Scan-To-Ar: from Reality-Capture to Participatory Design Supported by AR

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Abstract

This contribution presents state-of-the-art methods in 3D scanning and augmented reality for public-inclusive architectural programmes through rapid survey, accessible design tooling, and immersive visualisation outcomes. It follows an application case in Cantieri Culturali della Zisa, Palermo, part of a co-design workshop called *Everyday Experiences and Heritage in South European Cities: Digital Tools and Practises*, which invited architects, urban theorists, and local stakeholders to explore public-oriented reclamations of industrial-cultural-heritage sites. This contribution illustrates the benefits of pedestrian-operated 3D structure-from-motion survey for historic urban scenarios and details WikAR; a cloud-based augmented reality app modified for accessible proposal creation and visualisation.

Keywords
ICT, augmented reality, co-design, built heritage, 360 photogrammetry.

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Introduction

Challenged by urbanisation, economy, gentrification, migration, and climate change, the experience of historical spaces and buildings is fragmented, mirroring the disconnected perception of urban societies. Addressing the dilemma of mobilising the right resources for the reactivation of these spaces, the Working Group of the European Research Infrastructure Consortium on Digital Humanities and the Arts (DARIAH) about the use of digital practices for the study of urban heritage (UDigiSH) organised a workshop that focused on new ways of transforming neglected urban spaces and neighbourhoods in historic European cities in the Mediterranean basin. The paper presents a technical workflow developed as part of the novel methodology employed by the workshop [Artopoulos, Martinez 2021]. The event was held at the Cantieri Culturali, Palermo, a site located between a mixed-income residential neighbourhood and the Zisa Palace, a UNESCO-recognized Arab-Norman castle with considerable cultural as well as tourist interest. This campus is a reclaimed early 20th C. furniture factory [Fabrica, Ducrot 1890-1968]; once abandoned, this critical site of Sicilian industrial heritage now hosts a lively campus of university buildings, training schools, art studios, workshops and became home to many cultural institutions (Fig. 1a).

A Co-Design Methodology for Heritage Regeneration

Contributing to the existing literature, the workshop at Cantieri Culturali explored how abundant but disused urban heritage sites can become part of a reflective planning process, resulting in more legible, inclusive, resilient, and enjoyable cities [Rozman 2015]. The workshop offered to city authorities data-driven consultation actions by engaging cultural heritage institutions, scholars and researchers in digital humanities, city stakeholders, professional associations, urban communities, and citizen groups. The principal objective of the event was to enable cultural bearers and local stakeholders to engage with possible future conditions of the site by building on the existing assets and resources available on campus. In detail, the workshop offered to local stakeholders, who were previously mapped by the authors, creative opportunities for visioning [Garel et al. 2021, p. 54] through their engagement with the design process of architectural reuse and functional conversion of the campus. This participatory process drawing from existing literature [Castelnovo et al. 2016; Cruickshank , Deakin 2014] introduced local stakeholders and other users of the campus (e.g., students, passers-by) to a design brief that enquired about the future use and appropriation of the empty uncovered remains of a brick warehouse near the northern campus edge (Fig. 1b). Since the derelict warehouse sits between three campus plazas, the workshop invited design schemes with deeper contextual analysis by incorporating the diverse voices of public stakeholders and accounting for the existing activities around the site. Besides the discussion about its history, the process first introduced the participants to the architectural conditions of the site, such as the boundaries of the space, the spatial and visual continuity with its surrounding sites and open-air spaces, as well as the materiality of the existing remains of the structure of the heritage building on site. Design criteria considered in the conversations that were staged with the stakeholders and current users of the campus included possible functions and uses that are missing from the campus, the kind of form and position of specific interventions they envisioned implemented on-site, how any new structure on-site could be connected with the neighbouring spaces and functions, ways to offer better accessibility to the new proposed space, for all groups and individuals, the role of green spaces, the attractiveness and value of designing a space that would be naturally ventilated for occupant comfort and offering controlled micro-climate, and finally, ways for the space to enable social interaction and provide a sense of community, in the above order.

