A flexible QR-code infrastructure for heritage

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Abstract
QR codes are often used in outdoor cultural heritage settings. They are an established technology but inflexible, especially if the websites to which they point change their structure, or even disappear. This paper describes a web infrastructure for deploying QR codes that can be remapped dynamically, both as web resources move or change, but also to allow personalized and adaptable content. This is a small change in the underlying technology, but radically change potential applications. It can be used to personalise content to viewer's preferences such as language choices, but could be used to support bespoke events or applications such as school visits or treasure hunts. The infrastructure has been deployed at the Memorial Gardens in the lost village of Troedrhiwfuwch, to enable the stories of fallen WWI and II service men to be retold for the current generation.

Keywords
QR code, visual code, community heritage, historical archives, user interface architecture, data-driven interaction, accessibility

1. Introduction

QR codes are ubiquitous on products, posters and signage. Normally they link to a fixed URL that takes you to a web page offering more information. In cultural heritage settings this may be a plain website, or may be a web link offering access to more advanced material such as AR (alterative reality) content. The websites themselves may offer functionality such as user logins or language preferences, but are more often plain information.

This paper describes a flexible back-end infrastructure for QR codes, which can be reconfigured for changing content and can offer different kinds of content depending on the visitor's preferences or other dynamic criteria. This is a very small change from existing technology, but makes a radical difference to potential new applications. It has currently been deployed in the Memorial Gardens of Troedrhifuwch, a village in the South Wales valleys, that was nearly entirely demolished in the 1980s. However, we plan to deploy it more widely and would welcome offering it to other cultural heritage projects.

In the rest of this project, we start with an introduction to the background context of Troedrhiwfuwch. This is followed by a brief review and design-space analysis of a variety of visual codes. We then describe the actual installation and how this is implemented as a back-end web architecture.

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2. Background

2.1. Troedrhiwfuwch

Troedrhiwfuwch is small village in the South Wales valleys, that originally grew in the mid 19th century to serve the local coal mine at a time when Wales was a major hub for global coal and iron production. A geological survey of the valleys had been launched in the aftermath of the Aberfan disaster where more than 200 children died after a coal-tip (the waste heaps from coal mining) slid down and buried the school. Some years later, it was decided that the underlying geology of the mountain above Troedrhiwfuwch was unstable (there had been major falls on the opposite side of the valley) and the village was condemned. By 1985 only two houses remained where residents refused to move (Fig. 1). The villagers were relocated in neighbouring towns and villages, often with insufficient compensation for their lost homes.

However, the community has remained connected using a Facebook page and it has gathered a digital archive of photographs, documents and other materials numbering over two thousand items. Crucially, this is not restricted to those who know the village personally; one of the key archivists is a young woman who wasn't born until after the village was evacuated.

One of the few remaining landmarks is the War Memorial, which commemorates the exceptional sacrifice of young lives during the First Word War especially, when over one hundred young men went to war, more than one per household, and of these over twenty never returned. For many, the War Memorial is the only physical reminder as their bodies were never recovered. This has become one of the major foci of local interest, with community members developing extensive expertise digging into war records, census returns, and other sources.

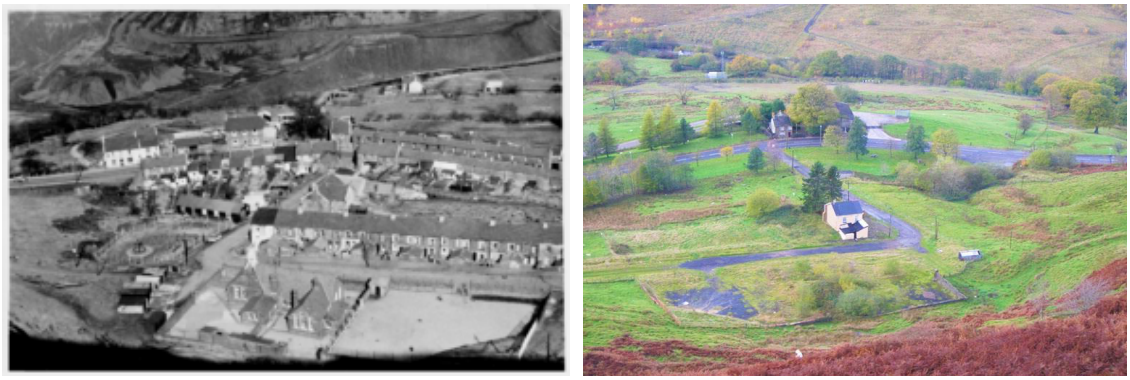

Figure 1: Trowdrhiwfuwch before and after evacuation and demolition

2.2. Closely related projects

Various forms of location-based information and augmented reality are common in research projects [10][13][15]. Some persist after the immediate project has ended, but many end with the disestablishment of the project team when funding ends.

