Submitted version Pre peer feedback

Inclusive museums and augmented reality. Affordances, participation, ethics and fun.

SUBMITTED VERSION PRE PEER FEEDBACK AND ACCEPTANCE BY *The International Journal of the Inclusive Museum*

Kieron Sheehy [a], Helena Garcia-Carrizosa [a], Jonty Rix [a], Jane Seale [a], and Simon Hayhoe [b]

[a] Faculty of Wellbeing, Education and Language Studies, Open University, UK

[b] Department of Education, University of Bath, UK

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Abstract. Augmented reality (AR) technology possesses several affordances that can support disabled museum visitors. A structured research review was used to examine the ways in which AR being used in, or developed for, museums to support access for disabled people and /or those with cognitive or sensory impairments. It also considers the extent to which the underpinning research approaches are inclusive. The findings suggest that AR can positively transform aspects of disabled users' museums experiences. However, disabled people's involvement in AR research, intended for use by them, appears problematic.

Key words. Inclusion, augmented reality, disability, technology development, museums.

Introduction

Many museums are seeking to become inclusive cultural centres, and there has been an increase in museums and cultural heritage sites that offer accessible exhibitions for people with sensory or learning impairments. However, in general it still remains relatively uncommon for cultural heritage centres to have developed ways of facilitating access for "casual visitors who are visually impaired, deaf or who have learning disabilities," (Partarakis et al. 2016, 237). One way in which this situation might be improved is through technologies that alter the ways visitors interact with the museum environment. Augmented Reality (AR) offers new opportunities for how museums can facilitate and construct their daily interactions with the public, in particular those with sensory impairments or learning disabilities.

This paper seeks to explore and analyze the ways in which AR is currently being used and developed to facilitate inclusive museum experiences. An evidence-based review in this area was lacking. This review aims to understand current practices in museums and AR research to give insights that can frame the construction of positive inclusive experiences with this developing technology. The focus of the in-depth review was on two questions:

> What characterises the ways in which AR is being used in (or developed for) museums to support access for disabled people and /or those with cognitive or sensory impairments?
> To what extent are the underpinning research approaches inclusive? I.e. involve the intended 'end users of the AR technology.

These questions have relevance for museums and AR researchers seeking to create inclusive, and accessible, spaces for a diverse public.

Augmented Reality

There is no standardised or agreed definition of augmented reality (AR) (Normand, Servières, and Moreau 2012) and the term is often used to refer to different forms of virtually mediated environments and virtual reality technologies (Sheehy, Ferguson, and Clough 2014). However, a defining feature of an augmented reality experience is that people using augmented reality technologies retain awareness of their physical world, which is overlaid to varying extents with digital information. This contrasts with the total immersion of virtual reality experiences. Because of this AR has been seen, by some early researchers, as a 'mixed reality' (Milgram et al. 1994) occupying the middle ground' between completely synthetic virtual environments and completely real telepresence (Azuma 1997, 2). Figure 1 below illustrates the way in which AR is created through this blending of real and virtual information. (For a review of taxonomies of augmented reality, see Normand et al 2012)

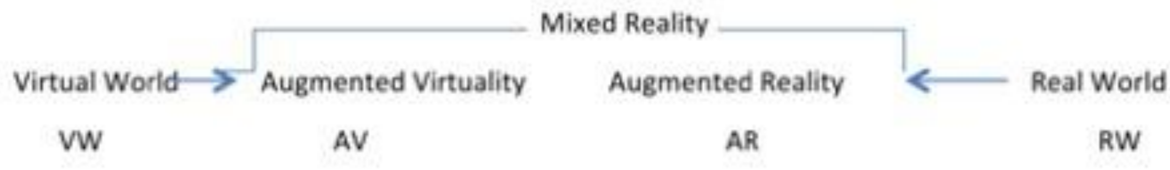

Figure 1. A continuum of reality and virtuality (adapted from Milgram et al., 1994)

AR augmentations of the world are increasingly common and readily accessed through everyday mobile technologies (typically tablets and smart phone apps). The type of digital/virtual information that apps use to augment a person's perception of the world can vary in nature. For example, 'Star-gazing' AR applications present real time updated information of satellites overlaid on the night-time sky (for example Star Walk ™). In contrast, other AR apps present information that is static and only relevant to a single location or object. Pokemon Go ™ was perhaps the first AR app to have a large-scale impact on public awareness. Several museums took advantage of the immense popularity of Pokemon Go™ to attract visitors by creating pokestops and 'gyms' (which players visit to collect and battle Pokemon™) within their premises, giving discounts to players and supporting players social media posts that included the museum (We Are Museums 2016; Museumhack 2018). These examples illustrate ways in which AR can be used to label, simplify and provide information and also to connect with others: for example, asynchronously accessing objects and information left by peers and synchronously sharing their responses in real time with social networks.

