museum System (SMN) entails the simultaneous consideration of a multiplicity of actors and information flows operating at different scales and oriented towards distinct objectives. The multi-level nature of this complexity renders sectoral interpretations inadequate; for this reason, the study adopts an integrated approach that combines, on the one hand, the centrality of users – according to the principles of human-centred design (ISO 9241-210:2019; Giacomin, 2014) – and, on the other, the valorisation of data as concrete tools to support decision-making processes, within a data-driven perspective (Diván, 2017).

The overall objective of the study was to explore the development of a prototype platform designed to transform collected data into operational knowledge aimed at optimising the usability of cultural sites for the widest possible audience. This objective was articulated into three partially overlapping specific sub-objectives, which structured the operational phases:
- predictive usability (Villani *et al.*, 2024), understood as the capacity of the prototype to simulate and optimise spatial flows and modes of use of spaces and contents;
- accessibility of spaces and contents in a holistic sense (Lauria and Ndreca, 2025), understood as the capacity of the prototype to monitor and optimise the use of aids for universal accessibility;
- user experience, understood as the capacity of the prototype to monitor the emotional dimension associated with the visit experience (King *et al.*, 2023).
On this basis, the methodological pathway was structured into two main, closely integrated macro-phases, each articulated into a series of operational domains (Fig. 1).

Phase 1 – Conceptual Development
The first phase, design-oriented in nature, concerned the definition of the conceptual and informational framework underlying the platform and included the following operational domains:
- Domain 1.1: Identification of users and analysis of their informational needs, with the aim of conceiving the prototype as a concrete, integrated tool for communication and coordination across different governance levels. This activity led to the identification, at the territorial scale, of (i) institutional decision-makers – corresponding to operators of the Directorate-General and Regional Directorates – interested in systemic and comparative large-scale views; and, at the building scale, (ii) museum operators, oriented towards continuous monitoring of usability dynamics; (iii) technical staff, focused on system performance; and (iv) the public, conceived as active users for whom the platform functions as an interface aimed at enhancing awareness of the visit experience;
- Domain 1.2: Identification of input data aligned with users' informational needs and the three specific sub-objectives, differentiated by scale (territorial or building) and by nature (static or dynamic);
- Domain 1.3: Definition of Key Performance Indicators (KPIs) to monitor the achievement of the specific sub-objectives, specifying for each the enabling data and calculation methods (Tab. 1);
- Domain 1.4: Selection of Capabilities, understood as the digital functionalities – Data Services, Integration, Intelligence, User Experience (UX), Management, Trustworthiness – that the platform must ensure in order to meet the design premises. This activity was conducted with reference to the "Digital Twin Capabilities Periodic Table", an international methodological framework developed by the Digital Twin Consortium (van Schalkwyk *et al.*, 2022);
- Domain 1.5: Preparation for the integration of the PEBA within the platform as a specific system capability, with the aim of correlating accessibility parameters with behavioural data. This involved formalising the descriptive information contained in this accessibility planning tool into structured data directly usable within an information system;
- Domain 1.6: Definition of enabling technologies and specific technological solutions for each Capability category, ensuring concrete implementability. To guarantee technical feasibility, choices were guided by three criteria: (i) adoption of open-source tools to ensure transparency and optimise economic sustainability; (ii) minimisation of the impact of data collection on the visitor experience and protection of personal data – central issues in the use of big data for behavioural analysis (Jingwen and Lin, 2023); and (iii) optimisation of technological solutions to reduce the complexity of the information infrastructure.

Phase 2 – Operational Development

The second phase, purely implementation-oriented, concerned the concrete configuration of the platform based on the conceptual premises defined in Phase 1. The ThingsBoard environment, selected for its open-source nature and capacity to manage real-time data, constituted the reference technological infrastructure (De Paolis *et al*., 2018). Within this infrastructure, the operational domains were articulated as follows:

- Domain 2.1: User profiling through the configuration of roles, permissions, and informational views at both the territorial scale (DGM, DRMN) and the building scale (museum staff, technical personnel, public);
- Domain 2.2: Structuring of assets, understood in ThingsBoard as the entities (physical or abstract) monitored by the system. This included (i) the definition of asset profiles – predefined models grouping homogeneous assets – distinguishing six profiles (DRMN, Building, Floor, Room, Exhibition, PEBA); (ii) standardisation and bulk import of attributes based on simulated static datasets; and (iii) the establishment of semantic relationships among assets through dependency graphs reflecting the multi-scalar logic of the analysed elements;
- Domain 2.3: Configuration of simulated devices: virtual entities replicating the behaviour of sensors and actuators installable in the experimental environments. This activity first consisted in the definition of device profiles: groups intended to characterise the behaviour of IoT devices in terms of their modes of data acquisition, transmission, processing, and visualisation.

Consistent with the design-phase technological choices, the profiles defined within the platform distinguish between: (i) medium-range (up to 1 metre) Ultra High Frequency (UHF) Radio Frequency Identification (RFID) readers to detect user presence near exhibitions through anonymised tagged wristbands provided at entry; (ii) short-range (up to 10 cm) High Frequency (HF) RFID readers to monitor direct interaction with accessibility aids (tactile maps, 3D prints, etc.);(iii) cameras equipped with Edge Artificial Intelligence (Edge AI) to anonymously detect and translate facial expressions near significant artworks into structured data; (iv) interactive totems to collect visitor feedback; and (v) QR codes to simulate access to in-depth digital content during the visit.

This phase also required a technical feasibility assessment regarding potential overlaps in reading ranges among spatially proximate devices. The explanatory results for the "Amedeo Maiuri" Hall, located on the first floor of the Archaeological Museum of the Italic Peoples “Amedeo Maiuri” in Veroli (FR) – the experimental case study – are shown in Fig. 2.

Domain 2.3 concluded with the configuration of semantic relationships between devices and assets, in coherence with the hierarchical structure of the system.