Using Interactive Visualisation for User Engagement in Co-Design

The overall co-design process relied on the iterative visualisation of alternative design scenarios and architectural function definitions of the site under study, in order for the participants

Fig. 1. a) Cre.Zi. Plus common spaces (site of the workshop). Source: Cre.Zi. Plus Official Fb profile. b) The *Spazio Incolto*, the remains of a brick warehouse.

to engage in a dialogue about their vision for the future of the place and, by doing so, to provide feedback to the authors about possible design interventions. The most popular design interventions were meant to be delivered to the local authorities, as favourable suggestions from the local communities and social groups who appropriate the campus. Central to this dialectic process that facilitated the expression of the needs and visions of the stakeholders mapped, played the use of digital tools that enabled the authors to visualise in an interactive way the spatial characteristics and visual experience of each design scenario implemented virtually on site. This was achieved using two distinct visualisation methods employed in practice, namely, table-top and full scale Augmented Reality interface, respectively.
In 2015, Google and Apple introduced native AR functionality to their mobile phones and tablets, allowing apps to access tracked device motion, camera overlays, and estimated scene geometry. Wikar, a Unity-based mobile app developed between The Cyprus Institute and the University of Illinois, extends these native mobile AR functionalities to visualise dynamically hosted [Marini et al. 2018] geometry in physical space. It is also programmed to support rapid interface prototyping for academic research and cultural events. This section will summarise the creation of Wikar's new proposal-design subsystem and reflect upon augmented reality visualisation outcomes with stakeholders.
In preparation for the workshop, we extended Wikar to create and share lightweight urban design proposals. The inspiration came from creative games like The Sims, which give players grid-based architectural elements to compose scenes. While Wikar already loads industry-standard 3D models at runtime, this simplified tile system was necessary to meet the outdoor workshop's performance requirements: mixed-range mobile devices and no wifi on site. Wikar's tile-based proposals are small JSON files describing tile placements, which reference 3D tile modules pre-bundled in the app. Proposal files are Kilobytes in size,

trivial for syncing between device and cloud server over 2G speeds. We used an open-source JSONObject library to containerize and exchange data between Unity and Clowder, our flexible cloud storage backend [Marini et al. 2018]. Figure 2a shows Wikar's default tile family, including walls, vegetation, and urban furniture. After initial stakeholder meetings, we created additional tile families to ensure we could represent ideal programmatic outcomes – including playgrounds, restaurant seating, urban gardens, and enclosure systems. While 3D model repositories like Sketchfab offer free-to-use materials, we found its offerings too dense, detailed, and distracting for our use case. Instead, we carefully modelled tiles to communicate design intentions without over determining aesthetics.
Figure 2b shows Wikar's tile system employed for two pilot proposals built from stakeholder input; the two extreme outcomes encourage meaningful reflections from participants during the visualisation phase. The top proposal, representing a connected urban common space, shows a shaded park with flexible interior programming and play spaces for children, complementing the site's adjacent public plazas. The bottom is a fully enclosed theatre/office space similar to previous rehabilitation projects. Its flank includes an urban garden for a nearby cafe. Methodological design research by Rosa and Reucker (2020) suggests that greater contrast between prototypes serves a didactic function, opening a wider field of interpretation for reviewers. Local workshop participants, who have been underserved concerning green spaces in the city, were overwhelmingly positive about a shaded park for daytime use, especially when compared with the more conservative alternative.
To show proposals to stakeholders, we used Wikar's QR-code-based placement system. As illustrated in Figure 2c, printed QR codes point to proposal URLs and contain arguments about their position, rotation, and scale relative to the code. During a QR code scan using a Z-Xing library, the device camera and AR tracking subsystems collaborate to anchor a virtual scene origin in tracked space, after which the viewer can explore the loaded content freely. For 1:1 scale onsite visualisations, we placed QR codes in strategic positions around the site, using a Grasshopper script to calculate their offset parameters with a Rhinoceros 3D site model as reference. This digital-twin site model synthesised GIS data, available site plans, and 3D scans from the 360 SFM acquisition. Because minor geometric errors become glaring in a 1:1 overlay, the accurate 360 SFM geometry was critical for validating and unifying all the other materials.
For off-site visualisations, we created QR codes for 1:30 scale 'model-village' walkthroughs. Additionally, a printed campus plan became a 1:500 'table-top' visualisation. Unlike the 1:1 scale walkthrough, miniature visualisations included the 360 SFM model for site context. Each of the three visualisation scales prompted different responses from stakeholders. We found that while miniature model visualisation fostered discussions on overall intentions and cost-benefit analyses, representation at a 1:1 scale invited granular input from participants, who readily offered critiques, additions, and insights for refinement. This observation maps to the traditional modalities of architectural media: diagrams, renderings, and scale models are tools to shape reviewer discourse and reflections toward particular aspects of building proposals. Codesign facilitators should likewise consider the scale of interactive AR visualisation for its effect on viewers in a critical mode.

