Smart Objects and Replicas: A Survey of Tangible and Embodied Interactions in Museums and Cultural Heritage Sites

Tangible and Embodied Interactions in Museums: A Survey

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Tangible and Embodied interactions are areas of research within HCI and Interaction design. They refer to a way in which interacting with computer systems is closer to the way we interact with the real world. Instead of using devices such as a computer or a phone, we interact using seemingly non-technological objects, by moving our bodies or by using gestures. Since the early 2000s, tangible and embodied interactions have been applied and researched also in Cultural Heritage and museums, in an attempt to overcome issues induced by screen-based devices that may disengage visitors from the objects, their materiality and the physicality of the visit. This article surveys tangible and embodied interactions in museums, over a period of two decades since 2000. Over 120 projects have been researched and analysed thematically to provide a categorization based on cultural communication, interaction features and museological aspects. This categorization offers a conceptualization of tangible and embodied interactions in museums and Cultural Heritage; it suggests a terminology to describe the design characteristics of tangible and embodied interaction interventions, therefore facilitating the orientation of future research efforts in the field.

CCS CONCEPTS • **Human-centered computing~Human computer interaction (HCI)~Interaction techniques**

Additional Keywords and Phrases: tangible interaction, embodied interaction, tangible user interfaces, smart objects, smart replicas, museums, cultural heritage

1 INTRODUCTION

Since the mid-80s museums and cultural heritage sites have been adopting various types of technologies to enrich the visitors' cultural experience. Over the years these have taken on the form of multimedia computers, interactive kiosks, PDAs, virtual reality, mobile and mixed reality applications (i.e., augmented reality and augmented virtuality). As embedded technology emerged, the creation of tangible and embodied interactions appeared, shifting the interaction with computers towards a paradigm centred on body movements and the manipulation of physical objects. Within cultural heritage and museums, tangible and embodied interactions held much potential for the integration of digital technology with the materiality of the objects and the physicality of the visiting experience.

Surveys have been published on the topics of virtual museums [Styliani et al. 2009], virtual reality for tourism [Guttentag 2010], mobile AR for cultural heritage communication [Casella et al. 2013] and on the general topic of mixed reality for cultural heritage [Bekele et al. 2018]. This contribution

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extends this set of surveys toward tangible and embodied interactions in the context of museums and cultural heritage (CH in the following).

In analysing over 120 projects, this paper proposes a categorization and conceptualization of different design aspects that pertain to tangible and embodied interactive systems. It provides an exhaustive frame of reference of what tangible and embodied interactions are in the CH/museum fields and offers a detailed terminology. We believe our contribution can facilitate researchers' orienteering within a complex and multifaceted domain and support further development on the topic.

After providing a definition of tangible and embodied interactions (Section 2), we discuss the methodology adopted in the survey and the analysis of the projects (Section 3) and we report the results of our survey and analysis (Section 4). The article closes with reflections and conclusions (Section 5).

2 TANGIBLE AND EMBODIED INTERACTIONS

Tangible interaction (TI) is an area of research within HCI and Interaction design. Research in this field, as well as in the areas of augmented reality, augmented virtuality and ubiquitous computing became prominent in the mid-90s as an attempt to overcome the limits of desktop computing and virtual reality, in particular the fact that such technologies estrange people from the real world [Shaer et al. 2010]. Indeed, in both desktop computing and virtual reality, information and multimedia content are provided on dedicated devices away from the environment we inhabit and where the interaction occurs, reinforcing "a great divide between the worlds of bits and atoms" [Ishii et al. 1997]. Augmented Reality, Augmented Virtuality, Tangible Interaction and Ubiquitous Computing are all research areas that aim to reduce this separation. Such technologies can be referred to as mixed reality technologies [Milgram et al. 1994, Coutrix et al. 2006]. While augmented reality and augmented virtuality reach a better integration between the real and virtual world from a visual point of view (i.e., overlapping digital information to the real environment or vice-versa), tangible interaction allows for a better integration by proposing ways to interact with computer systems that are closer to the ways we interact with the real world [Ishii et al. 1997]. Instead of using technological devices like the mouse or the keyboard, we interact using everyday or seemingly non-technological objects or using bodily interaction such as movements or gestures.

Various disciplines have contributed to the field of tangible interaction - namely, Computing and HCI, Product and Interaction Design, Interactive Arts - to the point that today tangible interaction can be considered as an umbrella term inclusive of several meanings and encompassing "a broad range of different systems and interfaces relying on embodied interaction, tangible manipulation and physical representation (of data), embeddedness in real space and digital augmented physical spaces" [Hornecker et al. 2006 p. 437]. Although the expression "tangible interaction" has very broad meaning, the term "embodied interaction" is preferred by some authors especially when referring to whole-body and gestural interaction [Dourish 2001, Marshall et al. 2013], limiting the use of "tangible interaction" to those systems where the interaction is by means of physical objects. This ambivalence has been embraced by the research community and the term TEI (i.e., "Tangible, Embedded and

Embodied Interaction") has been introduced to explicitly include both tactile and bodily/gestural interaction.

In the early 2000s, mixed reality technologies have started to be applied in CH as a way to engage visitors with the physicality of the visit [Ciolfi, et al. 2003, Stevens 2004, vom Lehn et al. 2003]. The separation between the real and the digital worlds is indeed particularly relevant in CH where connecting with the heritage sites and the exhibits is a fundamental part of the experience, as discussed in several works in museum studies [Chatterje et al. 2008, Pye 2007, Dudley 2010]. Alongside early experimentations with Augmented Reality [e.g., Vlahakis et al. 2002] and Augmented Virtuality [e.g., Steinicke et al. 2009], tangible and embodied interactions started to be applied in museums too. Following pioneering research in the early 2000s [Bannon et al. 2005], many tangible and embodied interaction interventions have been designed, developed and deployed in the last twenty years both in research and museum practice, giving rise to a large variety of systems. One of the goals of this paper is to facilitate an understanding of this complexity, by providing a state-of-the-art review of the field.

In this paper we use the term "tangible interaction" (TI) in the narrow sense, referring only to an interaction that requires contact – through touch and manipulation - with a *smart object*, a physical object embedded with digital technology that presents itself as an ordinary object while having digital properties such as the ability to sense and react to human interaction.

We use the term "embodied interaction" (EI) to refer to an interaction in which the visitor moves or gestures in front or in the presence of a technological system without making contact with it. In embodied interaction, this technological system can be either a smart object or a more traditional one. By a traditional technological system, we intend one that, differently from a smart object, overtly manifests its technological nature such as, for example, VR-head mounted displays, Kinect-based interactions with a PC, or other natural interaction systems [Wigdor et al. 2011, Norman 2010, Pietroni et al. 2012].

In this paper, we survey both tangible interaction and embodied interactions *with* smart objects. In other words, the presence of a smart object to interact with is the reason for including a project in the survey. Therefore, we exclude forms of embodied interaction with traditional devices.

3 METHODOLOGY USED FOR GATHERING AND ANALYSING DATA

To build the survey, tangible and embodied interaction systems developed as part of academic projects were surveyed through Internet-based search, consulting publication databases, international projects websites and their deliverables and by reference mining. Although the focus of this article is mainly academic research, we include interventions developed as part of non-research-related activities such as museum exhibitions that we considered particularly relevant, either because they introduced a different paradigm or because they are significant in the field. These projects are generally documented online in photos, web pages and videos.

The selected papers and documentation were assessed to include only those that provided a detailed description of a tangible and/or embodied interaction to support the analysis and that illustrated applications of interactions we judged of interest, as described in Section 2.

Overall, we gathered 124 projects designed and/or developed between the years 2000 and 2020. A thematic analysis methodology was used to analyse the projects, combining an inductive (bottom-up) and deductive (top-down) approach to identify categories (or themes) and subcategories (or subthemes). The thematic analysis is a qualitative research method that is used "for identifying, analysing and reporting patterns (themes) within data" [Braun et al. 2006]. Although it is often used for the analysis of interviews (Ibid.), it is also applicable to the analysis of different types of data.

In the context of this article, data is intended to be the description of the characteristics and functioning of tangible or embodied interaction artefacts as reported in papers or other textual media (e.g., web pages) or documented via other types of media such as videos or photos.

These data were analysed thematically through repeated readings of the textual material and viewings of the videos or photos. The material was annotated with codes that describe common features in the data. A combination of empirical codes and a-priori codes were used [Gibson et al. 2009]. Empirical codes are those that emerged from the examination of the data (inductive). A-priori codes were derived from theoretical readings on museum studies and interaction design literature (deductive). The a-priori codes were the starting point: this initial set was refined and expanded with empirical codes as they emerged from the data during the analysis. As Ayres notes, "In thematic coding the analyst frequently begins with a list of themes known (or at least anticipated) to be found in the data" [Ayres 2008 p. 867). A-priori codes were particularly useful for us to see how and whether certain categories mentioned in the general museum studies and interaction design literature were applicable to tangible and embodied interactions in CH and museums.

The analysis was carried out as an exhaustive and iterative process, in which codes and subcodes, categories and subcategories were subsequently refined as more projects were analysed and a better understanding was gained.

4 STATE-OF-THE-ART REPORT

This section describes cultural heritage/museums TEI interventions according to the thematic analysis. Three main macro-themes emerged:

- communicating or enhancing cultural (or natural) assets (e.g., type of asset the installation refers to; locations of installation and reference asset);
- interaction design features (e.g. interaction styles, interaction devices, tasks and actions, output types and locations);
- museological aspects (e.g. social engagement, participation and personalization, target).

These macro-themes (as well as their themes, and subthemes) are not to be interpreted as mutually exclusive since they cover aspects that cross or overlap. Indeed, they are likely to be found together, in a given combination, in a single project.