- Domain 2.4: Data simulation to verify model coherence and functionality. This included (i) generation of dynamic simulated datasets in Python for each device profile; (ii) real-time data transmission to devices via the Message Queuing Telemetry Transport (MQTT) protocol; and (iii) time-based KPI calculation through the platform’s Application Programming Interfaces (APIs);
- Domain 2.5: Configuration of real-time malfunction alerts using ThingsBoard’s Rule Chains mechanism;
- Domain 2.6: Design and configuration of interfaces, defining unique coding systems, access permissions, thematic areas, and widgets. The relationships among dashboards were managed through the assignment of access permissions and dedicated navigation widgets across different system levels. A schematic overview of this phase is presented in Fig. 3.

Results

The entire development process – both conceptual and operational – of the platform within the ThingsBoard environment was carried out as an integral part of the experimental phase of the research, with the aim of verifying its flexibility and its capacity to support decision-making processes related to the inclusive usability of cultural sites. In this sense, the experimentation represented not only the validation of the methodological choices but also an operational verification within a concrete system.

A central element of the experimental phase was the continuous and iterative engagement with end users, both during the development stage and in the final testing phase. At the territorial scale, the dialogue involved the Directorate-General for Museums (DGM) and the Regional Directorate for National Museums of Lazio (DRMN Lazio), which promoted the collaboration agreement and was adopted as a representative case study. At the building scale, the process was guided by the staff of the Archaeological Museum of the Italic Peoples “Amedeo Maiuri” in Veroli (FR), selected as the experimental laboratory within the investigation of individual cultural sites. This interaction enabled the progressive calibration of the design premises and operational outcomes, orienting the development towards actual needs.

The experimental process led to the implementation of a prototype platform structured as a system of informational interfaces (i.e., dashboards) corresponding to the various levels of the SMN’s multi-scalar hierarchical structure. The proposed organisation coherently reflects the observation scale, user profile, and nature of the monitored data, ensuring informational continuity and navigability across levels, with the aim of fostering an integrated interpretation of phenomena related to usability.

At the territorial scale, the platform provides two main interfaces. The first (Fig. 4a), intended for the DGM, offers a synthetic and comparative overview of the SMN at the national level. By integrating maps, tables, and filters, it enables the aggregation of information concerning the Regional Directorates, highlighting systemic dynamics and potential criticalities. By interacting with territorial markers, users can access the immediately subordinate informational level, dedicated to the management of individual Regional Directorates and exemplified in the case study of the Lazio Region (Fig. 4b). This interface provides a territorial overview of cultural sites within the regional domain, displays attributes in tabular form, includes a KPI-dedicated area, and incorporates a filtering system to identify dynamics of interest.

At the building scale, the experimentation focused, by way of example, on the design of interfaces intended for the staff of the Archaeological Museum of the Italic Peoples “Amedeo Maiuri”. The first-level dashboard (Fig. 5a), accessible by activating the territorial markers in the immediately higher-level interface, addresses the entire cultural site and is organised into thematic sections: on the left, an area monitors real-time entries; at the centre, a section displays key KPIs related to usability and access to PEBA digitised content; at the bottom, a panel records system malfunctions; and on the right, a navigation area provides intuitive access to lower levels of analysis.

By selecting the names of individual rooms, users can access the room-level dashboard (Fig. 5b), exemplified by the “Amedeo Maiuri” Hall, which retains the same thematic structure while adapting data granularity and KPIs to the scale of analysis. Similarly, through the navigation area, it is possible to access an additional informational level dedicated to individual exhibition setups (Fig. 5c), structured according to the same logic, thereby ensuring coherence and intuitiveness in the user experience.

Although experimental in nature and open to further development, the prototype platform constitutes the operational translation of the proposed conceptual framework. It finds concrete expression in the

data-processing system accessible through the described multi-scalar interfaces and establishes the foundations for a replicable model of data-driven management of museum usability.

Discussion of results, limitations, and development trajectories

The innovative character of the research described lies in the implementation of an open-source platform that enables the various actors responsible for museum governance, as well as visitors, to interrelate spatial data, accessibility information, and usage dynamics within a single information environment oriented towards decision support for the SMN and for the entire life cycle of individual cultural sites. In its prototype configuration, the platform therefore represents an operational infrastructure for evidence-based management of usability (Zallio and Clarkson, 2021).

By overcoming analytical approaches that tend to treat data separately, the developed framework conceives usability as an integrated and adaptive system, capable of evolving in response to usage feedback within a dynamic information ecosystem that processes real-time data and enables predictive simulations.

In its current configuration, the platform allows the monitoring of relationships among indicators of regulatory compliance, the effectiveness of inclusive design solutions, visitor numbers, dwell times, and aggregated emotional responses. It thus provides decision-makers with knowledge elements concerning emerging criticalities and potential areas for improvement.

The interface, structured according to hierarchical levels consistent with the functioning of the SMN, enables learning from the actual use of spaces and the progressive adaptation of design and management choices, including the definition of intervention priorities, in line with the most recent adaptive management systems for the built environment (Yap *et al*., 2025).

A further aspect of interest concerns the possibility, at a more detailed scale, of correlating usability data with qualitative dimensions of the cultural experience. This opens the opportunity to evaluate not only spatial efficiency and flow management, but also engagement and the relational quality of the visit experience, thereby contributing to a broader interpretation of inclusivity.

The continuous dialogue with the Directorate-General for Museums, the Regional Directorate for National Museums of Lazio (DRML), and the management of the museum selected as case study throughout the experimental process made it possible to identify several limitations, whose shared discussion provided insights for subsequent developments. First, the experimentation conducted on simulated data does not yet allow verification of the robustness of the developed indicators. The actual installation of sensors in the case-study museum – already agreed upon with the DRML – and the collection of real data will constitute an essential step for evaluating the model and, if necessary, recalibrating the KPIs.