Although typically seen as a primarily visual experience (Martin et al. 2011) AR has the potential to present audio (Munnerley et al. 2012), haptic (Bau and Poupyrev 2012) and, albeit rarely, gustatory and olfactory (Normand et al., 2012) information. This creates a significant affordance in the ability to transform, or extend, the channels through which information is presented. For example, verbal descriptions can become visual ones, or vice versa (Radu 2012). AR can also enhance information presentation by making non-interactive static content responsive to, and interactive for, the user. This has the potential to create new, more accessible and engaging ways of getting information about the environment. Consequently, some museums have moved 'beyond simple static overlays' and have used AR avatars, where virtual historical characters are visualized in real museum surroundings (Fresh Creation 2007).

The impact of these location-aware technologies is arguably most profound for those who experience significant barriers to engaging with different aspects of the world and its culture. AR technologies can increase the autonomy of blind or visually impaired people in navigating known and unknown environments (Katz et al. 2012) and transform unseen visual object data into accessible auditory information (Dramas et al. 2008). AR can present information that people may otherwise struggle to access –for example reading aloud written text or adding helpful environmental information through voice, symbols or signing in person's own language (Sheehy et al. 2014). This range of applications means that AR, in its various guises, offers a valuable tool through which museum environments might be made more meaningful and engaging for a diversity of visitors.

Mapping the affordance of Augmented Reality technologies.

An important issue within AR is the impact that it has on the nature of an activity and how it is experienced by AR users. This experience is not uniform across people, technologies or contexts, and so a framework for mapping, and comparing, the affordances of particular systems is a useful analytic tool. The Affordances of Augmented Reality Systems and Applications framework (Sheehy, Ferguson, and Clough 2014) was developed to do this. It sees affordances as fundamental properties that determine how the technology could possibly be used (Norman 1999) and highlights eight of them.

In this framework Authenticity refers to experiences that users themselves rate as meaningful in their own lives, and those that reflect 'real-world' skills or are relevant to a particular community. The *Collaborative* affordances of Augmented Reality allow dialogues between users and can be important in supporting learning (Littleton and Mercer 2013). This collaboration can occur at distance, e.g. with people in different countries (Pemberton and Winter 2009), and through the sharing of virtual objects and data (Wojciechowski and Cellary 2013). Perhaps one of the most noticeable impacts of digital technology on our everyday lives has been the ways in which information and social contact is available directly and quickly. *Connectivity* reflects this affordance. For example, encompassing language translations from text or voice, or labelling aspects of the real world around the user and mediating the users experience of a place and activity. In this way it can transform the user's capabilities within, and conceptualizations of, their environment.

The other terms with the framework are more transparent, being concerned with the users own interests (*Student Centered*), linking to community of users (*Community*), Exploring a situation and Sharing knowledge. The final Multisensory affordance is seen as particularly important for disabled users, through the provision of additional or enhanced sensory (visual, auditory, haptic and olfactory) experiences (Nakevska et al. 2012), translating environmental data in this way, into alternative sensory modalities. This can offer people who are blind or have a visual impairment auditory information about the spaces around them and support navigation (Blum, Bouchard, and Cooperstock 2012), or provide haptic information to differentiate colours within their environment (Manaf 2012).

Each of these affordances might not exist to the same extent within a particular AR technology. To capture this variation the AR framework extended Twining's computer practice framework (Twining 2002) and categorises the impact of AR in five broad ways.

- Transforms – The experiences are different and could not occur without the AR.
- Extends –The activity or experience is different but could occur with this technology.
- Supports – The experience remains the same but in now automated or is technologically mediated. For example access to information could be quicker.
- Impairs - There is also a possibility that the AR has no influence on a person's experience or acts to impair the users experience creating a barrier to experience.
- Unknown. The impact cannot be ascertained form the data provided.

These five levels of impact are represented in the radiating axes in Figure 1. In Figure 1 the affordances of a particular AR book is mapped against the radial axes for each of the eight affordances. This profile will vary between different AR technologies.

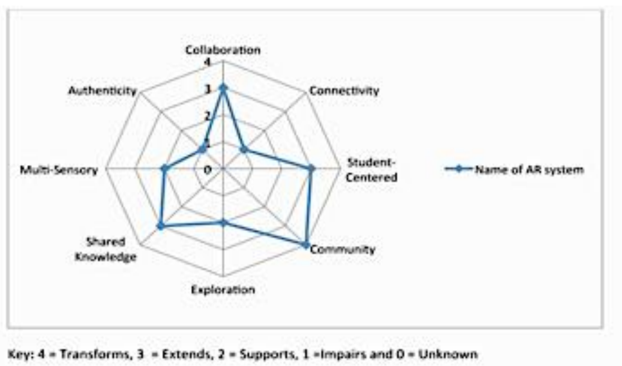

Figure 2. The Affordances of Augmented Reality Systems and Applications framework

This illustrates the way in which the eight affordances of AR technology can expressed differently within a specific technology. The eight axes represent the eight different affordances and this particular AR book extends the affordance of collaboration and supports the multisensory affordance. Other AR technologies would have a different profile, for example an AR navigation app might be able to transform a blind user's ability to explore a museum but have little impact in relation to collaboration.

Disabled people and the research process.

