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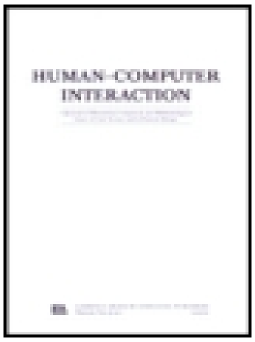

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Envisioning, designing, and rapid prototyping heritage installations with a tangible interaction toolkit

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1. Introduction

A body of HCI work focuses on cultural heritage settings, such as museums, galleries, and historic sites – domains where established digital technologies such as interactive screens and mobile guides are used by end-users individually and in groups, and where innovative designs can be deployed in order to augment the user experience through a variety of interaction frames, from mixed reality, to tangible, embedded, and embodied interaction (see Hornecker & Ciolfi, 2019 for a review). In recent years, the focus broadened from creating interventions and evaluating them with visitors, to realizing open-ended technological platforms that cultural heritage professionals (such as exhibition designers and interpretation officers) can adapt and appropriate for their institutions and to which they can contribute their own expertise. A common approach is the creation of *toolkits*, where software and – in some cases – hardware, and related support materials are made available to non-experts to realize digital experiences in museums and exhibitions. In this way, the introduction of novel digital technologies in heritage settings is no longer limited to external interventions (through specially commissioned commercial projects or collaboration with researchers), but is possible at the hands of cultural professionals who can bring their know-how on visitor engagement to interactive exhibition design.

This paper discusses the design rationale, user interaction, and the extended evaluation of the Tangible Interaction Toolkit, an online content editing environment and related hardware kit, that enables cultural heritage professionals (CHPs) and exhibition designers to create and adapt tangible installations in museums. Tangible interaction "*encompasses a broad range of systems and interfaces relying on embodied interaction, tangible manipulation and physical representation (of data), embeddedness in real space and digitally augmenting physical spaces*" (Hornecker & Buur, 2006, p. 437). Its use in the heritage domain has aimed to overcome the separation often occurring between the material, tangible qualities of heritage, e.g., the physical collection on display in a museum or the ruins in an archeological site, and the multimedia digital content that heritage institutions hold (Chu et al., 2016; Petrelli et al., 2013). We built upon work in museum studies that sees the material and embodied experience of heritage as instrumental for deeper and more meaningful visitor engagement (Davidson et al., 1991; Joy & Sherry, 2003; Dudley, 2010; Van Schijndel et al., 2010; Wehner & Sear, 2010; Naumova, 2015), augmenting it with digital multimedia to engender an emotional connection and a sense of wonder.

The Tangible Interaction Toolkit's online environment allows to create, customize, and monitor blueprints of tangible interactive installations and the digital content populating them, while the associated hardware underpins the hands-on interactivity that implements the final deployed installation. The Toolkit is the outcome of meSch (Material EncounterS with Digital Cultural

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Heritage), an extended research project that involved over twenty researchers (HCI and computer scientists, designers, and museum professionals) in an iterative process of co-design and evaluation that lasted 4 years (for a project overview see *Interactions*, vol XXVI.5, 2019). The evaluation we report upon in this paper refers to the third and final prototype of the Toolkit. Our effort was to make powerful and complex platforms and technologies, such as the Internet of Things and personalization techniques, usable by CHPs. In this, we were led by the types of applications and visitor experiences CHPs would envisage, and their potential use of the meSch Toolkit.

The aim of designing a simple interaction for complex technologies to be used by non-experts poses the challenge of how to strike a balance between two extremes: a simple interaction may exclude more advanced technical features and, conversely, advanced features may require a complex interaction. Previous work on toolkit design and end-user development has indeed aligned itself with one approach of the two: designing either for simplicity of use or for advanced features. In realizing the meSch Toolkit, we propose a solution that offers multiple entry points to accommodate different levels of expertise and attitudes: from the simple repurposing of existing blueprints of interactive installations, to the extension of the hardware platform with new sensors and actuators.

Toolkits and their impact are difficult to evaluate: toolkits provide an opportunity to engage with advanced technology that otherwise might be beyond the reach (technical and financial) of cultural institutions; however, CHPs can find it hard to dedicate time and effort to explore new opportunities, and their willingness to take up a new technology may be challenged by the difficulty to see the possible benefits, by limited time and perceived complexity. While some work has been done to study toolkits in the hands of users, there is as yet little data documenting what challenges CHPs face as users when exploring and using a toolkit.

In this paper, we first discuss relevant related work, highlighting how our research fills current gaps in the literature, and we introduce the exhibition design practice within the heritage context to explain how it underpins the design rationale. We then present the Toolkit and the methodological framing of evaluation workshops, followed by a description and discussion of the three events and how they unfolded from envisioning to designing and prototyping tangible interactive installations. The results contribute both to HCI for cultural heritage and to the field of HCI more in general, as toolkits for "user designers" and "user empowerment" are a lively trend in HCI (see for example, Desolda et al., 2018, 2018; Kanstrup, 2012) that requires further study and reflection.

2. Related work

HCI research for cultural heritage has a long history and, as well as contributing to our understanding of this specific application domain, it generated important knowledge for the broader discipline: from studies of how digital technologies mediate collaborative interactions (Hindmarsh et al., 2005; Weilenmann et al., 2013), to evaluations of mobile, augmented and tangible interaction frames and applications (Brown et al., 2003; Grinter et al., 2002; Hornecker, 2010; Rizzo & Garzotto, 2007). More specific to the heritage domain, HCI explored interactive technologies for supporting the portrayal of stories, museum objects, and contributions of visitors: whether designing for open-air museums (Ciolfi & McLoughlin, 2017; McGookin et al., 2017), science centers (Fleck et al., 2002) or traditional collection-based indoor museums (Barbieri & Celentano, 2011), a main challenge is to complement the spaces, artifacts, and sensory qualities that make heritage experiences immersive and memorable. Tangible and embedded interactions have been deployed for this purpose as part of exhibitions and visiting companions such as digital guides. For example, the "Re-Tracing the Past" interactive exhibition (Ferris et al., 2004) mimicked the qualities of a collector's study, and included tangible replicas of never fully interpreted museum objects that visitors could explore and discuss. The tangible qualities of the space, as well as the use of manipulable interaction triggers, such as the replicas, were greatly appreciated by visitors (Ferris et al., 2004).

As well as the interactions they support, the medium and form factor enabling tangible interactions can shape visitor engagement with the exhibition narrative: this was shown in Marshall et al.

(2016), where tangible replicas of museum objects were used as controllers to portray different personal perspectives of an exhibition. Evaluation showed that each different replica came to represent that personal perspective, rather than just the artifact itself. Furthermore, a study (Petrelli & O'Brien, 2018) comparing the use of a smartphone app, a smart card, and tangible replicas as controllers for unlocking stories in the museum shows that visitors of all ages tended to favor tangible interaction (via the smart card and the replicas) rather than the smartphone app. Tangible interaction allows for open-ended engagement. For example, the Magic Cauldron (part of a touring exhibition on magic) invited children to cast spells by throwing objects into an interactive cauldron that reacted with different sounds and lights depending on the object thrown in (Taylor et al., 2015); spells displayed in the exhibition (e.g., from Shakespeare's *Macbeth*), inspired children to invent their own and engaged their creativity at length. As another example, in the Interactive Tableaux installation, the tangible objects were a means to engender a conversation among the five characters that inhabited a historic house museum across five centuries, and the visitors and museum volunteers (Claisse et al., 2018). The Kurio installation (Wakkary et al., 2009) supported social interaction among family members via multiple tangible devices (a radio, a torch and a magnifying glass) with which to collect items in the museum. These objects complemented mobile phones and a tabletop installation as part of a game for families (Wakkary et al., 2009).

Overall, tangible and embedded interactions in heritage settings are still very much under exploration and have not been pervasively adopted by institutions in the way that other technologies have. Given the positive visitor experience documented in previous research, CHPs should be facilitated in considering and approaching these technologies, in envisioning tangible interaction experiences as part of exhibitions, and in understanding what these could do for their visitors and institutions.

In a study of the motivations of CHPs for adopting digital technologies (Maye et al., 2014), the majority of participants voiced their opinion that interactive exhibitions should be designed around stories, themes, museum objects or experiences that an exhibition aims to portray, rather than on a particular interaction frame. After the overall idea has been established, the CHPs would then consider how technology could support the chosen narrative. The tendency is to look for familiar or ready-made solutions requiring more limited take-up time and maintenance, rather than considering technologies that would better serve the envisioned experience but are less known. Therefore, it is important that relatively novel interaction frames such as tangible interaction, which can be highly effective but may be still unknown or perceived as too difficult to tackle, should be available to CHPs as a possible alternative. Furthermore, the CHPs interviewed in Maye et al. (2014) stressed the need to use technology in ways that do not distract from the physical aspects of objects or exhibition spaces, confirming the potential benefit of tangible interaction. One way to facilitate this is to create platforms intended for CHPs and other exhibition designers as main users, where blueprints of tangible interactions can be customized and extended as well as created from scratch, in order to suit varying degrees of interest and ability.

Indeed, related HCI scholarship focuses on "end user development," "user empowerment" and "user designers" (Desolda et al., 2018; Kanstrup, 2012; Turchi & Malizia, 2015) and explores the evolving role of users in adapting and modifying digital technology for themselves. End User Development investigates approaches and tools for supporting users, who may have little to no specialized technical knowledge, in designing technological artifacts (Lieberman et al., 2006). Another approach is *meta-design*, where systems or environments are left open for users to shape the design of technologies (Fischer et al., 2004; Giaccardi & Fischer, 2008). To support users as designers, toolkits not requiring specialized technical knowledge were created for domains such as education (Moundridou & Virvou, 2003; Wiedenbeck, 2005), pervasive displays for public spaces (Turchi & Malizia, 2015), community networks (Smyth & Helgason, 2017) and healthcare (Carmien & Fischer, 2008), as well as cultural heritage. One important consideration regards the level of participation that the user may want in the design process, as digital technology should support various levels of participation to suit varying user needs (Fischer, 2013). Additionally, creative support should be provided to users when using open systems for design such as toolkits, i.e. sources of inspiration from which they can creatively evolve their designs (Giaccardi & Fischer, 2008). In HCI, interactive exhibitions design has involved CHPs on many levels: from user-centered approaches where CHPs act as informants (Ferris et al., 2004), or where both they and visitors inform design (Baber et al., 2001), to participatory approaches granting CHPs greater involvement and decision-making power (Maye et al., 2017).

A growing emphasis is on toolkits for CHPs to independently design and implement interactive technologies, such as augmented reality (Koleva et al., 2009; Vayanou et al., 2014), multimedia tour guides (Ardito et al., 2010; Ghiani et al., 2009; Sylaiou et al., 2008; Weal et al., 2006), virtual reality (Wojciechowski et al., 2004), table-top (Sprengart et al., 2009), multi-touch installations (http://openexhibits.org/), and digital online exhibitions (https://omeka.org/).

In some cases, these tools have not been evaluated with CHPs (Sprengart et al., 2009). In others, the evaluation of the toolkit has not been systematic and was limited to small case studies (Kucsma et al., 2010), or it focused on how intuitive the system was to use (Ghiani et al., 2009; Wojciechowski et al., 2004), but not on how it supports the installation design process. Yet other toolkits have been evaluated in experimental settings, focusing on specific features of the toolkit, but not on its capacity to support creative ideation (Desolda et al., 2018). Furthermore, all these toolkits are focused on a specific technology, rather than on an interaction frame such as the one our project produced, and therefore the way in which they support and mediate the ideation of interactive experiences has been explored less, priority having been given to how they enable that technology's implementation. Koleva et al. (2009) argue that the design of toolkits ought to take an experience-oriented stance, exploring how different device connections could support the experience they intend to design. We agree that evaluating toolkits in this manner is important, also in light of work on the design of open systems, arguing that toolkits also ought to support users in exploring different ideas and concepts (Giaccardi & Fischer, 2008).

The meSch Tangible Interaction Toolkit supports a range of technologies and offers multiple means of realizing tangible installations. It seems therefore appropriate to compare our work with two toolkits designed to easily create tangible interactions – the Phidgets development environment (Greenberg & Fitchett, 2001), and context-aware applications – the Context Toolkit (Dey et al., 2001). These two were the first in a series of toolkits for embedded technologies that have been produced over the years mostly to facilitate the assembling and programming of electronics (e.g., Smart-Its (Gellersen et al., 2004), NET. Gadgeteer (Villar et al., 2012)), sometimes to support the cycle of fast prototyping of digital products (e.g., d.tools (Hartmann et al., 2006)) or to ease the exploration of electronics by non-technical users (e.g., littleBits (Bdeir & Ullrich, 2011)).

Phidgets provide developers with an abstraction from the hardware that allows the easy composition of simple sensor-actuator prototypes (Greenberg & Fitchett, 2001); this roughly corresponds to the lowest level of the meSch Toolkit architecture (described in Kubitza & Schmidt, 2017) that supports the easy re-use of hardware elements and the extension to new devices. As Greenberg and Fitchett show, abstraction from the hardware is the first step for fast prototyping tangibles, but it still requires a level of technical understanding and expertise to grasp the logic embedded in higher-level programming. Aiming to non-technical users, we needed to provide a much higher level of abstraction from the hardware that allowed CHPs to see how their collections and content could be augmented by technology rather than how known technology could be made easy to use.

The Context Toolkit provides a higher level of abstraction than Phidgets by classifying the elements that come into play in a context-sensitive application such as people, places, things, and functions, such as notify, query, poll (Dey et al., 2001). By fully defining the elements of the framework, the Context Toolkit limits its applicability to those situations that can be described by the predefined elements. With our toolkit we take a completely open approach and provide the CHPs with tools to define for themselves the elements that compose their context of use. In other words, with the meSch Toolkit it is possible to model situations that cannot be represented with the Context Toolkit.

To support CHPs in exploring creative uses of a much wider and broader range of technology, we designed and then evaluated the Toolkit from a holistic perspective, looking at how it can support the exploration of ideas, creative design, as well as rapid prototyping. As this is the first attempt at realizing a tangible interaction toolkit of this kind, we describe and discuss firstly the key points of its design, and subsequently how it facilitated non-expert users to understand the interaction concepts, possibilities and opportunities that this novel approach can offer for heritage institutions, and to adapt and customize tangible interaction blueprints.

3. Understanding exhibition design practice

Early in the meSch project we spent time with CHPs to understand what was involved in the process of creating an exhibition, from conception to public opening, and which role they had (Maye et al., 2014). This knowledge later shaped the design of the Toolkit in a way that supports current best practice.

