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Mobile Sensing, BYOD and Big Data Analytics: New technologies for audience research in museums

Theano Moussouri,
University College London, UK

George Roussos,
Birkbeck College London, UK

Abstract:
Over the past four decades, varied information technology and communication tools were incorporated in standard audience research methodologies thus becoming a ubiquitous feature of fieldwork and data analysis. In this paper, we highlight the costs and benefits of the application of these technologies to audience research through specific case studies set within varied museum environments. Collectively the findings of these studies suggest that mobile sensing supports the acquisition of richer and deeper data sets relating to the visitor experience that can potentially reveal a greater diversity of patterns of visitor behaviour as well as the changing dynamics of visiting over time. This can considerably extend our capability to conduct audience research and rethink the way museums conceptualize and deliver their interpretation. This paper also discusses the methodological, ethical and practical challenges emerging from the use of these technologies in the field as well as the limits of their application.

Keywords: smartphone, timing and tracking, audience research, research ethics and privacy.

1. Introduction

Over the past four decades, varied information technology and communication tools were incorporated in standard audience research[1] methodologies thus becoming a ubiquitous feature of fieldwork and data analysis. Indeed, the daily routine of most contemporary researchers would involve the use of databases and spreadsheets to manage and tabulate data, or statistical and text processing software for quantitative and qualitative analysis respectively. Web-based surveys and mobile logging systems for tracking are relatively recent additions to this set of tools and have further extended our ability to reach actual and potential audiences and improve the accuracy and detail of record keeping. Today, a new generation of mobile technology is rapidly becoming affordable and offers the opportunity to further develop the technology toolkit of audience research. Its core ingredients are the capability to automatically capture location and other sensor[2] input from commodity consumer devices carried by visitors and use this information to conduct analyses through a new generation of machine learning and visualization techniques.

The most common type of mobile sensing enables the recording of the location of the visitor at specific time intervals. In this way, it becomes possible to track visitors as they move through an exhibition or site without the active involvement of a researcher. There is however great variation in the capabilities of different technology alternatives to achieve this: when outdoors, visitors carrying a smartphone can be located using GPS to within a few meters of their actual position. When indoors, wireless networking infrastructure can be used to achieve the same goal also using the visitors' mobile phone but at coarser accuracy. Location and time are the attributes of a visit that can be most easily recorded but are by no means the only: mobile sensing technology can also be used to infer the activities that the visitors are involved in, the ambience of their immediate surroundings, and in some cases their emotional and cognitive responses to their museum experience.

Moreover, a current trend in information technology is towards consumerization in what is becoming known as the BYOD (Bring your Own Device) approach. BYOD advocates that IT in general and mobile sensing technology specifically is increasingly incorporated in consumer devices such as the mobile phones carried by visitors, and that such devices can be employed for the delivery of systems and applications offered by museums. For example, it is no longer necessary to provide a hardware-based audio or electronic guide to visitors but a museum can instead employ an app on the visitor's own smartphone offering the same functionality thus significantly extending the availability of such applications. Indeed, according to a recent study by the Survey of American Alliance of Museums and the Museums Association in the UK, approximately half of the population in the USA and Western Europe are already users of smartphones (Fusion Research + Analytics 2012). These smartphones can also be employed to conduct audience research capturing rich data sets that are amenable to a new generation of analysis techniques, commonly referred to as Big Data analytics (Barton and Court 2012), which can provide new insights on the underlying patterns of behaviour.

In this paper, we highlight the advantages and limitations of the application of these technologies to audience research through specific case studies set within varied museum environments, each employing technology that matches their particular requirements and characteristics. In each case, we also show examples of how the data has been analysed using modern Big Data techniques. Collectively the findings of these studies suggest that mobile sensing supports the acquisition of richer and deeper data sets relating to the visitor experience that can potentially reveal a greater diversity of patterns of visitor behaviour as well as the changing dynamics of visiting over time. This can considerably extend our capability to conduct audience research and rethink the way museums conceptualize and deliver their interpretation. Owing to the ability of this technology to be used both to provide interpretation and to collect visitor location data, it has the potential to embed audience research in the development of spaces and experiences and hence to provide organisations with access to information that can support on-going learning and decision making (often called 'thinking evaluatively'). In this paper, we also identify the methodological, ethical and practical challenges emerging from the use of these technologies in the field as well as the limits of their application. Throughout, we are mindful that technology is only the enabler and that in many cases such tools would be one of several alternatives available to researchers who must make choices guided by appropriateness for the investigation of specific research questions.

