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Published version

MARSHALL, Mark (2018). Interacting with heritage: On the use and potential of IoT within the cultural heritage sector. In: 2018 Fifth International Conference on Internet of Things: Systems, Management and Security. IEEE, 15-22.

Interacting with Heritage: On the Use and Potential of IoT within the Cultural Heritage Sector

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***Abstract*—This paper discusses the potential for the use of IoT technologies within cultural heritage, including the creation of new interactive experiences, visit personalisation, visitor data analysis, connected and distributed museum visits and the provision of pre- and post-visit experiences. We argue that cultural heritage offers a key opportunity for the development and deployment of new IoT systems, with potential benefits both for the cultural heritage domain and the IoT community.**

We present a number of areas of potential work for IoT researchers that are applicable to the heritage domain and to the broader IoT context, including challenges around poor connectivity, identifying and tracking visitors, and providing systems that are easily installed configured and maintained in environments with minimal infrastructure and poor technical support.

***Index Terms*—Internet of Things, Human-Computer Interaction, Ubiquitous computing, Cultural heritage**

I. Introduction

Museums and cultural heritage sites have often experimented with digital technologies as a means of providing new means of engaging with visitors. This has included a variety of different forms of interaction both on-site and online. Ranging from mobile apps, through interactive tables, tangible interaction and on-line post-visit experiences, these technologies have aimed to engage visitors in new and interesting ways and to promote interaction with the heritage outside of the more traditional museum text label. The increasing development of IoT technologies offers huge potential for cultural heritage sites to extend the ways in which they deploy such new technologies and the interaction possibilities that they offer for visitors.

While IoT research and development has mostly focussed on the home, the office, or the city, there is much potential for expansions of IoT research into other domains [1]. Cultural heritage and tourism are extremely broad domains that have a massive potential impact on society. In the EU alone, it is estimated that as of 2017 more than 7.8 million jobs are linked to heritage [2]. This provides both a potential market for IoT technologies and also an interesting test-bed for technologies with specific challenges, the solutions to which can have an impact across the wider IoT domain.

In this paper we examine a number of potential research and development areas in which IoT offers new and potentially game-changing possibilities to cultural heritage sites. Each of these areas is illustrated with specific examples and these are reflected on to provide future directions for research and development in IoT for cultural heritage. We begin with an overview of work on integrating technology into museums and heritage sites. This is followed by discussions of specific potential applications of IoT to cultural heritage: interactive museum experiences, visit personalisation, visitor data analytics, connecting physically dispersed museums and heritage sites, and providing pre- and post-visit experiences. Finally we present a discussion of the challenges if implementing IoT within cultural heritage sites and the potential areas of IoT research and development that arise from these challenges.

II. Integrating Technology with Cultural Heritage Sites

Museums and heritage sites have been deploying digital technology to engage with visitors since the 1990s [3]. The aim has often been to provide more information to visitors than is available from traditional museum text labels. This has included the creation of mobile museum guides [4]–[6], outdoor mobile experiences [7]–[10], indoor navigation systems [11] and social media-based visit recording [12].

Recently, there has been a focus on material engagement with museum objects. Research has shown that this provides visitors with powerful experiences at it enables them to understand and empathize with stories in ways that textual interpretations used on their own don't [13]. This has included the development of new tangible interactions for museums.

Tangible interaction involves "systems that rely on embodied interaction, tangible manipulation, physical representation of data, and embeddedness in real space" [14]. A number of interaction design works specifically addressed the tangible qualities of heritage and how bespoke technological solutions can meaningfully augment it [15], [16].

Such systems allow visitors to physically interact with physical-digital interfaces and which allow visitors to access digital content that enhances their visit, but to do so in a way that still links them to the physical, material qualities of the heritage objects on display [17]–[19]. Indeed, recent research has begun to show that such interactions are preferred by visitors to museums when compared to previous standalone kiosks or mobile guides [20].

The majority of such experiences are standalone, that is each interactive is unconnected (or minimally connected) to others within the exhibition. However, IoT would allow such exhibits to be interconnected and to provide more complex, personalised interactions to visitors. While some research is beginning into this, in general museum professionals still regard networked objects and IoT as a future development in the long term, rather than a more immediate possiblity [21].

