Digital and tangible tools for physical and cognitive accessibility of Palazzo Carignano staircase

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A CURA DI
Enrico Cicalò, Michele Valentino, Alexandra Fusinetti

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Digital and tangible tools for physical and cognitive accessibility of Palazzo Carignano staircase

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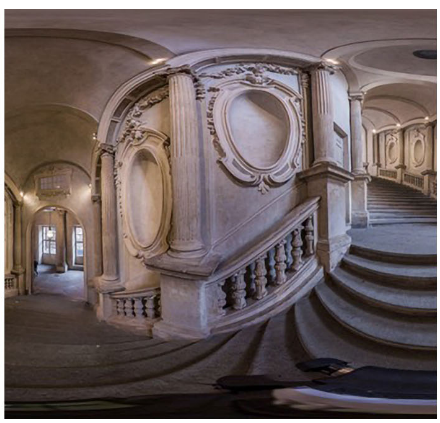


fruizione
modellazione
inclusività
comunicazione
interazione

fruition
modelling
inclusivity
communication
interaction

Questa proposta si inserisce in un progetto più ampio volto all'accessibilità fisica e cognitiva del Palazzo e Museo di Carignano, commissionato dalla Direzione Regionale Musei (DRM) - Museo di Palazzo Carignano. Il progetto è stato finanziato nell'ambito del PNRR (Piano Nazionale di Ripresa e Resilienza) nel settore Accessibilità e ha conclusione prevista per febbraio 2025.
Nel programma del progetto, è stata specificata la necessità di rendere la doppia scalinata fruibile senza la necessità di percorrerla fisicamente. La scalinata all'interno del palazzo barocco, progettata da Guarino Guarini, è uno degli elementi su cui vengono applicati la maggior parte dei dispositivi di comunicazione per l'accessibilità fisica e cognitiva. Questo obiettivo persegue due scopi: garantire la piena accessibilità dello spazio e facilitarne la conservazione limitandone l'usura.
Tre principali prodotti caratterizzano le strategie di accessibilità: un tour virtuale, un modello tattile sezionato in scala 1:50 e una visualizzazione in AR.

This proposal is rooted in a broader project aimed at the physical and cognitive accessibility of the Carignano's palace and museum, which was commissioned by the Direzione Regionale Musei (DRM) - Museo di Palazzo Carignano. The project has been funded as part of the PNRR (National Recovery and Resilience Plan) in the Accessibility sector and concluded in February 2025.
In the project program, the need to make the double staircase usable without the need to walk through was specified. The staircase in the baroque palace, designed by Guarino Guarini, is one of the elements on which most communication devices are applied for physical and cognitive accessibility. This objective pursues two goals: to ensure full space accessibility and facilitate its preservation by limiting its wear and tear.
Three main outputs characterize the accessibility strategies: a virtual tour, a 1:50 tactile cutaway scale model, and an AR visualization.

Introduction

The current proposal is rooted in a broader project aimed at the physical and cognitive accessibility of the Carignano's palace and museum, which was commissioned by the Direzione Regionale Musei (DRM) - Museo di Palazzo Carignano. In particular, the project has been recently funded as part of the PNRR (National Recovery and Resilience Plan) in the Accessibility sector. It was concluded and delivered at the end of February 2025.

Following the PNRR's goal of reducing obstacles, inequalities, and gaps that limit citizens' participation in cultural life and heritage, the project intended to enhance the accessibility to knowledge.

The research team established to carry out the project consists of scholars in the history of art and architecture, digital survey, 3D modeling and H-BIM, extended reality (XR) solutions for heritage [Innocente et al. 2023], and user experience (UX).

The overall project is divided into the activities of analysis, through integrated digital survey, and interpretive modeling, through the H-BIM process, of the entire domain under investigation. At the same time, communication strategies, methodologies, and tools range from reconstructive digital modeling, physical modeling, virtual tours, virtual reality (VR), and augmented reality (AR). Within the scope of intervention, museum spaces, missing structures, and architectural elements are presented using certain above-mentioned techniques, selected on a case-by-case basis according to the project objectives. The products created will be integrated into the installations and devices envisaged in the overall communication plan for the Palazzo Carignano Museum, which will probably be inaugurated in the autumn of 2025.

