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Technical Article

Exploring the Materiality of Augmented Reality Markers through Arts-Led Cocreation: Drawing, Weaving, and Tiling

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Abstract

This article explores the use of arts-led approaches to augmented reality (AR) marker design through the presentation of four commissioned projects featuring AR markers created using traditional techniques including drawing, hand weaving, and tiling. The physical-to-digital process to convert artworks into AR markers produces opportunities for cocreation with diverse participants and for materially to shape the AR experience. Reflecting on the materiality of the different techniques in relation to the temporal, spatial, and social settings of each project (arts festivals, a summer school, and workshops on heat wave-risk communication), the authors argue for a responsive approach to integrating multimodal dynamic markers.

Developments in computer vision techniques (Taketomi, Uchiyama, & Ikeda 2017) and WebXR (Cabanier, Jones & Goregaokar 2023) frameworks and libraries have broadened the device accessibility and affordances of augmented reality (AR) applications. From the predefined reference marker based on a two-dimensional matrix (similar to quick response [QR] codes) to representational graphics (Kato & Billinghurst 1999), such as Hirokazu Kato's Hiro marker [1], the solutions available for developing marker-based AR experiences continue to expand, allowing for more colorful and creative designs to be used as triggers of AR experiences (Neumann & You, 1999). AR markers are typically created using graphic design software before being printed on paper, card, or a similar base. However, emerging arts-led research into AR markers demonstrates the technical feasibility and procedures for inverting this digital-to-physical process to link digital content to a range of materials, objects, features, and sites (Nestler et al. 2019; Peiris et al. 2011; Park & Park 2010). We seek to extend this line of inquiry by critically reflecting on what happens when the making of markers and their material properties centers on the physical-to-digital processes of AR cocreation. By providing working examples across a range of mediums and arts methods---from drawing and painting to weaving and tiling---this discussion explores and develops the potential of emerging multimodal techniques to further develop innovative, web-based AR.

In recent years, the development of markerless AR solutions has introduced frameworks like Apple ARKit, Google ARCore, Niantic Lightship, and PLC Vuforia that have enabled the interplay between digital overlays and the physical environment (Carozza et al. 2014, Basori et al. 2015, Wang et al. 2017, Sadeghi-Niaraki & Choi 2020). The limited discussions of AR markers usually emphasize technical approaches, challenges, and the visible augmented outcome, rather than audience experiences of the markers themselves. (Peiris et al. 2011, Pathak et al. 2022). For example, discussing embroidered markers within an e-textile environment, Pathak et al. (2022) prioritize the efficacy of the technique rather than the affordances of the materials used in their discussion. Likewise, Zhang et al. (2020) describe a process of using colored transparent AR markers to enable multiple 3D digital objects to be displayed in space with only cursory mention of the user experience. Meanwhile, discussions of AR art tend to focus on interdisciplinary processes, digital content, and audience experience rather than the markers as the material interface (Geroimenko 2012, Portalés 2018). Taking an arts-led approach, this article seeks to contribute to these conversations by asking how the material and aesthetic properties of AR markers might help shape encounters with linked content in specific contexts. How can engaging traditional arts methods and

materials in the cocreation of AR markers enhance the AR experience? How might the AR integration of digital content open up and transform established arts methods?

This article presents a set of experimental case studies which, taken together, call for greater attention to be given to the materiality of AR markers as a means of conveying broader project aims. We suggest that the potential of AR to connect traditional techniques, such as drawing, painting, and weaving, with time-based digital media generates exciting opportunities for bridging knowledge systems through cocreation with researchers, artists, audiences, and communities. AR markers are, therefore, realized here as an interface---not only between "physical" and "virtual" realities, but also between different ways of sensing, interpreting, and communicating.

A Note on the Technical Method

AR is used to overlay digital features onto a real-time video feed or pass-through display, in effect combining the digital with the physical and thereby augmenting the real-world experience (Azuma 2001). The techniques and approaches that enable these experiences can be traced back to the late 1960s, when Sutherland (1968) developed a prototype of a see-through head mounted display that was able to project floating digital geometries within the user's field of view in real time. It wasn't until the 1990s that Caudell and Mizell (1992) coined the term *augmented reality* to describe this interplay between digital and physical realities through their work at Boing Computer Services Research. Subsequent research in this area contributed to increasing the accessibility of AR experiences via both handheld and wearable devices: e.g. smartphones and Microsoft Hololens (Höllerer et al. 1999, Azuma 2001). However, the signal breakthrough in making AR experiences more widely accessible came with the development of web-based technologies (Portalés 2018), which are essentially device agnostic. The projects discussed here respond to the opportunities offered by WebXR frameworks, in particular the open-source library AR.js, based on the influential ARToolkit developed by Kato and Billinghurst (1999).