The creation of an exhibition is a collaborative effort often partially outsourced (Maye et al., 2014; McDermott et al., 2014; Smithsonian Institution, 2002). The initial ideation for a temporary exhibition or the reorganization of the display of a permanent collection lies with the *curator*, a discipline expert that chooses the objects and decides what content to include. The *communicator* collaborates with the curator to prepare the content for the audience; an *educator* may be involved to develop complementary educational material and activities. Other two key figures are the *designer* and the *maker* in charge of the physical and graphic layout of the exhibition, and its final fabrication and installation. These latter roles require expertise in architecture and design, sometimes theater and video making for audio-visual material, in addition to traditional making such as carpentry for the final setup. Even large museums tend to assemble mixed teams with a curatorial team (curator, communicator, educator) from within the institution, and the more practical side (designer, maker) outsourced to contracted partners. This division maps different responsibilities: the curatorial team is concerned with the content, i.e. which stories to tell and how, whereas the implementation team (designer and maker) are in charge of the layout and the display, that is to say with the context in which the content will be delivered. When the exhibition has an interactive component, the implementation team includes expertise in digital technologies.

Two additional roles less relevant for this paper are the *manager* who ensures the project progresses on time and on budget, and the *technician* who is responsible for the final set-up and the day-to-day maintenance of the interactive installation. If the project is tendered (a usual practice in European heritage institutions), the manager is external and is the go-between the curatorial team within the museum and the implementation team without; the manager's role is to split the project into working units, subcontract (to providers of specific services, e.g., graphics or carpentry) and coordinate the work. Subcontracting can be critical when a digital component is part of the exhibition: subcontracting often results in fragmentation, lack of coherence and integration between the digital interactive and the exhibition, with the former seen as an extra, an "add on," rather than an integral part of the visiting experience. Therefore, a toolkit that facilitates collaboration could improve the communication of a diverse and dispersed team, it could reduce fragmentation and increase the mutual integration of the digital content and the physical context of an exhibition.

Generative co-design workshops with CHPs from inside and outside our project team helped us understand early in the design process opportunities and pitfalls of tangible interaction as a means to engage visitors in heritage settings (Avram et al. 2019). Participants were excited by the opportunities offered by such a way to use technology and willing to experiment, but, at the same time, they were concerned about lacking technical skills and facing overwhelming complexity. Our museum partners showed interest in sharing, repurposing, or designing exhibitions collaboratively via a project consortium, an increasingly common practice amongst science and technology museums that split the production costs then take turns in hosting the exhibition while customizing it with their own objects and content (see Ruiz (2012) for some examples). Sharing or repurposing hardware both within the institution and with partners is a guarantee against overly technical solutions that could result in an expensive, unreliable outcome with little return on investment: i.e. if others have used it before to good results, then it is worth investing in. Notably, while CHPs are happy to reuse hardware developed by others, they want to be in control of the stories told by the interactives in the same way as they are in control of the information panels around the exhibition.

Distilling findings from field studies and co-design sessions, we formulated a process for the conception, design, implementation and deployment of tangible interactive installations that has 6 distinct phases (illustrated in Figure 1):

(1) *Inspire*: heritage institutions aim to offer bespoke visiting experiences, but may not be willing to take the risk that comes with attempting ground-breaking installations. A collection of best practice examples, stored as blueprints, to browse allows CHPs to find inspiration, understand the requirements (e.g., devices and content), the costs, and the complexity in implementing a visitor experience.
(2) *Set-up*: it should be possible to modify an inspiring blueprint to fit the local needs, e.g., a different heritage setting, different target audience, etc.
(3) *Create*: the creation of the narrative that underpins the exhibition is core; here the curatorial team specifies the components for the interactive storytelling, i.e. content and interaction rules.
(4) *Configure*: tangible and embodied interactions use Internet of Things (IoT) technology such as sensors and actuators, which need to be assembled and set up for the given interaction in support of the narrative.
(5) *Test*: to deploy the content and the rules on the hardware configuration in order to perform the visitor's planned interactions and check whether the final installation functions as expected.
(6) *Share*: a complete and tested example is shared as a blueprint, to enable other institutions to reuse and repurpose it. In essence, sharing feeds step 1 of the cycle.

As illustrated in Figure 1, the process is split between curating the digital content, edited online and controlled by the curatorial team, and the tangible and embodied interaction set up by the implementation team in the physical world. The digital-physical split facilitates the reusing and repurposing of both media content and hardware, as the same content can be deployed on different hardware configurations with similar properties (e.g., detecting a selection can be done via button pressing, NFC[1] reader or proximity sensor) and the same context can hold different media (e.g., content in multiple languages for traveling exhibitions). This core feature allowed us to design the interaction around the concept of reusing, repurposing and upgrading existing installations, thus facilitating learning about the Toolkit while using it. Starting by finding inspiration from others and replicating their work, CHPs can then be guided through the process of modifying existing blueprint examples, thus building new skills that can facilitate the adoption of this sophisticated toolkit.

4. The meSch tangible interaction toolkit

The six steps process described above underpins the design of the user interaction with the Toolkit designed and developed in the meSch project. From the user point of view, the Toolkit is composed of two parts (that roughly correspond to the online and in-space sections of Figure 1):

(1) An online platform, the *Authoring Tool*, used to find inspiration, define the interactive behavior of the installation, manage the content assets, and deploy the installation; and

[1]NFC, Near Field Communication, is a communication protocol by which small microchips (attached to stickers) store minimal information that can be read by in-range (4 cm) mobile devices.

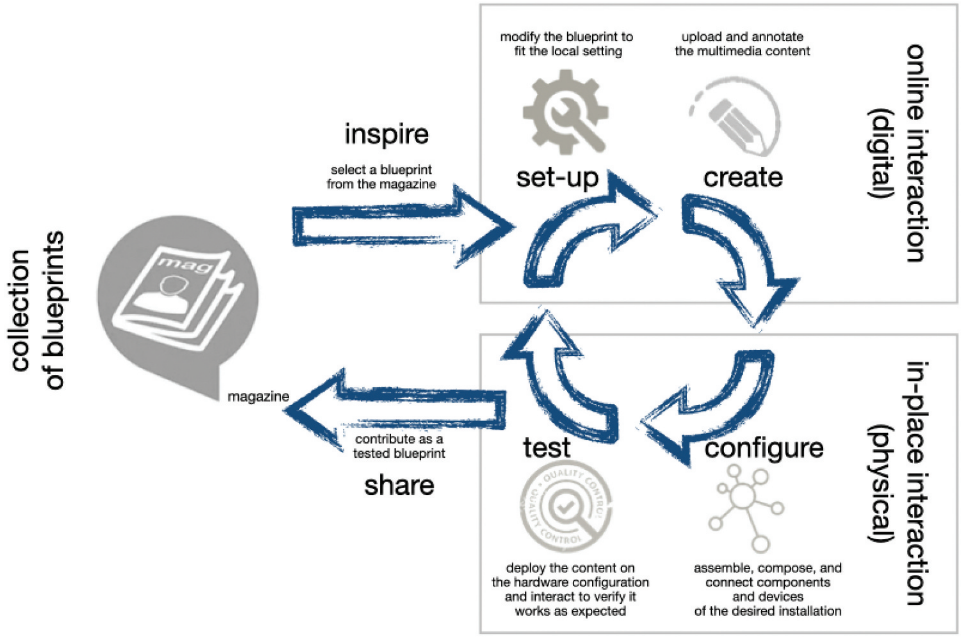

Figure 1. The identified steps of the creation and prototyping of tangible interactive installations.

(2) A set of tangible networked hardware components, the *IoT Kit*, with several sensors and devices (such as beacons, buttons, NFC tags and readers), a mini projector, a thermal printer, a smartphone and a mini-server, to be used in various configurations to assemble an installation and support the interaction.

We describe the interaction using as an illustrative example the repurposing of an interactive installation (Marshall et al., 2016), as it occurred during the pilot evaluation of the Toolkit at a "Museum Camp."[2] The interactive installation used as inspiration was designed by our team for an exhibition on the theme of World War II in the Netherlands, presenting three contrasting perspectives on historical events: the German Soldier, the Dutch Civilian, and the Dutch Civil Servant. Each perspective was represented by a smart replica of a historical object in the exhibition (augmented with an NFC tag). The replica controlled the delivery of multimedia content at an interactive station (via an NFC reader, Figure 2, left): placing the replica in a designated space on the station played the content, while removing it stopped the video that was projected on the display case glass from within the case itself and the audio recording playing.

On entering the exhibition, the visitor was invited to choose a replica to use during their visit: the six different replicas (Figure 2, right) represented the three perspectives in two languages, English and Dutch. Ten interactive stations represented locations in the city of The Hague affected by the German occupation in WWII: the visitor would walk through the city listening to the stories that map the chosen perspective. This exhibition uses 10 stations, each with NFC reader and projector, and 6 NFC tags concealed within the replicas.

At Museum Camp the blueprint of this installation was repurposed into the interactive exhibition "Mobility" (Figure 3). The case displayed objects found in different countries facing the East Mediterranean Sea to illustrate the mobility of people, ideas, art styles and objects in the period

[2]A Museum Camp is a professional training event usually run over a weekend.

Figure 2. The WWII installation had 10 interactive stations (left) controlled via NFC-augmented smart replicas (right), each replica paired a perspective to a language. The visitor on the left is following and listening to the civilian perspective in English represented by the sugar box replica.

Figure 3. The “Mobility” installation at museum camp; it repurposes the recipe developed for the WWII exhibition. The map of the Mediterranean Sea is under the display case; the mat is for the child to lay down while using the ancient Greek boat (see the orange ring next to the case base and top right) to visit the ports; this action starts a video projected on the top right of the case on an acetate sheet.

1000–335 BC. The installation was designed to be used by a child and an adult visiting together: beneath the case was an NFC-augmented map of the Mediterranean Sea with images of the objects located in specific places (Figure 3, bottom right); the child was supposed to lay on the mat under the case and use the ancient Greek boat (the orange ring, an NFC reader from the IoT Kit) to travel on the map, touching the different ports (that concealed NFC tags). The event of the boat arriving at a port triggered the projection of a video on the top right-hand side of the case; the content was designed so that the adult and the child had to work together to understand the significance of the object and to answer questions related to it.

This installation has only one NFC reader (the boat) connected to one projector (within the case) and 13 NFC tags attached to the map, one for each image.[3]

We will now follow the steps of the team at Museum Camp that repurposed the blueprint installation about WWII to create their own installation about Mobility in the Mediterranean.[4] This will provide an illustration of how the Toolkit works.

4.1. *Finding inspiration in the authoring tool*

The meSch Toolkit uses the metaphor of cooking to describe blueprints of interactive installations. Blueprints are called "recipes" and are collected in an online "magazine" (Figure 4); this magazine can be browsed or filtered, for example, to find recipes that used the same hardware, were authored for a similar heritage setting (e.g., for the outdoors), or created for a similar audience. The preview of a recipe lists the "ingredients" (the specific technical components), information on the interaction model, and its target audience (e.g., a quest for children vs. a self-led visit for adults). The Mobility team at Museum Camp chose the WWII recipe and cloned it into "My Cookbook," containing the recipes for the individual user account. Opening the cloned recipe takes the user to the editing section (Figure 5) composed of five tabs that map the steps needed to edit and deploy a recipe (steps 2 to 5 in Figure 1). A recipe is a blueprint of an interaction: by reusing the WWII recipe, the Mobility team learned how to use the meSch Toolkit by repurposing it to fit their own interaction concept.

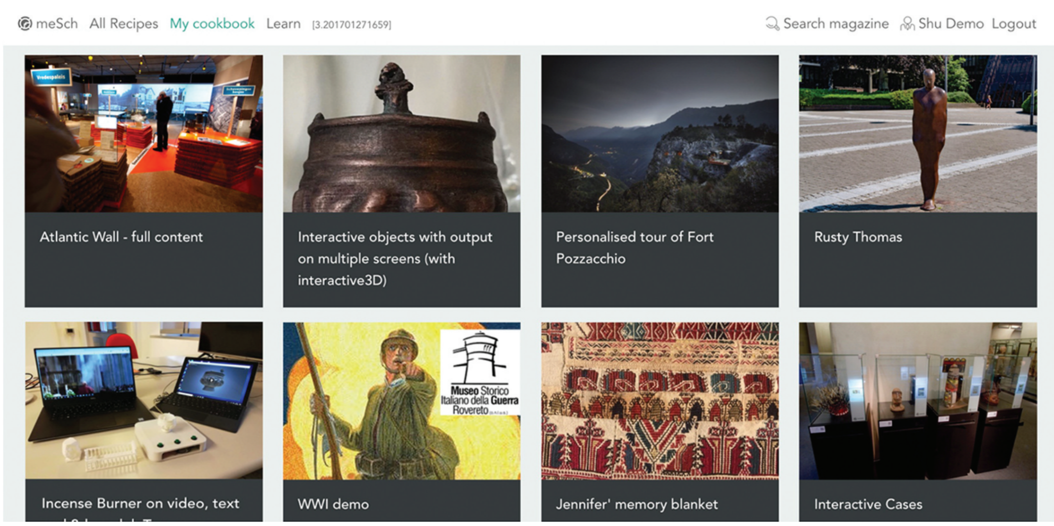

Figure 4. The catalog of recipes displayed in the authoring tool's magazine.

[3]The technology used in the two installations is precisely the same but used in reverse: in the WWII installation the visitor takes the NFC tag (replica) to the NFC reader (station), in the Mobility installation the visitor takes the NFC reader (the boat) to the NFC tags (the ports).

[4]The Mobility team chose the case as the exhibit to work with, decided the type of experience they wanted the visitors to have, and then started the implementation.

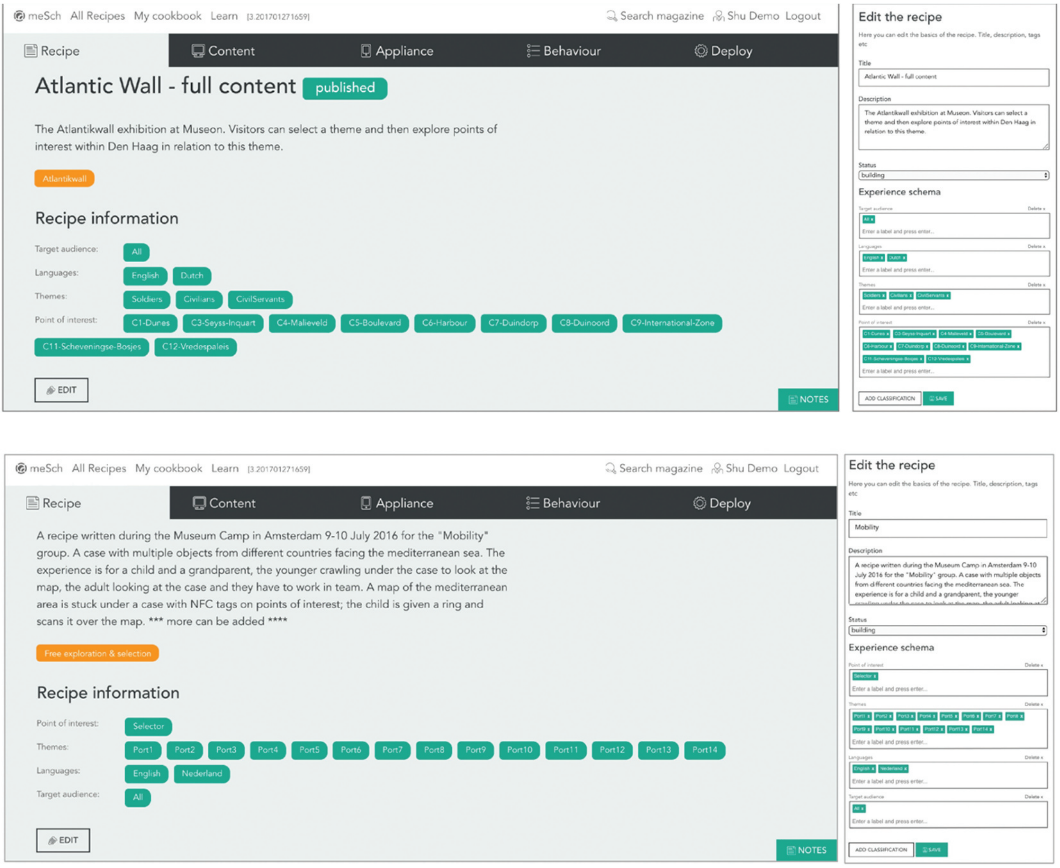

Figure 5. The recipe of the WWII installation (top) and the modified recipe for the mobility installation at museum camp (bottom).