Crowdsourcing and Data Mapping

One of the most pressing challenges in the current use and application of digital methods in heritage preservation and safeguarding is the availability of reliable data assets. There are numerous efforts to develop the appropriate workflows, standards and guidelines regarding data curation and interoperability, responding to the H2020 FAIR principles presented by the relevant literature [Angelaki et al. 2021]. However, many research practices in heritage face a significant drawback: data generation and sharing. EUROPEANA 3D and subsequently the TIME MACHINE network are occupied with the collection of 3D digital heritage assets made available to the public through open access platforms and standards.
Responding to this need and taking into consideration the particularities and operational cri-

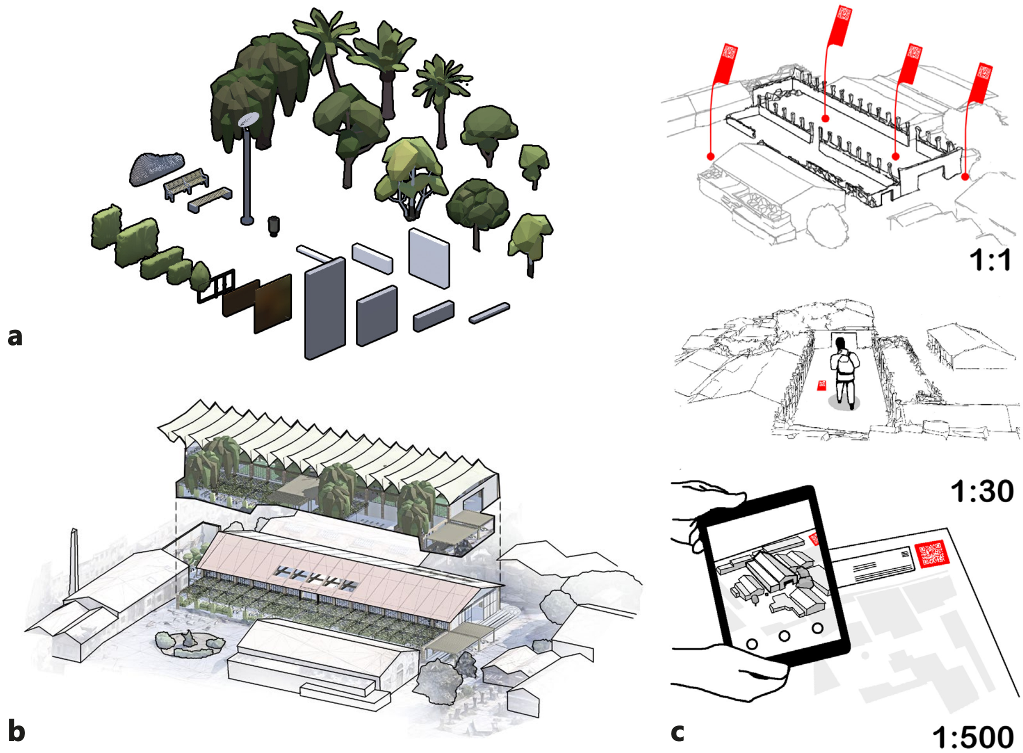

Fig. 2. a) Wikar's default tyle family; b) Two pilot proposals built from stakeholder input; c) QRCode applications.

teria of using 3D digital assets in architectural heritage conservation, as well as for regeneration and reuse, the authors applied in the case of the presented workshop in Palermo a novel spatial asset generation technique that facilitated the rapid acquisition of 3D datasets from the site under study. There are several crowdsourcing platforms for collaborative planning, design and governance tools, as well as for monitoring and evaluation, such as Decide from Madrid (https://decide.madrid. es/), Izboljsajmo Maribor (https://izboljsajmo.maribor.si/), or Wien.at (https:// smartcity.wien.gv.at/site/en/wien-at-live-app-2/) for Vienna. However, most of said tools offer 2D interaction opportunities through maps and metadata generation for crowdsourcing linked information in a semantically structured way [Mirri et al. 2014; Prandi et al. 2014]. Providing to the public and local communities the capacity to interact with geolocated metadata and spatial information through a 3-dimensional interface poses huge challenges in terms of visualisation, as well as in 3D data collection, management and access. As built space can be the result of historical narratives, human actions and events on site, a palimpsest of historical narratives [Merrill, Giamarelos 2019], which is assigned different cultural identities by different groups and communities, its documentation and representation can contribute highly to any public / stakeholder engagement process. Hence the necessity of the presented method for documenting rich representations of historical places under study, including survey of geometric aspects and material conditions.
However, 3D documentation processes can be highly technical and resourceful, and this is where the paper focuses on, in developing an easily accessible workflow of 3D documentation by the public which would accelerate the capturing and sharing of 3D data of built environments. This breakthrough application will multiply and accelerate the 3D documentation of historic sites, built heritage and whole city-scapes by hobbyists who are willing to participate and contribute to extensive, large-scale crowdsourcing operations, coordinated by research groups aligned with the scope of European infrastructure networks, such as the TIME MACHINE, E-RHIS and DARIAH-ERIC. Significantly, the authors aim to develop further and optimise this technique and the performance of its resulting data in order to eventually create a fully documented and replicable workflow of 3D spatial data acquisition for non-expert operators utilising a 360 structure-from-motion, image-based documentation process.