In this paper we present some of the possibilities offered by IoT for cultural heritage, with reference to some existing works in each area and direction on how new IoT-based systems can be developed to expand upon the existing digital capabilities in these areas. We also present some of the challenges and potential developments that emerge from the application of IoT for cultural heritage. We begin with a discussion of the use of IoT to provide interactive experiences within a cultural heritage site.

Fig. 1. Visitors interacting with an IoT-enabled exhibition at Museon in Den Haag, the Netherlands. The exhibition combined NFC, Arduino, Raspberry Pi, with a bespoke communication and logging system and an online post-visit experience [18].

III. IoT-based Interactive Experiences

As already discussed, museums have been experimenting and investigating the use of digital technologies for a number of decades. Alongside this, researchers in the field of human-computer interaction and other related disciplines have also been studying the design and deployment of interactive technology in museums (for examples see [19], [22]–[24]).

Over time, research in this area has moved from individual devices spread across an exhibition [24]–[26], to integrated visitor experiences that embed interactive technologies across the whole exhibition [18], [27]–[29]. Such experiences make use of technologies and devices such as NFC, Bluetooth LE, WiFi, smartphones, Arduino, and Raspberry Pi. This results in a very disconnected ecosystem in which developer must somehow integrate disparate devices and find a way of creating a compelling interaction by combining them. This also results in each exhibition being a complete new development; there is no re-use or extension of existing systems, instead the technology to support each new exhibition is deployed from scratch.

The Internet of Things can enable museums to more fully integrate technology into their existing practice, not just as part of a single exhibition, but allowing interaction across a wide range of contexts. For example, museums can use IoT to create networked interactive exhibits that respond differently to different types or numbers of visitors (such as that shown in Figure 1), that remember visitors across multiple visits, that integrate visits across multiple sites (even across different countries), or that allow visitors to interact both before and after their physical visit.

These same technologies can also allow museums to gather useful data about visitors to their exhibitions, including analysis which aspects of the exhibition attract the most interest, how long visitors interact with specific parts of the exhibition, the flow of visitors through the exhibition, and whether or not visitors are returning for multiple visits. This sort of data can be particularly useful to museums that are not externally funded and thus need to optimise their exhibits to attract as many visitors and as often as possible.

The use of uniform communication protocols (such as MQTT) can enable many different types of device to be easily integrated into a single system. As such a heritage site can deploy a single system and then add new devices to it as needed. Exhibitions can be extended with new devices as they are needed, or new technologies added as they become available. If multiple different sites make use of the same overall system and communication protocols then it even becomes possible for systems to interact across different sites, organisations and even countries. We will discuss this more in Section VI.

IV. Using IoT for Visit Personalisation

It is generally accepted within the heritage community that visitors to heritage sites each have different motivations, expectations, and needs [30]. Museums and heritage sites often attempt to deal with this by offering different experiences that visitors can partake of. This can include specific guided tours, education activities for school groups, or game-like treasure hunt activities for children.

However, the Internet of Things can allow such sites to make use of technology to dynamically alter delivered content and to personalise it to specific visitors [31]. Indeed, researchers have identified personalisation (and specifically dynamic, technologically-based personalisation) as a key area for future development within the field of cultural heritage [32].

There have been a number of implementations of personalisation in heritage sites, mostly based on the use of proxemic interaction; displaying content when a user approaches an exhibit or display, and tailoring that content to some aspect of user preference [33]–[35]. Such interactions are easily implemented with IoT technologies. Yet, this does not offer the full potential of visit personalisation that can be achieved with IoT.

Not and Petrelli propose that personalisation in heritage sites make use of the social and contextual aspects of the visit [31]. Visits to heritage sites can occur singly, or as part of a group. Groups can be homogeneous, or can contain a mix of people of different ages, nationalities, experiences and interests. Given this, it can be recommended that when creating systems for personalisation of the visits we "Design to model complex features" [31]. That is, we combine features of the visitors, the social context of their visit, the environment in which the visit takes place, and their evolving experience (including what has already occurred in this visit and perhaps extending to aspects of previous visits to this, or other, sites).

IoT systems, including devices installed on-site and those devices carried by visitors, can gather this information. We can allow visitors to create profiles for themselves, gather data on what they have seen when visiting a particular site, and even connect data from visits across different sites, something which will be discussed in more detail in Section VI. Complex, multi-layer personalisation systems can be built using this data to provide truly personalised experiences for visitors - and to ensure that future visits to the site offer new experiences, thus increasing the chance of recurring visits (a key aspect for many heritage sites). We can also use such data as part of online pre- and post-visit experiences, which can also leverage the online collections that many museums and heritage sites possess and which they often do not make much use of [36]. Again, we will discuss this more in Section VII.