Turning now to the AR interface, there are two established methods for connecting the physical and digital dimensions: marker-based and markerless (Sadeghi-Niraki & Choi 2020). Marker-based AR applications use a visual cue, which is encoded in a machine-readable format within the application, to trigger digital content that is dynamically linked to the position, rotation, and scale of the marker itself. By contrast, markerless applications use

computer vision techniques, such as simultaneous localization and mapping (SLAM), to recognize the physical environment and overlay vertical and horizontal virtual surfaces onto which the digital content can be placed. As Sernani et al. (2019) note in exploring work by Durrant-Whyte and Bailey (2008), SLAM is a technique used in robotics to build a map of an unknown environment and enable mobile robots to operate autonomously. Outside its original sector and scope (e.g. embedded robotics, unmanned aerial vehicles, and self-driving cars), SLAM has also been applied to AR with the aim of improving object tracking to achieve greater content stability. Though developed within markerless AR applications, this increased stability has significant implications for marker-based approaches, ushering in the possibility of multimodal markers to expand AR experiences.

Although they incorporate a range of approaches and arts methods, the following examples all utilize the same basic technique (with some minor variations) to translate visual materials into the machine-readable content needed to detect an AR marker with a smartphone. The underlying AR.js web-based library [2] inherits the same marker constraints from the ARToolkit library [3]. First, the marker requires a continuous black squared frame of a fixed ratio to trigger the AR content, which is in turn oriented according to the marker pattern. This places limitations on the design of the markers, which must fit within the square frame and be asymmetrical, and have high tonal contrast for effective recognition. The need for bold contrast links to the second constraint: the images need to be converted into machine-readable matrices of 16 x 16 RGB pixels as determined by the AR.js library (Fig. 5). The physical markers may be created using a variety of art materials but must then be processed using digital tools, including graphics software and photography, to produce reference images before being linked with digital media, such as real-time sensor data, audio-visual content, or 3D digital objects (Figs. 7,8). In the final step, the physical AR marker is tested with a smartphone to ensure pattern recognition and interactivity. It can then be altered if necessary.

The transferability of this process has enabled experimentation across a range of media and arts methods, from drawing and painting to weaving and tiling. The discussion that follows considers each approach in relation to their formative contexts, guiding concepts, and the opportunities they foster for engaging participants and audiences.

ARGH Mateys: Cocreating AR Site Markers with Young People

Fig. 1. Installation view of Angel's Backyard, by Angel Okoturo for ARGH Mateys, the Royal Docks, London, 2021–2023.

ARGH Mateys (Augmented Reality for Grounded Heritage: Digital Portals for Environmental and Youth Stories, 2020–2023) [4] is an interactive walk around the Royal Docks, East London, that features site-specific poetry and spoken word by young people (aged 18–24). Commissioned as part of the 2020 Join the Docks Festival, a month-long cultural celebration, the project was delivered in partnership with the local youth organizations Youth Empowerment, Fight for Peace, West Silvertown Foundation, and Royal Docks Learning and Activity Centre. The installation invites people to listen to the words and voices of participating artists accessed via AR markers installed at the artists' chosen locations. The eight AR markers also appeared alongside the text on an interactive web map, which was launched in October 2020 to support remote access to the project during the COVID-19 pandemic.