Our goal is partly to serve the specific needs of the Troedrhiwfuwch community now, but also to create an infrastructure that serves them into the future and is replicable to new sites

and new communities. It is worth therefore considering a couple of large-scale projects that flow beyond the confines of a specific site.

HistoryPoints (https://historypoints.org/) is a crowdsourced place-based historical resource operating across Wales since 2012. Local societies can create small pages hosted at the HistoryPoints site. They can then print a small information plaque that can be laminated and installed in-situ. Many thousands are placed around Wales. Contributors can update pages and there is also provision for translations and tours.

MonmouthpediA[11] was launched at a similar time to HistoryPoints as a joint project between WikiMedia and Monmouth local government. It was billed as "the world's first Wikipedia town" and is geographically limited to the town of Monmouth, but at a level of density that is highly unusual. Across Monmouth small plaques were placed that included QR codes many of which link to a special part of Wikipedia covering public buildings and other aspects of the town history. More major sites have ceramic plaques, whilst shops have laminated plaques, not unlike the HistoryPoints plaques, inside their windows. This was coupled with the installation of a free public WiFi network covering most of the central town area.

Where shops had their own website, the QR codes linked to them, but it was not uncommon to find 'generic' web pages, for example, a fish and chop shop where the QR code links to the Wikipedia page for 'fish'. This emphasises both the strength and weakness of QR codes. Linking to fixed web pages is well understood, but limited, both making it hard to update and also to personalise. For example, if someone is a Welsh speaker they may prefer the codes to link to Welsh version of the articles, where available, or school parties might prefer content targeted towards children. This desire to have a more open and personalisable experience is a major requirement for the QR code installation in Troedrhiwfuwch.

3. Connecting physical and digital resources

QR codes arose as a design option early in the project, partly because of their familiarity to the community, and relatively straightforward installation, especially considering the location where there is limited access to power. The fundamental need is to make it easy for people in the location to both (a) know that additional information is available (*discovery*); and (b) connect to that material without access to special devices (*access*). There are various alternative technologies that can connect physical locations and to digital resources, some of which are summarised below and in Table 1. For a more extensive analysis see [5].

3.1. Visual codes

QR codes are a highly visible technology and one that is now instantly recognised as offering an opportunity to action, or affordance [7][12]. An obvious alternative is simply printing URLs to web information. There are other less familiar forms of visual codes (also known as fiducial markers), that have different advantages.

One of the earliest was the use of small square printed tags in the open-source Alternative Reality Toolkit (ARToolKit) originally released in the late 1990s [9] and still used heavily today (hundreds of downloads a month). Special software is needed to read the codes, which are designed to be easy to identify even by a low-resolution video camera and when at an angle.

They are used both to identify objects and also form a visual reference to overlay material, such as moving 3D images. However, improved video in phones means that many AR systems now use ordinary QR codes for the same purpose.

A more recent alternative are Artcodes. These allow coded information to be embedded into pictures and graphic designs in ways that are not immediately apparent to the viewer. This is particularly useful to preserve the aesthetic qualities of objects and has been embedded into wallpaper and a decorated guitar [1][14]. However, like the early ARToolKit tags, they require a special application to read them and can only store a very limited amount of data, sufficient, for example, to distinguish objects in a room, but not sufficient to easily encode a globally unique identifier such as an URL.

Artcodes are not immediately obtrusive, but can be spotted by a trained eye. Special materials have also been used to print objects with 3D infrared codes embedded within them. These are recognised using IR sensitive cameras (many are naturally) and can be used for alternative/mixed reality applications [6].