Note that one of the main requirements for implementing visit personalisation is a means of identifying and tracking visitors. Installations such as those discussed in [37] and [18] do this anonymously, simply associating a unique session ID and access code with an object that is carried by the user, and allowing the user to later access their session data using the access code. Other systems require visitors to register either pre- or post-visit, so that their session ID can be associated with an email address or user account. This is one area where IoT offers much potential and we will discuss this further in section VIII-B.

V. Data Analytics for Heritage Sites

Museums and heritage sites often need to optimise their displays and exhibits in order to encourage repeat or new visitors. This can be influenced by their need to fund the museum itself; in many countries museums and heritage sites rely entirely on ticket and merchandise sales for funding. To do this they require information about what visitors do onsite, and what parts of the exhibition they like or dislike. Traditionally, such information is gathered using techniques such as observations and interviews [38]. However, such methods are costly both in terms of time and money, and the results can be somewhat subjective [39].

The use of Iot systems allow for the gathering of data on the visitor experience. We can log what the visitor interacted with, in what order, and for how long. Analysis of this data can deliver insights into how visitors move within a museum and what they look at. It can also reveal effects of factors such as age, language, and even time of day on the actions of visitors within a site [40]. This data can also offer useful insights on the design of an exhibition space, such as in the Atlantikwall exhibition [18], where analysis of visitor data showed a single exhibit that was almost completely ignored, due to it's location being obscured from visitors.

Another aspect of this is to allow museums to experiment with putting objects on display and using technology to gauge visitor interest in them. Combining location tracking, proxemics, attention sensing and even social media interaction can be used to gauge visitor interest in specific objects. By rotating the objects on display the museum can gauge interest in specific objects [41] and perhaps find new topics and themes for exhibits that will attract more interest from visitors or even bring more visitors to the site; again, this can be a key motivating factor for heritage sites to engage with IoT.

Visualisation of this data can often provide useful insights into the movements of visitors within a site, in a way which is easily and quickly understood, as shown in Figure 2. The ability to assign and visualise metrics (such as daily visitor numbers, or popularity of each display) can be key to proving the value of a specific exhibit or exhibition, or justifying further development of IoT technologies within a heritage site.

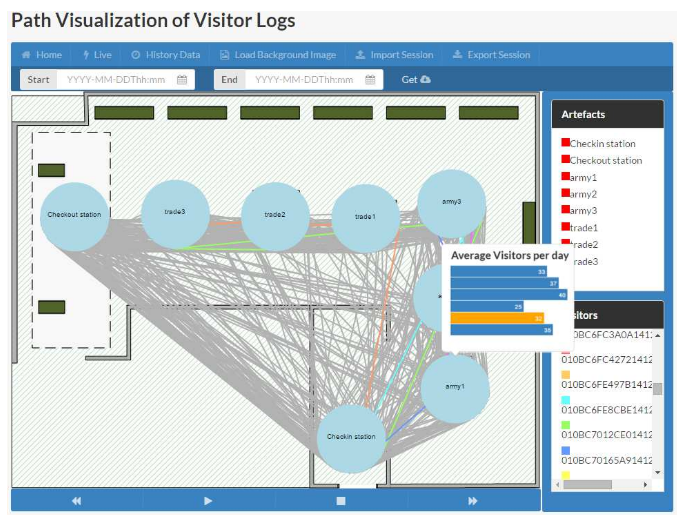

Fig. 2. A visualisation of visitor movement data within an IoT-enabled museum exhibition, together with simple metrics.

Data gathered from IoT systems in heritage sites can also be used to generate physical mementos of the visit, which can encourage visitors to remember the experience and perhaps re-engage with the site at a later time, as discussed in Section VII.

VI. Connected and Distributed Museums

Museums and heritage sites often enjoy many connections with each other. This can include regional networks of museums (such as the Trentino First World War Network[1]),

[1] http://www.trentinograndeguerra.it/

professional networks aiming at developing and improving museums (such as the Museums Computer Group (MCG) [2]), or thematic groups of museums within a country (such as the Science Museum Group [3] or the Museum Network[4]). Such networks allow museums the opportunity to work together to develop their audiences and to share the costs of technologies and exhibitions.