4.2. *Reuse and repurpose*

A recipe copied from the magazine to the cookbook is ready to be changed. When customizing a recipe, the first step is to modify the concepts that control the content activation rules. The WWII recipe (in Figure 5, top) lists: (1) Target audience ("all," as there is no audience segmentation), (2) Languages (English or Dutch), (3) Themes (the three perspectives), and (4) Points of Interest – PoIs (the ten interactive stations).

When repurposing a recipe, the elements that are changed from the original recipe depend on the intended reuse. The Mobility team made only minimal changes, adding and removing tag values from Themes and PoIs (Figure 5, bottom), but keeping the same structure (even if the concept "Point of Interest" represented the boat (Selector) instead of the Ports). More radical changes would be to remove existing concepts or to add new ones (via the "add classification" button, Figure 5 panel on the right); the user could then add values for that concept. For example, "genre" can be added as a new concept with "dramatic" and "historical" as its values. This mechanism, based on the user creating their own features, means moving away from a system that sets a priori the features that can be used (Ardito et al., 2018; Diaz et al., 2017; Vayanou et al., 2014) and allows to model any desired interaction; it enables CHPs to experiment with a very wide range of settings that, in turn, implement very different experiences.

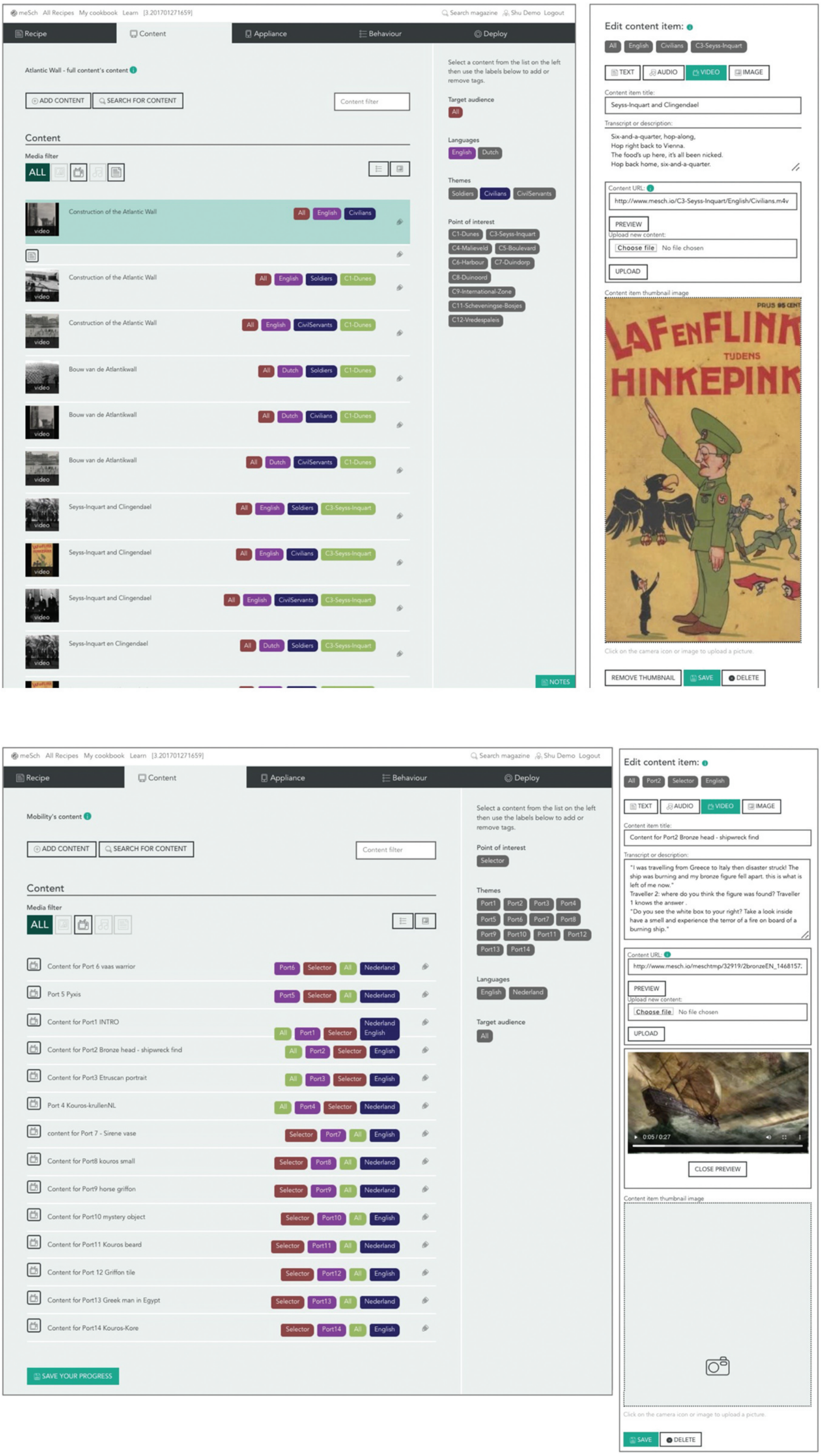

Figure 6. The Content tab of the WWII (top) and the Mobility (bottom): a content file is uploaded and its metadata edited (right); the content file is then tagged with the concept values (left).

4.3. *Structuring content*

When the concepts and their values have been defined, content can be annotated. Curators create multimedia content using the tools they are familiar with and upload the files, which are then tagged with the concepts defined in the previous step. To tag a file in the meSch Authoring Tool is to express the condition(s) under which this specific file will be delivered or played to the visitor. The Content tab (Figure 6, left) shows content files and the concepts with their values (tags): the user can attach or remove tags from the list associated with each file. A panel for editing the metadata and uploading the file unto the Authoring Tool opens when clicking on the pencil icon on each file line (Edit Content Item, Figure 6 right).

The editing of the content and its conditions (based on an abstract representation of files and tags) diverges from the popular map-based editing (Fidas et al., 2015; Katifori et al., 2014), as map-based editing does not support interactions that are not defined by the space such as single interactive installations (Wolf et al., 2015), single object augmentation (Van der Vaart & Damala, 2015), or the printing of personalized souvenirs (Not et al., 2017; Petrelli et al., 2016).[5] As such the meSch Authoring Tool allows to model a more extensive set of tangible interactions.

4.4. *Defining the tangible components*

The Appliance tab (Figure 7, left) specifies the physical components of the visiting experience. In symmetry with the Content tab, in the Appliance tab each physical element in the IoT configuration has a set of tags that specify what that hardware element represents: the actions of the visitor specified by the rule are those that trigger the corresponding file to play. The WWII exhibition appliances (Figure 7, top left) show that each Point of Interest maps a station in the exhibition, while each smart replica object represents a specific pair of values from the theme (Soldier, Civilian, CivilServant) and language (English or Dutch). When, for example, a visitor places the beer mug replica (Soldier, Dutch) on the interactive station C1-Dunes, the file tagged with the quadruple (Soldier, Dutch, all, C1-Dunes) is played.

The Mobility recipe has a similar logic but a different proportion of IoT components to reflect the different combinations of the same hardware elements (Figure 7, bottom left). When the boat (Selector) touches a port (Port3, English, all) the file corresponding to the quadruple (Selector, Port3, English, all) plays.

Each device's low-level attributes (such as the MAC address) can be edited (Figure 7, right); this information is then automatically included in the code that implements the behavior of the interactive installation.

The separation of the description of each IoT device into its logical representation (appliance) and its physical components (the hardware) enables the easy replacement of the device itself. For example, a recipe needs an appliance to detect proximity, but the type of hardware that could do it (which sensor technology e.g., infrared vs. ultrasound vs. video thermography) does not have to be specified.

Adding new hardware to the current IoT configuration can be done via "Load Available Devices" (Figure 7, bottom line on left panel), which automatically scans the environment (Kubitza & Schmidt, 2017) and displays the devices currently active in its surroundings; a click imports them into the editing area (the IoT Kit imported devices are shown in Figure 7 bottom left: MediaNode delivers the video output, Ring1 is an NFC reader, Tag# is an NFC tag). At this point, the editing of the cloned blueprint is complete and the new recipe can be deployed (as explained below) to the distributed physical devices, in the IoT configuration, ready to be tested.

[5]Moreover, editing via a physical map would make it difficult to rearrange an existing exhibition to another space, as it happens with traveling exhibitions.

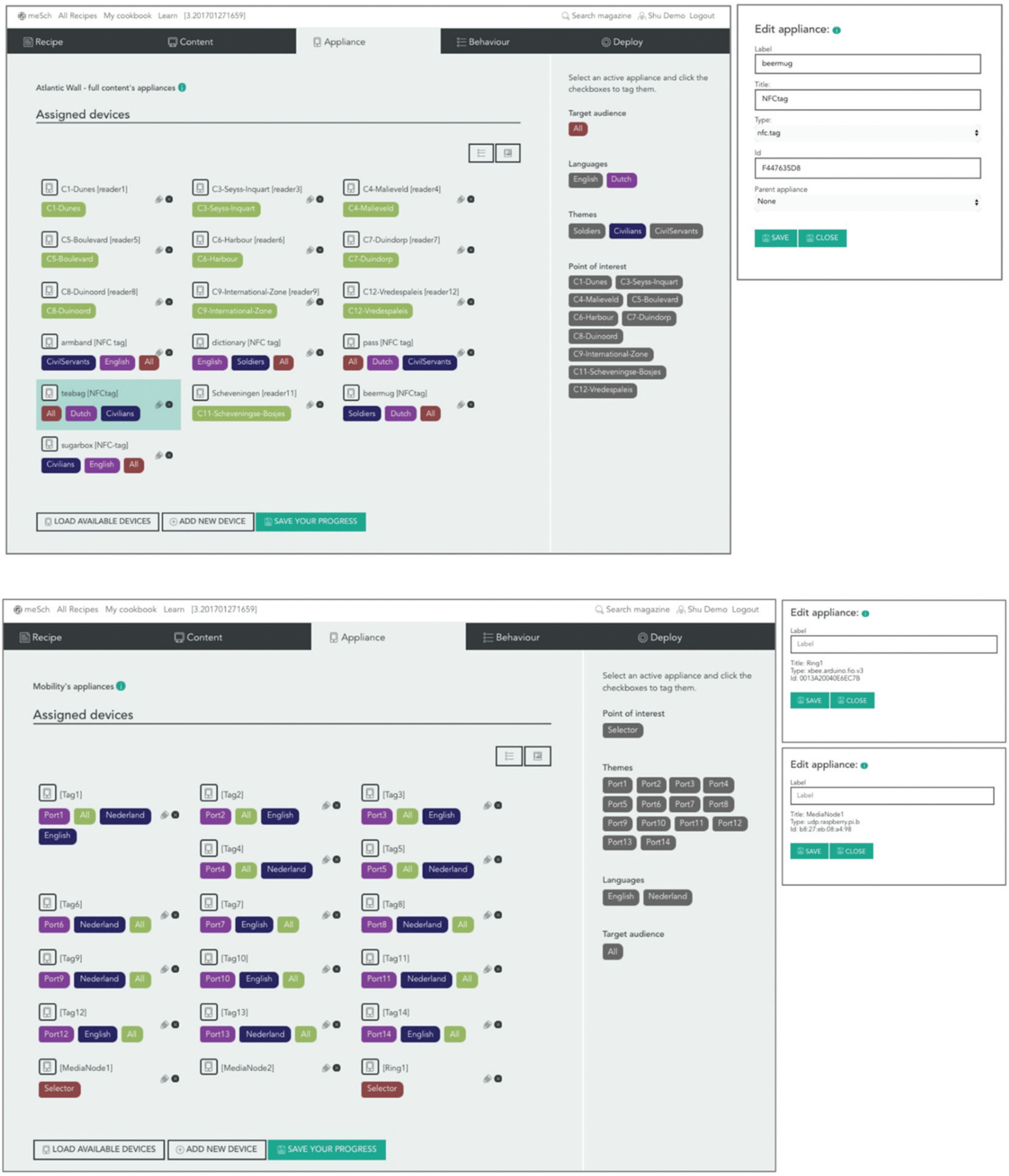

Figure 7. The appliance tab of the WWII (top) and the Mobility (bottom) recipes show how the same devices have been reorganized to support a different concept; each appliance is tagged with the appropriate part of the condition (left panel). Each appliance can be edited (right panel).

4.5. *Controlling the interactive behavior*

The "Behaviour" tab contains the actual instructions for execution, i.e. the script that will perform the interactive behavior when the installation is in use. Editing the behavior requires technical skills in both understanding what is already there and being able to modify it. The Behavior tab shows the interaction rules in their JavaScript format available for editing by users with programming skills (such as interaction designers who might collaborate with CHPs on an exhibition). In the case of the Mobility recipe, the JavaScript of the original WWII recipe needed a minor change in the way the video was played, which was implemented by technical support staff at the Museum Camp modifying the JavaScript.

When the editing of all the parts of the recipe is complete, the package of the content items (the narrative), the appliance (IoT configuration), the tags and the corresponding script are transferred from the online editor to the IoT devices for testing via the deployment functionality. This is done in the "Deploy" tab that also checks the consistency of the content-interaction-devices tagging. The deployment is instantaneous, so that the changes involving content, annotations or parameters can immediately be tested onsite (Kubitza & Schmidt, 2017), thus supporting fast prototyping and inviting users to experiment more broadly.

The recipe is now complete and the final installation can be taken onto the exhibition floor for the visitors to interact with. After testing it, the authors can decide to share their new recipe onto the magazine for others to see and reuse.