The method of site writing was proposed by Jane Rendell (2010) through her engagement with situated arts practices. Alert to its spatial contexts, site writing seeks to situate the reader as an active participant in the text. For this project, young people were commissioned and supported to develop site writing, spoken word, and AR markers over five weeks from October to November 2020. Each participant selected their preferred location during a walking workshop and began drafting their poems onsite through responding to a series of writing prompts designed to explore relationships to place: e.g. "choose a feature within this space and write as that feature", "write about a memory connected to this site,". The following extract by Angel Okoturo was written in response to the second prompt and developed over the subsequent weeks, with remote sessions providing space for sharing and peer feedback:

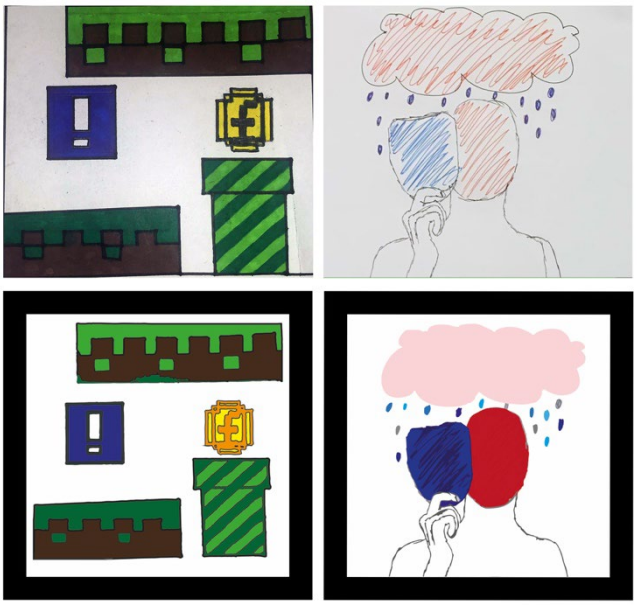

Fig. 2. ARGH Mateys workshop participants hand-drew images and photographed them as references for the AR markers for *ARGH Mateys*, 2021.

> My mother couldn't afford paying for every journey to get to A and B, so our alternative was to use our ten toes. When I tell you we walked everywhere, I REALLY MEAN IT. I didn't enjoy walking at first because keeping up with my mum's long legs was a myth. So, because of that my mum tried her best to make it as fun as possible for me. She used to take me through different routes to get to places.
>
> (Angel Okoturo, 2020)

The marker designs were sketched out on paper by the participants during these online workshops, and their drawings were used as reference images in Adobe Illustrator to create the signage for the installations (Fig. 2).

In most cases, the images the young people drew mirrored their developing poetic contributions. For example, Okoturo, reflecting on her childhood experiences of the Royal Docks as a game space, decided to reference the game world of Super Mario in her marker (Figs. 1,2). By contrast, Fatima Abukar's spoken word *Division* highlights the past and

present legacies of colonial racism imbricated in the Royal Docks: “Tell me who it was that extracted sugar from canes / Damn, Britain, are you not ashamed?” Her marker design features a rain cloud (“Did you listen to the sky today? / She cried with me, but today she’s been relentless”), above a masked figure that evokes Frantz Fanon’s (1967) signal anti-colonial work *Black Skin, White Masks* (Fig. 2).

Integrating the design of the markers as part of the cocreation process helped to ensure that the visual dimension of the installation was closely aligned to the audio, and that the markers were visually engaging enough to encourage interaction with the audio accessed through their digital portals. The markers were printed on aluminum sheet metal to ensure their outdoor longevity. At 20 months after installation, the markers are still in place and most remain usable, although their exposure to direct sunlight has faded their colors and diminished their reliability.