Some museums and heritage organisations have also worked together to collect and share their digital archives in a single online resource, such as Europeana[5] or Art UK[6]. These online portals provide a single point at which potential visitors may search for interesting artefacts and then learn where those artefacts may be available to view, potential encouraging future visits.

While museums will often work together on such projects, or sometimes pool resources, experiences and knowledge on specific topics (such as the use of mobile phones in museums [42]), they do not generally work together to link visits across different sites. As each site is interesting in maximising the number of visitors they receive, there is an inherent competition for visitors across sites.

However, it would be possible, using onsite IoT technologies and online tools, to link visits across different museums and heritage sites. Thus, visitors to one site might be encouraged (or have recommended to them) another site based on their actions when visiting, such as which exhibits or objects they seemed most interested in. While there is still an issue with convincing museums to work together in this way, there is some initial work currently taking place on this topic with organisations that maintain multiple sites in different locations [43].

Such technologies can allow heritage sites to connect with each other and to drive visitors to move back and forth between them. Thus, visitors gain an improved experience where each site visit is different from the last and where their curiosity results in personalised changes both at the current site and also at others. For the heritage sites themselves the potential for recurring visits is vastly improved and the also gain reach to potentially entirely new sets of active heritage visitors who were not aware of their specific site.

VII. Pre- and Post-Visit Experiences

Alongside the interest in personalisation of museum visits, there has come the understanding that the process of visiting a museum is not just about the physical on-site visit itself, but as Falk and Dierking state: "The museum experience begins long before the visitor arrives and continues long after the visit" [44, p. 284]. The visit experience can this be broken up into a pre-visit, the visit itself, and a post-visit. Integrating IoT technologies into the visit and combining these with some form of online experience can enable these three phases of the visit to interact with each other.

Generally, visitors use the pre-visit to get information about the site that they will visit and the collections on display there. This can include identifying specific collections or objects within a collection that the visitors wish to see. Normally the emphasis for this is entirely on the visitor, to determine what they want to see and to remember and find it once they get to the site. However, with smart technologies deployed onsite, it becomes possible for the visitor to register online pre-visit and for their online browsing to then influence what they see on site, from personalised content on specific themes of interest as discussed in Section IV, to smart navigation systems that help them find those collections or exhibits which are of interest to them (e.g. [45]–[48]).

From the museum perspective, the post-visit experience is about creating a long-lasting connection with the visitor, with the goal of encouraging further visits and/or that the visitor will promote the museum to others, whether in person or on social media [36]. This often involves simple online activities that the visitor can participate in, from posting and tagging photos on social media, to browsing the online collection, to sending invitations to friends to view or visit the exhibition. There is however little or no connection to the physical exhibition itself.

When IoT technologies have been embedded in an exhibition, on the other hand, the online post-visit experience can be directly influenced by the visit process. It can show visitors aspects of what they saw (including popular objects or themes), what they missed (particularly related to things they showed an interest in), and even recommendations for further online material or exhibits located at another site [36]. Such technology could even be leveraged by networks of museums, or organisations that maintain multiple sites, to encourage visitors to move back and forth between different museums or heritage sites, as discussed in Section VI.

The post-visit experience can also be enabled through some form of tangible souvenir that can be created onsite. This souvenir can be created using logged data from the visit itself, so that it forms a customised representation (and reminder) of the visit [37], as well as acting as an entry point to the online experience (such as custom postcards that contain a unique access key for an online representation of the visit [36]). Figure 3 shows an example of such a souvenir, taken from [36].

VIII. The Challenges for IoT in Heritage Sites

From an engineering perspective, heritage sites offer a number of challenges from IoT-related installations. In particular, many heritage sites have minimal connectivity, limits on the availability of power, restrictions on the ability to modify the site, and a lack of on-site technical support. Such limitations mean that any IoT solutions developed must be robust, must deal with limited (or inconsistent) connectivity, offer a means of identifying and tracking visitors and must be easily installed, configured and maintained. In this section we

[2]http://www.museumscomputergroup.org.uk/
[3]https://group.sciencemuseum.org.uk/
[4]http://www.museumnetworkuk.co.uk/
[5]https://www.europeana.eu/
[6]https://www.artuk.org/