3.2. Invisible technology

Other technologies are fundamentally invisible. The most familiar are NFC (near-field communication, earlier versions known as RFID) as found in many products in shops to prevent theft and used in payment cards or phones to allow rapid contactless payment. Due the volume of production these are very cheap and allow URLs to be programmed into them, so that they behave rather like QR codes, only with even less interaction, merely tapping your phone on the tag. The tags themselves are unpowered taking their power from the reader in the phone, so can be deployed in remote situations far from power sources.

The NFT reader must be nearly in contact with the tag, so suitable for very precise connections, as essential for payments, but less so for heritage applications. Bluetooth beacons are also relatively cheap and operate over a larger range. These are small battery-powered devices that can be connected to by Bluetooth and then offer various services or connectivity. However, Bluetooth pairing can be complex and these devices really come into their own when exploring using a specialised app that can simply use the presence of the Bluetooth beacon as an indicator of location, especially in indoor environments.

When outdoors, GPS location is usually both accurate and ubiquitous on phones. However, connecting location to content requires a special application. For example, the Frasan App on Tiree, that one of the authors helped create, allowed visitors to see information about location-relevant items in, An Iodhlann, the island archive [3]. While this was easy to distribute as a mobile-friendly off-line web page, the tourists still had to connect to it before use.

Many of these technologies rely on connection to the web. Happily, mobile signal is not a problem in Troedrhiwfiwch and mobile coverage is continually improving, however there are still problems in many rural areas, especially in woodland, which blocks wireless signals, or in deep valleys. One solution is to create small stand-alone webservers with their own local WiFi connection, disconnected from the internet. Qraqrbox used small solar panels backed up by batteries to power a Raspberry PI that delivered localised web content for remote natural history and heritage sites [2]. The hardware to provide this kind of service is now getting more affordable and easier to configure.

Table 1
Properties of different technologies to link physical and digital worlds

tech	discovery	access	familiarity	special app?	data volume
printed URL	Y	need to type it in	Y	N	URL link
QR Codes	Y	easy	Y	N	URL link
ARToolKit		OK with app	N	Y	low †
Artcodes		OK with app	N	Y	low †
NFC	need logo	single tap	Y	may need config'n	URL link
Bluetooth beacon	N	OK with app	N	Y	mostly just id, but can be more
GPS	N	OK with app	Y	Y	lat–long linked to more info ‡
local WiFi	need signage	need to follow simple signage instructions	web access familiar, local server may be confusing	N	large

† The special app can deliver arbitrary amounts of information, but needs to be site specific.
‡ As GPS is universal coordinate system, an application can deliver information on a wide or even global geographic area.

3.3. Understanding the design space

We have described the technologies starting with more visually apparent ones and moving towards those that are invisible. Visible codes can be obtrusive, especially when fitted to small objects. Artcodes were developed in large part to deal with these aesthetic problems. However, visibility is also important for two main reasons (see also Table 1):

- *discovery* – knowing that there is pertinent digital information available
- *access* – obtaining the relevant material

The QR codes are particularly useful for the former as people see them and recognise that this means further information is available. With Artcodes you need to know that Artcodes are available and point the phone camera in the general direction of the codes. the application can then spot the codes amongst the larger illustration. Some other form of notice needs to be provided to inform visitors that the information is available and giving instructions to obtain the app (maybe a QR code).

The tags differ in their *familiarity* to the general public while QR code and printed web addresses will be widely recognised. The more esoteric visual codes will not be immediately recognised. In the case of Artcodes, they may not even be noticed as, by design, they merge into the underlying images. Similarly wireless-based solutions (including GPS, Bluetooth, NFC and local WiFi) are invisible unless there is some sort of logo or signage.

NFT tags are strong on access, but weak on discoverability. NFT stickers can be attached to the backs of notices or embedded in devices to reduce their intrusiveness and reduce chance of damage, but almost always some visual indication if their presence needs to be given in order that users can know that they are there.

Another issue is that some technologies, such as ARToolKit and Artcodes, require dedicated applications (denoted '*special app*' in the table). Japan were early adopters of QR codes and for many years phones there have recognised QR codes 'out of the box'. Take-up in the UK was initially slower, for many years phones required an additional QR code reader app. Now-a-days most phone cameras have built-in QR support, and those likely to use them have a suitable app installed. NFC readers are also common in phones, but less familiar outside of their use in payments; so while the fundamental capability is pre-installed, it is not always enabled in personal settings, so they can be less easy to use than first appears.