After explaining how the Toolkit functions, we now move on to present the Toolkit's evaluation.

5. Workshops as evaluation methodology: the "Authoring Feasts"

The "Authoring Feasts" (AF) were a series of three two-day workshops where a number of participants external to our project were engaged in creating tangible interactive installations by means of the meSch Toolkit. This was the last stage of an iterative cycle where earlier prototypes were evaluated with CHPs engaged in the project. The AFs were held at partner sites in the UK, the Netherlands and Ireland, and were publicly advertised through channels such as mailing lists and social media. The AFs were not the only way the Toolkit was assessed, as it was used by project partners to develop interactive exhibitions, however it was the most substantial way in which the interaction of external users, unfamiliar with the Toolkit, was observed. The motivation for using workshops, rather than more structured evaluation trials, is threefold: firstly, for assessing the Toolkit's effectiveness to communicate the potential of novel technology; secondly to let participants be free in their creative ideation; thirdly to approximate a naturalistic use of the Toolkit as part of a collaborative way of working (rather than in standalone trials) as it happens most commonly in exhibition design in museums, where team members take on complementary roles and use professional tools in various ways. Workshops are a well-established methodology in interaction design and participatory design, not only for generating creative ideas but also for establishing platforms for cooperation and shared decision-making (Halskov & Dalsgård, 2006). They have also been effective for establishing community participation and rapport (Le Dantec & Fox, 2015). Rosner et al. (2016) discuss hands-on maker workshops as sites of research and opportunities for knowledge building, as well as reflexive opportunities for the researchers. Finally, workshopping is an established approach to facilitate and sustain DIY and technology exploration exercises, given their socially supportive frame (Lundbjerg et al., 2017; Mellis & Buechley, 2014). The Authoring Feasts facilitated all these aspects: they provided a frame for creative ideation and team cooperation through the Toolkit, established relationships between the project team and communities of external end-users in three countries, and provided a supportive frame for approaching and adapting a novel software/hardware platform.

5.1. *Authoring feasts design and planning*

As we mentioned earlier, the Toolkit was first tested with CHPs at Museum Camp. This first instance of use in the hands of external CHPs can be considered as a pilot and it was important for planning the Authoring Feasts (AFs). For example, we observed that groups of five were too large for each participant to have a satisfactory hands-on experience with the Toolkit. Furthermore, at the Museum Camp the facilitators moved between groups, with the result that each group received different and sometimes conflicting advice from different facilitators; it was then agreed that this should be avoided henceforth. We also saw that participants particularly enjoyed making tangible artifacts, and therefore decided that (digital) fabrication should be introduced as early as possible in the AFs. Finally, the three groups that used the Toolkit at Museum Camp (12 participants in total) showed an excellent degree of independence in using the Toolkit and were able to troubleshoot their own recipes without the intervention of the technical support. This gave us confidence to run a larger scale program of workshops.

All three AFs were organized around a general common structure, albeit with small variations to accommodate differences in participants and settings. The common intent was to gain a better understanding of the potential that the Toolkit holds for the cultural heritage sector, of how easy it is to use, how it fits in the creative process of designing interactive exhibits, and what can be achieved with it over a short and intensive period of time (2 full days). Participants used the full Toolkit – i.e., Authoring Tool and IoT Kit – for adapting, customizing, and deploying existing recipes or, in a few cases, to create new ones. The AFs were all held in design labs/studios at three partner sites and took place within a two-month period.

5.2. *Participants and procedures*

We were mindful of keeping participant numbers manageable in terms of the support that they might need: AF1 featured 11 participants split into 4 groups; AF2, 8 participants split into 3 groups; AF3 had 12 participants also split into 3 groups. A large majority of the participants were CHPs with limited technical knowledge (Table 1). Others were designers, postgraduate students and researchers with an interest in both interaction design and exhibition design – bringing a set of skills that would be likely to feature in an exhibition design team.

AF organizers made available to participants resources for prototyping or access to FabLabs, help with using software for content creation, and technical and fabrication support. The overall common structure of the AF was as follows:

- *Group forming*: to create balanced groups with museum, creative, and technical expertise, participants were assigned to groups by the organizers on the basis of their profiles.
- *Ice-breaker* group activities were used for the participants to get to know each other.
- *Overview of and tutorial on the Toolkit*: the rationale for the Toolkit, its features and the installations created as part of the project were presented; a hands-on familiarization task to explore and practice using the Toolkit was also available.
- *Brainstorming* on heritage topics: each group discussed selected heritage items they wanted to work with and identified the focus of their installation design.
- *Scenario detailing*: working independently, each group developed a tangible interaction scenario for the exhibit they chose; in this phase they took decisions about the narrative underpinning the installation.
- *Prototyping*: via storyboarding, paper prototyping, but also via digital fabrication.
- Implementation and testing: using the Toolkit, the groups materialized their ideas; they reused an existing recipe or coded a new behavior, created the content, set up the IoT configuration, deployed and tested the recipe, troubleshooted, and amended the recipe as needed.
- *Exhibition*: each group presented their work to the other participants.
- *Feedback*: comments on both the Toolkit and the workshop experience were collected via focus group or questionnaire.

Each AF resulted in several prototype installations conceived and designed by the participants at various levels of completeness and sophistication (see Table 1 and Appendix). How far a group would go toward implementing their concept depended on various factors, as discussed below. It should be noted that AF1 and AF3 had an open call for participation resulting in groups of strangers

Table 1. The 30 participants taking part in the authoring feasts, their group and installations. More information on the installations and group dynamics can be found in the Appendix.

Authoring Feast (AF)	Installation title	Installation description	Group members	Toolkit Use
Authoring Feast 1 (AF1) UK	Tea for one	A small teapot in the center of a table set for tea played the nursery rhyme *I'm a little teapot* when picked up and used to pour tea into a cup; placing the cup on one of the four places at the table played a snippet of oral history told by a war widow.	P1.1 – CHP (museum director) – M (male) P1.2 – CHP (content officer) – F (female) P1.3 – Interaction designer (academic) – F	Toolkit driven
	Fingertip browsing	A set of old glass projection slides depicting Australia in the 1800s could be browsed by pointing a finger at different positions in the stack, and a projector showed the slide currently "touched" by the user's finger. A slideshow went on continuously when the finger moved up and down the rack; when the finger stopped on a slide, a prerecorded voice delivered content connected to it.	P1.4 – CHP (museum education officer) – F P1.5 – Designer (academic) – M P1.6 – IT specialist (professional) – M	Installation driven
	My collection	Replicas of miniature souvenir books could be worn as brooches/badges while visiting an exhibition. Visitors could "collect" up to three favorite exhibits by scanning markers at chosen display cases with the brooch itself. When exiting the exhibition, the brooch would trigger the printing of content related to each collected exhibit, and the printout could be kept as memento.	P1.7 – Digital humanities (PhD student) – F P1.8 – CHP (digital library officer) – M P1.9 – IT specialist (technical officer) – M	Toolkit driven
	Vanity desk	A vanity unit with four desk drawers containing paper models of women's underwear and clothes from different eras. "Dressing" the silhouette of a mannequin placed on the desktop with either underwear or "formal" clothing played corresponding video in the mirror of the vanity unit.	P1.10 – CHP (museum volunteer staff) – F P1.11 – Digital humanities (academic) – F	Installation driven

(*Continued*)

Table 1. (Continued).

Authoring Feast (AF)	Installation title	Installation description	Group members	Toolkit Use
Authoring Feast 2 (AF2) The Netherlands	Interactive stethoscope	The prototype resembled an old stethoscope to fit the theme of a museum exhibiting a medical collection. One end of the prototype scanned different NFC tags embedded into objects' labels, each representing a category of information/ themed tour, while the other end contained a speaker for playing audio content when held close to the one's ear.	P2.12 – CHP (curator) – F P2.13 – designer working for NGO – F	Content driven
	Beaker interactive hologram	A hologram that showed how an ancient beaker (currently kept in a dark room in the museum, and going unnoticed by most of the visitors) was made and used. The hologram's projection was activated through a proximity sensor.	P2.14 – CHP – F P2.15 – CHP – F P2.16 – Interaction designer, M	Installation driven
	Who destroyed the dykes?	An interactive quiz for school children visiting a museum of maritime history. Four figurines of sea animals (a barnacle, a gribble, a pile worm and a sea mussel) were used to trigger different videos. The goal was to find out which animal is a threat to the dykes. In three of the videos, the animals were just floating around the dykes, while in the fourth the pile worm made the dykes disappear.	P2.17 – CHP – F P2.18 – CHP – F P2.19 – Designer, M	Content driven
Authoring Feast 3 (AF3) Ireland	Well of wisdom	Installation envisioned for an existing viewing platform near a wall mosaic depicting the legendary origins of the Shannon river. A visitor would choose a replica "hazelnut" signifying their preferred language and drop it into a "well of wisdom" (a receptacle with a projection and sound of water) to trigger an audio-video explanation of the legend in that language.	P3.20 – CHP – F P3.21 – CHP – F P3.22 – Interaction designer, M	Content driven
	Rusty Thomas	Installation inspired by a cast iron sculpture of a human figure by Antony Gormley, exhibited on campus and nicknamed "Rusty" or 'Brown Thomas.' Placing a university ID card on parts of the replica statue's body would trigger sound snippets on different themes: the brain triggered content on the history of the statue; the heart triggered motivational and encouraging phrases; etc.	P3.23 – CHP – F P3.24 – CHP – F P3.25 – CHP – F	Installation driven
	Leaf guide	A tangible multi-theme portable guide, called The Leaf, that delivers auditory content at different locations on the Campus Art Trail. The auditory content connects art with the natural world, both strong features of the campus and of its collection of public art.	P3.26 – CHP (Education officer), F P3.27 – Administrator, heritage organization, M P3.28 – Interaction Design PhD student, F P3.29 – Interaction Design master student, M P3.30 – Interaction Design master student, F	Content driven

working together, while AF2 worked with three pre-identified museums, and small groups of colleagues arrived at AF2 with preselected exhibits and content and, in one case, with a pre-set idea of what they wanted to implement.

5.3. Data collection, analysis, and results

During all AFs, we gathered data on how the workshops unfolded using multiple methods to collect a range of data types (i.e. observations, interaction logs, questionnaires, and focus groups). Although multiple methods introduce complexity in the data analysis and require fusing the results, they provide the means for triangulation, "the use of multiple sources to enhance the rigour of the research" (Robson, 2002). The data collected from the different sources may be unbalanced, e.g., observations recorded the behavior of everyone, while only some contributed to the focus group discussions; yet the multiplicity of data sources mitigates the limitation of a single method and increases the validity of the study.

In our study we performed *data triangulation* by using more than one method for data collection, *observer triangulation* by having more than one observer, and *methodological triangulation* by combining different approaches (Robson, 2002). The three combined do strengthen the validity of our findings:

- Triangulation allowed us to study multiple facets of the research simultaneously: individual participants were asked to *collaborate* to carry out a *creative activity* using the Toolkit as *technological support*. By triangulation we have been able to address both the process of collaborating on a shared creative task as well as to assess the structure of the Toolkit.
- Triangulation enhanced interpretability of the data: e.g., the logs provided evidence of observed behaviors, observations offered insights on the interaction patterns that emerged from the log analysis. By triangulation we were able to limit, possibly dispel, "inappropriate certainty", the belief to have found the right answer when a single method is used, as complementary data may reveal "negative cases" that need to be explained in the broader context of such complex research (Robson, 2002).

Data sources include: naturalistic and structured observations (through video, photos and note-taking); participant observation (by each group's facilitator); debriefings with participants post-activity (questionnaires and focus groups); and interaction logs. Each source provided different data to a different granularity, for example, only the logs allowed us to inspect the interaction with the toolkit at the level of a single action and therefore to identify patterns of use, while group dynamics emerged through the observations. As described in detail below, each data set was analyzed using the most appropriate technique for the type of data in hand; results from each source where then compared and contrasted in an iterative process that, at times, sent us back to carry out further or different data analysis to, finally, converge toward a single and coherent interpretation.

Observational datasets were analyzed thematically through repeated readings by individual researchers and in small teams, making connections between AFs (Braun & Clarke, 2006). Participants' opinions collected at debriefing (questionnaires at AF1, focus groups at AF2 and AF3) were aggregated and thematically analyzed to identify emerging issues across the three events. More in detail, different analysis techniques were used at different points: we started with repeated reading of the narrative-based material to identify recurrent issues that resulted in a set of codes. In the next iteration we applied aggregation techniques that started from the codes to abstract them into clusters and – finally – broad themes (see Table 2). Out of the 64 comments, three broad topics emerged: opinions about the toolkit (34 comments, both positive −24- and negative −10); forecasting adoption (23 comments, both obstacles −13- and potential −10); and comments about the workshops (7 comments) (Table 2). While some comments are consistent across the AFs, e.g., the consensus around the ease of use of the Toolkit or the need for more documentation, other

Table 2. An overview of the thematic analysis done on feedback comments collected from questionnaires and focus groups.

Themes	Clusters	Codes	"Quotes"(AFs)
Toolkit	Positive (24)	Ease of use, control, look and feel (11)	*"Easy integration of media and triggers"* (AF1) *"Easy to connect (visitor) behaviour and technology set up"* (AF2) *"Achievable, not overly technically difficult for the museum professional"* (AF3)
		Creative exploration and fast prototyping (7)	*"It was great to see ideas instantly in action"* (AF1) *"Easy for early testing and adaption/learning as part of the development process"* (AF2) *"The creativity of the past two days made me think of possible uses"* (AF3)
		Flexibility and adaptability (6)	*"I liked the modular approach"* (AF1) *"Applicable to many questions the museum might have in terms of interactivity"* (AF2) *"Adaptable, content and technology used for one installation can be extended and re-programmed for new exhibitions"* (AF3)
	Negative (10)	Technical help and support (7)	*"Instruction manual – with pictures – to support use back at home"* (AF1) *"A list of requirements & do/don't for interactive installations in museum (e.g., 'make sure you have a stable internet connection')"* (AF2) *"More information needed on the system's technical specifications"* (AF3)
		Technical limitation and extensibility (3)	*"Opportunities for more complex behaviour, conditionality, support for authoring in situ other than sat at a computer"* (AF1) *"Can it do smell & heat/cold sensory?"* (AF1) *"Add security features"* (AF3)
Workshop	(7)	Technical (2)	*"Fix the small bugs"* (AF1)
		Organizational (3)	*"More time and more laptops at the workshop to experiment with software"* (AF3)
		Inspirational (2)	*"Encourage more creative and explorative behaviours"* (AF3)
Adoption	Positive (9)	Value on the exhibition floor (7)	*"Enriching an exhibition"* (AF2) *"It's kinaesthetic aspect: one of the biggest points of criticism that we get in the library is that there is no touching – this is a way of creating 'feely, touchy' "* (AF3) *"Opens up possibilities for existing exhibits"* (AF3)
		Creativity and Independence (2)	*"It offers more scope for creativity and imagination in exhibitions"* (AF3)
	Negative (15)	Changing mind-set (3)	*"First it's necessary to change the old-fashioned mind set of curators who are averse to new technology"* (AF3) *"Buy-in from senior management/the rest of staff"* (AF3)
		Technical and creative challenges (5)	*"More understanding of how much input/expertise would be needed to set up in our museum, e.g., can we add our new appliances, what documentation is available? "* (AF1) *"I wonder about our own ability to design user-friendly devices for a museum journey"* (AF2)
		Costs and funding (5)	*"We are a charity organisation, it would have to be very clear how much realising something would cost"* (AF3) *"Funding is a key issue, and so is training"* (AF3)
		Impact on current layout (2)	*"Changes to current exhibition layouts would be needed to make space for any technology"* (AF3) *"Can one use it in an outdoor setting (National Park)? "* (AF3)

comments seem to cluster in a specific AF, e.g., issues with adoption in AF3, and in a few cases opposite comments are made by different participants in the same AF.