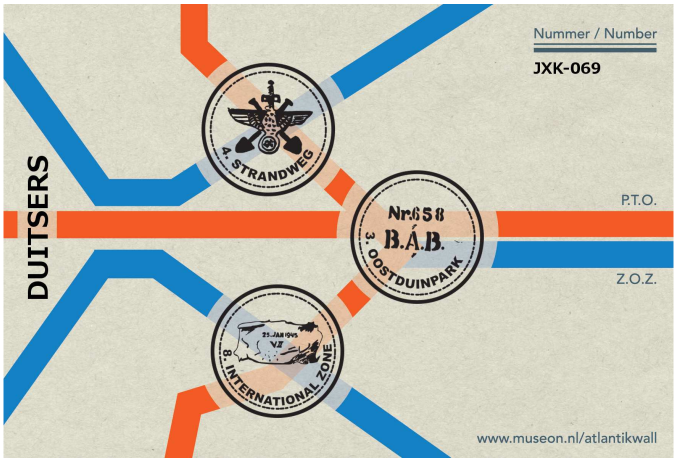

Fig. 3. A postcard generated by an IoT-enabled exhibition, as an access key to an online post-visit experience [36].

detail some of the challenges and resulting opportunities for IoT research and development offered by heritage sites.

A. *Dealing with limited connectivity*

Connectivity is perhaps the biggest challenge for many heritage sites. This is particularly true for sites that are located in remote areas, where there may not even be a reliable 3G signal. Other connectivity issues can arise in sites located within cities, but where it is not possible to an internet connection within the building (such as some house museums [49]), or sites where it is not possible to run cabling and the construction of the site makes wireless connectivity difficult (such as some underground sites, as shown in Figure 4).

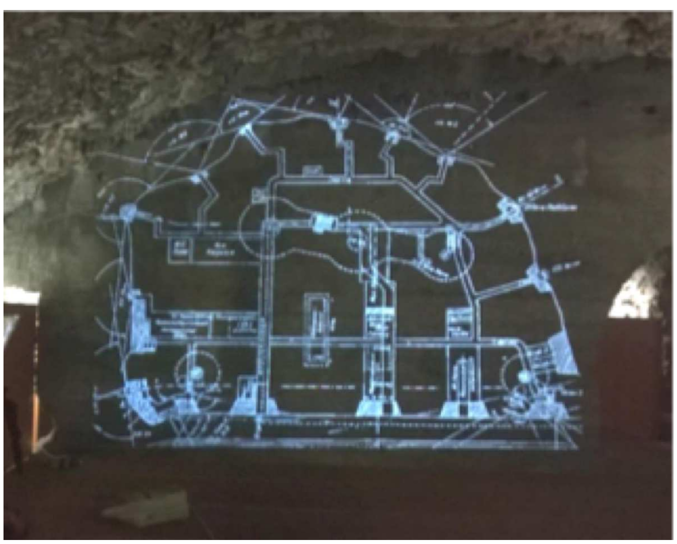

Fig. 4. Interactive projection as part of an IoT installation in an underground fortification dating from the early 20th Century.

Solutions to such issues include the installation of wireless networks outside (or at the edge of) the site that can penetrate to within the site (for example LPWAN networks [50], [51]), the use of existing infrastructure to facilitate networking (e.g. power-line networks), or the design of systems to allow for connectivity only at a single point. For example, in [37] the authors developed a system that would allow the visitor to carry their data logs with them (embedded in a tangible object that controlled the interactives) so that personalisation could happen on-site, with a single internet-enabled exit point at which the data could be transmitted to external systems for later online post-visit interaction.

Heritage sites offer a useful testbed for many such technologies, and can provide interesting case studies in dealing with issues particularly around connectivity and remote locations for IoT. As such, we feel that this is a topic well-worth further investigation.

B. *Visitor identification and tracking*

As previously discussed, there are a variety of uses within heritage sites for the ability to identify and track visitors. This includes visit personalisation, online pre- and post-visit experiences, connections across different sites and visitor anayltics. So far, museums have primarily used either anonymous session-based identification and tracking [18], [37], or have required visitors to register an email address or account with them [40].

However, through the integration of IoT technologies more thoroughly across heritage sites, a number of new options become available for identifying and tracking visitors. Combining IoT and computer vision, we can integrate vision-based identification systems (such as [52]), which in many heritage sites could be easily implemented due to the large number of cameras already installed in such sites.

Other possibilities include the use of NFC/RFID technologies [53], such as was already used in a number of museum installations [18], [37]. Such systems are robust and relatively cheap, although require methods of reading the NFC data, which can require either a specific interaction by the visitor, or the positioning of large scanner at points through which visitors must pass.