Unravelling: Weaving Digital Memories

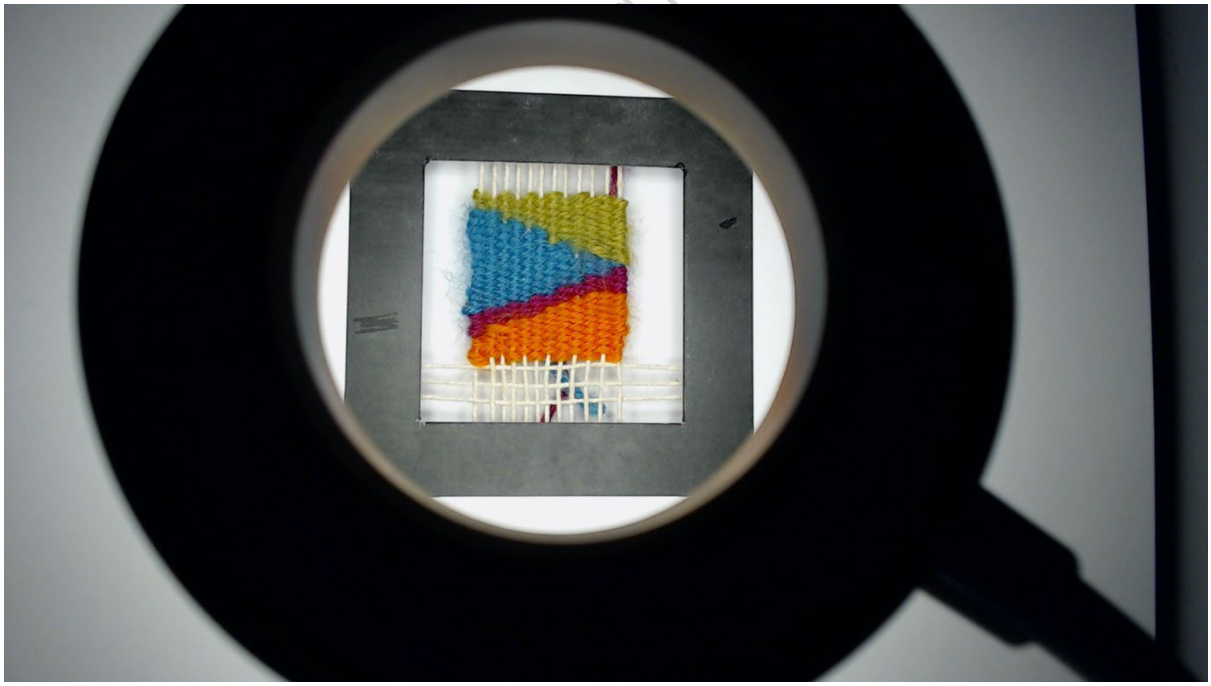

Fig. 3. Close-up of a woven marker created by a participant in *Unravelling*, *Festival of Intimacy*, Grant Museum of Zoology, London, 2021.

If *ARGH Mateys* confirmed the exciting possibilities of engaging AR in processes of digital cocreation, *Unravelling* [5] highlights the further scope for integrating traditional arts materials and methods (in this case, Gobelins weaving). We created *Unravelling* in collaboration with artist and weaver Fiona Mathison and dance artist Louise Klarnett for the Grant Museum of Zoology as part of the *Festival of Intimacy,* a day-long event sponsored by University College London (UCL) in June 2021. Conceived as a performance workshop, *Unravelling* invited audiences to weave their own markers as interfaces for digital mementos of the people, places, and things they missed in the context of the COVID-19 pandemic (Fig. 3). During the two sessions, participants created small samples of cloth using yarn from a garment knitted by Mathison and worn by Klarnett before being unraveled and passed down to the group from the first-floor mezzanine as part of Klarnett's slow spinning dance (Fig. 4).

The to and fro of wefts through warps in weaving finds a neat parallel in the 0s and 1s of binary code. James Essinger (2007) has traced the close links between weaving and digital technologies, identifying the Jacquard loom as a technological driver not only of industrialization, but also modern computing. Joseph Marie Jacquard's breakthrough use of punched cards enabled the production of complex and repeating textile designs. By programming the patterning of woven cloth and reducing the potential for human error, the loom attachment also closed off opportunities for creative chance.

Fig. 4. Performance stills of Louise Klarnett dancing with the knitted garment for *Unravelling*, Grant Museum of Zoology, London, 2021.

For *Unravelling*, we repurposed empty picture frames as handheld looms. Over the course of both hour-long workshops, participants wound their own bobbins and passed them over and under open warps to improvise simple geometric designs in cloth squares of approximately 5 x 5 cm in size. Hand weaving allows time for reflection. Building an image in cloth, line by

line from the bottom up, practically demands quiet attention. The tracking back and forth as the yarn passes through fingers and warps is a way of both passing and marking time: of remembering and conveying memory.

Fig. 5. Each woven sample was converted into a low-resolution matrix.

Unravelling created a bridge between traditional tapestry techniques handed down through generations and experimental AR technologies. Once completed, each participant's woven sample was photographed and converted into an AR marker. While suited to the capture of 3D objects, the photographic method introduced challenges; e.g. uneven surfaces casting shadows, color aberrations, and perspectival transformations can alter the marker pattern. In addition, lighting in the museum had to be kept to a low intensity for the preservation of the collection objects. To address both these issues, a webcam was directed through a portable ring lamp with a white light to ensure accurate color reproduction, remove unwanted shadows, and limit digital noise. As the resulting images were then converted on the AR.js marker training website [6] into low-resolution matrices of 16 x 16 RGB pixels in size, the use of a high-resolution digital camera would have provided no practical advantage (Fig. 5).