360 SFM Scanning for Rapid Acquisition

The short duration of the workshop required a rapid method of capturing site geometry for use in architectural design proposals and future developments. This section summarises the topic of expeditious digital surveying, describes the state of the art and motivates the choice of using 360 SFM for acquiring the site context.
In recent years, we have witnessed a surge of technologies and sensors for expeditious 3D acquisition [Gonizzi, Remondino, Visintini 2013]. The fastest way to accurately survey urban geometry has typically been vehicle-mounted mobile mapping systems (MMS). This approach enables expeditious mapping campaigns in complex environments. However, their application is limited to automotive-accessible routes, which excludes the narrow streets, pedestrian islands, and irregular forms typical of high-density historic urban centres [Barrera-Vera, Benavioles-Lopez, 2018]. In these cases, it is preferable to adopt pedestrian-scale tools such as spherical photogrammetry (also known as 360 SFM) or Indoor MMS tools, which benefit from their small size and lightweight.
Regarding spherical photogrammetry, Abate et al. (2017) and Barazzetti et al. (2018) have found that accurate metric reconstructions are achievable using low-cost camera sensors. In addition, Teppati Losè et al. (2021) verified compatibility between iMMS and spherical photogrammetry for the survey of the Montanaro bell tower. Although the 360 SFM methodology has thus far centred on interior survey, there are unrealised potentials in outdoor urban capture scenarios. We may visit a few reasons for this: the hardware is less expensive, non-specialists can conduct the acquisition phase, and the results obtained are comparable with iMMS capture, which is acceptable for urban scale representation in design contexts [La Russa et al. 2021].
The methodology's foundation is the acquisition of 360° panoramas, which, through photogrammetric processing, may reconstitute the site as a point cloud. In practice, this starts by setting a 360-degree camera rig to a recurrent capture interval of 2 seconds and subsequently walking through capture routes at a steady pace. The urban scale of the acquisition must take into account time of day and weather conditions to limit the presence of shadows on surveyed surfaces. For 360 SFM acquisitions, we used a GoPro Fusion 360 immersive camera. It has a CMOS 1 /2.3'' sensor and two 9 Megapixel lenses with a 180° angle of view, permitting the acquisition of spherical photos and immersive videos. Its small size (74 x 75 x 40 mm) and lightweight (220 g) present no obstacles to mobility—afterwards, the images.
To define the acquisition path, we considered the 3D model requirements for the AR application. The survey aims to provide viewable assets in the AR experience and provide a usable digital replica to develop the design proposals in AR. Therefore, we defined a path along the building facades around the central open space and the *spazio incolto*. Figure 3c shows the spherical panoramas' acquisition points (in blue). After the acquisition, we processed the data using Metashape software, which supports spherical captures. The results were acceptable for the requirements of the survey (representation scale 1:200). The choice to walk along the facades and not along the axes of the paths improved the resolution of homologous points as it produced adequate photo overlap at multiple distances. The obtained point cloud was scaled to known measurements from other documents and triangulated into a mesh for placement in the model (Fig. 3).

Discussion and Conclusion

The site's 360 SFM acquisition process supports rapid co-design processes. Approximately 5.055 sq. m. were acquired in less than 15 minutes. The tools used are low cost and provide a procedure that can be carried out even by non-experts. Further, it is worth considering how this digital approach can help organise longer-term codesign efforts that are untenable with current methods. Because Wikar QR codes lead directly to app download links, it can onboard users with no supervision, offering new opportunities for long term workshops as stakeholders can visit sites at their convenience and use personal devices. In anticipation of

Fig. 3. a) GoPro Fusion 360 and the acquisition on site; b) perspective view of the sparse cloud; c) top view of the dense cloud; d) focuses of the dense cloud.

such co-design initiatives, an area for future development is a commentary collection system allowing app users to mark up proposals in AR. This commentary, collected at scale, could be instrumental for planning teams and authorities seeking data-driven urban infrastructure design programmes.

In conclusion, the work carried out at the Cantieri Culturali della Zisa campus implemented an expeditious methodology integrating digital surveys and augmented reality to help interested communities explore future urban conditions and realise agency within the planning process.

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