In addition, the absence of native integration between ThingsBoard and Building Information Modeling (BIM) models – only partially mitigated through the use of customised widgets that facilitate immediate recognition of spaces for navigation – limits the platform's interoperability with broader lifecycle management processes of cultural sites.

A further limitation lies in the current lack of structured integration with advanced artificial intelligence modules and simulation tools, thereby constraining the platform's capacity to perform advanced predictive analyses and support alternative scenarios evaluation.

From the perspective of future developments, the integration of machine learning modules represents a promising direction, as it could enhance the predictive capacity of the system by enabling the assessment of user behaviour in relation to the usability of different design configurations, including wayfinding interventions. In this perspective, the system could support the evaluation of inclusivity across alternative solutions by measuring their effectiveness against objective indicators derived from behavioural data. Indeed, the use of machine learning algorithms in cultural contexts has recently been explored in relation to flow analysis and path personalisation, yielding positive results in the optimisation of the visitor experience (Li and Liu, 2025).

Concurrently, strengthening the adoption of open standards for data modelling and exchange could enhance the replicability of the platform at the national scale, contributing to the development of a shared infrastructure for data-driven management of cultural sites. Within a digital governance framework oriented towards the usability of cultural heritage, the platform could be configured as a strategic tool capable not only of supporting museum institutions in the management and enhancement of their sites, but also of promoting an inclusive design culture sustained by digital technologies able to monitor, predict, and dynamically update accessibility conditions. In this way, it could concretely contribute to reducing the gap between declared accessibility and accessibility effectively experienced, while simultaneously valuing the specificities of different museum contexts.

Conclusions

This contribution has sought to demonstrate how usability in cultural sites should be assumed as a structural indicator of design quality, embedded within a dynamic system that can be governed over time through integrated digital tools.

Although still at an early stage, the developed platform represents an initial step towards operationalising the paradigm of predictive usability, through an infrastructure capable of connecting spatial, behavioural, and accessibility data within a multi-level information environment reflecting the organisational structure of the National Museum System.

The experimentation conducted in collaboration with the Regional Directorate for National Museums of Lazio and the Archaeological Museum of the Italic Peoples “Amedeo Maiuri” made it possible to verify the operational validity of the model. This occurred both through the structured verification of the PEBA contents – considered as a reference framework for regulatory compliance in terms of accessibility – and, through simulated datasets, the monitoring of visitor flows and modes of spatial use. The results thus demonstrate the platform’s effectiveness as a decision-support tool and confirm its potential scalability and applicability within more complex museum contexts.

The proposed approach aims to provide tangible support to museum institutions in the management and enhancement of their sites and cultural heritage, fostering more informed governance practices. In particular, the value of the proposed digital infrastructure lies in its capacity to structure, within a single adaptive information ecosystem, a shared knowledge and operational framework across different governance levels. Furthermore, it promotes an inclusive design culture by consolidating the understanding of usability as a driving factor for the optimal functioning of the museum organism.

NOTES

[1] Within the framework of the National Recovery and Resilience Plan (PNRR), the objective of adapting museums to meet the needs of the widest possible range of users has been further reinforced by allocating part of Investment 1.2 of Component 3 of Mission 1 – “Tourism and Culture 4.0” to the drafting of a strategic plan of national relevance (structured by region), aimed at providing a comprehensive overview of the implementation of the inclusivity principles established by current legislation.

REFERENCES

Andrich, W., Daniotti, B., Pavan, A. and Mirarchi, C. (2022), “Check and validation of building information models in detailed design phase: A check flow to pave the way for BIM based renovation and construction processes”, *Buildings*, Vol. 12, 2, 154. Available at: https://doi.org/10.3390/buildings12020154

Ceccarelli, S., Cesta, A., Cortellessa, G., De Benedictis, R., Fracasso, F., Leopardi, L., *et al*. (2024),

"Evaluating visitors' experience in museum: Comparing artificial intelligence and multi-partitioned analysis", *Digital Applications in Archaeology and Cultural Heritage*, 33, e00340. Available at: https://doi.org/10.1016/j.daach.2024.e00340
Centorrino, P., Corbetta, A., Cristiani, E. and Onofri, E. (2021), "Managing crowded museums: Visitors flow measurement, analysis, modeling, and optimization", *Journal of Computational Science*, 53, 101357. Available at: https://doi.org/10.1016/j.jocs.2021.101357
De Paolis, L.T., De Luca, V. and Paiano, R. (2018), "Sensor data collection and analytics with ThingsBoard and Spark Streaming", *Proceedings of the 2018 IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems (EESMS)*, IEEE, pp. 1–6. Available at: https://doi.org/10.1109/EESMS.2018.8405822
Direzione Generale Musei (2022), *Piano strategico per l'eliminazione delle barriere architettoniche*. Available at: http://musei.beniculturali.it/wp-content/uploads/2024/09/2024-09-12-PN-peba.pdf (Accessed on 13/02/2026).
Diván, M.J. (2017), "Data-driven decision making", *Proceedings of the 2017 International Conference on Infocom Technologies and Unmanned Systems (Trends and Future Directions) (ICTUS)*, December, IEEE, pp. 50-56. Available at: https://doi.org/10.1109/ICTUS.2017.8285973
European Commission: Directorate-General for Communications Networks, Content and Technology (2025), *Common European data space for cultural heritage – Strategy 2025-2030*. Available at: https://data.europa.eu/doi/10.2759/9497280 (Accessed on 12/02/2026).
Gath-Morad, M., Melgar, L. E. A., Conroy-Dalton, R. and Hölscher, C. (2022), "Beyond the shortest-path: Towards cognitive occupancy modeling in BIM", *Automation in Construction*, 135, 104131. Available at: https://doi.org/10.1016/j.autcon.2022.104131
Giacomin, J. (2014), "What is human centred design?", *The Design Journal*, Vol. 17, No. 4, pp. 606-623. Available at: https://doi.org/10.2752/175630614X14056185480186
Hillier, B. and Hanson, J. (1989), *The social logic of space*, Cambridge university press, Cambridge.
Hillier, B. (2007), *Space is the machine: a configurational theory of architecture*, Space Syntax, London. Available at: https://discovery.ucl.ac.uk/id/eprint/3881/ (Accessed on 12/02/2026).
Hou, H., Lai, J. H. K., Wu, H., and Wang, T. (2024), "Digital twin application in heritage facilities management: systematic literature review and future development directions", *Engineering, Construction and Architectural Management*, Vol. 31 No. 8 pp. 3193–3221. Available at: https://doi.org/10.1108/ECAM-06-2022-0596
ICOM (2019), *Annual report*. Available at: https://icom.museum/wp-content/uploads/2020/07/2573_ICOM-RA-2019_V14_web_planches.pdf (Accessed on 13/02/2026).
International Organization for Standardization (2019), *ISO 9241-210:2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems*, ISO, Geneva. Available at: https://www.iso.org/standard/77520.html (Accessed on 16/02/2026).
Jingwen, Z. and Lin, L. (2023), "Limitations and ethical reflection on the application of big data in museum visitor research", *Museum Management and Curatorship*, Vol. 38, No. 4, pp. 416–427. Available at: https://doi.org/10.1080/09647775.2022.2111333
King, E., Smith, M.P., Wilson, P.F., Stott, J. and Williams, M.A. (2023), "Creating meaningful museums: A model for museum exhibition user experience", *Visitor Studies*, Vol. 26, No. 1, pp. 59–81. Available at: https://doi.org/10.1080/10645578.2022.2129944