The interaction with the meSch Toolkit was automatically logged. We recorded time-stamped actions such as navigation (i.e., moving between the magazine and the cookbook, as well as on the different recipe editing tabs), cloning and editing a recipe (i.e., changing concepts; uploading and tagging content; uploading and tagging appliances), the deployment of the recipe on the IoT configuration (i.e., marking the start of the testing phase). Overall, 5,388 log entries were recorded across the three events. Logs gathered at each AF were split by group; their actions were then analyzed to identify emerging patterns of behavior, e.g., the editing of a recipe vs. the browsing of the toolkit. The logs were cross-analyzed with the planned schedule of tasks over the 2 days to identify, for example, which part of the log mapped on the familiarization activity and which on the completion of a group's own recipe. The recipe on which groups were working on and the type of actions, e.g., browsing, saving, deploying, were also looked at to identify the type of activity they were engaged with, e.g., exploration, creation, testing. We also extracted specific log sequences and cross-examined them with observational data to identify specific patterns of use by different groups.

The observational, debriefing, and log data collected for each group were triangulated providing us with an in-depth understanding of each group's use of the toolkit and of their activities and attitude. The groups' data was then further analyzed across the three AFs using thematic analysis to identify phenomena recurring across all the events. Four dimensions emerged: toolkit in the context of group dynamics; process; toolkit's role in recipe reuse; and toolkit use instances. The discussion below clusters findings from across the data sets; where relevant, we explicitly refer to a specific data set.

5.4. Toolkit use in the context of different group dynamics

The ten groups displayed different dynamics in the way they developed ideas and worked, with corresponding differences in how the toolkit was used in support of their process. Broadly speaking, seven groups were observed to work with a very good degree of internal agreement, while three were less fluid in their collaboration. Of the seven groups that did not display major disagreements and arguments, all the three taking part in AF2 arrived at the event as an already-formed self-selected team, which means they had known each other longer, had already selected the exhibits they wanted to work on, and discussed the type of visitors' experience they wanted to achieve; if they experienced any disagreements, these did not seem evident or to affect how they worked together with the Toolkit at AF2. As we mentioned, three groups encountered significant difficulties in collaborating and finding agreement (Fingertip Browsing and My Collection in AF1; Leaf Guide in AF3), and they were unable to implement their concept. This seems to be due to using a lot of the time available for discussing and arguing their differences, rather than finding difficulties in using the Toolkit. Fingertip Browsing could not agree on the physical form of the installation and decided quite late on the second day leaving P1.6 frustrated at being unable to dedicate more time to explore the Toolkit: "*I spent very little time on the toolkit, I was busy building and making content. I do like it very much though from what I saw*" (P1.6 debriefing comments).

The My Collection group experienced tensions quite early during the familiarization task when two members (P1.8 and P1.9) found themselves at odds with each other several times on the "right" sequence of editing on the Toolkit. The toolkit is open, there is no prescribed sequence, and such openness might have impacted on how difficult it was for this group to negotiate and compromise, as both P1.8 and P1.9 were right in their views, and both sequences of editing were workable. Even when, on the second day, it was clear My Collection would not be able to test their concept (see discussion regarding recipe reuse below), this group did not try to rework their concept in order to quickly build it and test it, as Fingertip Browsing managed to do, possibly showing that either disagreements among the members of the group were still strong or that they were still behind in the process after belatedly finding an agreement.

Leaf Guide at AF3 also faced difficulties in collaborating, and their use of the Toolkit was affected by this. Two CHPs in the team put more effort in creating polished and extensive content and were not that interested in contributing to detailing the interaction; furthermore, the logs show two different appliances for the same content, a traditional audio guide (app on Android) and an NFC interaction that was never worked out in detail, showing that different group members had implemented different ideas on how the interaction should unfold.

5.5. Toolkit use in the collaborative process

The triangulation of observations and logs showed three different types of process driven by what the group was interested in the most: *content driven, installation driven*, and *toolkit driven* (see Table 1). The work of four groups was *driven* by the *content* they created: Interactive Stethoscope and Who Destroyed the Dykes in AF2; Well of Wisdom and Leaf Guide in AF3. Interactive Stethoscope and Who Destroyed the Dykes arrived at the event with ideas for the themes they intended to use for their exhibit. Interactive Stethoscope used text-to-speech software to create the digital audio files out of existing text from the museum catalog but soon realized that museum labels are not effective when played as audio, compelling them to write dedicated text for this medium. By arriving at the event with a general idea of what their installation could be about, Interactive Stethoscope were quick to prototype; this pushed them to reflect not only on the interaction, but also on the type of content that would be the best fit: the log recorded an uncommonly high number of actions, including several content deletions showing that this group was developing the content and the physical prototype at the same time.

The Who Destroyed the Dykes team showed a similar trajectory: they arrived with an exhibition artifact in mind (a damaged piece of wood), were quick to source mixed media mixed media (text, images, video clips) from their museum website to realize the concept of a quiz, and started to prepare the content before the overall interaction was completely defined. Further evidence for this content-prototyping approach is the media developed for the final installation: a set of stop-motion animations of sea creatures consistent across the installation, as opposed to mixed media reused museum material this group brought to AF2. The log confirms this: several files with text descriptions, images, and videos were uploaded but left untagged showing this group was uploading content before they had decided on an interactive context in which this content would fit. Interactive Stethoscope and Who Destroyed the Dykes contrast with groups whose process was driven by the toolkit or by their installation idea, as these groups uploaded in the recipe only content that was needed for the interaction they had in mind.

In AF3, Well of Wisdom and Leaf Guide showed a similar process driven by content. Whereas in AF2 the groups arrived with museum content, in AF3 the content was created during the workshop. These teams' time was dedicated to composing high-quality video and sound recordings (Well of Wisdom), reciting poetry and selecting music (Leaf Guide), leaving little to realizing a complete and functioning interactive.

Installation driven teams (Fingertip Browsing and Vanity Desk in AF1, Rusty Thomas in AF3) wanted to achieve a finished interactive installation. Both Vanity Desk and Rusty Thomas followed a logical progression of steps to achieve this: concept creation, detailed design, content creation, and testing. They were very efficient and only created and uploaded the content they needed to test and deploy their final concept as confirmed by their comments: "*the system is easy to use and logic [sic]*" P1.10 and "*Chance to work in a hands-on manner with technology for exhibition work*" P3.24. The dynamic of Fingertip Browsing was different: late on the second day, this problematic group agreed on using a proximity sensor that, when tested in the prototype configuration, could not provide the millimetric precision requested by the concept; the group then pragmatically changed their design to NFC tags to test and deploy their content on a working prototype.

The three teams that were *toolkit driven* (Tea for One and My Collection in AF1, Beaker Interactive Hologram in AF2) spent substantial time on the Toolkit exploring its many aspects (both AF1 teams) or pushing its boundaries (Beaker Interactive Hologram extended the hardware kit). The log clearly shows Tea for One's interest in what was possible to do with the Toolkit beyond the completion of the task: several activity sessions over the 2 days show Tea for One looked at the training tasks, at other recipes in the magazine, and at the JavaScript code after they made changes in their installation recipe. Their comments show they inspected the Toolkit with the eye of early adopters: "*it seemed that a sensor could only be programmed to trigger one piece of content*" P1.1. The members of My Collection also spent a lot of time exploring the Toolkit: this could be due to the fact that they were waiting for technical support to be available, however, two members of this team engaged the facilitators in extended discussions on what the Toolkit could or could not do, and the rationale behind certain decisions in developing the system.

The Beaker Interactive Hologram team arrived at AF2 with a chosen object in mind, its full interpretation, and the explicit intention of implementing an interactive hologram; they spent most of their time on the toolkit and making the key elements for their installation, as explained below.

5.6. *Role of the toolkit in reusing blueprint recipes*

A key concept in the design rationale for the meSch Toolkit was the reuse and repurpose of existing blueprints: i.e. the design rather than the underlying technology provides the novelty of the installation. Groups displayed three different approaches to this, which emerged in their use of the Toolkit: *reuse*, when a sample recipe was reused in its entirety and only adjusted; *add-on*, when a blueprint was modified by adding a feature; and *anew*, when a new interactive behavior was written from scratch and a new recipe created.

Four groups (Vanity Desk in AF1; Who Destroyed the Dykes in AF2; Well of Wisdom and Rusty Thomas in AF3) *reused* precisely the NFC-tags-and-reader blueprint used in WWII (Figure 2), while a fifth (Leaf Guide in AF3) shifted their design between reusing two given blueprints (NFC and audio trail). As they reused recipes, the creative efforts of these groups focused on imaginative interactions, content and making more refined installations.

Three groups *added-on* to existing recipes. Interestingly, two groups in two different AFs added the same feature, a mobile phone to deliver mobile audio (Tea for One in AF1, Interactive Stethoscope in AF2), which needed limited technical support. The My Collection team in AF1 instead aimed to add a printer to the NFC recipe so to print out a souvenir; an example of this (shown at the beginning of the event) was the inspiration; however, to realize My Collection the printer had to be connected to the NFC reader and therefore some coding was needed to reconfigure the appliances and amend the behavior in the recipe.

Two groups (Fingertip Browsing in AF1, Beaker Interactive Hologram in AF2) were explicit in their intention to create a recipe *anew*. The latter arrived at AF2 with the shared idea of an interactive hologram to highlight an important exhibit in their collection that was overlooked by visitors. On the other hand, P1.6 (an IT expert) was the influencer of Fingertip Browsing's decision: "*I wanted to push the Toolkit to its limit.*" As the meSch Toolkit was designed to be open and extendable, it is worth comparing these two cases.

As discussed above, this team had a complicated group dynamic. When the group finally found an agreement, the proximity sensor included in the IoT Kit was tested only to find out its sensitivity was insufficient to realize the design idea: it could not detect the position of the finger at the level of granularity requested by the design, i.e. a few millimeters change in the position. Adapting the recipe to introduce another more precise sensor (such as a potentiometer or a more accurate proximity sensor) was not feasible within the remaining time, as this would have required extending the Toolkit with new hardware. On the other hand, the Beaker Interactive Hologram team that arrived at AF2 with a precise design to implement: in this case the technical support had the time to help extend the IoT Kit. Indeed, the data log for this group shows many instances of saving the recipe, loading appliances, and deployment – far more than what recorded for any other group across all AFs. This can be tracked to the extension of the Toolkit to add the hologram as an output mode, as this required the JavaScript for the new interaction to be written, tested, and debugged. Forward planning was essential to allow coding the new behavior and extending the hardware kit demonstrating that extending the IoT Kit can be done easily, but time and expertise are of the essence.

5.7. Toolkit use instances

The analysis of the logs shows the finer details of how the Toolkit was used by the groups. We clustered their behaviors into: *efficient*, when the purpose seemed to be to get the job done as smoothly as possible; *experimental*, when the group tried many different things (i.e. different media content, or appliance configurations); and *explorative*, when the main purpose emerging was to get to know the different functionalities of the Toolkit in depth. For Well of Wisdom in AF3 the log was too limited to infer their overall approach to using the Toolkit as this group encountered technical difficulties. We acknowledge this is a broad-brush classification based primarily on the analysis of the logs with minimal input from other data sources (e.g., observations, comments). However, we consider this relevant as it gives an idea on the different approaches adopted by the groups and therefore it provides some evidence on the flexibility of the meSch Toolkit.

Efficient groups were Vanity Desk and Fingertip Browsing in AF1, Beaker Interactive Hologram in AF2 and Rusty Thomas in AF3. Specifically, Rusty Thomas, Vanity Desk, and Beaker Interactive Hologram used the Toolkit to implement their concepts straight away; however, Rusty Thomas, after implementing their concept, went on creating a variation of their recipe with a different appliance showing a step into an experimental attitude with using the Toolkit. A similar behavior of trying different appliances was displayed by Fingertip Browsing: after their preferred implementation had to be abandoned, they swiftly moved on to implement their concept using NFC tags and reader. What is common across those four groups is the use of the Toolkit focused on implementing the task at hand and a limited navigation of what else the Toolkit had to offer.

Groups that displayed an *experimental* approach used the Toolkit to fast prototype different implementations. As mentioned above, Rusty Thomas showed an interest in experimenting with different appliances, but only once their main task was over. Instead, Interactive Stethoscope and Who Destroyed the Dykes experimented with content: both groups arrived at AF2 with pre-prepared content taken from their museums' catalogs, but were quick to create new content when they realized the effect of reusing content snippets such as labels was not as they expected. They experimented with new content in a series of fast prototyping cycles of content creation, deployment, and test. Both groups, but Who Destroyed the Dykes in particular, recorded the highest number of actions on content (Who Destroyed the Dykes deleted content 6 times while some groups have 0 removals). For these groups the decision of what content to include in the installation was not taken at the design desk, but during live use of the Toolkit via prototyping and testing.

Three groups were *explorative* (Tea for One and My Collection in AF1; Leaf Guide in AF3); they spent substantial time going through the many recipes in the magazine, watching the tutorials, making changes and looking at the underlying JavaScript. Their motivations seem to be different, though. Tea for One alternated bursts of implementation and exploration activities: observational data suggest the design and the editing were done in parallel rather than in sequence, showing openness and curiosity: "*the novelty of tagging as a mode of coding behaviour*" (P1.3) and "*more understanding of how much input/expertise would be needed to setup in our museum*" (P1.2). Overall their approach seems to be aimed at fully understanding the Toolkit and its potential more than at implementing a final interactive installation. Both My Collection and Leaf Guide may have explored the Toolkit as much as they did because they were filling time while technical issues were addressed (My Collection) or while complex content was developed (Leaf Guide). Indeed, observations showed two members of My Collection (P1.8 and P1.9) exploring the Toolkit independently from one another while the third member of the group (P1.7) prepared extended content. So this behavior could be a result of the difficulties in the group also as they preferred to explore the Toolkit individually rather than working as a team on an alternative setup and see their concept implemented onto a different hardware configuration.