2. Tracking and Timing Outdoors

Location is the most common sensing modality readily available in a variety of consumer mobile devices. Smartphones in particular typically integrate multiple location-sensing technologies several of which we discuss in this and following sections. Location information can be *absolute* that is, reported with reference to a global coordinate system for example, latitude and longitude pairs. Or it can be *relative* in that it is expressed in relation to specific landmarks for example, twenty metres south from the London Zoo entrance. It can be expressed either numerically for example, 51 degrees North by 0.19 degrees West, or symbolically for example, "at the Zoo entrance gate." Each location sensing system is also characterised by its *accuracy* and *precision*: Accuracy refers to the distance between the reported position and the actual location where the calculation is carried out or else the error in the calculation of this estimate for example, five metres from the actual position. Precision refers to the percentage of time that is, how often we can expect to achieve this accuracy for example 98 per cent of the time better than two metres accuracy is achieved.

The most common location sensing system in current use is the Global Positioning System commonly referred to as GPS (LaMarca and de Lara 2008). GPS has been in operation since the late 1970s and consists of a constellation of satellites, which regularly transmit signals incorporating identification and timing information.[3] GPS receivers estimate their position through a process called triangulation by combining distance and time measurements from different satellites that are used as reference points. Receivers carry out these calculations independently and need not communicate back to the satellites or any other communications infrastructure. Such devices have become common in smartphones and other consumer electronics due to their low cost and their compact packaging for example, a typical receiver chip would measure just a few square centimetres and cost a few dozen dollars.

GPS accuracy and precision depends on a large number of environmental and technical factors such as visibility of satellites (the more satellites are visible the higher accuracy can be achieved), the quality of the receiver chip, atmospheric conditions, and sun activity. It is, thus, difficult to provide a figure for these attributes that would hold true under all circumstances. Having said that, when a typical smart phone receiver is used in North America and Europe, one can expect a few metres accuracy most of the time when used at open spaces. Access to supplemental satellite systems can further improve performance, for example receivers that augment GPS through the WAAS system in the UK can improve their accuracy to about one metre and over 99 per cent precision.

2.1 Tracking Visitors with GPS at the London Zoo

In a recent study we conducted during the spring of 2009 at the London Zoo in the UK, we employed GPS as part of our empirical examination of family visitor motivation and usage patterns. We employed a naturalistic approach combining self-reporting methods, specifically Personal Meaning Mapping (PMM), informal interviews, and tracking. We were able to combine the PMM and interview data with visitor trails to associate motivations for visiting and spatial behaviour (Moussouri and Roussos 2013).

We approached family groups as they were entering the Zoo, explained the purpose of the study and what their participation in it would involve. Forty-six families were approached as they were queuing to enter the Zoo and gave their consent to take part in the study. Out of the total of forty-six participating families, forty-three groups (130 individuals) completed all elements of the study. Of those, we have complete data sets (i.e., paired PMM and complete GPS traces) for thirty eight families (90 individuals). All age groups were represented in the group of participants (see **Table 1**).

Table 1: Visitor Profile by Age

0-4	**5-7**	**8-10**	**11-13**	**14-18**	**19-35**	**35-50**	**51-70**	**71+**	**Total**
18	**6**	**10**	**6**	**3**	**27**	**18**	**2**	**0**	**90**

There were more women than men and slightly more boys than girls (see **Table 2**).

Table 2: Visitor Profile by Gender

Men	**Women**	**Boys**	**Girls**	**Total**
22	25	20	23	90

Families were offered free entrance and were escorted to a sitting area near the main entrance. Participating families were asked to complete a PMM that was used to gather data about their prior knowledge, interests, imagined visit routes, and expectations of what family members would be able to do and see individually and as a group. In the informal interview that followed, all family members were asked their reasons for visiting. Often this information was also included in their PMM, in which case we prompted them to give more information.

Having completed the pre-visit PMM, families were then provided with a smartphone that was used to record their location for the full duration of their visit, which could last up to approximately five hours. Due to the fact that at the time smartphones were not as common as today, we opted to provide the same model device to all families so that the recorded location data would be of comparable quality. Specifically, we used the Openmoko Neo smartphone as our logging device integrating a precise Assisted-GPS unit with EGNOS functionality that achieves best accuracy in this locality. Tracking software was already installed and operational and the device was placed in a soft pouch that could be safely attached to a belt or placed inside a pocket or handbag. Visitor location was logged every second by a GPS unit integrated in the smartphone in order to have as detailed a record as possible.

Subsequently arrangements were made to meet the family visitors at a specified location but no fixed time was given for this. Families were free to choose when to terminate their visit and the purpose for the meeting was for the return of the device. After recruiting families the researcher would proceed to the agreed meeting place and wait for their return, at which point they were asked whether they were willing to continue the discussion. Once visitors had agreed to be interviewed, the exact same procedures used in the pre-visit data collection were repeated. At the end of the visit, visitors were asked to re-visit their PMM and add or modify any aspect they wished. The post-visit PMM captured information related to changes in knowledge and interests, reconstructed visit routes and the extent to which expectations were met. Three out of the forty-six participating families were not able to complete the post-visit PMM, due to time constraints, and were excluded from the study.