We also noted that some technologies have more limited *data volume* than others. This may mean that an object can be identified within a particular setting (almost always requiring a bespoke reader), but not globally unique. Note however, while the intrinsic information may be small (a URL or identifier), it is usually possible to link most of these technologies to further information resources either through the web or dedicated applications.

3.4. Ecologies of technologies

Finally, note that while we presented these as distinct technologies, in reality they can work together. Notably, while we are deploying QR codes, we are expecting that the web resources they link to will be entry points for GPS-based applications that take the visitor outside the memorial gardens in which they are (initially) encouraging exploration of the wider village site. In addition, we also envisage using them to connect to 3D reconstructions of the Church that once stood in the gardens, based on 3D scanning of the artefacts that were moved to Pontlottyn church when Troedrhiwfuwch church was demolished.

That is, it is better to regard an installation as an ecology of interlinked technologies, each fitting into niches where their strength is exploited.

Figure 2: Early working prototype for open day

4. From technology to deployment

4.1. Design process

Co-design meetings between community members and university staff started during Covid. Following initial discussions, where the community presented their archive materials, a series of mock-ups were made using PowerPoint slides. These demonstrated various technologies including phone-based augmented reality where old photographs could be aligned with the modern landscape and also QR-code-based explorations of the soldiers who died during the First World War. These envisionments were not intended as early designs, but as technology probes [8] helping the local community to see the potential of technology and therefore think of alternative uses suited to their unique situation.

Based on the outcomes of these stages three aspects moved to a second level of development. TalkOver is an application designed to help people talk about digital photographs recording both what they say and also what they point at in the photo [4]. Also, a group of PhD students have 3D scanned many of the items in Pontlottyn church and created a VR gallery. The third, was the QR-code based signage, which is the focus of this paper.

The community were planning to place a plant in the memorial gardens for each fallen soldier. They wished to link these to more extensive archive material. So small printable plaques were created that the community members were able to print, cover in plastic and use in open days to demonstrate their plans (Fig. 2). These initial plaques were simply linking to fixed web pages as is common with QR-codes. The first two of these are longer-term projects, requiring more technical development, but the last was closest to being able to be deployed and so has been pursued first.

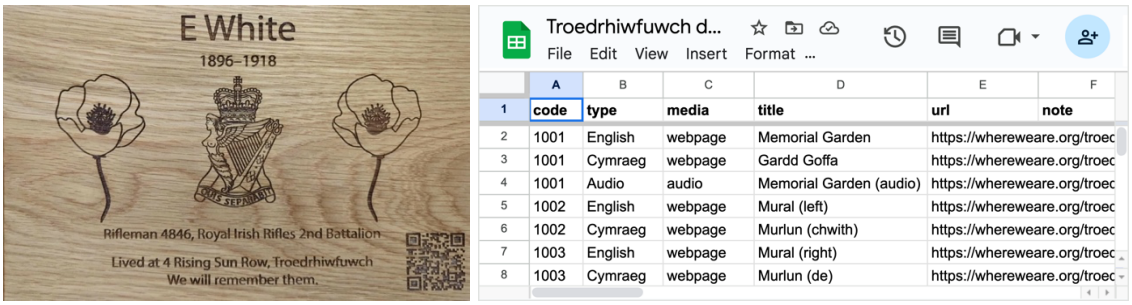

Figure 3: Final installation in Troedrhiwfuwch Memorial Garden: (left) Laser-cut plaque; (right) Configuration spreadsheet in Google Docs;

4.2. QR codes with a twist

As noted, we wanted to be able to easily reconfigure the Memorial Garden both to future proof the installation and also to create a research infrastructure for more innovative projects.

The final embodiment has been installed with a planned life of at least 10 years. Physical signage was created by FabLab Cardiff out of green oak as this is long-lasting and low maintenance. Some logos are laser-cut directly into the wood but the main information, including QR-codes, is printed onto wooden panels that can be replaced cheaply in case of physical degradation or graffiti (Fig. 3, left). Digitally, the QR-code aspect is designed to be

easily reconfigurable, both as a practical measure to ensure longevity and as a means to use the same physical installation as an experimental platform, for example, to show case the VR work.