Lauria, A. and Ndreca, A. (2025), "Rethinking Accessibility as a Cultural Generative Ecosystem", *Urban Science*, Vol. 9, No. 11, p. 478. Available at: https://doi.org/10.3390/urbansci9110478

Lei, Y., Bruno, N. and Roncella, R. (2025), "A Data-driven Information Modelling Approach for Cultural Heritage", *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, No. 48, pp. 813-820. Available at: https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-813-2025

Li, K. and Liu, H. (2025), "Machine Learning Framework for Adaptive Museum Tour Recommendation and Personalized Visitor Experience", *Information Resources Management Journal (IRMJ),* Vol. 38, No. 1. Available at: https://doi.org/10.4018/IRMJ.385723

Lo Turco, M., Giovannini, E. C. and Tomalini, A. (2022). "Parametric and visual programming BIM applied to museums, linking container and content", *ISPRS International Journal of Geo-Information*, Vol. 11, 7, 411. Available at: https://doi.org/10.3390/ijgi11070411

Massafra, A., Coraglia, U. M., Di Turi, S. and Palladino, D. (2026), "Federated Data Modelling for Heritage Building Performance Management", *Buildings*, Vol. 16, No.1, 27. Available at: https://doi.org/10.3390/buildings16010027

MIBACT (2018), D.M. 113 del 21 febbraio 2018, Adozione dei livelli minimi uniformi di qualità per i musei e i luoghi della cultura di appartenenza pubblica e attivazione del sistema museale nazionale. Available at: https://www.icom-italia.org/wp-content/uploads/2018/04/ICOMItalia.SMN_.D.M.21FEBBRAIO2018.21febbraio.2018.pdf (Accessed on 12/02/2026).

MIBACT (2018b), Linee guida per la redazione del Piano di Eliminazione delle Barriere Architettoniche (PEBA). Direzione Generale Musei. Available at: http://musei.beniculturali.it/wp-content/uploads/2019/05/Linee-guida-per-la-redazione-del-Piano-di-eliminazione-delle-barriere-architettoniche-P.E.B.A-nei-musei-complessi-monumentali-aree-e-parchi-.pdf (Accessed on 12/02/2026).

Niccolucci, F., Markhoff, B., Theodoridou, M., Felicetti, A. and Hermon. S. (2023), "The Heritage Digital Twin: a bicycle made for two. The integration of digital methodologies into cultural heritage research", [version 1; peer review: 2 approved with reservations], *Open Research Europe*, Vol. 3, 64. Available at: https://doi.org/10.12688/openreseurope.15496.1

United Nations (2006), *United Nations Convention on the Rights of Persons with Disabilities*. Available at: https://www.un.org/disabilities/documents/convention/convention_accessible_pdf.pdf (Accessed on 26/02/2026)

van Schalkwyk, P., Whiteley, S. and Goldman, M. (2022), *Digital Twin Capabilities Periodic Table*, Digital Twin Consortium. Available at: https://www.digitaltwinconsortium.org/initiatives/capabilities-periodic-table/ (Accessed on 16/02/2026).

Villani, T., Romagna, G. and Oddi, A. (2024), "Optimising usability in museums – Integrated management of data on the use of space and cultural content", *AGATHÓN International Journal of Architecture, Art and Design*, 16, pp. 220–231. Available at: https://doi.org/10.19229/2464-9309/16192024

Yap, J. R., Roman O., Tyrone Adey, B. and Maheshwari, T. (2025), "Trends and opportunities in adaptive planning for the built environment: a literature review, *City and Environment Interactions,* Vol. 26, 100196, Available at: https://doi.org/10.1016/j.cacint.2025.100196

Zallio, M. and Clarkson, P. J. (2021), “Inclusion, diversity, equity and accessibility in the built environment: A study of architectural design practice”, *Building and Environment*, Vol. 206, 108352, Available at: https://doi.org/10.1016/j.buildenv.2021.108352