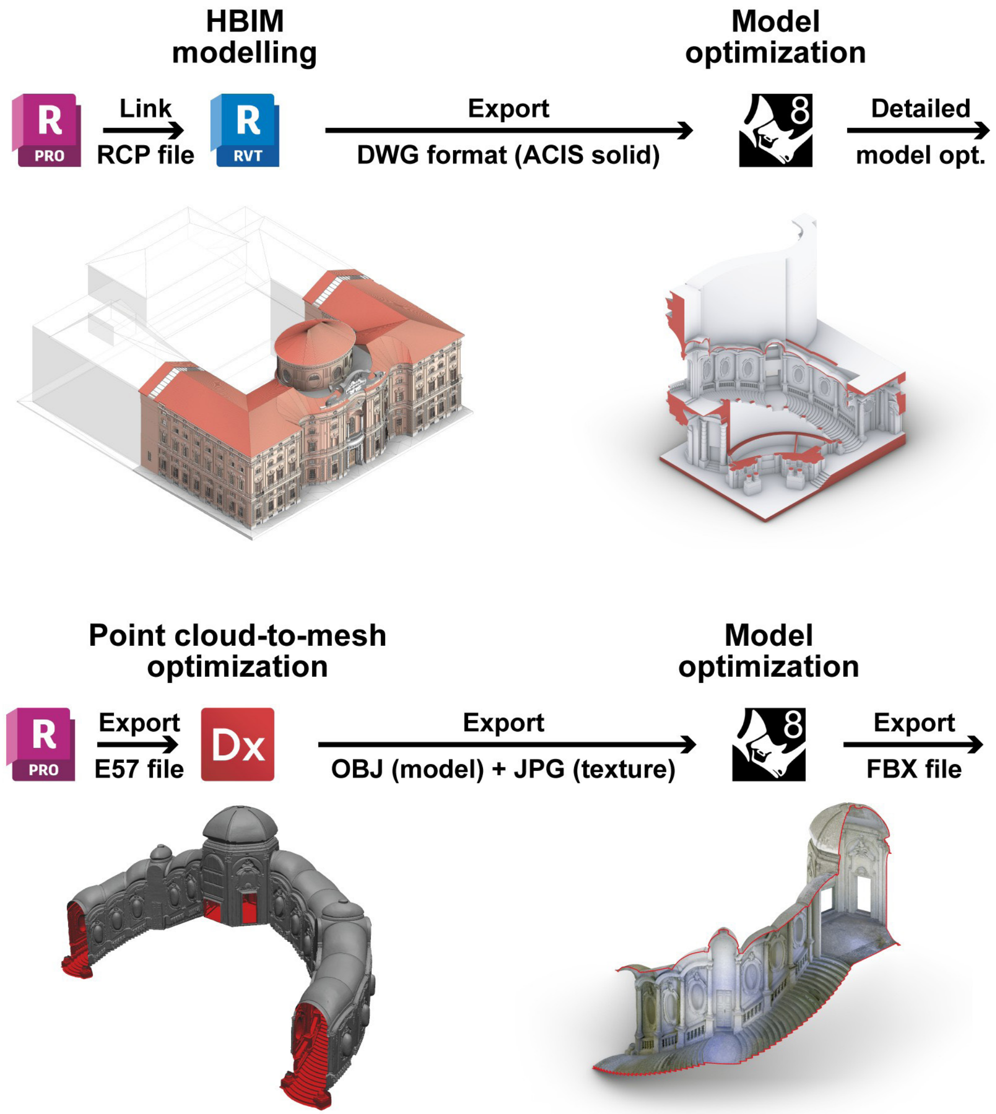
Research pipeline and accessibility outputs

Palazzo Carignano was built to a design by Guarino Guarini. The double staircase, the subject of this in-depth study, is one of the elements on which most communication devices are applied for physical and cognitive accessibility. In the project program, the need to make the staircase usable without the need to walk through was specified. This objective pursues

Cover image
Communication tools for the staircase of Palazzo Carignano: physical model, virtual tour, and AR experience. Editing: M. Vitali.

Fig. 1
HBIM into NURBS optimization for physical model. Processing: F. Natta.

Fig. 2
Point cloud processing for optimized FBX mesh. Processing: F. Natta.


HBIM modelling
Model optimization
Link
RCP file
Export
DWG format (ACIS solid)
Detailed
model opt.
Point cloud-to-mesh optimization
Model optimization
Export
E57 file
Export
OBJ (model) + JPG (texture)
Export
FBX file

two goals: to ensure full space accessibility and facilitate its preservation by limiting its wear and tear.