In some, remote heritage areas, visitor identification and tracking has previously required significant investment in technology, such as the use of satellite observation, mechanical triggers or seismic sensors [54]. Again, here IoT offers many possibilities. The ability to track visitors using either their own personal phone [55] or to deploy a large number of small, cheap, ultra-low-power sensors across the site can drastically change the way sites track visitors. Indeed, these technologies can allow heritage sites that were never before able to deploy visitor tracking or interactive systems (due to the lack of infrastructure) to do so.

Indeed, energy-efficient sensing has been identified as an important area for further work in IoT in general [1], in particular for deployments in areas like air quality monitoring, noise level mapping and other aspects of smart city sensing. This would allow work on this topic within the domain of heritage to also be applied to the broader IoT research area.

Note also however, that the technologies that we use for visitor identification and tracking, and the resulting personalisation systems, raise a number of issues around privacy. As a result of recent changes in laws on data collection and storage, particularly the EU's General Data Protection Regulation (GDPR), systems also need to be designed to offer both safe, secure storage of data, store only the minimal possible data and also offer means of deleting visitor data should they so request.

C. Installation, configuration and maintenance

One of the current issues for IoT is that of device installation and configuration. Currently, many IoT systems are designed either to be deployed in an industrial context, where a technical installation process is acceptable, or in the home, where simple WPS-based networking is possible. In many heritage sites however, there are somewhat secure or restricted networks, with no real onsite technical support. As such, the ideal for heritage sites would be for IoT devices to "not require any technical configuration" [56].

In the ideal world for heritage sites, IoT devices would simply have to have power applied and require no configuration. While this is not actually possible (due to the requirements of network security), there should still be a goal of minimising the technical installation process for such devices. This should include clear user interfaces for network configuration, but also some level of automatic configuration and smart self-annotation of the devices, so that they can be used as quickly and easily as possible.

There is already some research into such topics, including the user of self-annotation [56], as well as the creation of new IoT platforms to allow for non-expert users to configure and even program such devices [57]–[59]. Indeed, projects such as meSch[7] have specifically investigated the creation of such environments and tools for heritage sites, but the resulting systems have still required the presence of technical expertise for installation and configuration.

On top of this, comes the issue of maintenance. As already mentioned, heritage sites often lack on-site technical support staff. This means that systems must be easy to maintain. Ideally, any IoT system to be deployed in a heritage site should offer intelligent self-diagnostics, reporting and (where possible) automated maintenance. Some museums are reluctant to deploy new technologies due to previous poor experiences with devices that regularly stop working and cannot be easily repaired. As such, there is a major market for IoT systems with good diagnostic and maintenance abilities within heritage.

However, it should be noted that alongside this ease of configuration, installation and maintenance, there needs to be a focus also on security [60], particularly for those systems that will integrate visitor data and actions across visits and sites.

IX. Conclusion

In many ways, the Internet of Things is still emerging in terms of devices, technologies, applications and domains. As stated by Gubbi et al: "The evolution of the next generation mobile system will depend on the creativity of the users in designing new applications" [1]. While existing IoT research and development has focussed on smart homes, smart office and smart cities, other domains may offer potential in terms of the development of new IoT applications and also the development and improval of IoT technologies to support these applications.

In this paper we have proposed that the cultural heritage domain offers a unique opportunity for IoT. It is still a relatively undeveloped market for IoT, but is also one that is open to new technologies, particularly those that support the creation of new user-centered, data-rich experiences for visitors. This is an excellent match for IoT.

Alongside the opportunities that IoT offers for cultural heritage, the domain also offers a number of interesting challenges and opportunities for IoT. In particular, the need to create robust, low cost, easily deployable and maintainable systems present a number of interesting challenges, the results of which could easily be extrapolated to broader IoT domains such as smart cities.

Coupled with an interest in smart personalisation based on rich user data and the opportunities offered by linking multiple sites, even across different organisations and even countries, we believe that there are numerous benefits both for IoT researchers and cultural heritage organisations in further work in this area.

[7] http://mesch-project.eu

Acknowledgments

This paper has in part emerged from work that took place within the scope of the meSch project (2013-2017) that received funding from the European Community's Seventh Framework Programme, "ICT for access to cultural resources" under the Grant Agreement 600851.

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