As the final step, the AR markers were linked with digital content that had been shared with us ahead of the event by the participants. These digital assets were chosen as mementos of someone or something that had been lost during the global pandemic. By interacting with the woven markers, visitors to the museum could explore a collective tapestry that included a cello scroll, a 3D modeled rabbit, and photographs of discarded objects. After the event, participants were invited to take their individual looms and markers as keepsakes.

ARTES: AR Tiles for Environmental Sensing

Unravelling embraced the slow temporality of weaving to make the connection between memory, memorialization, and the AR experience. By contrast, ARTES: AR Tiles for Environmental Sensing [7] engaged with real-time data and rapid prototyping techniques appropriate to the learning environment.

ARTES was a day-long workshop for 12- to 14-year-olds delivered as part of the East Summer School (2021), an annual event hosted by the Queen Elizabeth Olympic Park, London, in partnership with East Bank organizations including UCL. The Summer School aims to give young people from the surrounding London boroughs of Hackney, Newham, Tower Hamlets, and Waltham Forest an opportunity to engage with project-based learning beyond the school curriculum, develop new skills, and discover future educational and career possibilities. Within this broader program, the Connected Environments lab facilitated two interconnected activities drawn from teaching and research: first, building and programming an Arduino-based sensor to monitor the amounts of light and water given to plants, the moisture of their soil, and the temperature of their immediate environs; second, designing and making an interactive AR marker by pulling data from the plant sensor and accessing that real-time data via a smart device.

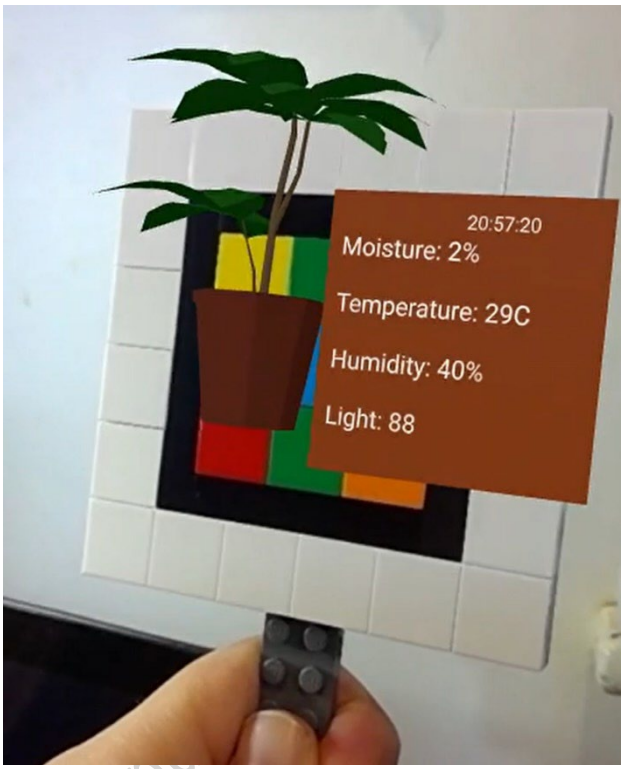

Fig. 6. Tiled AR markers were used to trigger digital plant models with real-time data from a plant monitor built by students of the East Summer School, London, 2021.

We had initially considered using mosaic tiles to create the AR markers, a method pioneered by urban artist Space Invaders to develop QR codes in 2008. However, in view of the limited time available for the activity and the numbers of participants (around 30), the decision was taken to use LEGO 2 x 2 flat tiles instead. The limited color range and regular shape of the tiles enabled us to streamline the process for generating the pixel matrices. Black flat LEGO tiles of 1 x 8 were used to create the AR marker border. Additional white tiles were placed on the outer edge of a LEGO 12 x 12 plate to facilitate the detection of the marker (Fig. 6). Instead of capturing the tiles using a digital camera, we recreated the 3 x 3 colored LEGO tile grid on an interactive website and presented it on a smart device (Fig. 7). This enabled the students to choose the colors of the tiles and customize their own marker both physically, using the LEGOs, and digitally, via the website. Linked to real-time feeds of data collected from the sensing devices, the marker was built in a parallel session to monitor the

environmental conditions of their plants. The data feeds were displayed alongside a 3D model of a potted plant, which showed green leaves when conditions were favorable and red leaves to indicate the need for more water or access to light.