Images

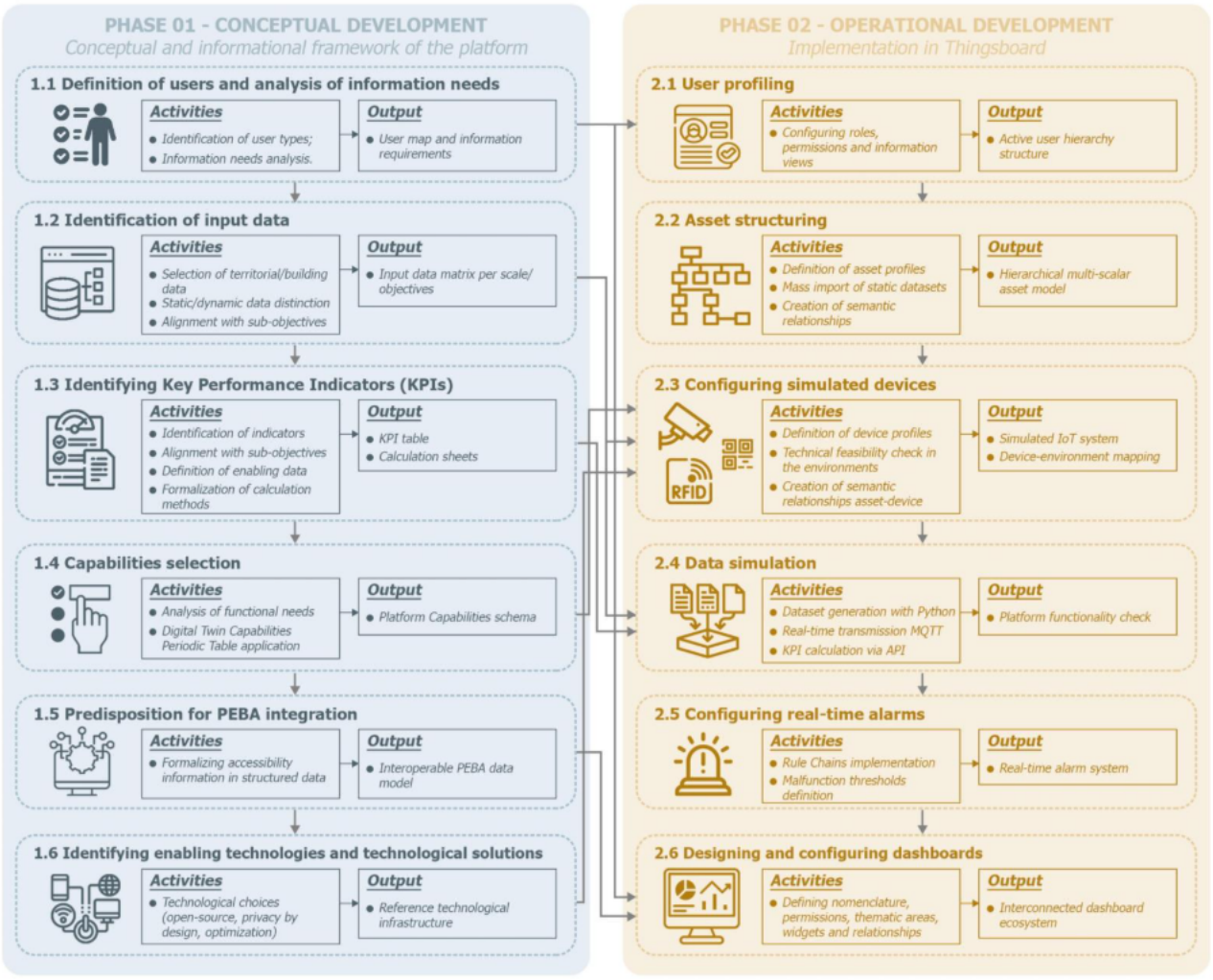

Fig. 01 – The methodological path for the development of the platform, structured in two macro-phases, each divided into distinct interconnected operational domains.