The staircase represents a *unicum* in the panorama of Baroque architecture. It was essential in defining the building's conformation in the Guarini design process, which ended in 1679 [Cerri 1990]. It engages in a close formal dialogue with the fulcrum of the composition constituted by the atrium and the main hall above it, as well as the other rooms connected to the ceremonial route: the entrance hall, the side vestibules, and the vestibule leading to the main hall. In particular, the double staircase connects the two side vestibules with the upper vestibule, on which the two flights land.

Each staircase consists of two curvilinear flights of 25 and 22 steps, respectively, first convex and then concave, following the shape of the intermediate oval landing and progressing as it rises, overcoming a height of 8.51 meters. Currently, it is accessible only during the museum's guided tours.

Therefore, it was planned to offer a rich range of accessibility possibilities through:

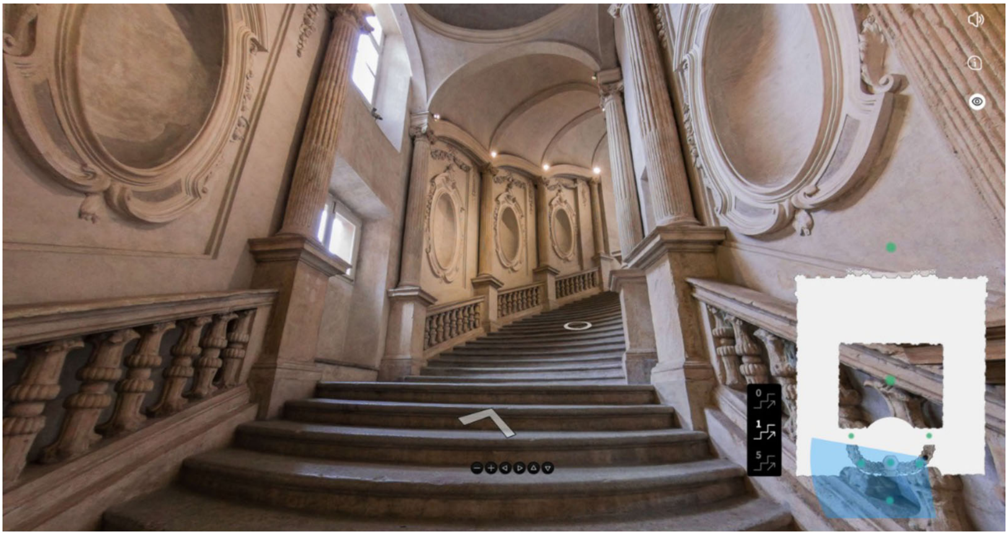
- a virtual tour generated by a sequence of spherical images linked together by graphic elements that allow the photographs to be visited and scrolled through. The virtual tour was realized for the entire project scope. It will be available on the museum's website and usable on-site via totems and handheld devices;
- a 1:50 tactile cutaway scale model of one flight of the staircase, completed by the outer façade and the connection with the entrance system, made by additive 3D printing;
- AR visualizations activated through an app for iOS and Android mobile devices for visualizing the staircase (in the mesh model format) by anchoring it to the palace's main façade, creating a kind of X-ray view.

Fig. 3
Spherical image of the staircase. Acquisition: M. Russo.

Fig. 4
Interface of the virtual tour developed, detail of the staircase. Virtual tour run in software 3DVista developed by M. Russo; UX research and design: M. Rinascimento.

Digital and physical iconographic choices

The criteria that guided the design and realisation of the products oriented to the accessible fruition of the staircase of Palazzo Carignano are marked by effectiveness and user-friendliness. In particular, the construction of the physical model required:



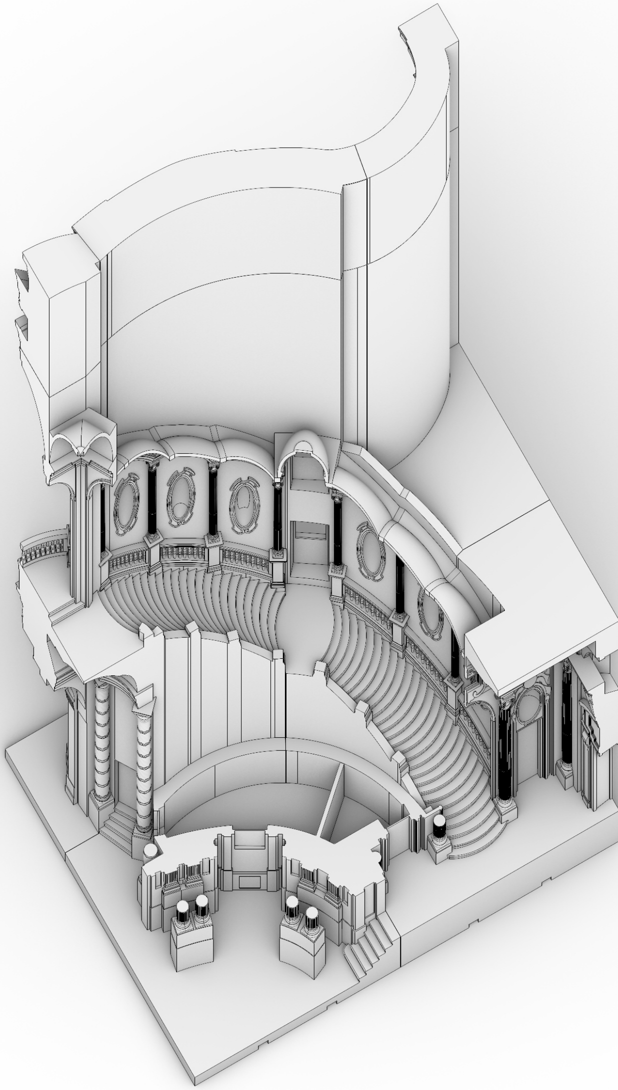
- the definition of the portion of the object to be printed, concerning tactile exploration modes and the opportunities to convey spatial understanding through the model, in its relations between the interior and exterior of the building;
- an appropriate level of detail, so that it would be compatible with additive printing techniques and, at the same time, suitable for the user experience, both visual and tactile;
- a careful choice of colour, which would convey the materiality of the staircase in a symbolic key, guaranteeing good resistance to dirt in tactile use and a good level of legibility of the forms even for users with visual impairments.
- an opaque printing filament to minimise light reflections for the benefit of greater colour vibrancy and a good perception of the spatial characteristics of the staircase.

Modelling workflows for tactile and digital accessibility tools

The development of accessibility tools for the staircase involved distinct digital modelling strategies tailored for physical fabrication and augmented reality (AR) deployment. The tactile model was derived from the previously established HBIM model of the building, created in *Autodesk Revit 2025* from point cloud data. The HBIM model was exported as DWG (ACIS solids) and imported into Rhinoceros to facilitate additive manufacturing. This environment enabled the necessary geometrical optimisation, converting parametric elements into NURBS surfaces suitable for generating a watertight mesh [Montusiewicz et al. 2022]. The resulting physical model focuses on the midnight flight of the staircase while incorporating cutaway views of the vestibule, side vestibule, atrium, and the main floor vestibule, thereby illustrating the ceremonial path and interconnectivity of spaces (fig. 1).

Conversely, the digital model aimed at AR visualisation originated directly from the raw laser scanner point cloud. Managed initially in *Autodesk Recap Pro*, the point cloud data (exported in E57 format) was processed in *Geomagic Design X*. This involved isolating the region of interest, performing cloud correction and initial decimation, followed by mesh generation. Critical optimisation steps included verifying surface normals, filling

Fig. 5
Result of the model engineering process aimed at digital fabrication by FDM 3D printing. Processing: E. Pupi.



discontinuities (holes), and applying significant mesh simplification – reducing triangle count by 80-90% to ensure fluid real-time rendering performance in AR applications [Bertola et al. 2024]. The textured mesh was exported as FBX. Further refinement in Rhinoceros involved sectioning the mesh to match the building façade behind the staircase precisely, ensuring coherence between the façade and the digital representations [Banfi 2021]. The final lightweight, textured mesh was exported again in FBX format, optimised for integration into AR platforms (fig. 2). These parallel workflows highlight the need for tailored data processing pipelines depending on the final output medium and its specific technical constraints.