The three macro-themes, along with their themes and subthemes, are described in Sections 4.1, 4.2, and 4.3 respectively. For most of the themes, percentages are included in Section 5 (Fig 14) to provide an indication of the occurrence of each category in the corpus.
To review the 124 projects individually is out of the scope of this paper; a table is included as Appendix A to report the main features for each project along with bibliographic references. Although we made an effort to avoid repetitions in the text, a project could be an ideal example for several aspects or categories, therefore sparse repetition could not be avoided.

4.1 Communicating or enhancing cultural or natural assets

4.1.1 Reference to tangible and intangible assets

Interactive installations in museums are generally devoted to communicating or enhancing the experience and understanding of one or more assets that are chosen as the subject of the installation.

These assets can be material objects, either human-made (such as works of art, artifacts, architectures, and buildings) or natural objects. We globally refer to them as *tangible assets*. On the other hand, there are assets that, unlike objects or places, are immaterial, abstract or ephemerals. We refer to them as *intangible assets*. These include those aspects that are included in the concept of intangible heritage, meaning oral traditions, languages, traditional performing arts, knowledge systems, values and know-how [Deacon 2004]. However, in our understanding, intangible assets are not limited to those listed, and we also include other immaterial aspects such as personal memories, personal experiences, and personal meanings, that are often chosen as subjects of the installation.

In some of the reviewed installations, the main focus is a tangible asset and its physical properties alone. In these cases, TEI is used to allow the visitor to experience the material qualities of an object that otherwise could be not directly accessible. In the "Virtual Touch Machine" [Fraser et al. 2004], for example, TI is used to allow visitors to experience the material qualities of an object belonging to the Hunt Museum (Limerick, Ireland) collection. The object is represented as a virtual 3D model displayed on a screen framed as a painting; the visitor holds a tangible magic wand that can be rotated or tapped against the 3D representation of the object in order to experience its shape, texture and sounds of the object. Many other projects [Kobeisse et al. 2020, Mann et al. 2019] use 3D-printed replicas as interfaces: the visitor manipulates the physical replica to control a digital representation of the same object, possibly digitally restored to show the genuine artefacts' appearances and physical characteristics.

In other projects, the focus of an installation is intangible assets such as concepts or knowledge [Zheng et. al 2005, Horn et al. 2009, De Berigny Wall 2010, Clarke et al. 2015, Taylor et al 2015, Okerlund et al. 2016, Culén et al. 2016, Loparev et al. 2017], personal stories or experiences [Filene et al. 2011, Ceconello et al. 2016, Poole 2017, Dagan 2018, Hai et al. 2018, Koolbergen et al. 2018, Studio

TheGreenEyl n.d.], practises [Fischer et al 2002, Maquil et al. 2017, Hai et al. 2018], traditions and rituals [McGookin et al. 2018, Pereda et al. 2020, Fraietta 2020]. In these cases, TEI is used to give a material form to intangible aspects. An example is the "Whispering Table" [Studio TheGreenEyl n.d.] for visitors to learn about different rituals, symbols and beliefs related to food: visitors sit around a table and listen to stories triggered by physical ceramic dishes, bowls and jugs when placed on certain locations on the table. Here, the main focus is not the objects but stories as the ceramic pieces do not replicate exhibits; rather they have a role in the specific rituals. The objects are props that provide a material way to access stories.

What emerges from the analysis, though, is that in the vast majority of cases (Appendix A), an installation does not exclusively refer to either a tangible or intangible asset. For example, the visit to the WWI Trenches on the Italian Alps [Marshall et al. 2015] (tangible asset) is augmented by the personal stories of soldiers and civilians (intangible assets) and the latter are as important to the experience as the historical site itself. By tangible interacting with a wearable belt, inspired by the WW1 military clothes, the visitor can select a theme of interest; and by embodied interacting with the environment -i.e. walking close to specific points of interest- the visitor activates the telling of the stories.

Another example is "ec(h)o" [Wakkary et al. 2007], where informal comments and anecdotes by scientists (intangible assets) related to exhibited objects (tangible assets) can be selected and listened to by visitors by manipulating a cube in proximity to the physical objects.

These examples show how both tangible and intangible assets are often present in the same installation, the latter being interpretable as intangible values related to the former. When this happens, TEI can be interpreted as a means of enabling a connection between intangible values and tangible assets.

The categories of assets discussed in this section are summarized in Fig. 1.

CULTURAL/NATURAL ASSETS									
Tangible assets					Intangible assets/values				
Works of art	Artifacts	Natural objects	Architectures and buildings	Etc..	Concepts and knowledge	Personal stories and experiences	Practices	Traditions and rituals	Etc..

Fig 1 Types of reference cultural assets

4.1.2 Location of the tangible asset with respect to the installation

Considering the location of the cultural or natural asset with respect to the installation that refers to it is important since the location is a potential "distraction" for visitors from the original object on display to the installation. Obviously, this aspect is applicable only to the analysis of those projects

referring to an existing tangible asset. The location can be analysed on a continuum that goes from installations where the object is embedded within the installation itself to those where the installations are remote (e.g. another museum) passing through intermediate situations where the object is close to the installation or the case in which the object is far yet located in the same museum or heritage site (Fig. 2).

Different strategies for incorporating objects in the installation can be identified, sometimes combined in the same installation. These include:

- the use of the reference object as an interaction device. In "Frammenti di Memoria" [Repetti 2005], original artefacts belonging to the farming traditions are used as interaction devices. Touching an object, stories of farmers and light effects are presented to the visitor;
- the provision of an output that is tightly coupled to the focus of the object, meaning that the output is overlapped onto the object, it comes from the object or from the environment around the object. In the "Winnipeg Art Gallery's interactive case" [Hincapié-Ramos et al. 2014], the information is projected on the glass case where the original object is exhibited, therefore appearing as overlapped to the object;
- the provision of an interaction that has to be done in the presence of the object (as in the case of augmented reality systems). An example of this type of interaction is the one provided by the "meSch Loupe" [Damala et al. 2016a], a mobile phone encased in a magnifying glass wooden frame that displays information on the object it is pointed at.

Along the close-far continuum are installations next to the object. At the Ename Museum in Belgium, the "VIRTEX – Ivory object" tangible installation, a larger scale 3D print of the head of a pastoral staff [Pletinckx 2007], is located near the glass case where the original religious object is displayed.

The highest potential distraction occurs when the reference object and the installation are far apart inside the same museum/cultural site or in totally different locations. An example of the former is the "Interactive Stela" installation [Sportun 2014], located in a different room in Manchester Museum compared to that where the original Egyptian Stela is exhibited. An example of the latter is the "VIRTEX - Ara Pacis" installation [Capurro 2014] in the Allard Pierson Museum, presenting content related to the Ara Pacis Monument in Rome.

It should be noted that a great distance of the installation from the related object does not always and necessarily entails a high level of distraction. Indeed, often strategies have been put in place to foster the experience of remote objects. These strategies are actions that the visitor performs before or after interacting with the installation, including the experience of the original object or monument. In the "Nottingham Castle Installation" [Fraser et al. 2003], interactives on the castle history are exhibited in a specific section of the museum. In order to overcome the distance between the interactives and the locations they refer to in and around the castle, the visitors are given an electronically-tagged paper clue they have to take to specific locations. When there, they are asked to carry out certain tasks using the paper clue (e.g. drawing); only after the paper clue can be used to get digital information about the visited location at the interactive stations in the museum. Similarly, in "Reminisce" [Ciolfi et al. 2011], at the Bunratty Folk Park in Ireland, visitors must first get specific physical tokens

and record personal memories using mobile phones in the various dwellings to activate the interactive desk at the end of the experience.

LOCATION OF REFERENCE TANGIBLE ASSET			
Embedded in the installation	Close to the installation	Located somewhere else in the museum (distant)	Located in another place (very distant)

Fig. 2 Possible location of the reference asset with respect to the installation

4.2 Interaction design features

4.2.1 Single/Multi-stations Interactive Installations

Although many tangible or embodied interaction interventions have a single point for interaction, many have multiple distinct interactive stations. Multiple stations have been considered as part of the same installation if they hold a strong interconnection with one another irrespective of them having the same theme or being placed at the same location. Such integration is achieved by designing an experience that asks the visitor to carry objects or cards from one station to the others. For example, at "The Hague and the Atlantic Wall" exhibition [Marshall et al. 2016] the visitor chooses a replica at the start and uses it at the ten interactive stations to control multimedia content. A similar dynamic is implemented in "Retracing the Past exhibition" [Fraser et al. 2004]: on entering a fictional room the visitor collects cards representative of objects and uses them at different interactive stations (a trunk, a desk, a radio, etc.).

SINGLE/MULTI-STATIONS INSTALLATIONS	
Single installation	Multi-stations installation

Fig. 3 Distinction between single and multi-stations installations

4.2.2 Interaction styles

As already mentioned, the literature reports two types of interactions with smart objects. The first requires contact through touch and manipulation with a smart object. We refer to this type of interaction as *tangible interaction* in the strict sense. In "My Roman Pantheon" [Petrelli et al. 2018], for example, the visitor takes part in Roman religious traditions by collecting a physical votive lamp at the shrine of Juno and using it to make offerings to the chosen deities. Offerings are made by swiping the lamp on stands next to altars and relives on display in the museum. Returning the votive lamp to Juno, the visitor receives an oracle (a personalised postcard) that is based on the choices they made.

The second type of interaction does not require any contact with a smart object, as the system view the presence of smart objects that can recognize the free gestures or body movements that the visitor – intentionally or unintentionally - performs. We call this type of interaction as *embodied interaction*. In "Engaging Constable" [vom Lehn et al. 2007], by walking towards an interactive 'replica' (a screen placed in a painting frame) of Constable's painting "Salisbury Cathedral from the Meadows", or moving in front of it, the visitor reveals the underlying x-rays layers for the part of the painting that matches their silhouette.

However, a rigid classification would not reflect the complexity of tangible and embodied interactions and in some projects both types of interaction are present. The "Olivetti MP1" exhibit [Rawat 2005] combines embodied and tangible interactions. In the idle state, the visitor sees and hears hands typing on the typewriter keyboard; as they approach the typewriter exhibit, another video is triggered showing a set of instructions (embodied interaction); then pressing specific keys, video contents are projected on the typewriter's sheet of paper (tangible interaction).