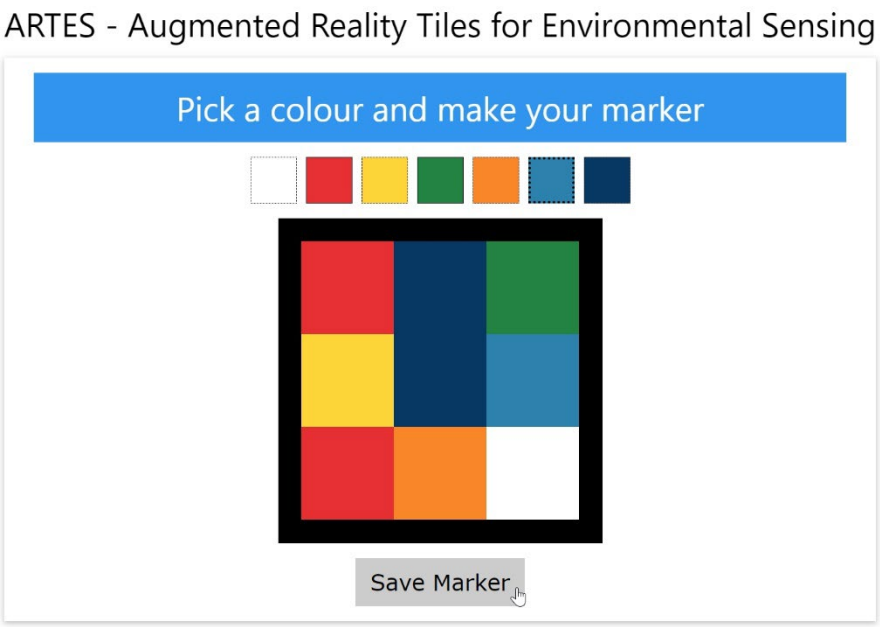

Fig. 7. The web-based touch interface used by the students during the workshop to digitize their physical marker.

Unlike in the other examples discussed here, the task of transforming the material marker into a machine-readable pattern was completed by the participants rather than the researchers facilitating the project. As a result of this involvement in the end-to-end design process, the students went beyond the planned activity by initiating their own experiment with the size and scale of the markers and testing patterns on a 6 x 6 grid. In fact, the participants in our workshop were as curious to explore the material properties of the markers as the environmental data to which they were linked, signposting further opportunities for using AR to engage participants in processes of digital cocreation.

ThermoInteractive Markers: Communicating Heat Wave Risks in Real Time

In our final example, we introduce the concepts of temperature and state into the creation of AR markers to demonstrate the technology's potential for communicating information relevant to environmental conditions through environmentally responsive materials.

Between 2021 and 2022, we partnered with the Red Cross Red Crescent Climate Centre, the British Red Cross, and Thames Life (formerly Thames Ward Community Project) to explore arts-led approaches to communicating and managing urban heat wave risks. Heat waves are becoming more frequent and intense across the world due to human-induced climate change and pose increasingly serious threats to human health, society, economy, and infrastructures (IPCC, 2022). Furthermore, heat is a major health inequality issue in so far as it disproportionately affects young children, older adults, those who are pregnant , people living alone with limited support networks, those who are unhoused and who work outdoors, . As structures and materials in cities absorb and radiate heat, the urban heat island effect can amplify the intensity of extreme temperatures, prevent cooling, and exacerbate the heat wave-induced burden on urban populations. Relatively simple adaptations at the individual, community, and city-wide levels can help to manage these risks. However, most people and organizations fail to recognize themselves as vulnerable and so remain insufficiently aware of the severe threats posed by urban heat waves, in part because risk communication has been dominated by conventional warning systems that fail to inspire action.

Fig. 8. Thermochromic AR markers shown in a cool state (left), a hot state (center), and overlaid with digitally linked content in AR (right).