6. Discussion

The data logs, observational notes and video recordings of episodes and moments in the interaction within each group for all AFs show that, while the composition of the groups meant that the flow and organization of work among them was (predictably) slightly different in each team, the meSch Toolkit was flexible enough to allow them to arrange work in ways that suited them and their overall goals, both as groups and as individuals. Tasks were assigned and roles held and sometimes shared. Everyone who was involved with the technology was able to use it and to weave it into their assigned tasks, albeit to different degrees of depth and complexity. The participants' comments (Table 2) confirm this: they consistently remarked on the ease of use and the flexibility of the kit across the three AFs.

Over just 2 days, it was possible for all groups in all AFs to envision an original concept and complete (or to come very close to completing) a tangible installation. With the exception of the Beaker Interactive Hologram in AF2, the fully completed installations (such as Tea for One and Vanity Desk in AF1, Interactive Stethoscope and Who Destroyed the Dykes in AF2, and Rusty Thomas in AF3) were a reworking of existing recipes using NFC technology, and this showed the ease of adapting the Toolkit to different settings/exhibition concepts, and the clarity of the "reuse" potential. Showing examples and inviting reuse and repurpose makes meSch different from other IoT toolkits that use examples as to jump-start projects (Content Toolkit by Dey et al., 2001), or as a quick-start guide (.NET Gadgeteer by Villar et al., 2012). Rather than supporting the single user, our intent is closer to that of building a community of makers (e.g., Arduino or LittleBits (Bdeir & Ullrich, 2011)) where people showcase their projects and share their experience, as well as code. Being part of a community inspires and facilitates learning, but it does not in itself stimulate creativity. To be creative means to generate one's own ideas. Some groups were more daring than others, and more coaching could push the more conservative/hesitant participants to try new things ("*Tell participants to 'think big' from the onset*" P3.24; "*Encourage more creative and explorative behaviours*" P3.26). It also suggests that perhaps the Toolkit could include links to resources for creative thinking (e.g., card decks[6]), teamwork support (e.g., activity planner), or other helpful external tools. For example, the groups who could not reach full completion spent a lot of time negotiating competing ideas: a more structured workshop that asked groups to deliver a solid concept earlier in the day may have forced those groups to find a compromise earlier leaving enough time for implementation, including an extension of the Toolkit.[7] This might be mitigated in situations not confined by the workshop format (e.g., more time available and the possibility to develop stronger working relationships). Furthermore, more technical support would be beneficial, particularly in the workshop format ("*More clarity on technical expertise needed during the prototyping process – this is unclear*" P3.21; "*We encountered technical difficulties*" P1.7).

All groups but one were able to use the Toolkit to assemble their multimedia content without any support; although Well of Wisdom did successfully complete the familiarization exercise with the Toolkit, they were stopped by technical issues. This seems to indicate that when the concept is clear in the users' mind, the mechanics of the meSch Toolkit are understandable and approachable.

The design of the Toolkit interface and interaction intended to support different roles we identified in exhibition design teams (curators, exhibition and content designers, interaction designers), as well as the different phases of the design process: from finding inspiration (the magazine with its many recipes), to amending an existing installation (editing the overall recipe), to uploading content (files and tagging) and setting up the physical components (appliances and devices). This "division of labour" follows from the fact that such varied expertise often belongs to different people from different institutions: the Toolkit would allow them to work independently and

[6]The GIFT project developed the VisitorBox Ideation Cards specific for museums https://gifting.digital/visitorbox-design-cards/ (accessed 2.6.2021).

[7]Beaker Interactive Hologram shows that the meSch Toolkit is extensible. However, one of the incomplete concepts, Fingertip Browsing, was implemented to a working prototype the day after AF1 by using a finer grained sensor.

asynchronously on different parts of the same project implemented by the different tabs/ functionalities.

meSch's ability to simultaneously cater to users with different skills sets it apart from other toolkits discussed in the literature that, instead, focus on a homogeneous group: either to facilitate non-technical users to include hardware in their concepts (Desolda et al., 2018; Hartmann et al., 2006), or programmers to easily integrate hardware in their systems (Villar et al., 2012; Marquardt & Greenberg 2012; Dey et al., 2001). Moreover, splitting the work seemed to focus the group's attention on a specific sub-task; in a way, the tabs decomposed the complex task of designing a new interactive exhibition into small, targeted, and manageable units. Each group then appropriated the Toolkit the way they saw fit: some did all the editing first and the testing after, some alternated the two, adding and testing a content item at the time, some worked individually on sub-tasks, while others did everything as a team. Comments from CHPs underline these points: "*It is collaborative – I have a strong sense that the Toolkit evolved from collaborative work with museums*" P3.22. This is a very different approach from the other toolkits for cultural heritage professionals (e.g., Ardito et al., 2018), which focussed on lowering the technical threshold to "enable [] end-users, not familiar with programming to create their interactive tools, thus becoming smart experience designers" (Desolda et al., 2018, p. 59). In meSch we designed sections to match expertise: a tab for those that curate the content, a tab for those who can code behavior, a tab for those that can handle hardware. In their final evaluation of ARTECT with museum professionals, Koleva et al. (2009) found that more technical users could not implement more advanced solutions and acknowledge that "the mixed skill sets of the teams involved in the assembly of hybrid artefacts also suggested the need for multiple levels of access to the underlying infrastructure" (pg. 1981). As the meSch Toolkit was co-designed with an extended group of museum professionals (Avram, Ciolfi et al. 2019, September-October), the different needs of the many experts involved in the process of designing, developing, and deploying interactive exhibitions were part of our initial brief. Below we discuss how the Toolkit's fit into the articulated process of designing and prototyping interactive installations.

6.1. *Envisioning*

In the early stages, groups had to imagine what installation they wanted to design, given the exhibit/ object they chose, irrespective of the technology available. As well as using their imagination, participants browsed through the dozens of recipes in the magazine to find inspiration, and some groups/individuals spent more time than others doing this. However, groups across the three AFs did not have the same attitude to the creative phase and did not spend time brainstorming different options. In AF2, the CHPs were invited to bring an object to the event around which their team would design the interaction; the Beaker Interactive Hologram team went further and arrived with a well-formed idea on what they wanted to implement. If, from one side, this attitude gave them enough time to extend the toolkit and create a new recipe, on the other it prevented them from brainstorming and exploring more tangible interaction concepts.

To think of interactions around heritage in the ways that the Toolkit enables them to was generally found inspiring: "*Love how it essentially integrates digital interactivity into a very physical activity – VERY COOL!*" P1.1; "*It allows people to interact with artefacts in a better way*" P3.24; this can also be seen as challenging: "*I wonder about our own ability to design user-friendly devices for a museum journey*" P3.21. Therefore, any support scaffolding the group vision and leading them toward possible implementations is of the utmost importance. The issue of how to strike a balance between giving examples and encouraging creativity is both essential and difficult. While in the course of a workshop, this can be adjusted by the facilitator, when the Toolkit is used independently, recommendation techniques and services could be used: for example, recommending a variety of suitable recipes for new users and their organizations (Not & Petrelli, 2019). Overall, there is a need to think of ways to inspire new concepts to go beyond the models of previous installations, and this is a more general point that emerged out of all the Authoring Feasts. One option could be to cluster the recipes in progressively more complex groups so that users can move from beginner to proficient. Another option is to design workshops dedicated to learning more advanced features, where for example, interaction designers could learn how to extend the meSch Toolkit with new hardware, whereas curators could learn how to use the Toolkit's personalization features so to prepare multiple content alternatives for specific audiences on the same hardware settings.

Fingertips Browsing, My Collection, and Beaker Interactive Hologram required extensions to the IoT Kit. While this was possible – as shown by Beaker Interactive Hologram, it required technical knowledge and time, both critical resources in the workshops and in everyday settings (for example, in small museums without in-house technical staff). The successful strategy for Beaker Interactive Hologram was a technical facilitator working with the group from the beginning as they arrived with the idea of a hologram. For Fingertip Browsing, the time was sufficient to extend the Kit, but the sensor available did not offer the precision required by the design, pointing to the need for a wider set of available components. My Collection also needed technical expertise, but the group just ran out of time. While the issue of technical expertise could be easily addressed in a workshop by providing more technical support, the issue remains open when the toolkit is in use at heritage institutions. The sharing of expertise within the Toolkit user community is key and is embedded in the magazine concept: most groups could see themselves contributing to this knowledge repository, sharing, and allowing others to be inspired and to reuse their work. The magazine could also be a source of forging new collaborations, for example, technically savvy users could share or offer their expertise to other users who are lacking on this front.

6.2. *Designing*

The organization of the meSch Toolkit user interface (motivated by the fact that exhibition design requires different roles, bringing together professionals with different skills) supported design group work: people could work asynchronously and independently on different parts of the same project. This supported division of labor, possibly by specialisms and interests, and allowed the groups to work following the process that suited them best. We saw clear examples of this earlier with some groups focusing mostly on the content, and others on the installation. While for some groups this was a reasoned choice, there was clearly friction within other teams. This resonates with previous research on how CHPs design interactive exhibitions (Maye et al., 2017, 2014): the composition of teams and the skill set applied to a project, no matter how small, are key to shaping how design will progress. The collaborative work facilitated by the Toolkit was one of the highlights for many participants, but this was of no help in groups with a tense relationship among members. While this is outside the remit of the Toolkit design, it is something to carefully monitor and consider for future reference. We could imagine how the Toolkit magazine could include resources for planning the work, with hints and tips on how to keep the project focused. The need for further support documentation was expressed by participants also with regard to other issues, such as technical specifications and possible IoT security issues.

The tab-based interface seemed to focus a group's attention on a specific part of the design process, reducing a complex problem into manageable subtasks. As we saw, this also allowed each group to appropriate and use the Toolkit for design in the way they saw fit: some did all the editing first and all the testing after and iterated to fix mistakes; others alternated uploading and testing, and proceeded by one small step at the time; others extended the Toolkit to include the technical feature they wanted their installation to have, as discussed above. This last instance is particularly important from the perspective of end-user programming, as it shows the potential for full appropriation of the tool.

6.3. *Rapid prototyping*

Overall, the meSch Toolkit was easy to use by all: while some had greater technical knowledge and expertise than others, all participants successfully used it for a variety of tasks. Participants were particularly fluent when working on their own implementation, i.e. having planned the prototype installation from the start and following a clear plan of action. This is evident particularly in the logs of those teams that were able to implement, test, and troubleshoot their installation in about 2 h in complete autonomy. Moreover, groups showed that the Toolkit could be effectively used by members of the same team with very different expertise working on different aspects of the same task: this was particularly clear in the work of the Beaker Interactive Hologram group, where the technical members of the team coded the behavior, extended the IoT Kit and edited the same recipe, while the museum experts prepared and uploaded the content. Furthermore, other groups split the work in such a way that they could work in parallel on different aspects of the same project. Some groups used the rapid prototyping stage to experiment with the IoT configurations, others to try out different types of content. The focus on the content was, for some groups, detrimental as it delayed the point in which they used the Toolkit to implement their concept, thus resulting in unfinished projects. A stricter schedule and closer coaching could help; however, it might be difficult to strike the right balance between leaving the group to freely discuss and explore and helping them focus their thoughts and progress.

Some participants commented on the fact that the technology has been clearly developed with and for CHPs: the design of the meSch Toolkit separates the content from the context of the interaction, and enables the CHPs to focus on what they care about the most – for some is the content, for others is the interaction. This is captured in the variety of the installations produced. Indeed, we found evidence throughout the datasets of much exploration in support of prototyping, e.g., looking at the many recipes in the magazine, playing the tutorials or copying and testing some recipes, and discussing alternatives to their own designs by testing them. Stimulating this explorative attitude was one of our goals in designing meSch: by reviewing and trying out what others have done, participants learned and built-up confidence in their ability to master the Toolkit and realize an actual installation.

The hands-on approach and the possibility of seeing their ideas implemented over two short days made many CHPs imagine the adoption of the technology at their institution. Table 2 shows that concerns were several and varied: internal resistance to digital technology, not having enough funding and expertise, not being creative enough, having to change the current exhibition layout. However, some CHPs expressed the opposite opinion stating that "*[the Toolkit] opens up new possibilities for existing exhibits*" P3.26, and "*there is more scope for creativity and imagination in exhibitions*" P3.21 possibly highlighting the diversity of attitudes in the heritage sector, with some institutions open and advanced in using technology and others being more reluctant or less skilled/informed.

There is evidence from observations and participants' comments that their experience of heritage shaped and affected their thinking: "*In a way [this technology] can be discreet – I am in an 18th century library setting, we do not want overuse of modern technology in historical settings.*" P3.21. Some prototypes were more difficult to realize through adapting existing recipes, such as Well of Wisdom and Leaf Guide in AF3 intended for large public art pieces. This is a matter of which recipes are available in the magazine to provide ideas and inspiration for various types of heritage and institutions. A definite improvement to the meSch Toolkit would be introducing examples to cover a wider variety of heritage settings. A broader take-up and lively community features on the platform could also mitigate these risks.

7. Conclusions

This paper offers two major contributions to HCI research: (i) the design of a toolkit with a strong physical component (e.g., sensors and actuators) for exploring and making tangible interactives in cultural heritage settings and (ii) a method to assess it that takes into account use in a socio-technical sense. A secondary contribution is the detailed evaluation of such a toolkit in use. We recognize the limitations of our study due to the workshop format, occurring outside of the everyday practices of museums and being limited in time (although, usually, workshops in HCI projects are limited to 1 day while ours lasted for 2 days), and featuring a selected 30 participants. We do feel, however, that the AFs were effective as frames for knowledge building and collaboration, and for relating instances of use of the meSch Toolkit with particular behaviors and attitudes that emerged in the groups when it came to teamwork and process. As such, our approach goes beyond the ways in which toolkits are generally evaluated (demonstration, usability, performance and heuristics (Ledo et al., 2018)) as we combine demonstration (finding inspiration in the magazine), usage (hands on by reusing a recipe), and performance (fast prototyping) with a group context (the teamwork) that resemble as close as possible the type of collaboration that occurs within heritage organizations. Our work thus significantly extends existing knowledge of what happens when toolkits are in the hands of end users. We go beyond the evaluation of the Toolkit and outline the transformational potential of democratizing advanced technology in the context of cultural heritage. This perspective fits with Fischer's framework of end-user development systems as means for transforming culture rather than simply as technological tools designed for users to build their own artifacts (2013). To transform a culture, such systems need to have specific characteristics with respect to their: (1) socio-technical environment; (2) meta-design; and (3) culture of participation. This means that to transform a culture a toolkit must be designed with certain specific features of openness and extensibility to allow its users to change it to fit their needs, but it should also support self-reflection and collaboration to foster creativity and evolution of skills and goals (Giaccardi & Fischer, 2008). Here we discuss how meSch fits Fischer's framework comparing it with other toolkits which have a strong hardware or physical component.