The interaction may include wearable technologies to activate objects or environments that, in turn, are perceived as smart. For example, the "Reading glove" [Tanenbaum et al. 2010] is a tangible interactive narrative system consisting of a wearable RFID-reading glove that allows the visitor to extract fragments of stories from a set of RFID-tagged objects by grasping and holding them. Another example is "Tooteko" [D'Agnano et al. 2015] that provides the visitor with a high-tech ring to be worn and used to trigger audio content during the exploration of a tactile model of a cultural heritage object. In these two examples, the wearable is used as a way to detect the tangible interaction with other objects, however there are also cases where wearables are used to detect embodied interactions with objects or environments. For instance, an interactive belt inspired by the WW1 army uniform detects the position of the visitor in relation to specific points of interest and triggers the playing of stories in place [Marshall et al. 2015].

INTERACTION STYLE	
Interaction with contact with a smart object (tangible interaction in the strict sense)	Interaction without contact with a smart object (embodied interaction)

Fig. 4 Possible interaction styles in TEI

4.2.3 Devices - An analysis on the form of the smart objects

A distinctive feature of TI systems (and of the type of EI systems considered in the survey) is the presence of smart objects acting as an interface between the user and the system. Differently from traditional interaction devices that overtly manifest their technological nature, smart objects strive to hide their technological nature inside the appearance of non-digital objects. These devices can act as input devices, as output devices or simultaneously as input and output devices.

We distinguish two categories of smart objects on the basis of the relation between their forms and the tangible cultural or natural asset: *primary smart objects* and *secondary smart objects*.

Primary smart objects directly relate to the cultural or natural asset as when:

- the original object is made smart. We call these objects *smart originals*. In the "Olivetti MP1" exhibit [Rawat 2005], the visitor interacts directly with the original Olivetti typewriter. Pressing specific hotkeys, video contents are projected on the typewriter's sheet of paper animating the object;
- a copy of the reference object is made as a *smart replica*. The already mentioned "Interactive Stela" installation belongs to this category, consisting it of a plastic sensorized replica of an Egyptian stela [Sportun 2014];

- the object is derived from the reference object through a process of abstraction or translation. We refer to this type of smart object as a *smart derivative*. For instance, in "Interactive Histories" [Kettner 2013], the interactive objects are shapes (a circle, an ellipse, a triangle) that represent objects in the collection (i.e., part of a niche from a Samaritan house in Damascus, a vase from Ctesiphon, a piece from a Spanish carpet). In the "Talking Painting" [Touch Graphics 2015a], a Juan Sànchez Cotàn's still life painting is "translated" into a bas-relief to offer a tactile experience to the visually impaired.

Not all smart objects, though, have a relation to the form of reference cultural heritage or natural asset, but take a different appearance. We define *secondary smart objects* those belonging to this category, including:

- smart objects different in shape from the main reference assets yet with a clear reference (*related secondary objects)*, for example because they represent objects that belong to the same historical context. In "Voices from the Trenches" [Marshall et al. 2015], the heritage is the remains of the open-air WWI trenches and fortified camp, while the smart object is an interactive wearable belt inspired to WWI army uniform. In other cases, the object belongs to a context of activities related to the reference object. An example is the already mentioned "Loupe" [Damala et al. 2016a], inspired by a magnifying glass used for the close observation of details. Other examples are objects typical of museum visits such as traditional visiting aids (e.g., leaflets, books, labels or information panels) or exhibition equipment (e.g., glass cases, drawers, etc.). An example of the latter is at the Fryderyk Chopin Museum [Chin 2010] where a piece of furniture is made smart: opening the drawers, the visitor sees Chopin's original scores while hearing its music and observing information projected on the top surface. Finally, some smart objects connect to the CH asset because they represent its contemporary counterpart. In the "Interactive Anglo-Saxon Table" [Smith 2014] made for the Maidstone Museum and the Bentlif Art Gallery in the UK, contemporary objects are used to activate contents about the Anglo-Saxons, for example, a plastic mug plays information about an Anglo-Saxon glass cup. It must be noted that the distinction between originals, replicas and derivatives could be applied also to related secondary objects;
- smart objects that have no apparent relation with the main reference cultural or natural asset. We can refer to them as *ancillary secondary objects*. Often they are abstract objects like cubes, balls, etc., used to activate contents. In "ec(h)o" [Wakkary et al. 2007], a wooden cube with three coloured sides is used by the visitor to select specific audio contents in front of specific exhibits.

A consideration should be made regarding those installations whose main focus is not tangible assets but intangible assets like concepts, stories, practises, rituals, etc. In these cases, tangible and embodied interactions materialise intangible assets to be bodily experienced by visitors and, for this reason, the resulting smart objects and experiences could be considered as *smart materializations*. A few examples have been provided in 4.1.1. Another example is "Interantarctica" [De Berigny Wall 2010], an installation to communicate the impact of human activities on the environment. The action of picking up an object (physical representation of an item whose use has a positive or negative impact on the emission of CO2) becomes a metaphor for using that object with the related consequences on the environment. A more recent example is the "Cloakroom" [Dagan 2017], where visitors can experience stories of personal relationships by wearing jackets suspended onto hangers, searching for objects in their pockets and using those objects to activate the stories by placing them in a basket near

the jackets. In this installation, each jacket and the related objects become a materialisation of personal relationships stories.

SMART OBJECT					
PRIMARY SMART OBJECT			SECONDARY SMART OBJECT		SMART MATERIALIZATION
Smart original	Smart replica	Smart derivative	Related object	Ancillary Object	

Fig. 5 Categorization of a smart object according to its form

4.2.4 (Inter-)Actions

In this section, we analyse the actions required to interact with tangible and embodied interaction systems and to receive digital outputs in response.

Most systems require the execution of *codified* actions, that do not correspond to actions specific to the heritage. Here, the designer defines a new vocabulary of actions, and the visitor is required to carry out these to achieve the goals, for example, placing a mug down on a hotspot [Marshall et al. 2016], pressing a button on a replica [Capurro 2014], moving an object on a surface as in the "Yongzheng emperor's interactive tabletop" [Hsieh et al. 2010]. These are actions that are not culturally meaningful with reference to the specific cultural heritage asset, they do not belong to the repertoire of actions associated with it in reality (present or past). As a consequence, within the context of the interactive installations, these objects see their function redefined along with the gestures associated to them.

Other installations ask visitors to perform actions that are part of the repertoire of gestures that are culturally meaningful for that heritage. These are *performing actions*. In the "Virtual Conductor" installation in the House of Music in Vienna [Koster 2008], the visitor can lead a video projection of the Vienna Philharmonic Orchestra by using a replica of a conducting baton, and through doing so they experience what conducting an orchestra feels like. Another example is "The Drinking Symposium" installation [Damala et al. 2016b] in the Allard Pierson Museum (Amsterdam). Visitors are part of the ritual in ancient Greece: they pick up, rise a bowl, or recline on a daybed, and, in so doing, trigger to action the Greek characters, projected on the room walls, that animate and react accordingly. Such installations implement the "Performing Heritage Mode" proposed by the EU project MeLa* (European Museums in an age of migrations). According to this model, "intangible heritage is experienced in the first person by the user, who can play and perform cultural practises, alone or in a shared situation" [Lupo et al. 2014]. In other terms, "cultural content is performed and re-produced, individually or in a social context, in a space that becomes a stage, created by users' gesture" (Ibid.).

A further distinction is between *online* and *offline* actions [Esteves et al. 2013, Clarke et al. 2015]. The former are actions detected by the system (e.g., placing a mug on a hotspot in the Atlantic Wall exhibition), while the latter are those, that, although required to the visitors, are not recognized as input by the system (e.g., taking the earpiece to the ear in the "Atlantic Wall" exhibition).

ACTIONS	
Codified actions	Performing actions

Fig. 6 Types of actions

4.2.5 Output: media, devices and location

In Interaction Design, the term output refers to the feedback provided by an interactive system to the user in response to the input and can involve various sensory channels (visual, audio, haptic, and sometimes smell and taste) [Saffer 2009]. In most of the reviewed TEI systems, the output consists of visual feedback (images, 3D models, light effects, videos and texts) and audio feedback (music, vocal texts) that are often coupled together (see Appendix A). A minority of cases use haptic feedback (e.g., vibration), smell, kinetic movement, physical output, or behaviours, alone or in addition to visual and audio feedback.

An interesting project that uses a combination of sound and haptic feedback is "The Lost Palace" [Chomko & Rosier 2016]. A bespoke wooden screen-less handheld device allows visitors to 'scan' the environment to listen to hidden stories of the Palace of Whitehall (London) now destroyed. In addition, at various points, visitors can engage more with the stories and their characters, for example by using the device as a torch or a sword; towards the end of the tour, the device starts to beat, thus becoming the heart of the soon to be executed Charles I. The visitor thus traces Charles' final journey, arriving in front of the place of the execution where the heart stops. An experimentation has also been done using a wooden, heart-shaped object, creating a haptic heartbeat [Chomko & Rosier 2015].

The "Interactive Tableaux" [Claisse et al. 2018] is an example of an installation where smell is used as output in addition to sound and mechanical movements. The installation, created for Bishops' House, a 16th-century historic house in Sheffield (UK), consists of five tableaux placed in different rooms in the house. Each tableau represents a fictional character who lived in the house in a specific century. Each century is represented by an object that the visitor chooses at the entrance and scans at a tableau to trigger a reaction from the character represented by the tableau such as stories, smells, noises, lights and mechanical movements, that create a multisensory experience.

Some installations produce a physical output, a physical object given to the visitors in response to an input. For example, a personalised postcard with an oracle is printed in "My Roman Pantheon" (Section 4.2.2) upon returning the votive lamp to Juno's shrine while in "The Hague and the Atlantic Wall" at the last station the smart replica prints a personalised postcard of the visit and enables further online interactions [Petrelli et al. 2017].