An emerging issue with the design of technological innovations, such as AR, is the role of the 'user group' in their creation. This reflects a longstanding awareness that disabled people and/or those with learning difficulties should have a significant role within the development of new technological developments to problems of access. The UN Convention on the Rights of Persons with Disabilities (United Nations 2006) required governments to meet the needs of their disabled citizens (Borg, Lindstrom, & Larsen 2011) and notes the central role of assistive and digital technologies and promotion of access to them, and information about them (see United Nations, 2006, Article 4(g) Article 4(h)). Fundamentally, it sees technology research as essential in supporting the rights of disabled people. It directs researchers to support the engagement of participants within the research process itself (Wright et al. 2011). This led to situations in which some researchers have worked with participants from user groups and viewed them as 'members of the team' or used technologies to ensure that their voices are heard in the research and development process (Wright et al. 2011). Reviews of assistive technology research (Abbott et al. 2011), noted this type of participatory design is becoming more common in relation to education. Therefore, in considering the development of AR technologies to support inclusive museum experiences it is important to examine the extent to which user groups informed the creation of the AR.

Method

This literature review sought to understand the characteristics of how AR is being used (or developed for) museums to support access for disabled people and examine the extent to which the underpinning research processes are inclusive. In order to do this a structured literature review was carried out [see https://eppi.ioe.ac.uk/cms/Default.aspx?tabid=67]. This is an established method, used to explore inclusive practice and the use of new technologies respectively in other contexts, such as education and health environments (Bernd, Van Der Pijl, and De Witte 2009). In addition to being transparent and replicable, it is important that this type of research is relevant and useful to the users of the research.

The initial search was carried out using keyword terms, within the SCOPUS research database, for research published between 2010 to April 2017. The Scopus database was chosen because it has the world's largest peer-reviewed citation and abstract database, and covers a broad academic field including social, life, physical and health sciences. The keywords used for the search were:

1. Augmented reality
2. Museum
3. Disability
4. Visual impairment
5. Hearing impairment
6. Learning disabilities
7. Cognitive disabilities

These keywords were identified from the terminology of existing AR and museum research.

The Keyword searches utilized specific inclusion criteria.

Inclusion criteria.

- In English language
- Between 2010 to April 2017
- Concerned with adult participants.
- Contains 1 & 2, & 3 or 4-7

Abstracts that did not meet these inclusion criteria were excluded.
Whilst 'AR and Museums' produced 360 potential articles, the use of the keywords 3-7 profoundly reduced the number of articles that fell within the review. This initial screening produced 53 articles. These were downloaded, to create a 'descriptive map' of the studies, which gave an overview of the studies and an indication of their aims, methodologies, interventions and outcomes. This information, for 53 articles, was reviewed, independently, by two reviewers. Where disagreement or uncertainty on inclusion/exclusion occurred (20%), the full article was obtained and reviewed, with respect to the inclusion/exclusion criteria. This resulted in 18 articles being selected for inclusion in the final review.

The selected publications were conference papers (61%) and journal articles (39%), with the majority published in 2016 (see figure3) and in the United States of America (see figure 4).

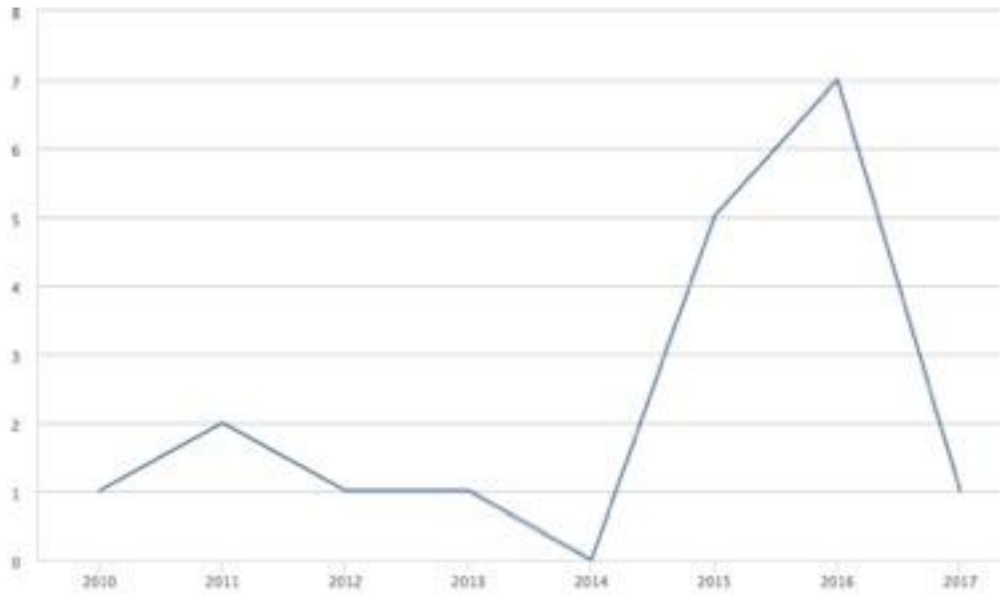

Figure 3 . Review publications by year.