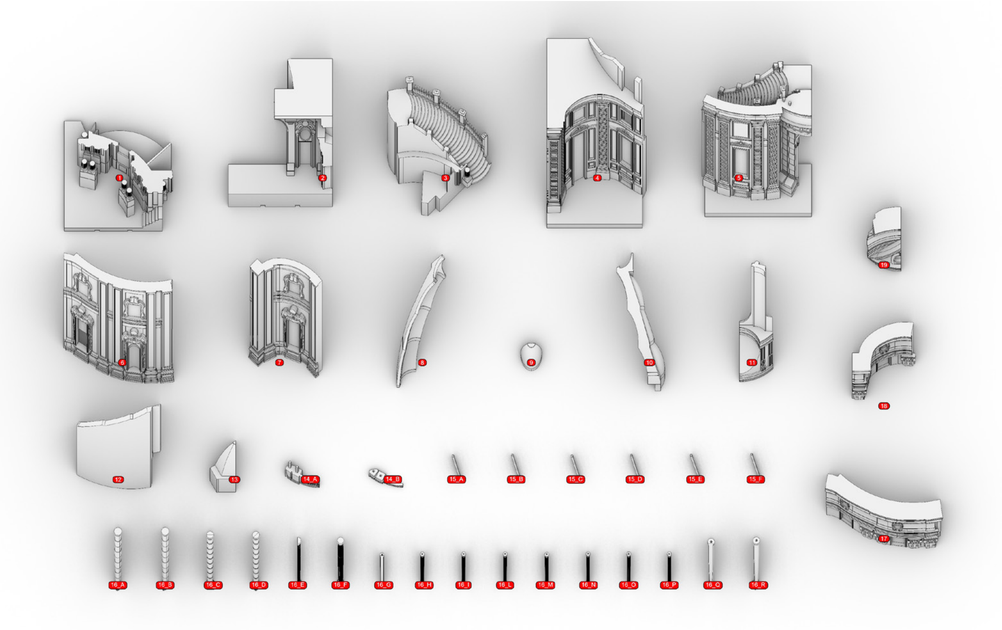
Virtual tour creation

The construction of the virtual tour aims to make accessible a space that otherwise cannot be explored by those with mobility disabilities [Paladini et al. 2019; Lasorella et al. 2021]. Therefore, the spherical image acquisition project was planned by optimizing the position and density of station points to gradually access most of the contents in space. The spherical photographs were acquired with an INSTA360 X4 camera. The camera has a 1/2-inch sensor, an aperture of 1.9, a focal length (35 mm equivalent) of 6.7 mm, and the ability to capture images up to 72MP (11904x5952). In the virtual tour of the staircase, the highest resolution was used to capture most of the details despite the size of the space. The result is a 360-degree high-resolution image (fig. 3).

The staircase's particular lighting condition refers to the co-presence of natural light from three directions – ground floor, mezzanine, and second floor – and artificial light. So, a proper camera set-up was planned to define the best acquisition parameters (ISO, shutter speed, and white balance). It reduced artefacts that could be balanced in post-production. Each individual photograph was acquired with a tripod.

The images were imported within the 3DVista program, within which the UI (User Interface) can be customized to adapt to the user experience of the virtual tour. In this sense, the necessary information was introduced, safeguarding the visibility of the image. As for the network of stations, the continuity

Fig. 6
Isolation of the 40 components to be exported separately in STL format. Processing: E. Pupi.



of the route and the inter-visibility between the capture points were promoted. The possibility of interacting on two different levels (path between all stations and interactive keymap with a selection of the most important stations) made it possible to combine optimized map visualization and more complex path content. Finally, to save the virtual tour, an initial lossless compression of the images was carried out, but a light version with undersampled images was prepared.

UX and UI for virtual tour fruition

In order to make the virtual tour as accessible and easily navigable as possible for the broader target audience, during the design phase of the digital outputs' interfaces, some design choices meeting UX research and design methodologies were made. A benchmarking analysis addressing already existing virtual tour solutions distributed by museum institutions, proposing a digital exploration of the collections exhibited, was conducted, and it made it possible to spot out the standardised digital interactions and users' expectations regarding virtual tours. Following, a simple yet effective icon set was designed for users to experience appealing and smooth interactions with the virtual tour. The implementation of a set of icons for control, visualization, and exploration allows users to have all the useful and essential tools at hand and customize the appearance of the interfaces, resulting in an easy, intuitive, and fast navigation of the virtual tour (fig. 4).