Finally, few installations have physical behaviours as output. For example, at the "Robot Park" exhibit at the Boston Museum of Science, visitors learn the basics of programming, by using Tern, a tangible programming interface consisting of chains of wooden blocks, to control the movement of a robot [Horn et al. 2009].

In some cases, traditional devices (screens, loudspeakers, mobile devices, HMDs, etc.) are used to deliver the output, other times the output is provided through smart objects or environments.

The output can occur in various locations with respect to the input (i.e., the smart object). The location of the output with respect to the interactive object can influence the level of embodiment, that is, the perception of the computation as embodied in the object the visitor is interacting with [Fishkin 2004]. The four levels of embodiment proposed by Fishkin have been applied to the analysis of the projects. The first category includes projects in which the output is on a separate visual device (distant), most often a traditional output device such as a screen. In "VIRTEX - Ara Pacis" [Capurro 2014], pushing a button on a miniature model of the Ara Pacis, visual and textual information is displayed on a nearby screen. Sometimes the output is on another physical object, for example in the interactive story tent station in the "Nottingham Castle" installation [Fraser et al. 2003], the visitor interacts by means of paper clues and a turntable, and the output is projected on a story tent.

In the second category, the output surrounds the user, like in "Frammenti di Memoria" [Repetti 2005], where light effects are created in the environment when objects are touched.

In the third category, the output is tightly coupled to the input because of close proximity. This is typical of tangible tabletops where the information is shown on the table surface next to the object [e.g. Hsieh 2010] and in augmented reality systems where the output overlaps the object [e.g. Mann et al. 2019].

Finally, the fourth category concerns installations characterised by the highest level of embodiment as the output device corresponds to the input device as in the "Olivetti MP1" exhibit [Rawat 2005].

OUTPUT MEDIA					
Visual	Audio	Haptic	Smell	Physical	Behaviours

Fig. 7 Different output media in TI

OUTPUT DEVICE		
Traditional device	Smart object	Smart environment

Fig. 8 Different types of output devices in TI

LOCATION OF OUTPUT (WITH RESPECT TO THE INPUT DEVICE)			
Output device is the input device	Nearby (output tightly coupled to the focus of the input)	Environment (the output is around the user)	Distant (the output is on another screen/object)

Fig. 9 Possible locations of the output with respect to the input device

4.3 OTHER RELEVANT MUSEOLOGICAL ASPECTS

4.3.1 Social Engagement

Research in museum studies has investigated sociality in museums establishing it as "a primary factor in visitors' motives and satisfaction" [Debenedetti 2003]. Social engagement among visitors is affected by the way interactive experiences are designed [Hornecker et al. 2006].

Some TEI installations in the corpus reviewed are designed for the individual since they prevent social engagement. An example is the delivery of audio content through headphones. In the "Non linear stories told by cups and saucers" exhibition [De Reus et al. 2013], replicas of cups and saucers from the museum collection are on display, visitors wearing headphones move in the space and receive audio clips and information according to their positions and their actions with the objects. Another impediment to socialisation is the use of small screens that make it difficult to share the contents with visiting companions or other visitors.

Although social behaviours could emerge also in the interaction with installations designed for a single user, some of the reviewed installations show the clear intention to foster social engagement among visitors. Regarding this aspect, two types of installations can be identified. The first includes installations designed for spontaneous social behaviours to emerge - e.g., broadcast audio so that nearby visitors or companions share the experience rather than using headphones. This strategy has been implemented in "Voices from Forte Pozzacchio" [Petrelli et al. 2016] and in the "Companion Novel" [Ciolfi et al. 2013]. A similar strategy is used by installations that provide visual outputs on large screens or surfaces that can be comfortably viewed by more people at the same time, rather than on small screens that are mainly suitable for personal use [e.g., Pletinckx 2007]. Other ways to elicit spontaneous social behaviours is to enable independent interaction in close proximity as it happens in some tabletop interactives [e.g. Hsieh et al. 2010] or those providing multiple similar 'workstations' [e.g. Filene 2011, Conley-Zilkic 2011].

The second type of social engagement proposes specifically designed activities that require more visitors to get involved in defined roles designed for different modes of social engagement. Drawing on Simon's me-to-we design model for social engagement [Simon 2010], we distinguish three different modes: personal experiences with social awareness, indirect social experiences, and direct social experiences.

Personal experiences with social awareness are those in which the visitor does not interact with anybody else, but they are nonetheless made aware of the choices and opinions of the other visitors and of how their interests and actions are located inside a community of visitors. The traditional guest book is an example of an analogic tool that enables a personal experience with social awareness. Belonging to this first category is the installation "Re-tracing the Past" [Fraser et al. 2004]. Using a phone located in the "room of opinions", the visitor records a personal interpretation of an object. When this happens, a murmuring sound, played in the room based on previous visitors' recorded opinions, increases in volume as the new opinion is added to the others. Furthermore, a new brushstroke is added to a digital painting located in the same room. Through these strategies, the

visitors become aware that their opinion contributes to the interpretations of the same object by the community of visitors. A similar social engagement is in the "Social Display Environment" installation consisting of an interactive showcase that invites visitors to add narratives about their experience with the object on display, and to watch, comment or vote on the narratives created by others that are shown superimposed on the showcase [Dìaz et al. 2015].

Indirect social experiences are those that are completely mediated by the device and do not require physical contact with other visitors. Sharing pictures or comments on the web or communicating through personal devices are two examples of indirect social experiences. In addition to the type of social experience described above, the installation "Re-tracing the Past" also enables a form of indirect social experience in that the comments left by visitors are recorded and made available for listening to other visitors using an interactive radio station located in the "study room".

Finally, in the *direct social experiences*, the visitor interacts face-to-face with other visitors either using or not using a device, for example when engaging in a group activity or a game around an interactive table. The "Historical Orchestra" installation [Sen et al. 2011] was designed to enhance the experience of a 16th-century Turkish manuscript that documents with illustrations an arts and crafts festival hosted by Sultan Murad III for the celebration of his son's circumcision. Using three musical interfaces that replicate those represented in the illustration, the visitors can impersonate the players and make the animation go on (the players move forward; the audience increases in the number of people; the Sultan appears on the Palace window only when all the players arrive there).

A complex example of social activity experience is that of "Kurio" [Wakkary et al. 2009] with direct and indirect social experiences: as part of a game, members of a family use tangible interfaces (the pointer, the reader, the listener and the finder), a PDA and a tabletop to collaborate to accomplish a mission. The players are time travellers stuck in time and in need to fix their time map. The missions are received on the PDA by a family member that assigns challenges to the other members. The challenge requires participants to collect information in the museum using the tangible interfaces. Finally, a tabletop display can be used to assess their progress in the missions and get rewards in the form of videos and additional information.

In general what emerges from the survey is that, while many projects present characteristics that might elicit spontaneous social behaviours, only a few incorporate activities (e.g. collaboration, competition, conversation, game activities etc.) that call for collective involvement for the installation to become truly meaningful.

<table>
<tr><th colspan="4">SOCIAL ENGAGEMENT</th></tr>
<tr><td rowspan="3">Installations designed for a private visit</td><td colspan="3">Installations designed for social engagement</td></tr>
<tr><td rowspan="2">Spontaneous social behaviours</td><td colspan="2">Specific social activities</td></tr>
<tr><td>Personal experiences with social awareness</td><td>Indirect social experiences</td><td>Direct social experiences</td></tr>
</table>

Fig. 10 Categorization of TEI installations with respect to social engagement

4.3.2 Personalization

People visit museums driven by different motivations and needs based on their identities, personal experiences and memories [Falk 2009]. In this context, personalization becomes key as it allows to "treat visitors as individuals" [Simon 2010] and to provide "audience-centric ways to enter and access cultural experiences" [Simon 2010].

When applied to interactive technologies, personalization connects to the topic of interfaces adaptation widely studied in the HCI field [Paternò 2013], which searches for ways to adapt the various aspects of the user interface (presentation, dynamic behaviour, content) according to the changes in the context of use (user-related aspects, technology-related aspects, environment-related aspects, social aspects).

Personalization of interactive technologies in museums has also become the object of several studies, as summarised in [Ardissono et al. 2011] and [Kuflik et al. 2012]. In this section, we analyse how adaptation and thus personalization has been applied in TEI installations in museums. For the analysis, we used four categories inspired by the HCI literature and by a classification proposed in [Hincapié-Ramos 2014], that are:

- absence of personalization;
- manual filtering of content, a basic form of personalization to allow visitors for an open exploration through the selection of the contents they are interested in rather than forcing the visitors to follow a predefined navigation path through content;
- explicit declaration of visitor' characteristics such as user type, preferred mode of interaction, preferred topic/perspective (adaptable interfaces);
- automatic personalization on the basis of user models (adaptive interfaces).

Installations that are characterised by the absence of personalization are quite rare and almost exclusively found at the level of individual stations that are part of a wider installation. In "Frammenti di Memoria" [Repetti 2005], for example, touching a specific object that is part of the installation, a story and light effects are generated that are the only ones available for that object.

The vast majority of installations provide manual filtering personalization. In single-station installations, visitors activate only the content they are interested in, as in "VIRTEX – Ivory object"

[Pletinckx 2007]. Multi-station installations, instead, provide a basic form of personalization through filtering since the visitor chooses the stations they want to interact with.