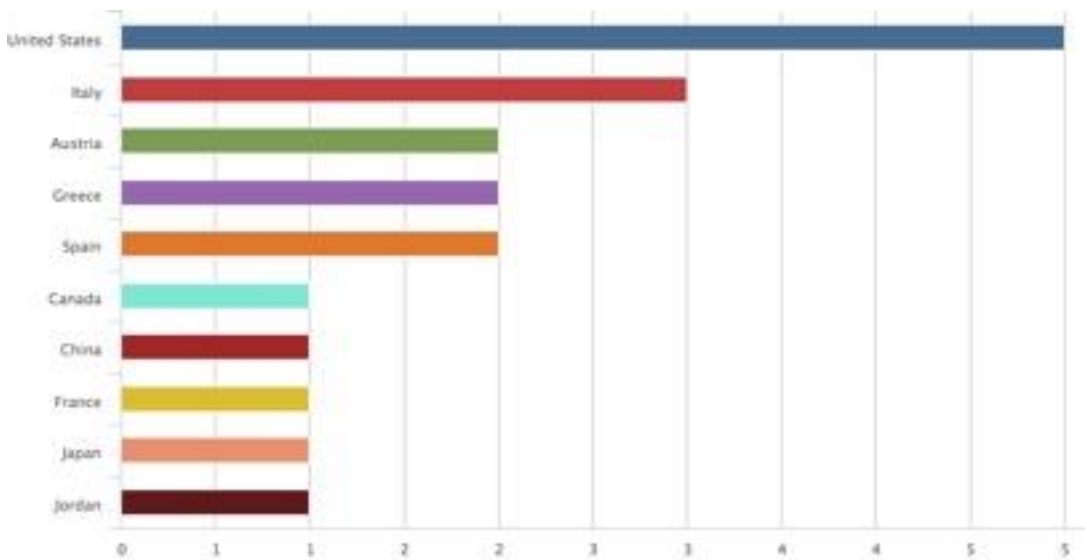

Figure 4 Review publications by country.

Although the majority of publications came from the field of computer science (as determined by SCOPUS classification), a wide range of other research disciplines were represented (see figure 5).

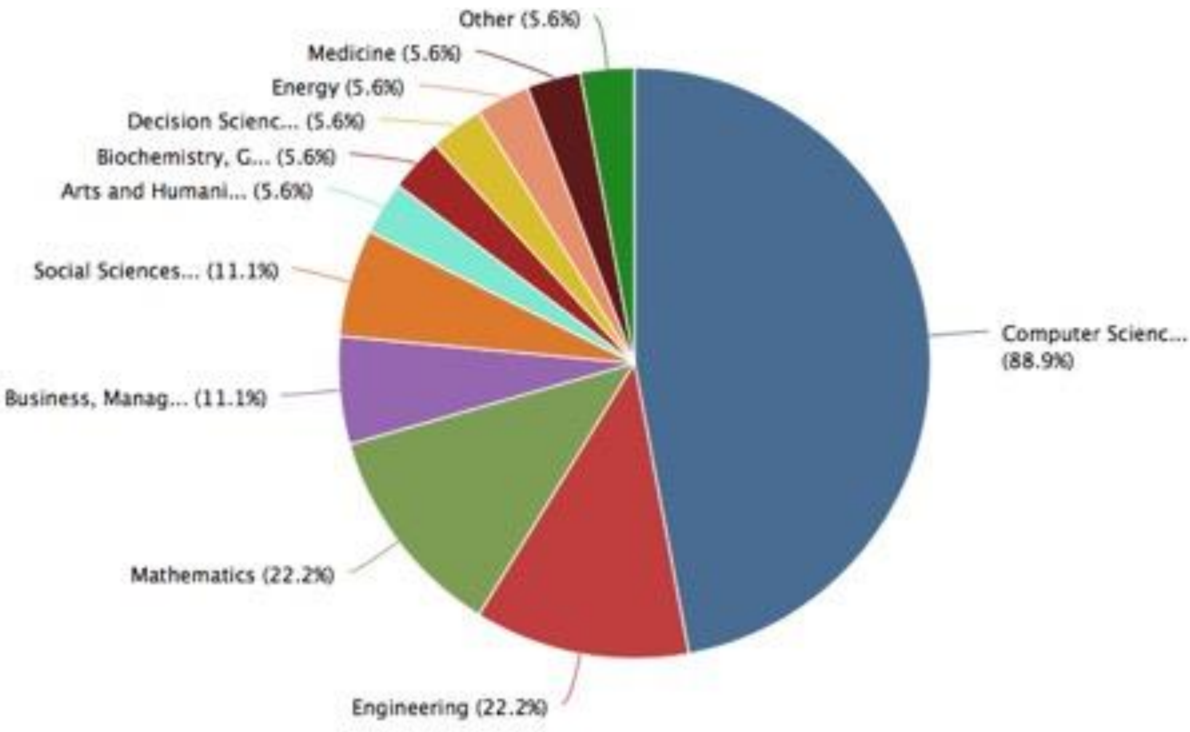

Figure 5. Review publications by discipline.