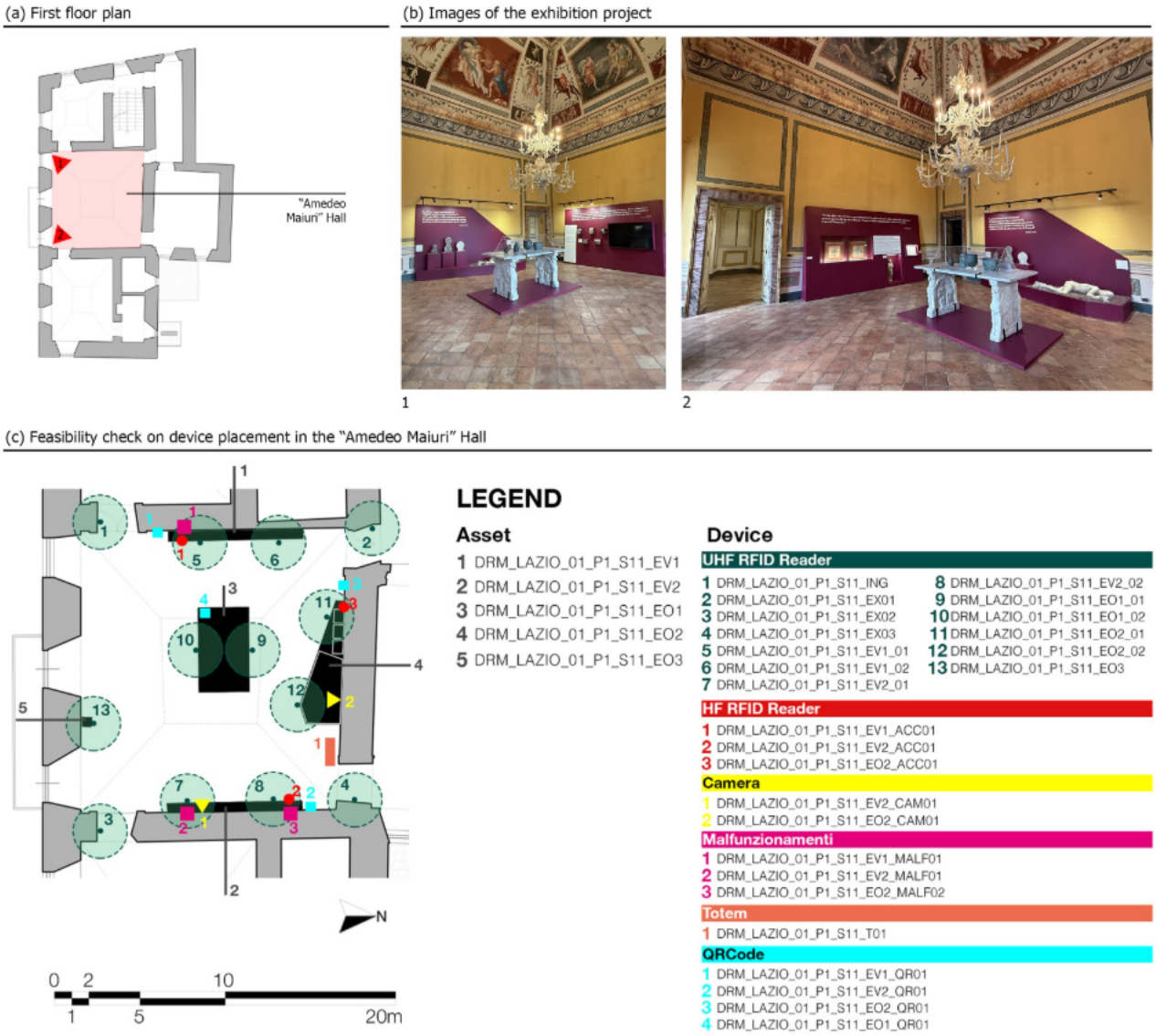

Fig. 02 - The “Amedeo Maiuri” Hall of the Archaeological Museum of the Italic Peoples in Veroli: (a) the planimetric framework on the first floor; (b) images of the exhibition layout; (c) the feasibility check for the positioning of the devices and the overlapping of the reading beams in the experimental configuration.

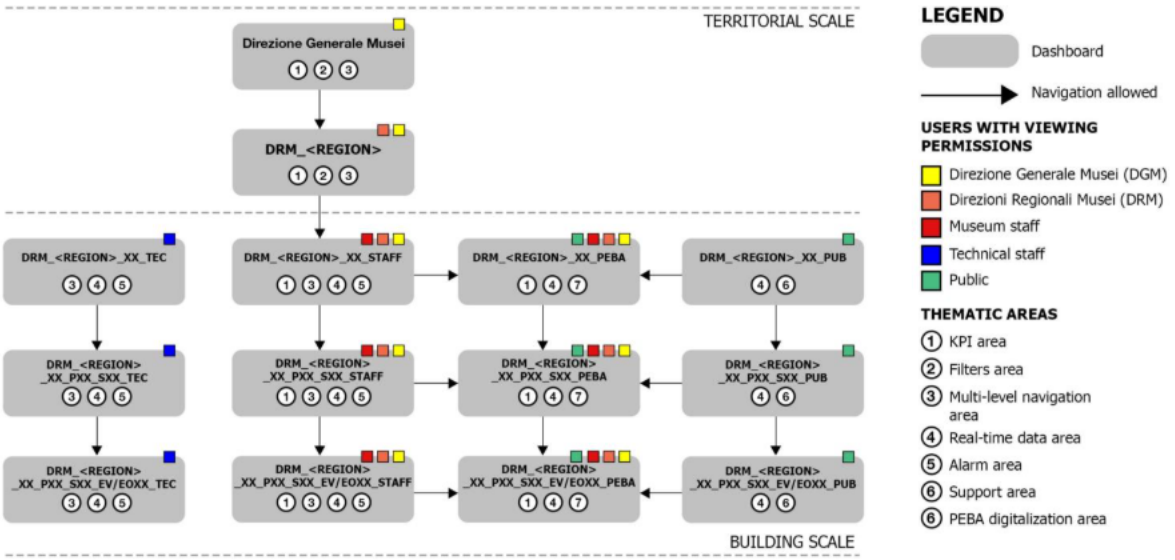

Fig. 03 – Summary diagram of the system of relationships between the platform's dashboards, indicating the target users and thematic areas.