Some installations provide some form of adaptability, e.g., allowing visitors to get different contents on the basis of certain preferences, like visitors' characteristics, preferred perspectives, etc. The expression of preferences is however done in different ways in the various installations. One possibility is to design objects that are symbolic of possible preferences or profiles. In "The Hague and the Atlantic Wall" exhibition [Marshall 2016], the visitor chooses one or more smart replicas, each representing a different perspective and language on the subject of the exhibition. When reaching interactive cases, the visitor uses a replica to activate stories with the chosen perspective and language. As an alternative to the design of different objects representing different profiles, there are installations that provide only one type of object for the visitor to pick up, complemented by an interactive way to select preferences to be associated with the object itself. In the "Keys to Rome" exhibition at the Allard Pierson Museum [Pescarin et al. 2015], the visitor scans a card at a station with a touch screen to associate the card to a favourite perspective with regard to the exhibited objects (Egyptian, Roman, Lowland). Once the association is done, the card can be used in the various stations in the exhibition to access digital content from the selected perspective. Sometimes the two adaptability strategies are combined together as in "Interactive Histories" [Kettner 2013], where a welcoming station allows the visitor to choose among different physical tokens each representing a different thematic tour of the exhibition, but also to associate other preferences to it such as their level of background knowledge and their age.

To conclude this overview, it is important to observe that installations that provide forms of adaptivity based on user models and automatic rules are extremely rare. The most complex example of adaptivity is provided in "ec(h)o" [Wakkary et al. 2007], requiring the visitor to explore the exhibition while carrying a wooden cube with three different coloured sides while wearing headphones. While the visitor moves through the exhibition, they can hear immersive sounds providing a context for the nearby objects and attracting them to go closer. Then, approaching the object's showcases, different audio contents can be selected and listened to by turning the cube in various directions. The content provided by the system is dynamically selected on the basis of the visitor's movement in the exhibition and the interaction history.

PERSONALIZATION			
None	Manual filtering	Adaptable interfaces	Adaptive interfaces

Fig. 11 Different types of personalization

4.3.3 Participation

Participation is another important aspect of the visit. It concerns the possibility for the visitor to "create, share, and connect with each other around contents" [Simon 2010]. Projects based on the participatory model strive for the visitor's involvement in the creation of content. Visitors become

producers of content as opposed to more traditional models that view visitors as simply consumers of content.

In the vast majority of the surveyed projects, visitors are just consumers of content. However, there are few examples in which the person can participate in the generation of content, usually consisting of comments, opinions, drawings, etc. that are generally shared and can be later accessed by other visitors. Participatory installations require the presence of both a way to allow visitors to generate and record their content, and a way to enjoy the content other visitors have already shared. These two functionalities can be designed either separately by creating two separate stations as part of the installation or can be integrated inside a single interactive station. "Re-tracing the Past" is an example of the first type (see Section 4.3.1). Belonging to the second type is instead an installation about genocide at the United States Holocaust Museum [Conley-Zilkic 2011]. It consists of a series of desks where visitors can hand-write a pledge about how to face the problem of genocide today. After depositing the pieces of paper in a glass vitrine, the text appears in a big pledge wall projection nearby.

PARTICIPATION	
Visitors as consumers	Visitors as contributors

Fig. 12 Categorization of TI installations with respect to participation

4.3.4 Target

Regarding the target, most of the installations are targeted to the general able-bodied public, while some are designed specifically for children. For example "Magic Worlds" [Taylor et al. 2015] is a travelling exhibition about magic with interactive stations such as the "Delay Magic Mirror" and the "Witch Cauldron" where children can make an active experience of magic.

Only a few interactive installations are targeted to people with disabilities such as blind and visually impaired people to enrich their tactile exploration of objects (or replicas) with information. For example, in the "Talking Painting" installation at the San Diego Museum of Art [Touch Graphics 2015a], audio descriptions are activated by the visitor as they touch a replica of the painting. Finally, there are also projects designed for and by people with learning disabilities, aiming at improving the access to and engagement with heritage and museum displays through the use of sensory objects [Hollingworth et al. 2014].

MAIN TARGET			
General able-bodied public		**People with disabilities**	
Adult	Children	Blind and visually impaired	Learning disabilities

Fig. 13 Target of surveyed TI installations

5 DISCUSSION AND CONCLUSIONS

The survey in this article investigates TEI in museums and cultural heritage from a design perspective. Consequently, it mainly focuses on how TEI has been applied in the CH and museums domains, looking, on the one hand, at the basics of interaction and, on the other, at the resulting visiting experiences. A multifaceted panorama of projects and experiences emerges, proposing different

design formulas to bodily engage visitors and overtly aimed at enhancing the communicative power of CH assets and, consequently, the institution. Far from being judgmental about the projects collected here, we conclude this article by pointing out aspects and choices we consider relevant for researchers and professionals when embarking on the design of TEI experiences in the cultural and museum domains.

A first consideration emerging from the analysis regards the cultural communication purposes of TEI systems. In particular, starting from the analysis carried out in Section 4.1.1, we identified three different uses of tangible interaction for cultural communication:

- to associate intangible values to tangible assets;
- to give material forms to intangible assets or practices;
- to make people experience specific material properties of a physical object.

These different uses should not be considered as mutually exclusive but as intersected. Indeed, a TEI installation often addresses multiple goals at the same time. We believe our conceptualization can provide more clarity and awareness about the meaning of designing a TEI system in the cultural sector. It can help to define the cultural communication goals one wants to achieve with the interactive system before embarking on the design.

From a more general perspective, different motivations for using tangible and embodied interactions underpin the various projects, that can be summarized as follows:

- making the interaction with an interactive installation easier or innovative;
- fostering memory retention of information associated to the object [Petridis et al. 2006];
- reducing the distraction of technology from the material cultural asset;
- giving a low-tech appearance to an exhibition without renouncing the power of technology;
- allowing the visitor to have an embodied engagement with CH assets, especially if they are (at least partially) of intangible nature;
- improving the accessibility of cultural heritage to visually impaired visitors;
- creating connections between the different interactives in an installation and between these and the original object [Fraser et al. 2003].

We offer this list of motivations as output of our reflection following the reading and analysis of the literature. These motivations are our own interpretation of the many projects we surveyed and our own contribution to knowledge. Therefore, the classification and analysis of projects we propose in this paper should not be considered as explicitly declared or expressed by the authors of the projects.

A second consideration is that every design choice has effects on (1) how visitors will experience the installation and (2) how they will construct meaning. The categories outlined throughout the article (sections 4.1 – 4.3) reflect the choices that designers have to make –more or less consciously– while envisioning TEI experiences. Every choice matters. Choosing primary or secondary objects as manipulable interactive devices, asking visitors to act according to codified or performative actions, and selecting the kind of output affect visitors' perception and experience, affect visitors' perception and experience, thus influencing aspects such as the social involvement and the meaning-making process. These categories and subcategories (and percentages of occurrences) are summarized in the

following table, and all together they create a conceptual framework for TEI applied to Cultural Heritage and museums.

CULTURAL/NATURAL ASSETS									
Tangible assets (21%)					**Intangible assets/values** (75%)				(2.4%)
Works of art	Artifacts	Natural objects	Architectures and buildings	Etc.	Concepts and knowledge	Personal stories an experiences	Practices	Traditions and rituals	Etc.

LOCATION OF REFERENCE TANGIBLE ASSET			
Embedded in the installation (32.2%)	Close to the installation (9.7%)	Located somewhere else in the museum (distant) (17.7%)	Located in another place (very distant) (4%)

SINGLE/MULTI-STATIONS INSTALLATIONS	
Single installation (66.1%)	Multi-stations installation (32.3%)

INTERACTION STYLE	
Interaction with contact with a smart object (tangible interaction in the strict sense) (91.1%)	Interaction without contact with a smart object (embodied interaction) (18.5%)

SMART OBJECT					
PRIMARY SMART OBJECT (48.4%)			**SECONDARY SMART OBJECT** (43.5%)		**SMART MATERIALIZATION** (22%)
Smart original (19.3%)	Smart replica (29%)	Smart derivative (6.4%)	Related object (29.8%)	Ancillary Object (15.3%)	

ACTIONS	
Codified actions (60.5%)	Performing actions (48.4%)

OUTPUT MEDIA					
Visual (78.2%)	Audio (52.4%)	Haptic (3.2%)	Smell (2.4%)	Physical (4%)	Behaviours (0.8%)

OUTPUT DEVICE		
Traditional device (39.5%)	Smart object (58%)	Smart environment (9.7%)

LOCATION OF OUTPUT (WITH RESPECT TO THE INPUT DEVICE)			
Output device is the input device (24.2%)	Nearby (output tightly coupled to the focus of the input) (20.2%)	Environment (around the user) (6.4%)	Distant (the output is on another screen/object) (34.6%)

SOCIAL ENGAGEMENT				
Installations designed for a private visit (13.7%)	**Installations designed for social engagement**			
	Spontaneous social behaviours (79%)	Specific social activities		
		Personal experiences with social awareness (3.2%)	Indirect social experiences (1.61%)	Direct social experiences (10.5%)

PERSONALIZATION			
None (4%)	Manual filtering (81.4%)	Adaptable interfaces (15.3%)	Adaptive interfaces (1.6%)

PARTICIPATION	
Visitors as consumers (89.5%)	Visitors as contributors (11.3%)

MAIN TARGET			
General able-bodied public (87.1%)		**People with disabilities** (2.4%)	
Adult	Children (11.3%)	Blind and visually impaired (1.6%)	Learning disabilities (0.8%)

Fig. 14 Summary of all categories and subcategories identified in the analysis of TEI projects applied to CH and museums

A topic that implicitly emerges in this article is the meaning of tangible and embodied interaction systems for the visitor. Certainly, tangible and embodied interaction can associate intangible values, thus meaning, to tangible cultural heritage assets [Duranti et al. 2016]. This association can be made by acting on the different elements that characterise a TEI installation, i.e., the smart object, actions, output, and their relations. To reach this goal one should define an output that is representative and communicative of an intangible value and physically link this meaning to an object. Sometimes, design defines the shape of the objects that become symbolic of specific intangible values (embedding meaning); design can also integrate actions that are representative of certain intangible values related to an object (embodying meaning). Under this perspective, TEI can be interpreted as a practice of meaning-making. On one side, there is a designer who, through their design choices, influences the meaning-making process of the visitor. On the other side, a visitor tries to make sense of what they experience and in doing so they are influenced by the designer's choices. While a divergence between intended meaning created by the designer and actual meaning constructed by the visitor can occur, and sometimes has to be encouraged, this does not diminish the importance of informing design in order to create more meaningful experiences. The topic of the meaning in TEI systems applied to cultural heritage surely deserves further investigation, also with the help of the tools provided by a discipline that, more than others, deals with issues of meaning, the Semiotics [Bianchi et al. 2010; Zingale 2016].