From digital to physical: methodologies for tactile scale modelling

The transition from digital to tactile modeling required several assessments consistent with digital fabrication requirements and constraints [Antonucci & Fallavolita 2023]. Through collaboration with ModLab Arch at the Department of Architecture and Design of the Politecnico di Torino, FDM (Fused Deposition Modeling) printing technology was utilized, with awareness of the dimensional limitations imposed by the production volumes of the employed printers, two Bambu Lab P1S units.

Fig. 7
Photographs of the tactile physical model of the grand staircase. Photo: E. Pupi.

The digital model was maintained in NURBS (Non-Uniform Rational Basis Spline) format to avoid the polygonal subdivision typical of mesh models. Modeling for generating print files was executed in McNeel Rhinoceros 8, with measurement units set in millimeters and working at the printing scale of the physical model, 1:50 (fig. 5).

Several interconnected criteria guided the segmentation of the model into 40 distinct components:

- Respecting the maximum print volume of the Bambu Lab P1S (256x256x256mm).
- Minimizing the visibility of joints between shells, seeking division lines integrated with the overall geometry of the staircase.
- Optimizing each component's print orientation to limit support structures and enhance the structural integrity of more fragile elements.
- Virtually prototyping the assembly process, identifying potential interferences.

A fundamental step involved integrating printing tolerances: to compensate for the typical dimensional expansion in FDM technology and ensure precise interlocking, 0.2mm gaps were created along horizontal contact surfaces. Subsequently, individual elements were converted to mesh geometry and exported separately in STL format (fig. 6). The Bambu Studio slicer was utilized to generate G-code files.

The printing phase required about seven days of printing, consuming five 1kg spools of Polymaker PolyTerra PLA Cotton White 1.75mm filament (tab. 1). Material selection prioritized the tactile quality of the final model, minimizing the perception of layering. The 40 printed and cataloged pieces were subsequently assembled using UHU adhesive.

The whole scaled tactile model measures approximately 460x400x500mm (fig. 7).

Exploring interiors through AR

Augmented Reality (AR) represents a powerful digital tool in cultural heritage contexts, enhancing visitor engagement through interactive, intuitive visualizations and accessible information delivery [Amin & Govilkar 2015; Bekele et al. 2018].

Tab 01
Table shows the values of printing time and material consumption for each of the 40 components. Processing: E. Pupi.

Shell	Printing time	Material consumption
1	7h 51m	298g
2	17h 35m	665g
3	9h 54m	378g
4	24h	950g
5	27h	978g
6	12h	376g
7	7h 18m	229g
8	3h 15m	78g
9	33m	12g
10	4h 44m	129g
11	3h 42m	90g
12	2h 45m	83g
13	1h 4m	28g
14A	31m	10g
14B	18m	5g
15A	15m	2g
15B	15m	2g
15C	15m	2g
15D	15m	2g
15E	15m	2g
15F	15m	2g
16A	1h 36m	23g
16B	1h 38m	24g
16C	1h 30m	20g
16D	1h 30m	19g
16E	1h 20m	9g
16F	1h 24g	15g
16G	48m	5g
16H	54m	5g
16I	54m	5g
16L	54m	5g
16M	54m	5g
16N	54m	5g
16O	54m	5g
16P	54m	5g
16Q	1h 20m	13g
16R	1h 20m	14g
17	5h 1m	171g
18	3h 23m	105g
19	3h 46m	112g
TOT	**163h 14m**	**4886g**

Recent advancements have facilitated AR applications on mobile devices, improving object recognition, spatial anchoring, and efficient management of complex photogrammetric data [Boboc et al. 2022].

The developed app uses AR technology to deepen visitor comprehension of the staircase of Palazzo Carignano, providing a virtual overview of the architectural space, particularly benefiting visitors unable to access it physically. Created using Unity and leveraging the Vuforia AR kit, the app is compatible with Android and iOS platforms.