A socio-technical environment that embraces an "end-user as developer" approach places its user, as owner of the problem, in charge of defining and developing the solution; it allows and supports the users in creating, adapting, and changing the technology for their own individual goals (Fischer, 2013). The users become prosumers: they produce a solution to their problem and consume it. It could be argued this is the role of a toolkit: to enable its users to create their own complex solution starting from simpler blocks. However, how much effort is needed and who has the knowledge to use it depends on the toolkit itself. Most toolkits are designed for a specific user group, the most common distinction is between programmers (Context Toolkit by Dey et al., 2001; .NET Gadgeteer by Villar et al., 2012; Phidgets by Marquardt & Greenberg 2012) and non-technical users (ARTECT by Koleva et al., 2009 and Desolda et al, 2018 both targeted to cultural heritage users; d.tools by; Hartmann et al., 2006 to support designers of electronic products). We argue that toolkits should be designed to accommodate different skill levels and invite users to develop and move up the proficiency ladder. meSch acknowledges that the team involved in creating interactive exhibitions comprises different skills, including substantial technical knowledge, and cater to all: the creation of an interactive installation is split into sub-tasks for members of the team to work on the same goal while focussing on different aspects on the visitor's experience. Koleva et al. (2009) found later in their study with heritage professionals that more technical users would have liked to make a more advanced use of ARTECT than the interface allowed, confirming the value of our approach.

While meSch tab-interface allows technically savvy users to work on the hardware or code, the pivotal design choice of reusing and repurposing of existing recipes is a clear example of supporting non-technical users in successfully creating interactive installation with limited knowledge and in a short period of time. The workshops showed how participants adapted existing recipes to implement their own concepts in an autonomous way; their confidence in their ability to use the meSch

Toolkit increased with their growing understanding driven by their independent explorations. It shows the importance of *seeds*, "piece[s] of knowledge, content, or code that can be fundamentally created, evolved, and recombined by mechanisms that allow its sharing and modification." (Giaccardi & Fischer, 2008, p. 9) The value of "seeds" is clear in communities of makers such as Arduino or Instructables; but seeding mechanisms are rarely designed as part of a toolkit[8]; at the most, toolkits provide a few examples to get started. Some toolkits, particularly those targeted to programmers, allow users to add new modules (e.g., Context Toolkit by Dey et al., 2001; d.tools by Hartmann et al., 2006; NET. Gadgeteer by Villar et al., 2012). A form of seeding is toolkit extensibility, an expression of *meta-design* that "extends the traditional notion of system design [...] to allow users become co-designers and co-developers" resulting in the users being able to add to the system because of a mismatch between what the system offers and their needs (Fischer, 2013, p. 4). The meSch Toolkit is an example of meta-design as it can be extended with new hardware, as we saw with the Interactive Beaker and Fingertip Browsing groups who became co-developers of the Toolkit itself and created new seeds for others to reuse. Extensibility may be seen as in contrast with simplicity of use particularly for non-technical users in the sector of cultural heritage. Indeed, the two toolkits that specifically address the design of interactives in heritage limit their users to a single technology resulting in a single type of application, visual markers in ARTECT (Koleva et al., 2009) and RFID in EFESTO-SE (Desolda et al., 2018). In contrast, the set of sensors and actuators available in meSch is varied and expandable resulting in a much wider range of concepts that can be implemented starting a positive loop of sharing and reuse.

A culture of participation changes the role of the user from that of a prosumer (who produces and consumes their own application) to a more active role where insights and new knowledge are shared. By inviting users to share their recipes in the magazine for others to reuse, the meSch Toolkit provides the means to actively participate in the enrichment of the toolkit itself and in the community of practice that surrounds it. meSch recipes are "seeds [that] keep the system open to be adapted to emerging needs and situations" (Giaccardi & Fischer, 2008, p. 9). For the user extensions to become part of the toolkit and available to others, the toolkit itself has to be designed with a sharing platform such as the magazine in meSch. This, however, is not a step taken by any of the toolkits we surveyed, thus the expansion of the toolkit is limited to the individual creator-user.

In summary, discussing meSch in relation to other toolkits in the literature shows some key features that should be considered in future toolkit design:

- Inclusive of different user's expertise: it should have a low-threshold and a high-ceiling; the low-threshold enables newcomers to effectively create something meaningful to them with limited knowledge, while the high-ceiling allows skilled users to achieve more complex designs.
- Flexible and expandable: the toolkit should be fully customizable to enable reuse and repurpose of existing solutions; it should be open to support addition of new features and modules to keep its relevance over time.
- Participative: inclusivity and flexibility are the basic mechanisms for a toolkit to be relevant to many users and over time; however low-skilled users are unlikely to succeed unless an effort is made to create and support a community around the technology that encourage less-knowledgeable users to start and improve their skill and, potentially, become contributors.

A toolkit with these three features is an instrument of change. The being "unfinished" is seen "as an opportunity (by extending design time indefinitely) rather than as an obstacle or as something to be avoided" (Fischer, 2013, p. 5). This framework shows such end-user development systems as being in continuous growth and regeneration via the active participation of its users that repurpose blueprint recipe to be shared again. However, such democratization risks creating repositories that

[8]An exception is LittleBits (Bdeir 2009), now part of *sphero*, which collects dozens of examples and resources for education https://sphero.com/pages/littlebits

are too large and/or of poor quality and that therefore need powerful search mechanisms (Fischer, 2013). Although the workshops did not shed any light on how the magazine could evolve (only one group did publish their recipe), issues of searching and filtering a large repository of recipes have been addressed (Not & Petrelli, 2019).

Reflecting through the lens of Fischer's framework (Fischer, 2013) allows us to see how our choices in designing the meSch Toolkit resulted in a system with transformative potential. Our holistic evaluation findings show that meSch successfully mediated the envisioning, designing and rapid prototyping of interactive installations across a variety of group configurations and dynamics, supporting creative ideation by enabling participants to contemplate tangible interaction scenarios that differ from any other digital technology that they had experienced in museums and galleries. The feedback collected praised its simplicity, adaptability and its clear fit with the skills and expectations of CHPs. The meSch Toolkit's openness supported evolution and expansion by adding new hardware to create interactions that have not been anticipated and are not part of its current design, and by collecting shared recipes within a vibrant and dynamic community of interest. As such, the meSch Toolkit has the potential to transform the current practice in cultural heritage as it "breaks down the strict separation between 'designer' and 'user' by supporting richer ecologies of participation" (Fischer, 2013, p. 8).

For such new ecologies to become viable and successful, there must be a sufficient number of users taking on active participation (Fischer, 2013). This is a concern, as a major issue expressed by participating CHPs is the mentality of many curators and museum managers, who are hesitant about digital augmentation. While addressing these issues is beyond the scope of our work, it is important to flag them as community adoption is an intrinsic challenge of end-user development.

Overall, our study provides important transferable findings for the HCI field. First, it shows the value of open-ended design for end-user development systems that can evolve and change with use. Flexibility was intentionally designed and it was not a trivial task. To design an "unfinished" infrastructure that could be extended, we constantly had to check our design against a wide range of possible conflicting scenarios of use to make sure the open toolkit could support them all.

A number of interaction design choices made complex technology manageable. Among the most successful ones is the symbolic representation of the hardware as appliances that made non-technical users see their own project rather than the devices they were actually manipulating. Similarly, the tagging system to define the personalization rules is intuitive and can be customized in all its parts. Finally, the magazine with recipes allowed new users to quickly go beyond getting started moving to prototype and test their own ideas. The meSch Toolkit is a step in the direction advocated by Tatteroo et al. (2013, p. 247) to make tangible interaction to transition "from a topic of research, to a technology that can be put to use in a wide variety of application areas." This effort has its own specific challenges such as encouraging users to generate and develop their ideas of tangible interaction, or making available new hybrid digital-material building blocks for the easy realization of their own ideas (Tatteroo et al., 2013).

As such, the meSch Toolkit has the potential to transform the current practice in cultural heritage as it "breaks down the strict separation between 'designer' and 'user' by supporting richer ecologies of participation" (Fischer, 2013, p. 8).

Our work also demonstrates the suitability of such a workshop frame repeated in different contexts for conducting the holistic evaluation with a variety of intended end-users, particularly for open toolkits designed for collaborative use. This breadth might be challenging to achieve, but it does provide important insights on how complex systems designed to be left in the hands of end-users might fare in different scenarios.

Our findings also show the fine line between what a toolkit can support and related issues that might affect its take-up and use. Overall, the work we reported in this paper provides insights on how openness can support the creative process of a variety of relevant end-users in different settings, going beyond existing studies in several important ways.

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Notes on contributors

Daniela Petrelli research interests focus on how the digital and the material worlds juxtapose, merge, diverge and clash. Within this framework, she has been empirically investigating tangible, embedded and embodied interactions at home and for leisure. She started working on technologies for cultural heritage in 1996 designing one of the first context-sensitive personalized interactive mobile guides. Recently she led the European project meSch that explored the use of the Internet of Things and Cloud Computing to implement tangible and embodied interactions in museums and heritage sites. meSch has received international awards and recognitions. Dr Petrelli's other research interests include personal and family memories, data visualization, multimedia and multilingual information access. In her career, she has published over 100 international peer-reviewed contributions and received 12 awards both from academia and industry. Dr Petrelli is Professor of Interaction Design at Sheffield Hallam University (UK) and director of the Digital Materiality Lab, an interest group looking into new digital-material hybrids.

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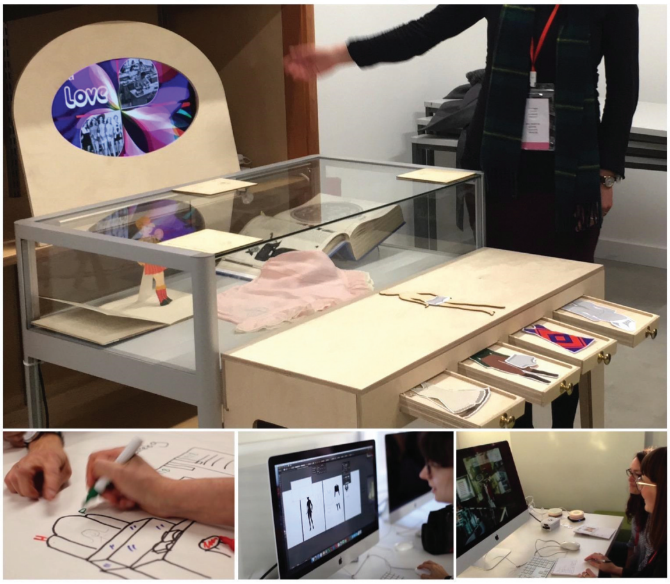
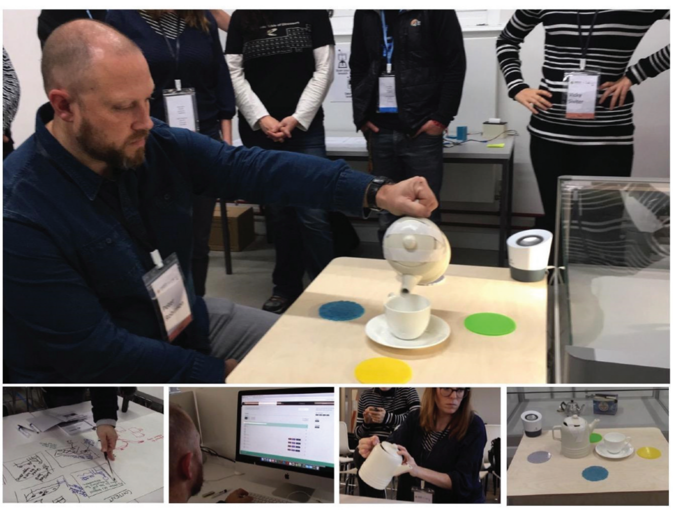
APPENDIX

AF1: Vanity Desk



A souvenir pair of women's underwear from the Festival of Britain (a national fair held in the Summer of 1951 across the UK) inspired an installation on the changing role and status of women throughout the twentieth Century.
The same historical period is different when seen from the personal or the public point of view. This was embodied in models of underwear (representing the personal dimension of women's lives) and clothes (representing the public and social) representing four periods in British history: 1920s voting rights for women; 40s women working in factories during WWII; the contraceptive pill and the sexual revolution of the 60s; and the 1980s with law to rebalance the power in a marriage.
The concept is a vanity desk with four drawers with the paper models and the silhouette of a mannequin on top. When the visitor dressed the mannequin with either underwear or "formal" clothing, a corresponding video played in the mirror of the vanity desk.
The group reused a simplified version of the WWII recipe. The NFC reader is positioned under the silhouette, the tags are in the paper models.

AF1: Tea for One



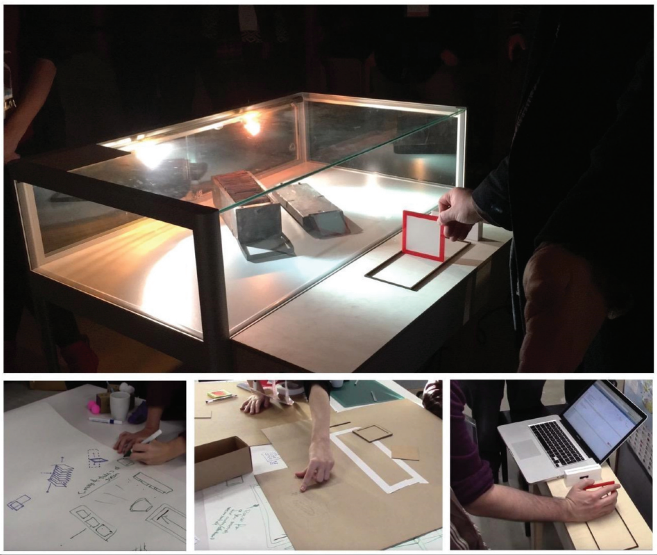
Tea for one was built around a small teapot for one person that became widely used in the UK by the many widows left after WWII, when the previously social activity of making and drinking tea became a rather lonesome one.
Inspired by this story, the group created a table set-up for tea that would tell different stories. The teapot played the nursery rhyme "I'm a little teapot" when used to pour tea into a cup; when the cup was placed on one of the four coaster places around the table, a sound snippet of oral history told by a war widow was played.
The interaction is composed by two parts:

(1) The nursery rhyme is played by a phone hidden within the teapot and triggered by the phone accelerometer when the teapot is picked up
(2) The WWII recipe with 4 NC readers under the coaster and a single tag under the teapot. The stories would be played via a loudspeaker placed on the table.

(*Continued*)

(Continued).