Finally, in this survey, we have identified topics deserving further exploration. One is the social engagement of visitors through tangible and embodied interaction. While many projects present features that can elicit spontaneous social behaviours, only a few propose activities requiring more people to participate in order for the installation to work or become more meaningful (Fig. 14). Second is the design of participatory TEI experiences as only a few exist. Further research could also be useful in the area of design of installations targeted to specific sectors of the public, such as children, visually impaired people, and people with learning disabilities as these categories can benefit from a multisensorial experience augmented by technology [Levent et al. 2014]. Finally, how tangible and embodied interactions can give material form to intangible assets is worth exploring: TEI is generally used to associate values to existing tangible objects rather than as an attempt to materialise intangible assets.

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A APPENDIX

The table below describes the tangible interactive systems reviewed for this article. It provides a description of their characteristics as emerged from the analysis. The abbreviation "n.a." is used to indicate "not available" information; "-" is used when the specific classification criteria is not applicable.

REFERENCES	NAME	ORIGIN	INTERACTION STYLE	LOCATION OF CULTURAL ASSET	TYPE OF CULTURAL ASSET	SINGLE/ MULTI STATIONS	TYPE (SUBTYPE) OF SMART OBJECT	ACTIONS	OUTPUT MEDIA	OUTPUT DEVICE	VISUAL OUTPUT LOCATION	SOCIAL ENGAGEMENT	PERSONALIZATION	PARTICIPATION	TARGET
Hall et al., 2001	The visitor as virtual archaeologists	academic	tangible	embedded	tangible; intangibile	multi	primary (smart replica)	codified	n.a.	n.a.	n.a.	social activities (direct)	manual filtering	consumer of content	general able-bodied public
Ciolfi et al., 2002	Interactive ceramic figurines	academic	tangible	embedded	tangible; intangibile	single	primary (smart original)	codified	visual; audio	smart object; traditional device	tightly coupled to the focus of the input	spontaneous	manual filtering	consumer of content	general able-bodied public
Fraser et al., 2003	Nottingham Castle Installation	academic	tangible	distant	tangible; intangibile	multi	secondary (related, unrelated);	codified; performing	visual	smart object	distant; tightly coupled to the focus of the input	spontaneous	manual filtering	consumer of content	general public
Fischer et al., 2003	Tangible Interfaces to explain Gaudi's use of ruled-surface geometries	academic	tangible	-	intangibile (practice)	single	smart materialization	codified	visual	traditional device	distant	spontaneous	n.a.	producer of content	general able-bodied public
Wiener Philharmoniker, 2003	Waltz-Dice-Game	non-academic	tangible	n.a.	tangible; intangibile	single	primary (smart derivative); secondary (related)	performing	visual; audio	traditional device	distant	social activities (direct); spontaneous	n.a.	producer of content	general able-bodied public
Fraser et al., 2004	Retracing the past	academic	tangible	distant	tangible. tangible; intangibile	multi	primary (derivative); secondary (related, unrelated)	codified; performing	visual; audio	smart object	distant; tightly coupled to the focus of the input; output device is the input device	social activities (personal experiences with social awareness; indirect); spontaneous	manual filtering	producer of content	general able-bodied public
Repetti, 2005	Frammenti di memoria	non-academic	tangible	embedded	tangible; intangibile	multi	primary (smart original)	codified	visual; audio	smart environment	around the user	spontaneous	manual filtering	consumer of content	general able-bodied public
Rawat, 2005	Whispering Table (Wonder Objects)	academic	tangible; embodied	embedded	tangible; intangibile	single	secondary (related)	performing	visual; audio	smart object	tightly coupled to the focus of the input	none	manual filtering	consumer of content	general able-bodied public
Rawat, 2005	Interactive book (Wonder Objects)	academic	tangible	embedded	tangible; intangibile	single	secondary (related)	performing	visual; audio	smart object	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Rawat, 2005	typewriter + magic mirror (Wonder Objects)	academic	tangible; embodied	embedded	tangible; intangibile	single	primary (smart original); secondary (unrelated)	performing; codified	visual; audio	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Rawat, 2005	typewriter (wonder objects)	academic	tangible; embodied	embedded	tangible; intangibile	single	primary (smart original)	performing	visual; audio	smart object	the output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Zheng et al., 2005	Interactive skipping rope	academic	tangible	-	intangibile (concept)	single	smart materialization	performing	visual	smart object	output device is the input device	spontaneous	-	consumer of content	children
Hsi et al., 2005	eXspot	academic	tangible	n.a.	n.a.	multi	secondary (unrelated)	codified	visual	n.a.	n.a.	spontaneous	manual filtering	producer of content	general able-bodied public
Wakkary et al., 2007	ec(h)o	academic	tangible; embodied	embedded	tangible; intangibile	multi	secondary (unrelated); primary (original)	codified; performing	audio	traditional devices	-	none	manual filtering; adaptive interfaces	consumer of content	general able-bodied public
vom Lehn et al., 2007	Engaging Constable	academic	embodied	distant	tangible; intangibile	single	primary (smart replica)	codified	visual	smart object	the output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Lee et al., 2007	REXband	academic	tangible	n.a.	tangible; intangibile	multi	primary (smart replica)	performative	audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Ballagas et al., 2007	REXplorer	academic	tangible	n.a.	tangible; intangibile	multi	secondary (related)	codified	visual; audio	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Studio TheGreenEyl, n. d.	Whispering Table	non-academic	tangible	-	intangibile (stories)	single	smart materialization	performing	audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public

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Pletinckx, 2007	VIRTEX (Ivory object, Archaeological Museum Ename, Belgium)	academic	tangible	close	tangible; intangibile	single	primary (smart replica)	codified; performing	visual; audio	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Koster, 2008	Virtual Conductor	non-academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica); secondary (related)	performing	visual; audio	smart object/environment	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Horn et al., 2009	Robot Park exhibit	academic	tangible	-	intangibile (concepts)	single	smart materialization	performing	physical behaviour	smart object	distant	spontaneous	-	-	general able-bodied public
Wakkary et al., 2009	Kurio	academic	tangible	close; embedded	tangible; intangibile	multi	primary (smart original); secondary (unrelated)	codified; performing	haptic; visual	smart object	output device is the input device	social activities (direct; indirect)	manual filtering	consumer of content	general able-bodied public
Dindler et al, 2009	RuneTable	academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica); secondary (related)	codified	video	traditional device	tightly coupled to the focus of the input	spontaneous	manual filtering	producer of content	general able-bodied public
Hsieh, et al., 2010	Yongzheng emperor's interactive tabletop	academic	tangible	n.a.	tangible; intangibile	single	primary (smart derivative)	codified	visual	traditional device	tightly coupled to the focus of the input	spontaneous	manual filtering	consumer of content	general able-bodied public
De Berigny Wall, 2010	Interantarctica	academic	tangible	-	intangibile (concept)	single	smart materialization	codified	visual; audio	smart object	tightly coupled to the focus of the input	spontaneous	manual filtering	consumer of content	general able-bodied public
Tanenbaum et al., 2010	The Reading Glove	academic	tangible (wearable)	embedded	tangible; intangibile	single	primary (smart original); secondary (related)	performing	audio	traditional device	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Chin, 2010; Andy Wheatcroft, n.d.	Musical drawers	non-academic	tangible	embedded	tangible; intangibile	single	secondary (related)	performing	visual; audio	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
AVCNYC, 2010	The "Interactive Artifact Exploration Cabinet"	non-academic	tangible	embedded	tangible; intangibile	single	primary (smart original, smart replica); secondary (related)	codified; performing	visual	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Bacconi, 2010	Oggetti interattivi e interfacce tangibili (Museo delle culture di Lugano.	academic	tangible	distant	tangible; intangibile	multi	secondary (unrelated)	codified	visual	traditional device	distant	spontaneous	manual filtering; adaptable interfaces	consumer of content	general able-bodied public
Ciolfi et al., 2011	Reminisce	academic	tangible	distant	tangible; intangibile	multi	secondary (related)	codified	audio	smart object	-	spontaneous; social activities (indirect)	manual filtering	consumer of content; producer of content	general able-bodied public
Conley-Zilkic et al., 2011	Holocaust Memorial Museum pledge installation	non-academic	tangible	-	intangibile (concept)	multi	smart materialization	performing	visual	smart object; traditional device	distant	spontaneous; personal experiences with social awareness	-	producer of content	general able-bodied public
Filene, 2011	The dining table installation (Open House: If These Walls Could Talk)	non-academic	embodied	-	intangibile (stories)	single	smart materialization	performing	visual; audio	smart object	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Filene, 2011	The coin installation (Open House: If These Walls Could Talk)	non-academic	tangible	-	tangible; intangibile	single	secondary (related)	codified	visual; audio	smart object	distant	spontaneous	none	consumer of content	general able-bodied public