Data extraction and analyses.

The process of data extraction and analysis followed three stages. The final selection of papers was imported and analysed thematically using QSR NVivo 10.00. Information that might be related to the two research questions was highlighted (Phase One). In Phase two, a thematic analysis of this extracted data was then carried out and finally the original papers were reviewed again in light of the themes to ensure accuracy of interpretation and distinctiveness form each other. The research questions were addressed through thematically analysing the descriptive accounts of research within papers, rather than examining outcome measures from the studies. Therefore, weight of evidence ratings were not given to the studies.

Findings.

Thematic analysis is a search for themes that are important for the description of a particular phenomenon (Fereday and Muir-Cochrane 2006). Four such themes emerged from our analysis, and each is considered in turn. Given a diversity of terminology across the studies, the generic terms disabled people is used.

Theme 1. Stage of Development.

The first theme captured the stage of development of the AR technology. For nine papers the research was seen as being at a feasibility stage, where technological devices or systems were designed or proposed for museums but being developed outside of them. A second category contained pilot studies or ‘prototypes’. In these seven papers, new technology was being developed and tested for various periods of time within museums, and finally ‘Active’, referring to projects researching technology that was already ‘installed’ within a museum (Dubois et al. 2011). The trend in numbers across the three categories is likely to reflect a development process, in which a larger number of technologies are proposed, fewer are piloted and fewer again become implemented in situ. Alternatively, it may be that there is less incentive to research ‘installed’ technology.

Table 1. Stages of Development.

Active	*Prototype Pilots*	*Feasibility stage*
(Stanco et al. 2017) (Girotto & Pisu 2015) Dubois, Bortolaso, Bach, Duranthon, & Blanquer-Maumont 2011)	(Doush, Alshattnawi, and Barhoush 2015) (Navarro Delgado & Fonseca 2011) (Dubois, Bortolaso, Bach, Duranthon, & Blanquer-Maumont 2011) (Reichinger, Fuhrmann, Maierhofer, & Purgathofer 2016b) (Stanco et al. 2017)	(Zhang et al., 2016) (Kay 2016) (Anagnostakis et al., 2016) (Villanueva, Albertos, F., esoriero, R., Hernández, & Penichet 2013) (Guttentag 2010) (Capi 2012) (Hussain, Chen, Mirza, Chen, & Hassan 2015) (Park, Ryu, & Howard 2015) (Di Franco et al 2015) (Reichinger, Fuhrmann, Maierhofer, & Purgathofer, 2016a) (Partarakis et al. 2016a) (Villanueva et al. 2013) (Franchi et al. 2016)

*Two articles featured cultural heritage sites of worship, rather than traditional museums.

Theme 2. How are disabled people involved in the research?

Many of the papers gave accounts of how the technology was created and piloted. This informed a theme that captured the variety of ways that disabled people involved in the research and development process. The following codes were created to capture this variety:

- Consultative. This consultation could be in the form of interviews to suggest issues that were of importance to the user group, and also usability evaluations in which feedback was sought after observed interactions with the technology.
- Experiment or quasi experiment. This research included lab based experiments and instances where some non-disabled participants were used (e.g. (Di Franco et al. 2015) or where none of the participants were disabled people. For example, research that included one blind participant with others being blindfolded sighted participants (Zhang et al. 2015).
- Participatory research. In this approach the ‘end users’ of research collaborated with the researchers and were indicated as active members of the research team, rather than passive research participants or experimental participants.
- No involvement. Research is undertaken but disabled people did not feature within the research, other than being indicated as potential end users of the technology.
- Review/proposals. These papers describe a developed system or proposes a new one. For example (Girotto and Pisu 2015) describes a technology that is running at a museum, whereas (Reichinger et al. 2016a) describe the construction of a potential new technology. In this sample these two papers did not involve any indication of disabled group members as authors, although this has been noted elsewhere, albeit rarely, in technological research review papers (Wolbring and Ball 2018).

Whilst each code represents a distinctive aspect of the paper, multiple theme elements can exist within in each research study. Table 2 below indicates the ‘cross over’ between codes and the selected studies. For example, where a researcher consults disabled people prior to developing their technology (e.g (Capi 2012) or (Reichinger et al. 2016b) or through post-trial usability feedback (Anagnostakis et al. 2016).

Table 2 Disabled people's involvement in the AR research process.