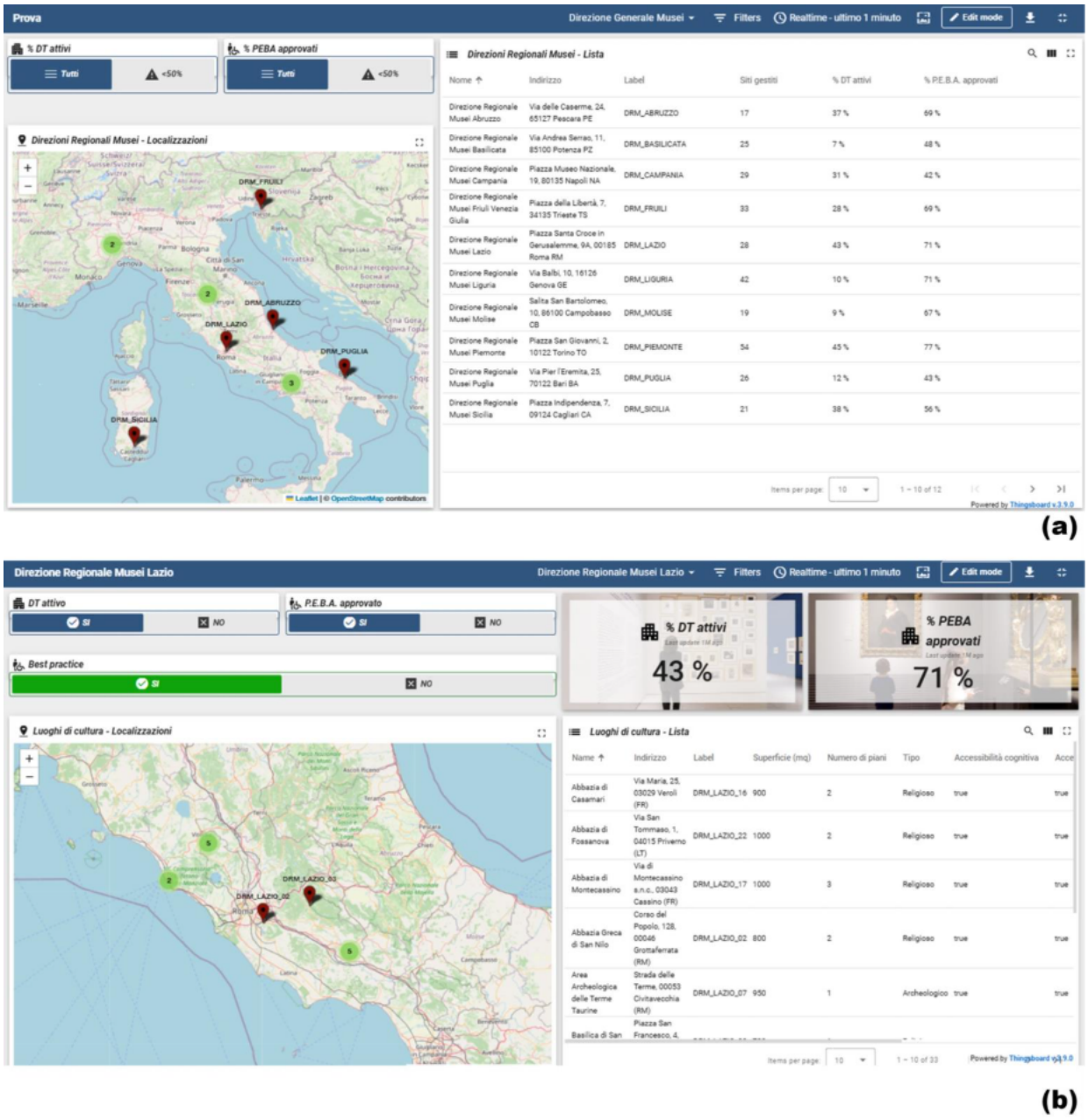

Fig. 04 – The interfaced related to the the territorial scale: (a) the Directorate-general for Museums (DGM) and (b) the individual regional Directorates for national Museums (DRMN), with the example of the Lazio region.