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Ueda et al., 2011	Diplomacy and Sevres Porcelain, Prestige and the French art of living in the 18th century	academic	tangible	distant	tangible; intangibile	single	secondary (related)	performing	visual	traditional device; smart object	tightly coupled to the focus of the input; output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Sen et al., 2011	Historical orchestra	academic	tangible	n.a.	tangible; intangibile	single	secondary (related)	performing	visual; audio	traditional device	distant	social activities (direct)	adaptable	consumer of content	general able-bodied public
ERASME, 2011	Le cabinet des Fables	non-academic	embodied	embedded	tangible; intangibile	multi	primary (smart original)	codified	audio	smart environment	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Grammenos, et al., 2011	Paperview	academic	tangible	very distant	tangible; intangibile	single	secondary (unrelated)	codified	visual	smart object	output device is the input device	spontaneous	none	consumer of content	general able-bodied public
De Reus, 2013	Smart replicas	academic	tangible; embodied	distant	tangible; intangibile	multi	primary (smart replica)	performing	audio	traditional device	-	none	manual filtering	consumer of content	general able-bodied public
Ciolfi, et al., 2013	Companion Novel (Sheffield General Cemetery)	academic	tangible; embodied	embedded	tangible; intangibile	multi	secondary (related); primary (smart original environment)	performing	audio	smart object/environment	-	spontaneous	manual filtering; adaptable interfaces	consumer of content	general able-bodied public
Kettner, 2013	Interactive histories	academic	tangible	close/distant	tangible; intangibile	multi	primary (smart derivative)	codified	visual	traditional device	tightly coupled to the focus of the input	spontaneous	adaptable	consumer of content	general able-bodied public
Kockelkorn, 2013	Seal Hunting in the museum	academic	tangible	close	tangible; intangibile	multi	secondary (unrelated)	codified	visual	smart object	output device is the input device	none	manual filtering	consumer of content	children
Smith, 2014	The Really Simple Object Recognition Anglo-Saxon Table	non-academic	tangible	distant	tangible; intangibile	single	secondary (related, unrelated)	codified	visual; audio	smart object	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Sportun, 2014	Interactive stela	academic	tangible	distant	tangible; intangibile	single	primary (smart replica)	codified	visual; audio	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Díaz, 2014	Havis Amanda, Mon Amour	academic	tangible	distant	intangibile; tangible	single	secondary (related)	performing	visual	traditional device	tightly coupled to the focus of the input	spontaneous	none	consumer of content	general able-bodied public
Díaz, 2014	Oral history of Finnish designers project	academic	tangible	close	tangible; intangibile	multi	primary (smart replicas)	codified	video, audio	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Vaz, 2014	Interfaces tangíveis no contexto da experiência da visita a um museu	academic	tangible	embedded	tangible; intangibile	single	primary (smart original); secondary (related)	performing	visual; audio	smart object; traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Pescarin, 2014	Revealing flashlight (head of Caesarion; marble slabs; oscillum)	academic	embodied	embedded	tangible; intangibile	single	primary (smart original)	performing	visual	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Pescarin, 2014	rfid card, Allard Pierson Museum, keys to rome	academic	tangible	close; distant	tangible; intangibile	multi	secondary (related)	performing	visual	traditional device	distant	none	manual filtering; adaptable interfaces	consumer of content	general able-bodied public
Capurro, 2014	VIRTEX (Ara Pacis at Allard Pierson Museum)	academic	tangible	very distant	tangible; intangibile	single	primary (smart replica)	codified	visual	traditional device	distant	none	manual filtering	consumer of content	general able-bodied public
Capurro, 2014	VIRTEX (Augustus of Prima Porta)	academic	tangible	very distant	tangible; intangibile	single	primary (smart replica)	codified	visual	traditional device	distant	none	manual filtering	consumer of content	general able-bodied public
Hincapié-Ramos, et al., 2014	Winnipeg Art Gallery's interactive case	academic	tangible; embodied	embedded	tangible; intangibile	single	primary (smart replica); secondary (related)	codified; performing	visual	smart object	output device is the input device; distant	spontaneous	manual filtering	consumer of content; producer of content	general able-bodied public

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Chu, et al, 2015	Mapping Place	academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica)	performing	visual	tabletop; environment	tightly coupled to the focus of the object; distant	spontaeous; social activities (direct)	manual filtering	producer of content	mainly children
Louvre - DNP Museum Lab, n. d.	"The painting, a material object"	non-academic	tangible	distant	tangible; intangibile	single	secondary (related, unrelated)	codified	visual	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Clarke, et al., 2015	Offline tangibles at an interactive painting exhibit in a children's cultural centre	academic	tangible	-	intangibile (concept)	single	smart materialization	performing	visual	smart object; traditional device	tightly coupled to the focus of the input; distant	spontaneous; social activities (personall experiences with social awareness)	manual filtering	producer of content	children
D'Agnano, et al., 2015	Tooteko for church of San Michele in Isola	non-academic	tangible (wearable)	close	tangible; intangibile	single	primary (smart replica); secondary (unrelated)	performing	audio	traditional device	-	none	manual filtering	consumer of content	blind and visually impaired
Taylor et al., 2015	Magic Worlds - the delay magic mirror	academic	embodied	-	intangibile (concept)	single	smart materialization	performing	visual	smart object	output device is the input device	spontaneous	-	consumer of content	children
Taylor et al., 2015	Magic Worlds - the caleidoscope mirror	academic	embodied	-	intangibile (concept)	single	smart materialization	performing	visual	smart object	output device is the input device	spontaneous	-	consumer of content	children
Taylor et al., 2015	Magic Worlds - the magic cauldron	academic	tangible	distant	tangible; intangibile	single	related; materialization	performing	visual; audio	smart object	tightly coupled to the focus of the input	spontaneous	-	consumer of content	children
Marshall, et al., 2015	Companion Novel (Voices from the Trenches)	academic	tangible; embodied (wearable)	embedded	tangible; intangibile	multi	secondary (related); primary (smart original environment)	codified; performing	audio	smart object/environment	-	spontaneous	manual filtering; adaptable interfaces	consumer of content	general able-bodied public
Damala, et al., 2016b; Waag, 2015	Drinking Symposium	academic	tangible; embodied	distant	tangible; intangibile	single	primary (smart replica)	performing	visual, audio	smart environment	around the user	spontaneous	manual filtering	consumer of content	general able-bodied public
Muntean et al., 2015	ʔeləwiḵʷ-Belongings	academic	tangible	distant	tangible; intangibile	single	primary (smart replica); secondary (related, unrelated)	codified	visual; audio	traditional device	distant; tightly coupled to the focus of the input;	spontaneous	manual filtering	consumer of content	general able-bodied public
Touch Graphics, 2015b	Talking Sculpture, San Diego Museum of Art	non-academic	tangible	distant	tangible; intangibile	single	primary (smart replica)	codified	audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Touch Graphics, 2015a	Talking Tactile Exhibit Panel, San Diego Museum of Art	non-academic	tangible	distant	tangible; intangibile	single	primary (smart derivative)	performing	audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Antoniou, 2015	Micro-augmentations	academic	embodied	embedded	tangible; intangibile	single	primary (smart original)	performing	audio	n.a.	-	spontaneous	-	consumer of content	general able-bodied public
Alletto et al., 2015	Indoor Location-aware System for an IoT-based Smart Museum	academic	embodied (wearable)	embedded	tangible; intangibile	multi	secondary (unrelated)	performing	visual; audio	n.a.	n.a.	spontaneous	manual filtering	producer of content	general able-bodied public
Díaz et al., 2015	The Social Display Environonment	academic	tangible	embedded	tangible; intangibile	single	secondary (related)	codified	visual	smart object	tightly coupled to the focus of the input	social activities (personal experiences with social awareness)	manual filtering	producer of content; consumer of content	general able-bodied public
Ma et al., 2015	The plankton population exhibit	academic	tangible	-	tangible; intangibile	single	secondary (related)	codified	visual	traditional device	tightly coupled to the focus of the input	spontaneous	manual filtering	consumer of content	general able-bodied public

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Nicolas et al., 2015	Weighting activity	academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica)	performing, codified	video	traditional device	tightly coupled to the focus of the input	none	manual filtering	consumer of content	general able-bodied public
Marshall, et al., 2016	The Hague and the Atlantik Wall: War in the City of Peace	academic	tangible	embedded	tangible; intangibile	multi	primary (smart replica)	codified	audio; physical (postcard)	smart object; traditional device	distant	none	manual filtering	consumer of content	general able-bodied public
Damala, 2016b	Tondo Installation	academic	tangible	close	tangible; intangibile	single	primary (smart replica)	codified	visual	smart objects	output device is the input device;	spontaneous	manual filtering	consumer of content	general able-bodied public
Ceconello et al., 2016	Leonardo Plays Leonardo	academic	embodied	-	intangibile (historical character; stories)	multiple	smart materialization	performing, codified	visual; audio	holographic screens	-	spontaneous	none	consumer of content	general able-bodied public
Culén, 2016	Eco-A - Informative videos installation	academic	tangible	-	intangibile (concepts)	single	smart materialization	codified	visual	traditional device	distant	spontaneous	manual filtering	consumer of content	children and youth
Culén, 2016	Eco-A - Critical questioning installation	academic	tangible	-	intangibile (concepts)	single	smart materialization	codified	visual	traditional device	distant	spontaneous	manual filtering	consumer of content	children and youth
Culén, 2016	Eco-A - opinions installation	academic	tangible	-	intangibile (opinion)	single	smart materialization	codified	-	-	-	spontaneous	-	producer of content	children and youth
Damala et al., 2016a	The meSch Loupe at Allard Pierson	academic	tangible	embedded	tangible; intangibile	multi	secondary (related)	performing; codified	visual	smart object	output device is the input device	none	manual filtering	consumer of content	general able-bodied public
Maye, 2016	The Loupe at the Hunt Museum	academic	tangible	close	tangible; intangibile	multi	secondary (related)	codified	visual	smart object	output device is the input device	none	manual filtering	consumer of content	general able-bodied public
Petrelli et al., 2016	Voices from Forte Pozzacchio	academic	tangible	very distant	tangible; intangibile	multi	secondary (related, unrelated)	codified	visual, audio, physical (postcard)	smart environment	distant	spontaneous	manual filtering; adaptive interfaces	consumer of content	general able-bodied public
Chu et al., 2016	Sensing History (Visual Voyage)	academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica)	performing	visual	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Chu et al., 2016	Sensing History (Experiencing Spirituality)	academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica)	performing	visual; audio	traditional device	distant	spontaneous	none	consumer of content	general able-bodied public
Chu et al., 2016	Sensing History (Scents of Power)	academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica)	performing	visual	smart object; tabletop	output device is the input device; tightly coupled to the focus of the object	spontaneous	manual filtering	consumer of content	general able-bodied public
Anagnostakis et al., 2016	Accessible museum collections for the visually impaired:	academic	tangible	n.a.	tangible; intangibile	multi	primary (smart replica)	performing	audio	traditional device	-	spontaneous	manual filtering	consumer of content	blind/visually impaired people
Okerlund et al., 2016	Synflo	academic	tangible	-	intangibile (concepts, knowledge and skills)	single	smart materialization	performing, codified	visual	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Romano et al., 2016	Augmenting Smart Objects for Cultural Heritage	academic	tangible	embedded	tangible, intangibile	multi	secondary (related)	codified	visual, audio	smart object	output device is the input device.	spontaneous	manual filtering	consumer of content	general able-bodied public
Chomko & Rosier, 2016	The Lost Palace	industry	tangible	embedded	tangible; intangibile (stories, and place that no longer exists)	multi	secondary (unrelated)	codified	audio; haptic	traditional device; smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public