The QR codes themselves are a fixed technology, and can only provide small snippets of text or link to a URL. However, we were able to transcend the fixed nature of QR codes by linking to an intermediate URL, akin to TinyURL or bit.ly (see Fig. 4). This is partly to protect against changes in the websites linked from the QR codes.

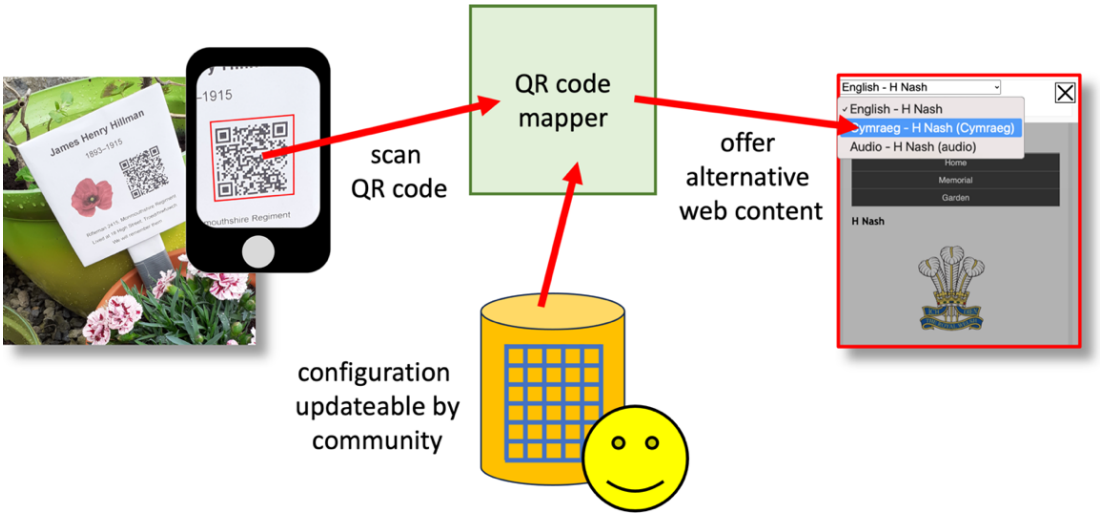

Figure 3: Architecture of QR flexible infrastructure

Crucially this makes it possible to have different forms of content available from the same link. Currently we have dual language English and Welsh content and also audio for accessibility (see Fig. 3, right). When a visitor first accesses a QR code at the site they are redirected to the default web page, but with a small pop up allowing them to choose alterative formats. This is then recorded locally on their device and thereafter this will be their default medium. It would of course be possible for the target website to provide such a service, but this would require a complex web installation, by moving this into the central infrastructure the community can use simple site builders.

Digging deeper, the QR codes are of the form:

`https://whereweare.org/QR/t/`{app-id}/{code-id}

The server-side meta-information for each application (such as the Troedrhiwfuwch installation) includes a link to a Google Docs configuration spreadsheet (Fig. 3, right). This spreadsheet associates arbitrary identifiers with content URLs, which can be updated by community members if the target URL changes. The configuration spreadsheet is automatically checked for updates by the application backend so that changes are rapidly reflected in the field. In addition, each identifier may have more than one URL associated to it, with an extensible set of application-defined types. Currently, in the Troedrhiwfuwch install, these are ‘English’, ‘Cymraeg’ (Welsh) and ‘Audio’. The infrastructure returns a wrapper page to manages content selection, with the content in an iframe.

This is in many ways a minimal change in the QR-code technology, but turns the normal fixed link of the QR code into a dynamic and open infrastructure enabling a wide variety of new applications. That is innovation in terms of the overall human–technology system.

5. Future Work

The initial installation was quite late in the year, in time for the annual Remembrance Sunday gathering at the War Memorial, but not at a time of the year conducive to spending time in the garden. By this summer the shrubs will be planted for each soldier, and we hope to be able to obtain informal and formal evaluation of the effectiveness of the installation. We are planning versions with child friendly text, as well as more bespoke content, such as allowing teachers to modify the material presented to their class to fit with their educational goals for a school visit, or temporary material such as a treasure hunt. In addition, we aim to integrate the 3D scanned objects from Pontlottyn church into a full-size AR experience of the church where it originally stood. We are also very open to collaborating on installations at other sites. From a research perspective, the in-situ installation is effectively an innovation platform for exploring different forms of interactive location-linked experiences, while also providing a robust day-to-day service supporting community heritage.