In setting out to investigate how arts-led methods of cocreation might be used to visualize and engage people in managing urban heat wave risks, we paid particular attention to understanding the potential applications of heat- and light-responsive materials and processes. Thermochromic pigments are an affordable and commercially available technology that change color in response to environmental stimuli. Despite the relative familiarity of thermochromism via commercial products such as color-changing mugs, we found the transformation of the leuco dyes from colored to colorless at a predetermined temperature threshold fascinated participants and audiences, even without the integration of

AR technologies (Suarez, 2022). This popular appeal combined with the availability of pigments engineered to change color at a range of temperature thresholds commensurate with heat waves (including 27℃, 31℃, and 40℃ [80.6°F, 87.8°F, 104°F]) makes thermochromic art especially effective at prompting conversation and engagement around the risks of extreme heat.

An early experiment in combining thermochromism with AR technologies gestures to opportunities for creating dynamic markers for real-time risk communication before and during extreme heat events (Fig. 8). By incorporating thermochromic elements into the design, it is possible to produce a single image that may adopt one of two (or more) states and, therefore, be read as different markers according to the ambient temperature. Each marker can then be linked to risk communications related to the environmental conditions and corresponding recommendations for either heat wave preparedness (cold state) or heat wave action (hot state). A rapid prototype by Connected Environments researchers focused on communication around domestic and intimate partner violence, which is known to increase during extreme heat events. Interacting with the test marker in the cold state revealed a statement intended to raise public awareness of the risk; in the hot state, the marker directed users to safe spaces. A subsequent iteration of the marker design depicted a silhouette in profile that appeared bound and silenced when the temperature threshold was exceeded, leveraging the opportunity to convey key risk messages symbolically through the material interface, as well as through digitally linked content.

Future Directions

The open-source working examples presented here reflect an experimental approach to applying AR technologies in processes of digital cocreation with participants and audiences. A signal advantage of open-source and web-based libraries over native solutions is that they enable rapid prototyping and customization of outcomes. The results are more accessible to the end user, since they may be run on older devices. They also significantly reduce the cost of deployment thanks to the availability of free web hosting services such as GitHub Pages, which provides sufficient technical capacity for projects without requiring the publication of sensitive data and attendant privacy measures, such as access control and secure data storage systems. By contrast, publishing native applications in both Apple and Android digital stores requires a paid developer account and time to approve the app on the store, in addition to the

cost of software licenses. Notwithstanding their relative flexibility, web-based tools also require certain resources, including technical expertise, and time to develop bespoke solutions. However, we found the adaptability of AR.js increased the number of opportunities to integrate a broad range of materials and practices into digital AR experiences.

The presently discussed projects engaged drawing, weaving, tiling, and thermochromic pigments in the creation of AR markers. This list is by no means exhaustive, but rather indicates the creative potential for further experimentation with a greater variety of visual media and processes. The materials and practices highlighted herein were considered exemplars in engaging diverse audiences, over varied timescales, in specific contexts, and according to distinct aims. The repetitive movement and gentle attention required for weaving, combined with the ritualized environment of the museum, created space for quiet contemplation and collective remembering in *Unravelling*. By contrast, the students who joined us for the ARTES workshop as part of East Summer School responded to the digital application of LEGO tiles as an invitation for playful experimentation, as well as a chance to go beyond the dimensions we had provided in the code and create larger AR markers. Similarly, the participants in ARGH Mateys realized opportunities for distilling images from their site writing and spoken word commissions into visual form through markers designed for on-site installation. While conveying information through our state-changing ThermoInteractive AR markers has yet to be tested with audiences, previous practice-led and collaborative research into raising awareness around heat waves through thermochromic pigments indicate the appeal and suitability of this medium to risk communication (Suarez 2022).

As a group, these examples suggest that giving attention to the materiality of markers within AR design enables different points of entry into digital cocreation projects, opening a door to audiences who may not otherwise seek to engage with the digital. One effect of approaches that focus on technical feasibility when creating AR experiences is that they tend to frame AR as a fixed output. This may be partly consequent of developing technical approaches within disciplinary silos, which limits opportunities to share knowledge and reveal the affordances of these technologies in different contexts. We advocate for an alternative approach that emphasizes AR as one tool among many that can be used to engage participants. Considering the potentialities of arts-led methods and materials in the design of AR markers can enable new modes of participation in practice. Keeping pace with the

continuous evolution of AR technologies, we are already testing other open-source WebAR solutions that allow for borderless marker design and gesture-based interactivity with linked digital content. Our aim is to continue exploring beyond the borders of any individual discipline to signal new areas for technical development and discover creative methods that can resonate with as-yet unknown audiences.

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