

Supplementary Table 1 Summary of the case studies and their results

From: Transforming Urban Experience Through Virtual Tours: A digital storytelling of Gdańsk and its Heritage

Virtual Tour	Stage 1 Walk+ Mobile application	Stage 2 Mobile application / Virtual Immersion	Stage 3 Virtual Immersion
Case study/ name	Poland / Gdańsk / Jane's Walk & Virtual Tour Gdańsk 2023 :“Lower Town Fortifications – Gdansk”	Poland / Gdańsk / Virtual Tour, Gdańsk 2023, entitled: “Długa Stories: Swan, Princess and Musicians & Knock, Knock - Długa street - CS axis - Kings road”	Poland / Gdańsk / Virtual Tour, Gdańsk 2024 entitled: “Enchanted by history. Discover the allure of Mariacka Street’s historic balconies and entryways”
Experience environment	Real Space + Virtual Extension Overlay of digital content on the physical environment. (AR apps on smartphones/tablets)	Augmented Space Virtual Space+ Real Space VS overlapping Real Space Augmented Reality (AR) Overlay of digital content on the physical environment. (AR apps on smartphones/tablets)	Virtual space VS in Real Space Overlay of digital content on the physical environment. (AR apps on smartphones/tablets) Fully immersive, computer-generated environments possibility
Model of experience: real / virtual SPACE	Walk with mobile application InTheCity Mostly in real space	Walk + virtual tour by 3D Vista Virtual Tour walk with augmented space	Walk + virtual tour by 3D Vista Virtual Tour walk in virtual space
Immersive tech. Digital tool used	Mixed space application InTheCity https://inthecityplatform.eu/ application “In the City” based on Augmented Reality and QrCode solutions	Augmented space walk with virtual tour by 3D Vista Virtual Tour	Virtual space virtual tour by 3D Vista Virtual Tour
Characteristic of Digital environment and tools	Phase 1: Development of Digital Tools -Mobile app and platform integrating Augmented Reality (AR) - QR code solutions; Phase 2: Educational and Skill-Building Introduction of “edutainment” features: -Tutorials and written material on technology use. -Opportunities for non-skilled users to participate by uploading content and images. -Focus on enhancing digital literacy and practical application. Phase 3: Interactive Walk and Storytelling -App provided reconstructions, visualizations, drawings, stories, and additional data at selected stops. -Interaction with surroundings via smartphones, merging physical exploration with digital storytelling. -Digital Platform accessed by mobile computing devices (smartphone , tablet, laptop)	Phase 1: Data Acquisition and Survey -Acquisition of 360° photographs and panoramic images using a laser scanner. -Creation of a comprehensive point cloud as the basis for digital modeling. Phase 2: Research and Scenario Development - Digital drawings for historical facade analysis integrated into the Virtual Tour of Long Street and Long Market. (based on archival research including literature review and iconographic analysis). Phase 3: Digital Modeling and Storytelling Design -Integration of point cloud data and digital models into 3D Vista Virtual Tour software. -Visual representation: use of graphic narratives and digital drawings, use of 360° photographs and panoramic images for immersive storytelling. -Integration of color filters, legends, and interactive points of interest for intuitive navigation. -Multimedia integration: sounds, visuals, and texts for accessibility and interactivity. - Identification of points of interest and implementation of guided paths to structure navigation	Phase 1: Digital Survey -Creation of a digital replica of the entire street using fast survey techniques (Mobile Laser Scanners (Leica BLK2GO) used to map pathways and generate a comprehensive 3D point cloud. Phase 2: Documentation of Architectural Feature - Detailed survey of distinctive elements: balconies, entryways, openings, rainwater systems, and shops. - Digital photography via mobile phones and cameras. - Application of Structure from Motion (SfM) methodology for reconstructing architectural elements. Phase 3: Virtual Tour Design - Capture of multiple 360° panoramas with Insta360 X3 camera. -Integration of point cloud data and digital models into 3D Vista Virtual Tour software. - Post-production: hotspot integration for interactive navigation. - 3D digital street model with layered information on: Historical context, Architectural components, Decorative details and unique characteristics, Spatial qualities
Outcomes	- Heritage Discovery – Rediscovery of previously overlooked areas, adding new cultural value to the city. - Youth Engagement – Strengthened young adults’ interest in heritage through interactive, tech-driven experiences. - Digital Competence Building – Participants gained practical experience in AR, QR, and mobile app use. - Community Participation – Involvement of non-skilled users in content creation fostered inclusivity and ownership. - Educational Innovation – Blending of entertainment and learning (edutainment) enriched traditional city walks. - Sustainability and Transferability – Established a model that can be replicated for other heritage sites and cities. - Workshop Foundation – Created a basis for ongoing learning, collaboration, and further digital-heritage projects.	- Digital Heritage Documentation Creation of a comprehensive point cloud and digital models through 360° camera images and laser scanning. Provided a foundation for heritage valorization, architectural monitoring, and research-based scenario building. -Thematic Storytelling Development Archival research and iconographic study enabled the design of storytelling routes. - Historical analysis of building facades was integrated into a Virtual Tour of Long Street and Long Market. - Virtual Tour Implementation Application of collected materials into 3D Vista Virtual Tour software, accessible on mobile, desktop, and VR (Oculus), interactive features included hotspots, layered information, and scenario switching (g.s.1–g.s.4). -Development of guided storytelling paths highlighting predefined points of exploration. -Multimedia and Educational Innovation -Community and Cultural Engagement Virtual walk enabled participants to listen to stories of past inhabitants and reflect on urban heritage. -QR codes provided additional access to historical data, monuments, and local stories. -Established a replicable model for combining digital heritage documentation with virtual storytelling	- Digital Heritage Documentation Creation of a comprehensive point cloud and digital models through 360° camera images and laser scanning and digital drawing documentation -Tour designed for dynamic, autonomous user engagement beyond passive observation. -Personalized digital journeys created by combining different levels of street digitization. -Access provided via QR codes, ensuring broad public availability. -Support the concept of a wider Cultural Heritage Route through Gdańsk - Fostered a deeper understanding of Gdańsk’s past and present, while encouraging reflection on the future.
Impact / in number of participants	2 walks have been conducted ca. 50 people each -Application and platform open access	-Walk conducted during the experiment phase ca. 40 people + -Individual immersive experience via smart glasses, VR headsets, enhancing experience	-Walks conducted for the experimentation ca.30 people involved -After experiment open access platform