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Rubio Hernández, 2017	Vaprikki's optical telegraph	academic	tangible	-	tangible; intangibile	single	primary (smart replica)	codified	visual	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Petrelli, 2017	Festival of Britain Pink Knickers	academic	tangible	embedded	tangible; intangibile	single	primary (smart derivative); secondary (related)	codified	visual; audio	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Poole, 2017	Ghosts in the Garden	academic	tangible	-	intangibile (stories)	multi	smart materialization	-	audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Claisse et al., 2017	Containers of stories	academic	tangible	embedded	tangible; intangibile	multi	secondary (related)	codified	audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Javornik et al., 2017	MagicFace	academic	embodied	-	intangibile (historical character)	single	smart materialization	performing	visual; audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Maquil et al., 2017	BatSim	academic	tangible	-	intangibile (practice)	single	smart materialization	codified, performing	visual	smart object	output device is the input device; distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Loparev et al., 2017	Back pack	academic	tangible	-	intangibile (concepts, knowledge and skills)	single	smart materialization	codified, performing	visual	traditional device	tightly coupled to the focus of the input	spontaneous	manual filtering	consumer of content, producer of content	general able-bodied public
Petrelli et al., 2018	My Roman Pantheon	academic	tangible	embedded	tangible; intangibile	multi	secondary (related)	codified	visual; audio; physical (postcard)	smart objects	output device is the input device; distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Dagan, 2018	The Cloakroom	academic	tangible	-	intangibile (stories)	single	smart materialization	codified	audio	traditional device	-	spontaneous	manual filtering	consumer of content	general able-bodied public
Hai, et al., 2018	Interactive mural	academic	tangible	-	intangibile (stories)	single	smart materialization	codified	visual; audio	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	families; children
Hai, et al., 2018	Goldsmith simulator	academic	tangible	-	intangibile (practice)	single	smart materialization	performing	visual	traditional device (screen)	-	spontaneous	manual filtering	consumer of content	families; children
Hai, et al., 2018	Interactive Batu Boh grinder	academic	tangible	embedded	tangible; intangibile	single	primary (smart original)	performing	audio; smell; physical	smart object	-	spontaneous	manual filtering	consumer of content	families; children
Not et al., 2018; Not et al., 2019	Interactive Plinth	academic	tangible	embedded	tangible; intangibile	single	primary (smart original)	codified	visual; audio	smart object	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Claisse et al., 2018	Interactive Tableaux	academic	tangible	embedded/close	tangible; intangibile	multi	secondary (related)	codified	visual; audio; smell	smart objects	tightly couple to the focus of the object	spontaneous	manual filtering	consumer of content	general able-bodied public
Pescarini et al., 2018	Interactive maquette	academic	tangible	distant	tangible; intangibile	single	primary (smart replica)	codified	visual; audio	smart object; traditional device	output device is the input device; distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Pescarini et al., 2018	Invitation to dinner	academic	tangible	distant	tangible; intangibile	single	secondary (unrelated)	codified	visual	smart environment	around the user	spontaneous	manual filtering	consumer of content	general able-bodied public
Nofal et al., 2018a	The Djoser pyramid complex interative installation	academic	tangible	very distant	tangible; intangibile	single	primary (smart replica); secondary (related); materialization	codified	visual	traditional device; smart object	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Butnariu, et al., 2018	An Interactive Haptic System for Experiencing Traditional Archery	academic	tangible	n.a.	tangible; intangibile	single	primary (smart derivative)	performing	visual; haptic	smart object; traditional device	around the user	none	-	consumer of content	general able-bodied public
Dimitropoulos et al., 2018.	The Loom: Interacting Weaving	academic	tangible	close	tangible; intangibile	single	primary (smart replica)	n.a.	visual	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Scott et al., 2018	The augmented telegrapher	academic	tangible	embedded	tangible; intangibile	single	primary (smart original)	performing	visual	traditional device	around the user	n.a.	n.a.	n.a.	general able-bodied public

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Gaugne, et al., 2018	Virtual Reality (VR) interactions with multiple interpretations of archaeological artefacts	academic	tangible	n.a.	tangible; intangibile	single	primary (smart replica)	performing	visual	traditional device	-	none	manual filtering	consumer of content	general able-bodied public
Koolbergen et al., 2018	Identification Rumble	academic	tangible	-	intangibile (stories)	multi	smart materialization	codified	visual, audio	smart object	-	spontaneous	manual filtering	consumer of content	general able-bodied public
McGookin et al., 2018	Proximity triggered multimodal boxes	academic	embodied	-	intangibile (traditions)	multi	smart materialization	codified, performing	audio; smell	smart object	-	spontaneous; none	manual filtering	consumer of content	general able-bodied public
Ardito, et al., 2018	Mouth of Truth	academic	tangible	embedded	tangible; intangibile	multi	secondary (related)	codified	visual	smart object	output device is the input device	social activities (direct)	manual filtering	-	general able-bodied public
Rey et al., 2018	Totem de Personnalisation	academic	tangible	n.a.	n.a.	n.a.	secondary (unrelated)	codified	n.a. (perhaps physical - printing)	n.a.	n.a.	social activities (direct)	adaptable interfaces	consumer of content	general able-bodied public
Nofal et al., 2018b	Graethem Chapel	academic	tangible	embedded	tangible; intangibile	single	primary (smart replica)	codified	visual	traditional device	distant	spontaneous	manual filtering	consumer of content	general able-bodied public
Torpus, 2018	"The Roman trade centre Schmidmatt"	academic	tangible; embodied	embedded	tangible; intangibile	multi	primary (smart original)	performing	visual; audio	smart object/environment	around the user	spontaneous	-	consumer of content	general able-bodied public
Torpus, 2018	Open-Air Museum Ballenberg (OMB): "Farmhouse Uesslingen"	academic	tangible; embodied	embedded	tangible; intangibile	multi	primary (smart original environment)	performing	visual; audio	smart object/environment	around the user	spontaneous	-	consumer of content	general able-bodied public
Torpus, 2018	Museum der Kulturen Basel (MKB): "meditation box"	academic	tangible; embodied	embedded	tangible; intangibile	single	secondary	codified	visual; audio	smart object/environment	around the user	spontaneous	manual filtering	consumer of content	general able-bodied public
Kidd, 2019	With New Eyes You See	academic	tangible	embedded	tangible; intangibile	multi	secondary (related)	performing	visual; audio	smart object/environment	tightly coupled to the focus of the objec	spontaneous	manual filtering	consumer of content	general able-bodied public
Mann et al., 2019	3D Printing for Mixed Reality Hands-On Museum Exhibit Interaction	academic	tangible	n.a.	tangible	single	primary (smart replica)	performing	visual	traditional device	tightly coupled to the focus of the input	none	manual filtering	consumer of content	general able-bodied public
Schou et al., 2020	The Diary of Niels	academic	tangible	embedded	tangible; intangibile	single	primary (smart original, replica)	performing	visual	smart object	distant	spontaneous	manual filtering	consumer of content	younger audiences
Nofal, et al., 2020	Touchtomb	academic	tangible	close/embedded	tangible; intangibile	single	primary (smart replica)	codified	visual	smart object	output device is the input device/tightly coupled to the focus of input	social activities (direct); spontaneous	manual filtering	consumer of content	general able-bodied public
Fraietta, 2020	Transient Relics	academic	tangible	-	intangibile (tradition)	-	smart materialization	codified	audio	smart object	output device is the input device; distant	social activities (direct)	manual filtering	consumer of content	general able-bodied public
Pereda, et al., 2020	Afrobits	academic	tangible	-	intangibile (music traditions)	single	smart materialization	codified	audio	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Yi et al., 2020	Scienscope	academic	tangible	embedded	tangible; intangibile	multi	secondary (related)	performing	visual; audio; haptic	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public
Kobeisse et al., 2020	Archeobox	academic	tangible	n.a.	tangible	single	secondary (unrelated)	codified	visual	traditional device	tightly coupled to the focus of the input	none	manual filtering	consumer of content	general able-bodied public

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Coppola et al., 2020	Domus	academic	tangible	n.a.	tangible; intangibile	single	primary (smart derivative)	codified	visual	traditional device	tightly coupled to the focus of the input	social activities (direct)	manual filtering	consumer of content	general able-bodied public
Rey et al., 2020	Build Your Own Hercules	academic	tangible	distant	tangible	single	secondary (smart derivative)	codified	visual	smart object	distant	spontaneous	adaptable interfaces	consumer of content	general able-bodied public
Rodrigues et al., 2020	Open Sesame	academic	tangible	distant	tangible; intangibile	single	secondary (related)	codified	visual; audio	smart object	output device is the input device	spontaneous	manual filtering	consumer of content	general able-bodied public