Consultative	*Experiment or quasi experiment*	*Participatory research*	*Review/propose*	*No involvement of disabled people*
(Anagnostakis & Antoniou 2016) (Capi, 2012) (Doush et al., 2015) (Reichinger et al., 2016b) (Franchi et al. 2016) (Hussian et al. 2015) Park et al 2015	(Anagnostakis & Antoniou 2016) (Capi 2012) (Di Giuseppantonio Di Franco et al. 2015) (Doush et al. 2015) (Dubois et al. 2011) (Zhang et al. 2016) Reichinger et al. 2016b) (Hussain et al. 2015) (Park et al. 2015)	(Dubois et al. 2011) (Navarro Delgado & Fonseca 2011)	(Reichinger et al. 2016a) (Kay 2016a) (Girotto & Pisu 2015) (Partarakis et al. 2016b) (Guttentag 2010) (Stanco et al. 2017)	(Di Giuseppantonio Di Franco et al. 2015) (Dubois et al. 2011) (Villanueva et al. 2013)

As Table 2 shows, the most common way in which disabled people were involved with AR research was as participants in quasi/experiments. Whilst there were two examples of participatory research, only one study involved disabled people as participatory researchers throughout the scoping and development process (Delgado 2011). In contrast Dubois et al (2011) used a participatory design, but did not explicitly mention participants with any sensory impairments or learning disabilities. This paper included 'end-users' visitor experiences: partners of the ANR CARE project home (for elderly and disabled people) and three groups of Master students.

A notable feature of this sample of AR research is the overwhelming focus on working with blind and visually impaired people. This was the sole focus of 11 of the projects. Only two projects concerned people with cognitive disabilities (learning disabilities). Whilst several papers mentioned the opportunities of AR to support Deaf people, none included Deaf participants or focused on this the needs of the group. Partarakis et al (2016) created imagined scenarios of three people with different impairments, and Girotto and Pisu (2015) saw the review's end users as "all types of audiences, blind and hearing impaired" (Girotto and Pisu 2015, 635). However, no study worked with groups of participants drawn from different disability categories.

Previous research into assistive technology has identified a common phenomenon in which research, that aims to increase access and support for disabled people, does not typically use technologies' abilities to support the participants engagement in the research process itself or support ethical processes such as gaining informed consent (Wright et al. 2011). This is particularly important given the potential power differentials and access issues, related to cognitive, sensory and physical issues that might need to be addressed within the research process. It was notable that the term 'ethics' or 'ethical' did not appear in any of the selected research documents. Two papers mention consent. Hussain et al (2015) reported that "All participants were informed they would be completing surveys and documenting items to which they fully consented." (531). Park et al (2015) report "Consents from adults or parents' consent along with verbal assents from minors are acquired prior to the experiment." (333). No further details were given in any of the studies about the ethical guidance informing the research or how informed consent was obtained from participants. Three papers used the term 'volunteer' to indicate that participants had agreed to take part (Doush et al 2015; Reichinger et al. 2016; Navarro et al. 2011).

No details were given of how this volunteering occurred, how participants were contacted or if issues such as right to withdraw were explained to them. (Di Franco et al. 2015) study did explain how visitors were contacted and recruited within a particular exhibit.

> In this room, they [visitors] were free to interact with any of the media and were then asked to voluntarily participate in a questionnaire and rate (Likert scale) their over- all experience with both the Powerwall and the other medium chosen.
> Sixty visitors agreed to participate in the questionnaire (256)
> Special thanks also go to all the people who agreed to participate in the experiments (261).

Ethical processes were relatively under represented and under reported across the studies

Theme 3. The (potential) Impact of AR on user experience.

This theme reflects judgements made about the impact that a particular technology will have on user experience, with reference to the Affordances of Augmented Reality Systems and Applications (Sheehy, Ferguson, and Clough 2014). Each of the technologies described in the 18 papers were mapped onto the Affordances of Augmented Reality Systems and Applications. The assessments made for the 18 papers are presented in Table 3.

Table 3. Affordances of AR indicated within the 18 papers

Paper	*Collaborate*	*Connectivity*	*Student centred*	*Community*	*Exploration*	*Shared knowledge*	*Multi-sensory*	*Authenticity*
(Stanco et al. 2017)1	0	4	3	2	4	0	4	4
(Franchi et al. 2016)2	0	4	4	0	4	0	4	4
(Reichinger et al. 2016b)3	3	3	2	0	4	0	4	4
(Anagnostakis et al. 2016)4	2	3	3	2	3	0	4	4
(Girotto and Pisu 2015)5	0	4	0	4	4	0	4	4
(Zhang et al. 2015)6	0	4	4	0	3	0	4	4
(Kay 2016)7	0	4	3	2	4	0	4	4
(Partarakis et al. 2016b)8	4	4	4	4	4	4	4	4
(Reichinger et al. 2016a)9	0	4	4	0	4	0	3	3
(Di Franco et al. 2015)10	3	4	2	3	3	0	3	3
(Park, Ryu, and Howard 2015)11	4	4	4	2	4	3	4	4
(Doush, Alshattnawi, and Barhoush 2015)12	0	4	4	0	4	0	4	4
(Hussain et al. 2015a)13	2	4	4	0	4	3	4	4
(Villanueva et al. 2013)14	0	4	2	0	4	0	4	4
(Capi 2012)15	0	4	3	0	4	0	4	4
(Dubois et al. 2011)16	0	3	2	3	3	0	4	4

(Delgado 2011)17	0	4	3	0	4	0	3	3
(Guttentag 2010)18	0	4	4	0	4	0	4	4
Mean	1	3.8	3.1	1.2	3.87	0.6	3.8	3.8

Key. The numbers 0-4 indicate the degree of impact against each of the 8 affordances (0=neutral/unknown, 1=impairs, 2= support, 3=extend, 4=transform.)