Supplementary Table 2 Summary of the case studies challenges and opportunities (extended version)

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Virtual Tour	Stage 1: Walk+ Mobile application	Stage 2 Mobile application / Virtual Immersion	Stage 3 Virtual Immersion
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Challenges	-Transformation of Urban Engagement – The introduction of Augmented Reality (AR) and QR code solutions reshaped the way participants experienced public spaces, shifting from passive observation to interactive exploration. -New Modes of Cultural Interpretation – Historical and fortified landscapes were no longer perceived solely through static narratives but were enriched by reconstructions, visualizations, and immersive storytelling. -Integration of Education and Entertainment (Edutainment) – The walk replaced traditional didactic methods with an interactive format that combined learning with playful discovery, making cultural heritage more appealing to young audiences.	-Technological Complexity – Processing point clouds, panoramic imagery, and 3D models required advanced technical skills, raising barriers for less experienced participants. -Data Volume and Post-Production – The acquisition and conversion of large datasets into exchange formats posed challenges in terms of storage, processing time, and workflow efficiency. -Accuracy vs. Storytelling – Balancing the scientific accuracy of architectural documentation with engaging narrative storytelling risked oversimplification or loss of detail. -User Accessibility – While platforms like 3D Vista enabled multi-device access, ensuring smooth usability across mobile, laptops, and VR headsets remained challenging. -Sustainability and Maintenance – Long-term preservation of digital models and keeping virtual tours updated with new research or content required institutional and technical support. -Engagement Design – Creating intuitive navigation and ensuring that users follow guided storytelling paths without losing autonomy demanded careful interface design.	-Technical Complexity – Combining mobile laser scanning, Structure from Motion photogrammetry, and 360° imaging required advanced technical skills and careful coordination among participants. -Data Management – Large datasets from point clouds, panoramic images, and architectural documentation posed storage, processing, and integration challenges. -Accuracy vs. Storytelling – Balancing precise architectural documentation with an engaging narrative risked oversimplification or loss of critical details. -User Accessibility – Ensuring smooth navigation across devices via QR codes, interactive panoramas, and layered information required careful interface design and testing. -Time-Intensive Post-Production – Processing, structuring, and integrating data into a coherent virtual tour demanded significant post-production resources. -Sustainability and Updates – Maintaining accuracy, adding new content, or updating the virtual tour over time requires ongoing technical and institutional support.
Opportunities	-Development of Digital Competences – Young adults improved their ability to use mobile applications, digital tools, and online strategies for extracting and contextualizing information. -Strengthened University–Community Collaboration – The co-creation process with students and academic institutions fostered a sustainable link between higher education, cultural heritage, and urban life. -Scalable Educational Framework – The app and workshops can serve as a model for similar cultural and educational initiatives in other cities or heritage sites. -Enhanced Accessibility of Heritage – Digital storytelling makes complex or inaccessible aspects of the fortified landscape understandable and engaging for broader audiences, including non-experts. -Urban Value Creation – By combining physical exploration with digital layers, the initiative increases the cultural capital of the city and stimulates its attractiveness for cultural tourism and local identity building. -Platform for Continued Innovation – The digital walk provides a foundation for further workshops, technological experiments, and community-based cultural projects, ensuring long-term relevance and adaptability.	-Heritage Valorization – High-resolution 3D documentation and virtual storytelling enhanced appreciation of Gdańsk's multicultural history and architectural heritage. -Innovative Pedagogy – The active participation in archival research, 3D modeling, and narrative design, strengthening skills in digital heritage and interdisciplinary collaboration. -Immersive Public Engagement – The integration of sound, visuals, and interactivity transformed static urban exploration into a dynamic edutainment experience. -Accessibility and Inclusivity – Multimedia elements broadened access, enabling engagement by diverse audiences, including those with different abilities. -Rediscovery of Urban Spaces – Overlooked or reconstructed areas of the Royal Route gained renewed cultural and educational relevance through digital augmentation. -Scalability of Methodology – The workflow—from data acquisition to narrative-driven virtual tours—offers a transferable model for other heritage sites. -Future Research Platform – The case study establishes a foundation for further studies in digital storytelling, architectural monitoring, and the integration of VR/AR in cultural tourism.	-Heritage Valorization – High-resolution 3D documentation and virtual storytelling enhanced appreciation of Gdańsk's multicultural history and architectural heritage. -Innovative Pedagogy – Students actively participated in archival research, 3D modeling, and narrative design, strengthening skills in digital heritage and interdisciplinary collaboration. -Immersive Public Engagement – The integration of sound, visuals, and interactivity transformed static urban exploration into a dynamic edutainment experience. -Accessibility and Inclusivity – Multimedia elements broadened access, enabling engagement by diverse audiences, including those with different abilities. -Rediscovery of Urban Spaces – Overlooked or reconstructed areas of the Royal Route gained renewed cultural and educational relevance through digital augmentation. -Scalability of Methodology – The workflow—from data acquisition to narrative-driven virtual tours—offers a transferable model for other heritage sites.