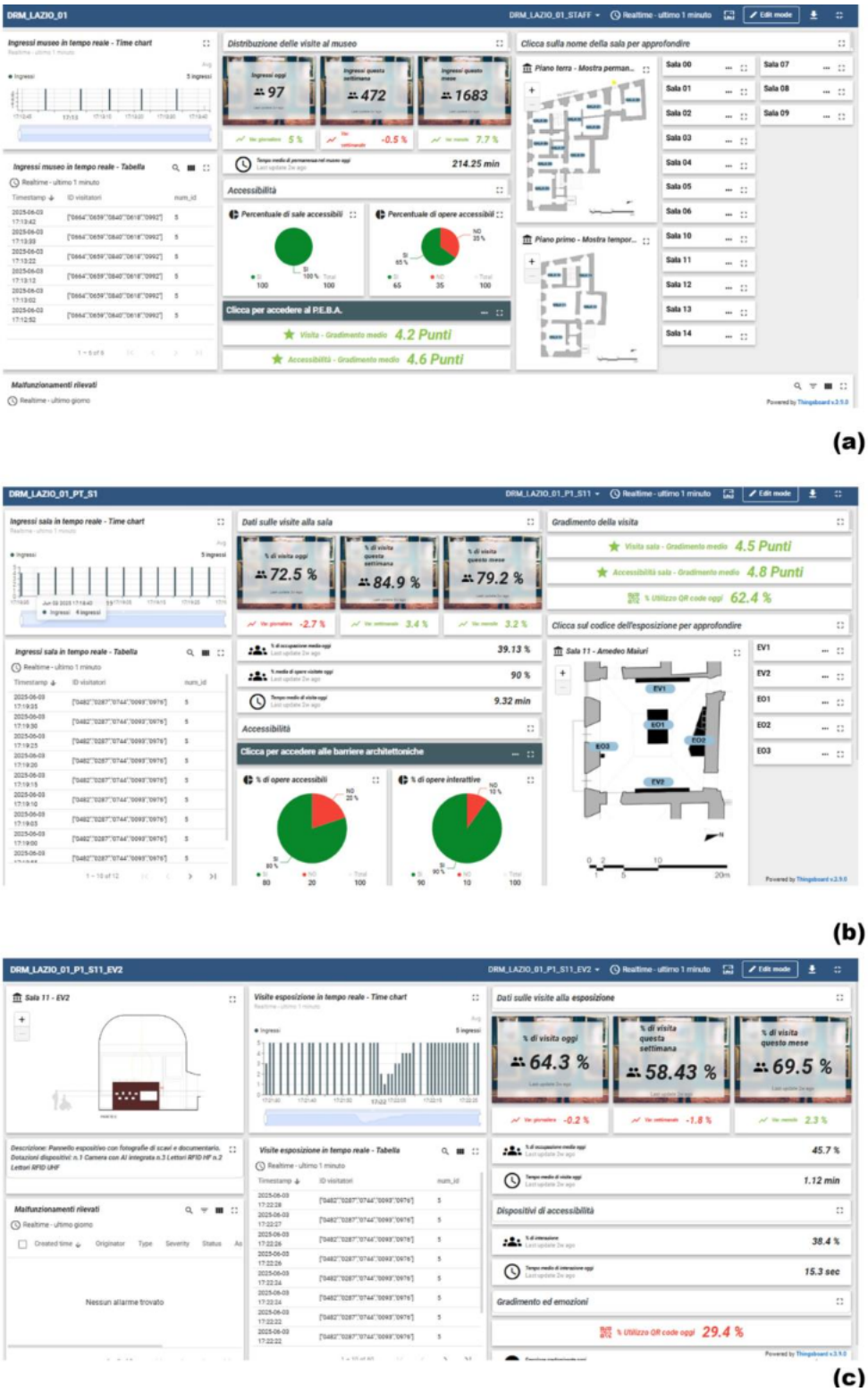

Fig. 05 – The interfaces related to the building scale exemplified in the case study of the Archaeological Museum of the Italic Peoples "Amedeo Maiuri": (a) the scope of investigation of the entire building, (b) the "Amedeo Maiuri" hall and (c) the individual exhibition.

Tables

Scale	Cod	KPI	Calculation method	Objectives	Input data	M.U.
Territorial	1	Percentage of active Digital Twins	(n. sites with active DT/n. tot. sites) x 100	• • •	-n. active DT; -n. managed sites	%
	2	Percentage of PEBAs approved	(n. sites with PEBA/ n. tot. sites) x100	•	-n. PEBAs approved; -n. managed sites	%
Building	3	Distribution of site visits	n. visitors/ hour/ day/ week/ month	• •	-n. site visits -timestamp	n.
	4	Percentage of visits per floor	(n. floor visits/ n. tot. visits) x100	• • •	-n. site visits -n. floor visits -timestamp	%
	5	Percentage of visits per room	(n. room visits/ n. tot. visits) x100	• • •	-n. site visits -n. room visits -timestamp	%
	6	Percentage of visits per artwork	(n. artwork visits/ n. tot. visits) x100	• • •	-n. site visits -n. room visits -timestamp	%
	7	Room occupancy rate	(n. room visits/ max. capacity) x100	• • •	-n. room visits -max. capacity -timestamp	%
	8	Sub-areas occupancy rate (artwork)	(n. sub-areas visits/ max. capacity) x100	• • •	-n. sub-areas visits -max. capacity -timestamp	%
	9	Average time spent in the site	Tot. time spent in the site/ n. site visits	• •	-n. site visits -timestamp	Sec.
	10	Average time spent in the rooms	Tot. time spent in the room/ n. room visits	• •	-n. room visits -timestamp	Sec.
	11	Average time of interactions with the artworks	Tot. time of interaction/ n. artwork visits	• •	-n. artwork visits -timestamp	Sec.
	12	Percentage of multimedia device usage	(n. interactions/ n. tot. visits) x100	• •	-n. site visits -n. interactions -timestamp	%
	13	Average time of interactions with multimedia devices	Tot. time of interaction/ n. tot. interactions	• •	-n. interactions -timestamp	Sec.
	14	Rate of change in turnout	(Current/ previous turnout) x100	• • •	-turnout -timestamp	%
	15	Device malfunction frequency	n. malfunctions/ monitoring time	•	-n. malfuntions -timestamp	n.
	16	Percentage of accessibility aids usage	(n. interactions/ n. tot. visits) x100	• • •	-n. site visits -n. interactions -timestamp	%
	17	Average time of interacions with accessibility aids	Tot. time of interaction/ n. tot. interactions	• • •	-n. interactions -timestamp	Sec.
	18	Percentage of accessible rooms	(n. accessible rooms/ n. tot rooms) x100	• •	-n. accessible rooms - n. rooms	%
	19	Percentage of accessible artworks	(n. accessible artworks/ n. tot artworks) x100	• •	-n. accessible artworks - n. artworks	%
	20	Percentage of interactive artworks	(n. interactive artworks/ n. tot artworks) x100	• •	-n. interactive artworks - n. artworks	%
	21	Percentage of artworks visited per room	(n. visited artworks/ n. tot. artworks) x100	• •	-n. visited artworks -n. artworks	%
	22	Predominant emotion per artwork	Max (emotions)	•	-emotions	n.
	23	Average satisfaction level with the visit	sum of scores (1-5)/ n. answers	•	-scores -n. answers	n.
	24	Average satisfaction level with accessibility	sum of scores (1-5)/ n. answers	• •	-scores -n. answers	n.
	25	Percentage of QR codes usage	(n. uses/ n. tot. site visits) x100	• • •	-n. uses -n. site visits	%

Legend of specific sub-objectives

• Predictive usability • Accessibility to spaces and contents

• User experience

Tab. 01 – Summary of KPIs at various scales. For each, the sub-ojectives they refer to and the input data required for their calculation are indicated.

Acknowledgments
This research, entitled “Methodologies and Digital Tools for Predictive Evaluation of Museum Usability. Applications to the Archaeological Museum of the Italic Peoples Amedeo Maiuri in Veroli (FR)”, was conducted under the scientific supervision of Teresa Villani (Sapienza University of Rome).
The project was funded through a third-party research contract with the Regional Directorate for Museums of Lazio (protocol no. 3386, 8 May 2025), within the framework of the National Recovery and Resilience Plan (PNRR), Mission 1 – Component 3 (M1C3) – Measure 1 “Cultural Heritage for the Next Generation,” Investment 1.2: “Removal of Physical and Cognitive Barriers in Museums, Libraries, and Archives to Enable Broader Access to and Participation in Culture” – Action Line 7 “Training of Cultural Operators” – Project Exhibition Design for Communicating Accessibility at the Archaeological Museum of the Italic Peoples “Amedeo Maiuri” in Veroli (FR), funded by the European Union – NextGenerationEU.
The authors gratefully acknowledge the collaboration of the Regional Directorate for Museums of Lazio and the Associations of persons with disabilities in the Province of Frosinone.