All of the technologies are identified as being transformative or extending the users experiences in relation to offering authenticity, multi-sensory affordances, connectivity and exploration. As Table 3 above illustrates the median ratings for each of these affordances are 4, 4, 4, and 4.

For example, Zhang (et al. 2015) developed a prototype assistive AR navigation system, which was evaluated by blind users. This system gave users access to a real time authentic mapping of the museum as they moved around its space. The user lets the system know their intended destination through speech and system scans and plots a suitable route and translates the visual map and route to the user to give speech directions. Rather than giving detailed 'robot style rigid' commands (1461), the directions follow a general path. In this way the users' sensory experience of the museum is transformed. The technology also transforms the users' potential for active exploration of museum environment. In stark contrast are the profiles of the papers in relation to collaboration, community and shared knowledge. The median ratings for each of these are 0, 0, and 0 respectively. Typically, this occurred because accounts of the AR technology being developed or used did not mention collaborative use between people, sharing of experiences or being part of a community of users.

The assessments of student-centered affordances are the most varied (range 0-4, mean 3.1). This reflects the degree to which the technology was developed to present a particular exhibit in an accessible format versus the agency the technology gives the user of which exhibits the users may choose and how they interact with them.

Theme 4. Fun and enjoyment/function not fun.

Eight papers mentioned fun or enjoyment to varying degrees. This included participants' ratings of the technology, or assumptions that the technologically mediated experience would increase users' enjoyment. In a technology that is strongly associated with fun in other contexts such as gaming and education (Xu et al. 2008; Bujak et al. 2013; Kerawalla et al. 2006) this is not unexpected. The notions of fun that appeared were different within the papers that mentioned it. Within Franchi et al (2016) fun and enjoyment appeared synonymous with access to the exhibits. The fun was produced by the existing activity/museum resource, and the addition of new AR information allowed people to access this experience. In this way, for example, the AR technology could help the user navigate to the museum and, once there, to enjoy the exhibits through an AR guided visit. Some researchers sought to increase users' enjoyment beyond access to existing information or activities. One way to do this was via delivering new entertaining information that was associated with the exhibits.

> Featuring great visual effects (thus preferred to the more common, but less attractive QR Codes), .. TAGs where developed..one to show curiosities about the building (the Mole Antonelliana), one for cinema's fun facts and anecdotes like "Did you know that…?" and one specifically designed to visually and hearing impaired. (Girotto and Pisu 2015, 367).

Similarly, Dubois et al (2011) explicitly set out to design an increase in enjoyment through combining new information with increased physical involvement.

> When designing MIME, the first increment was the definition of a mixed interaction technique, replacing traditional mouse-based interaction: the goal of the mixed technique was to increase visitors' immersion and fun. The result was the design of an interactive technique based on the physical manipulation of a tangible artefact to explore the 3D tree from the inside. (Dubois et al. 2011, 13)

The immersion described by Dubois et al (2011) occurs through the manipulation of tangible augmented artefacts and it is this increased physicality and engagement, engendered by the AR mediated activity, that enhances the fun.

In the preceding examples fun is an outcome that is assumed. Two other studies mentioned fun as an important part of evaluating users' experiences. Hussain et al (Hussain et al. 2015a) asked participants to rate their impressions of audio information. (7-level assessment: Feeling Good (7)–Uncomfortable (1), Enjoyed (7)–Painful (1), Love (7)–Hatred (1), Fun (7)–Boring (1), Calm (7)–Annoyed (1) p.532). This data was used to inform the way in which information was being presented by the technology, to reduce irritation through presenting too much information and so increase enjoyment. As a result, repetitive speech instructions were replaced with (non-speech) icons. Reichinger (Reichinger et al. 2016b) collected open comments from users about their technology, in which one participant indicated that their experience was fun. Feedback on enjoyment was also sought in Villanueva et al (Villanueva et al. 2013) using a specific question about enjoyment of using the software. Others (Guttentag 2010; Partarakis et al. 2016b; Stanco et al. 2017) mentioned enjoyment as an aspect of the AR museum experience but collecting data on enjoyment was not part of the methodology or discussed within the paper.

Discussion

The review offers some unique insights in answering the research questions. Firstly, regarding *What characterises the ways in which AR being used in museums to support access for disabled people and /or those with cognitive or sensory impairments?* The research indicates that AR technologies are being utilized in variety of ways, most noticeably in using mobile data connections to create different forms of multi-sensory experiences for users. This variety encompasses 'everyday' text to speech applications (Hussain et al. 2015b) and less common haptic telepresence (Park, Ryu, and Howard 2015). The majority of the articles described ways in which AR was transforming or extending users experiences in relation to particular affordances (see Table 3), namely authenticity, multi-sensory affordances, connectivity and exploration. A noticeable feature of the mappings of affordances is the apparent lack of shared knowledge and collaboration. One explanation of this may be that these affordances are an intrinsic feature of ubiquitous smart phones. Consequently, it may be taken for granted as something visitors will bring with them. There may be an implicit assumption that visitors (or visitors' supporters) will be able to share information to their own social networks through their own choice of personal technology and social media. This may also reflect the origins, and limitations, of the affordances model. This framework emerged from educational research, where sharing of information within appropriate peers and networks is seen as a key part of learning process, and where the use of personal smartphones remains uncommon (Cooper, Montgomery, and Sheehy 2018). Museum visitors are typically not members of a formal learning group, any sharing is voluntary and peripheral to the focus of their museum visits. Consequently, these affordances appear less necessary for AR designed for this context. The examples of collaboration that were noted, were of sharing and discussing augmented artefacts within the museum, rather with a broader social network.