Acknowledgements

This work was made possible by funding and support from AWEN Institute (Part-funded by the European Regional Development Fund (ERDF) through the Welsh Government), Cherish-DE (EPSRC, Grant ref. EP/M022722/1), CHART (Swansea University's Centre for Heritage Research and Training) and Cardiff FabLab. Thanks also to the members of Troedrhiwfuwch Memories and History for use of archival materials and their participation in co-design sessions.

References

[1] S. Benford, G. Giannachi, G. How a guitar started to self-document its 'identity': The future of art documentation. In *Documentation as Art* (pp. 185-196). Routledge, 2023.

[2] A. Dearle. (2020). Qraqrbox. (Dated 24/6/2020, accessed 1/5/2023) https://al.host.cs.st-andrews.ac.uk/project/qraqrbox/

[3] A. Dix, (2013). Mental Geography, Wonky Maps and a Long Way Ahead. *GeoHCI, Workshop on Geography and HCI,* CHI 2013. http://alandix.com/academic/papers/GeoHCI2013/

[4] A. Dix, E. Jones, R. Cowgill, C. Armstrong, R. Ridgewell, M. Twidale, J. S. Downie, M. Reagan, C. Bashford, D. Bainbridge, C-A Neads, V Davies (2024). Enriching Cultural Heritage Communities: New Tools and Technologies. *Interacting with Computers*, (in press).

[5] A. Dix, S. Gill, D. Ramduny-Ellis, J. Hare (2022). *TouchIT: Understanding Design in a Physical-Digital World.* Oxford University Press.

[6] M. D. Dogan,, A. Taka, M. Lu, Y. Zhu, A. Kumar, A. Gupta, S. Mueller (2022). InfraredTags: Embedding Invisible AR Markers and Barcodes Using Low-Cost, Infrared-Based 3D Printing and Imaging Tools. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22).* Association for Computing Machinery, New York, NY, USA, Article 269, 1–12. DOI:10.1145/3491102.3501951

[7] J. Gibson, (1979). *The Ecological Approach to Visual Perception.* New Jersey, USA, Lawrence Erlbaum Associates

[8] H. Hutchinson, W. Mackay, B. Westerlund, B.Bederson, A. Druin, C. Plaisant, M. Beaudouin-Lafon, S. Conversy, H. Evans, H. Hansen, N. Roussel, B. Eiderbäck (2003).

Technology probes: inspiring design for and with families. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '03).* Association for Computing Machinery, New York, NY, USA, 17–24. DOI:10.1145/642611.642616

[9] H. Kato, M. Billinghurst. "Marker tracking and hmd calibration for a video-based augmented reality conferencing system.", In *Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR 99),* October 1999.

[10] T. Kuflik, S. Omer, Y. Peter. "Visual cues for cultural heritage urban navigation with smart glasses." In *Proceedings of the 2022 AVI-CH Workshop on Advanced Visual Interfaces for Cultural Heritage*. CEUR-WS. org. 2022.

[11] MonmouthpediA (2023). accessed 1/5/2023. https://monmouthpedia.wordpress.com

[12] D. Norman, 1998, *The Design of Everyday Things*. MIT Press.

[13] E. Petrov, A. Monroy-Hernández (2023). Dream Garden: Exploring Location-Based, Collaboratively-Created Augmented Reality Spaces. In Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (CHI EA '23), April 23--28, 2023, Hamburg, Germany. ACM, New York, NY, USA 6 Pages. DOI:10.1145/3544549.3585810

[14] W. Preston, S. Benford, E-C. Thorn, B. Koleva, S. Rennick-Egglestone, R. Mortier, A. Quinn, J. Stell, M. Worboys (2017). Enabling Hand-Crafted Visual Markers at Scale. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17).* ACM, New York, NY, USA, 1227-1237. DOI:10.1145/3064663.3064746. 2017.

[15] M. Vayanou, K. Christodoulou, A. Katifori, Y. Ioannidis. "Magicarts: On the design of social vr experiences." In *Proceedings of the 2022 AVI-CH Workshop on Advanced Visual Interfaces for Cultural Heritage*. CEUR-WS. org. 2022.