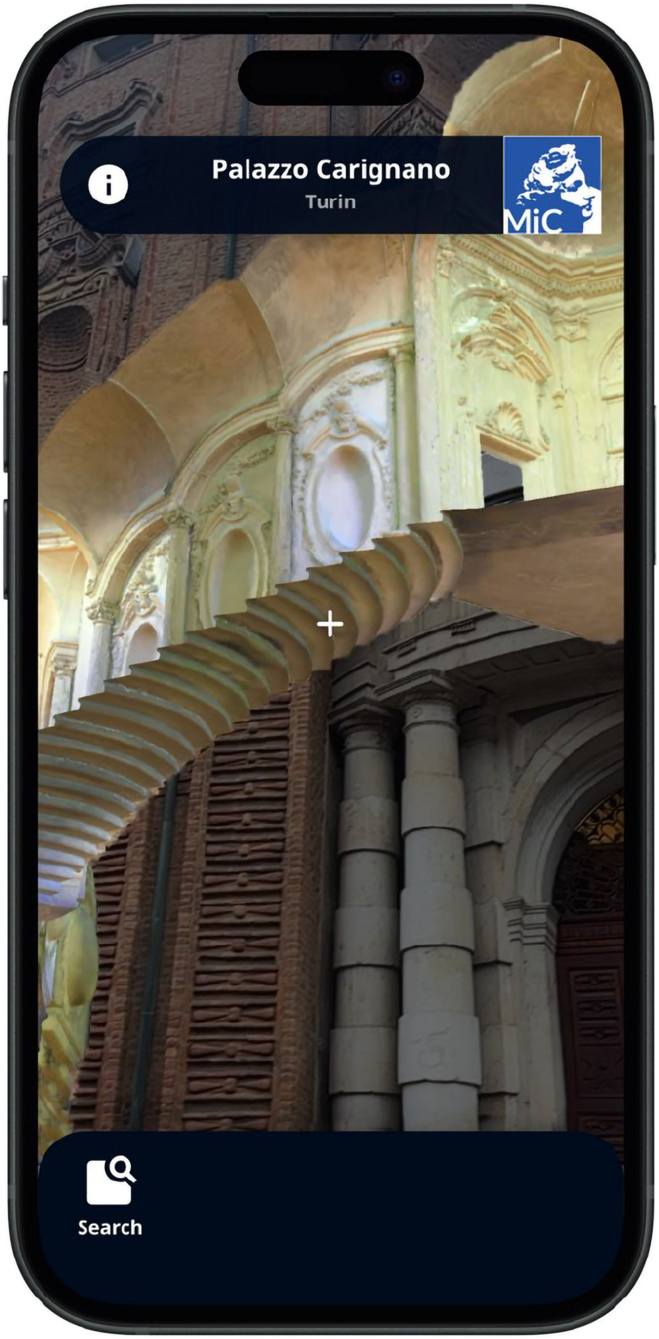
The optimized 3D mesh ensures smooth AR visualization across widely used mobile devices. Anchored directly to the building's façade, the model offers users an intuitive 'X-ray' view, illustrating the geometric structure of the staircase and its spatial relationship with the curved façade and adjacent ground-floor spaces (fig. 8).

During the development process, two image-tracking methods were evaluated: printed AR targets and *natural feature tracking* (NFT). The printed-target method employs placing a recognizable two-dimensional object (*e.g.* a sign or panel) centrally, near the building's entrance. Upon recognizing the target, the app guides users toward an optimal viewing point, indicated in AR by a circular area at a suitable distance from the target, ensuring a clear perspective of the staircase. In contrast, the NFT method relies on capturing a broad portion of the façade (a 10x10 meter central square). This approach allows immediate staircase visualization and does not require precisely positioned physical targets. However, due to the curvature of the façade, which is interpreted as a flat surface, NFT demonstrated reduced reliability and stability in tracking, though this did not significantly impact usability. Selecting the most appropriate solution for the visitor experience may require further testing, gathering user feedback across diverse mobile devices, and considering specific exhibition constraints.

Conclusions

The real-virtual *continuum*, set up in the project workflow, makes it possible to optimize the process and avoid redundancies while providing a wide range of possibilities to

Fig. 8
AR visualization of the internal staircase space at the façade of Palazzo Carignano on a mobile device. Editing: V. Palma.


Palazzo Carignano
Turin
MiC
Search

foster cognitive accessibility for the community in the broadest sense and physical accessibility for the visually and motor disabled.

Credits

This paper, whose authors shared the methodological framework, was written by R. Spallone *Research pipeline and accessibility outputs*, M. Vitali *Digital and physical iconographic choices*, F. Natta *Modelling workflows for tactile and digital accessibility tools*, M. Russo *Virtual tour creation*, M. Rinascimento *UX and UI for virtual tour fruition*, E. Pupi *From digital to physical: methodologies for tactile scale modelling*, V. Palma *Exploring interiors through AR*. The authors wrote together *Introduction* and *Conclusions*.

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