The majority of the studies focused on developing or using AR technologies to support blind or visually impaired users. Other groups were less well represented. This might reflect the significant opportunities that AR's facility for locational awareness offers. Five of the studies focused on navigation, four within the museums, including in a project to support people with learning disabilities to get to the site itself, and one study used telepresence robots. The lack of focus on the needs of Deaf people might be because the technologies to support Deaf visitors are relatively well developed. For example, voice to text technologies are commercially available (Bakken et al. 2019), live translation systems are well established (Anonymous 2011) and signing avatars are founds in apps (Milicchio and Prosperi 2016). The issue here is no longer the development of technologies for Deaf Communities, but their useful deployment and integration into museum experiences. Our sample suggests that deployment is less likely to feature as a focus within AR museum research publications.

Secondly, regarding *To what extent are the underpinning research approaches inclusive?* Although the AR technologies within the review were explicitly intended to be of use to disabled people, it was notable that they were largely passive 'subjects' within the research or absent from it. This could be due to the rarity of disabled researchers within technology research, a consequence of the positioning of this group in relation to STEM in general (Wolbring & Ball 2018). At a more fundamental level, the studies sought to improve the experiences of these users and yet consultation with this group, about what they might need, often appeared 'light touch' at best. This lack of involvement could be more fundamental than opportunities for being a researcher, participatory or otherwise, and influenced who provided 'user' data. This appeared when using non-disabled people to speak for the needs and experiences of disabled people. For example, 3 studies involved blindfolded participants, as proxies for blind or visually impaired people, and 2 others involved non-disabled participants. This type of practice lessens the involvement of disabled people in research decisions about their own lives, and has been criticized for creating inaccurate estimations of disabled peoples' capability and needs (Silverman, Gwinn, and Van Boven 2015). Navarro Delgado (2011) provided a model of research that was more participatory. It built on previous work by the researchers, which had shown that "by involving users in the different phases, results have a higher effectiveness." (237) and explicitly aimed to achieve "a satisfactory experience for developers and end users" (237). To this end the project was constructed as a joint endeavour between disabled people and non-disabled students of architecture. The research had six phases, with disabled people involved across each phase, from the initiation (based on the preceding project) to evaluation of prototypes and then real-world trials.

Another indication of the agency and positioning of disabled people within the AR research process is the attention given to research ethics. Overall there was a relative absence of an explicit acknowledgement of ethical issues, a need to consider them, or reference to guiding professional principles. There are numerous examples of ethical guidelines for researchers produced by professional bodies and research funding organisations (Wright et al. 2011), there are also guidelines specifically in relation to good practice in research with disabled people ("Ethical Guidance for Research with People with Disabilities | The National Disability Authority" n.d.) and it is established practice for research proposals to require an ethical review. This suggests that individual researchers are likely to be aware of ethical issues. However, it is clear that demonstrating and promoting this awareness is not required within the journal publications themselves, or by the associated reviewers or editors. These authorities represent and shape the standards of the broader community of AR researchers. At best this means that opportunities for sharing good practice are missed, at worst a professional discourse is created that undermines the importance of ethics in relation to research for/with disabled people. Technology research is essential in supporting the rights of disabled people (UN Convention on the Rights of Persons with Disabilities (CPRD 2006)), and it is argued these rights should be explicitly reflected in the research process itself and those who read this research.

As with other reviews of technology research, publication can occur several years after the end of the review period (Boot et al. 2018; Rintala et al. 2018). However, whilst new research may appear during this period, the issues identified in this review appear to be robust in nature. A significant characteristic of AR technologies being developed for museums is their use of Connectivity to extend or transform particular aspects of the user experience. AR is able to optimize navigation through museum spaces, and present accessible personalized information in a time efficient fashion, with the potential to facilitate a profound personal impact (Stanco et al. 2017). In this respect researchers are using the affordances of AR to go beyond access alone and to make possible new enjoyable multisensory exploratory experiences for disabled people. This review indicates that successful steps towards this future have been made, with the possibilities for sharing experiences already an everyday option outside of the developers' focus. Models of inclusive practice exist, but this is within a context in which inclusive practice is not explicitly promoted through publication and researcher gatekeepers. Consequently, the position of disabled people themselves within the creation of this future appears less certain.

Acknowledgement

This paper was developed as part of ARCHES (Accessible Resources for Cultural Heritage EcoSystems), a Horizon 2020 funded project. [https://www.arches-project.eu]

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