AF1: Fingertips Browsing

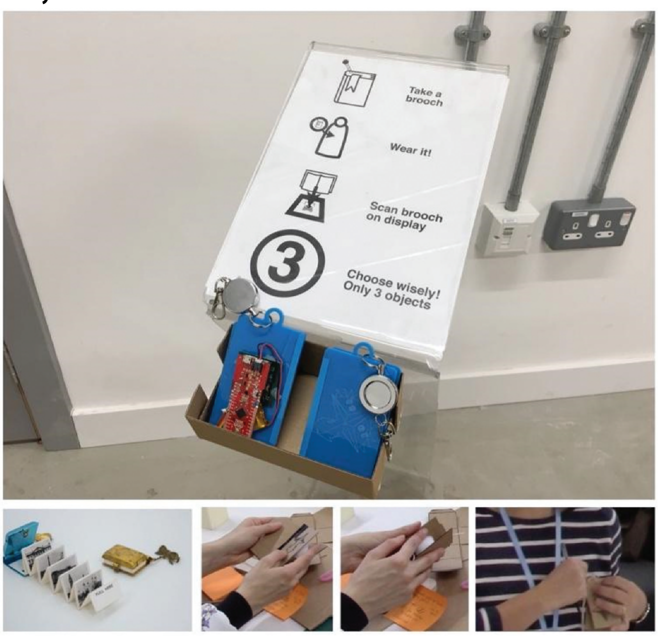


Fingertips Browsing invited visitors to explore a set of old glass projection slides depicting Australia in the 1800s. A rectangular outline in front of the display case mimicked the rack of slides. In the initial concept the visitor used their finger to point at different positions in the stack (the rectangle) and the projector would show the slide currently "touched" by the user's finger. The implementation used a plastic frame for the proximity sensor to work properly.

In the interaction a slideshow went on when the frame moved up and down the rack; when it stopped on a slide, a prerecorded voice delivered content connected to the displayed slide.

The history of the slides is unknown: the group was very imaginative with the content that was often humorous and provocative.

AF1: My Collection



This concept was inspired by a miniature souvenir book of photographs that could be pinned to clothing as a brooch.

The group designed replicas of the miniature books that could be worn while visiting an exhibition, to enable users to "collect" up to three favorite exhibits by scanning markers at chosen display cases with the brooch itself.

When exiting the exhibition, the brooch would trigger the printing of special content related to each exhibit collected by the visitor, and the printout could be kept as memento.

This concept was reusing an existing recipe but was not fully implemented as a technical issue emerged when interfacing the brooch with the printer. Unfortunately, it was too late in the event to fix the issue and the concept was not fully implemented and tested.

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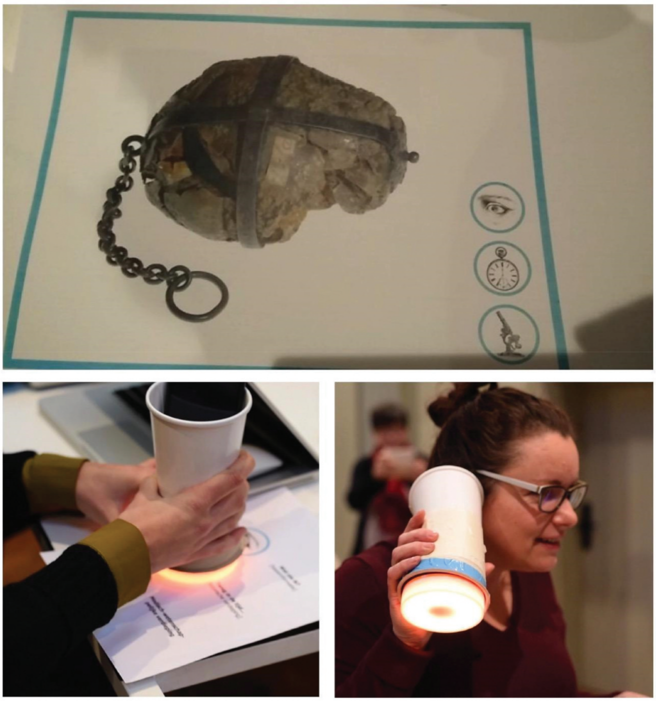
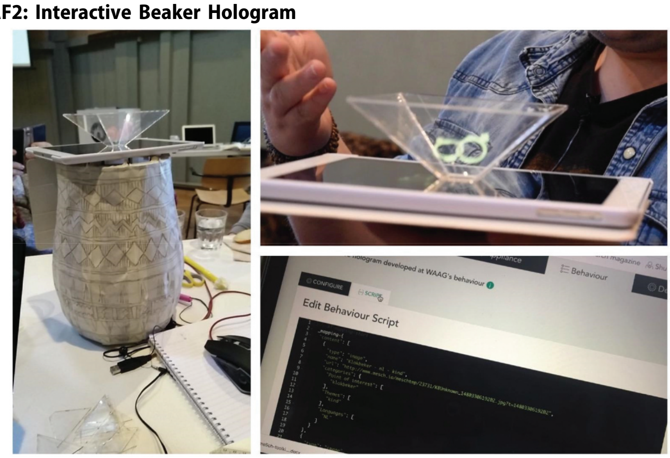
AF2: Interactive Stethoscope



The participants in AF2 arrived with one object from their museum and the content they wanted to use.
The CHPs from the museum of medicine brought a giant gallstone, developed the concept of an interactive stethoscope to be used to listen to the different stories an object had to tell.
Old stethoscopes were shaped like a trumpet: it was mocked up in the workshop with two cups with an NFC reader embedded within one end and a phone to play the audio content on the other end.
Three different stories for the gallstone were prepared, each marked with a different symbol, an eye, a watch and a microscope. The symbols next to the object concealed an NFC tag.
Initially the content was the text for that object from the museum catalog and text-to-speech software was used to generate the digital audio files. When testing, the group noted how text on the museum label was not effective when played as audio. They then wrote ad-hoc text for this medium, rather than reusing content created for labeling purposes.
This group reused a simple NFC recipe with only three themes and a single NFC reader.

AF2: Interactive Beaker Hologram



The object is an ancient beaker currently kept in a dark room in the museum, and thus going unnoticed by most of the visitors. Investigations showed that it contains the ashes of a child.
The CHPs wanted to attract visitors' attention to the beaker by creating a holographic view of the circumstances in which the beaker was made and used.
To prototyping this concept the team made a replica in laser-cut wood that was then covered in paper and painted. Plexi trapezoids were cut and assembled in the lab to create the means to display a small hologram using an iPad playing a specially designed video.
The toolkit did not have any recipe for the hologram so a new one had to be created for a new appliance (hardware). This new component was then integrated with the proximity sensor in the toolkit. By approaching the beaker on display the visitors would automatically trigger the projection of the hologram.

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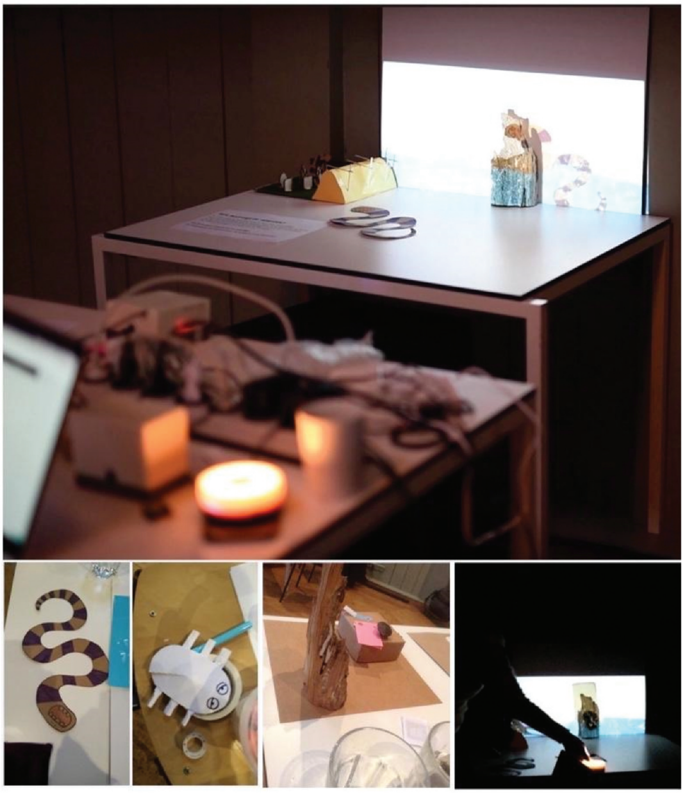
AF2: Who Destroyed the Dykes?



The group created an interactive video installation (using stop motion animation) that accompanied a quiz on the protection of Dutch landscape from natural threats.
The group reuse a simple NFC reader recipe with one reader and four tags (embedded in figurines representing sea animals) to identify the culprit for the destruction of the dykes. This interaction was designed with school visits in mind, allowing young visitors to try and guess which one of the four animals represented (a barnacle, a gribble, a pile worm and a sea mussel) was actually guilty of destroying the dykes. Each figurine triggered a video; in three of them the animals were just floating around the dykes, while the fourth -the pile worm- made the dykes disappear.
The log shows an interest in the different components of the recipe, the magazine, and cookbook.
Observational data shows the group needed support from the facilitator to define the details of the interaction. This could be due to their focus on already prepared content before the overall interaction was completely defined: several files with text descriptions, images, and videos were uploaded but left untagged showing there was not yet an interactive context in which this content would fit. The group displayed an experimental attitude: they fast prototyped content as well as the interaction: they have the highest number of actions on content including six removals of content (some groups have 0 removals), showing that the decision of what content to include in the installation was not taken at the design desk, but via prototyping and testing. Further evidence for this content-prototyping approach is the media developed for the final installation, a set of stop-motion animations of sea creatures: this solution provides consistency across the installation in a way that reused material from the museum labels (uploaded in an early version of the recipe) would have not.

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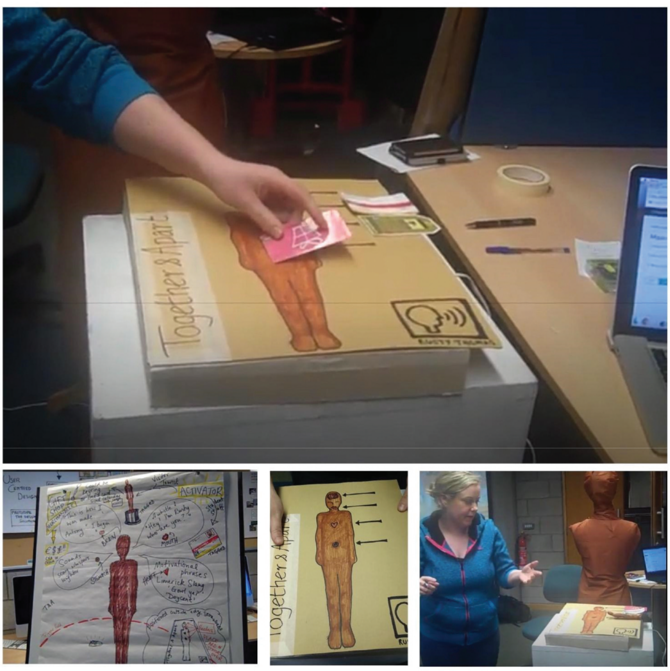
AF3: Well of Wisdom

The Well of Wisdom was envisioned for an existing viewing platform near the Sionna wall mosaic, depicting the legend of the origins of the Shannon river. A visitor would choose a “hazelnut” signifying their preferred language and drop it into a “well of wisdom” (a receptacle with a projection and sound of water) to trigger an audio-video explanation of the legend in that language.
After deciding on the concept, the group created ad-hoc audio and visual content by surveying the site and taking high-quality digital images of the mosaic, as well as recording the sound of the river.
A limited small-scale mock-up prototype was realized with two NFC-enabled wood tokens (hazelnuts) representing two languages, and the Well of Wisdom as a low-fi prototype (with a NFC reader at its bottom).

AF3: Rusty Thomas



Rusty Thomas was inspired by a cast iron sculpture of a human figure by Antony Gormley, now covered in rust and playfully called “Rusty” or “Brown Thomas” by the campus community.
The concept was built around a life-size replica of the sculpture that would react to the bodily interaction of those living and working in the University campus. The envisaged interactions of embracing or touching the statue were implemented via the university ID cards of both students and staff. Placing the ID card on parts of the replica statue’s body would play sound snippets on different themes: the brain triggered content on the history and craftsmanship related to the creation of the statue; the mouth a recording of the artist talking about his practice; the ID card placed on the heart triggered playing motivational and encouraging phrases; and placed on the stomach, it would trigger jokes and other humorous content to be played.
Besides being an important artwork, Rusty Thomas is a beloved character on campus, thus the concept envisioned that content would regularly change during the academic year (for example, at exams time, Rusty Thomas’s heart would give appropriate encouragement to the students).
A scaled-down version was implemented as an interactive plinth using NFC tags, NFC readers and appropriate digital content. For this the group reused the NFC recipe with multiple readers and tags.

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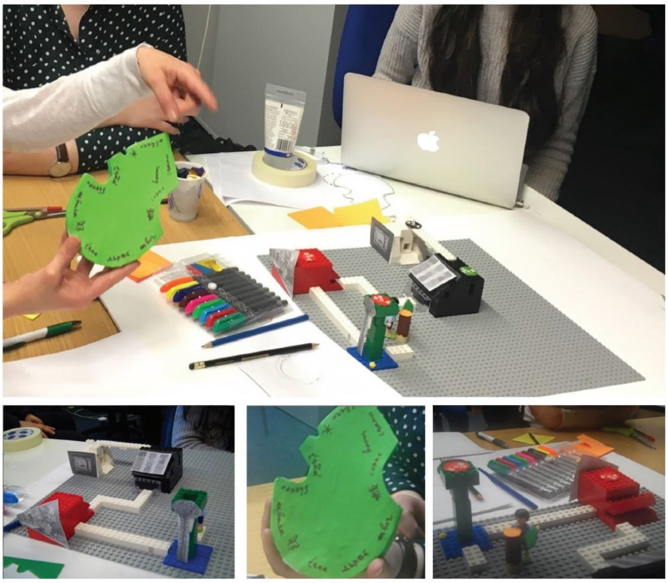
AF3: Leaf Guide



The third concept used a sample recipe to create a tangible multi-theme portable guide, called The Leaf, to deliver auditory content at different locations on the Campus Art Trail. The auditory content connects art with the natural world, both strong features of the campus. The group faced difficulties in collaborating and making decisions together thus delaying the prototyping phase, probably due to the size of the team (5 participants), and to the contrarian perspectives of the two CHPs on the team. They also put more effort in creating content than in detailing the interaction, often reverting to the mechanisms of a traditional audio guide. The implemented prototype used NFC tags and an NFC reader on a small-scale model of the trail built with Lego bricks.
The log data confirms the group's focus on content: the recipe contains four long poems recited over a background of traditional Irish music. The Appliance tab shows two devices (an NFC reader and an Android device) as a further demonstration of their struggle to move away from the structure of a standard guide. The log also shows that half of the activities undertaken were focused on exploring the tool. One possible explanation is that the members of the group in charge of uploading content were making use of the long time it took others to create the extensive content. Interestingly, this was the only group that considered publishing their own recipe on the Magazine for others to reuse.