Figure 1: Time-lapse animations of the track recorded by one of the participant families in the London Zoo study. The track has been superimposed the open source Open Street Maps system.

The recorded data were used to reconstruct time-ordered sequences of locations visited (cf. **Figure 1**) and from these sequences we were able to infer different elements of the visitor's spatial behaviour, for example their presence at particular places and their interactions with specific exhibits. The tracking information provided a rich data set which we investigated using the Big Data analytics system developed by Audience Focus specifically for this purpose (Kostakos *et.al.* 2011, Papadogkonas *et.al.* 2008). Firstly, the usual descriptive statistics for tracking and timing studies (Yalowitz and Bronnenkant 2009) were calculated noting that because the captured data were already in a machine-readable form there was no need for manual transcription, a fact that facilitated the processing of considerably larger quantity of data. Contrary to the specialised but highly complex tools provided by commercial and open source systems such as Oracle Spatial and ArcGIS, and PostGIS, QGIS and OSGEO[4] respectively, this software has been designed to cater to the typical workflow of audience research thus supporting advanced spatial statistical processing via an intuitive interface. **Figure 2** shows the annotated map representing particular areas of interest at the London Zoo and statistics associated with one of these locations such as number of visitors and average dwell time.

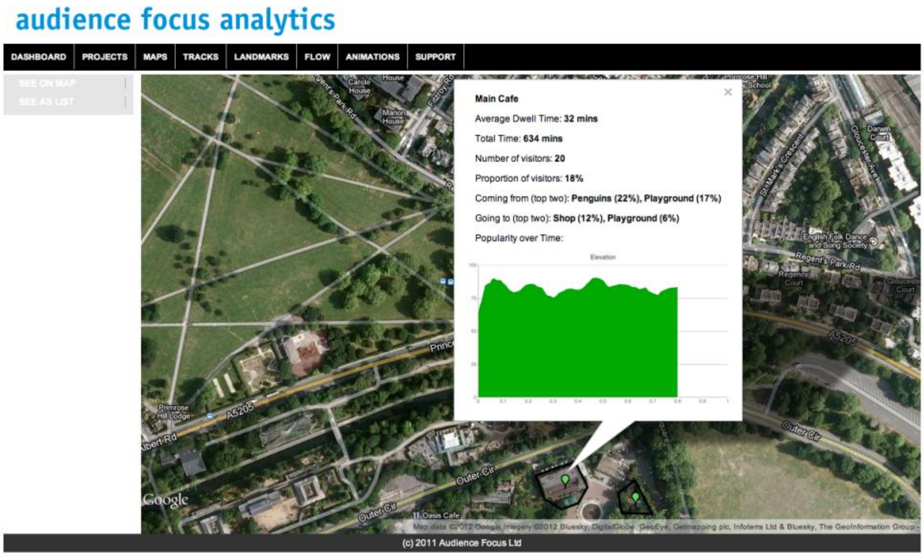

Figure 2: Dwell time and related descriptive statistics associated with a user-defined region corresponding to the café area at the London Zoo. The statistics have been automatically calculated and displayed by the Audience Focus Analytics system.

An alternative way to visually represent space occupancy is through the heatmap (cf. Figure 3), a technique that superimposes colour intensities on locations to represent the relative length of visitor dwell times at those locations. Heatmaps are a common technique in Big Data analytics due to their effectiveness to visually communicate the relative frequency by which specific places are used and can help to quickly identify places of intense interest for visitors such as "hot" exhibits and how individuals group around them. For example, a quick visual inspection of **Figure 3** reveals the main areas where the particular family spent most of their time. This technique has also been used to analyses visitor traces at the site of the Minoan palace and city of Zakros, Crete, Greece (Chrysanthi 2012).

Figure 3: The heatmap created by analysis the track of a single family visit at the London Zoo. The image was constructed using a modified version of the open source gheat software (Whitacre 2008).

3. Coarse-grain Tracking Indoors

GPS is an ideal solution for tracking and timing in many outdoors situations but building structures and the presence of large reflective surfaces in relatively close proximity to the receiver adversely affect the satellite signal. As a result, GPS measurements become unreliable in interior spaces and in most cases completely unusable so that alternatives must be considered. The implication is that it becomes necessary to deploy purpose-specific infrastructure usually at significant cost including installation, calibration and general maintenance and operation. Cost is directly related to the desired precision and accuracy, the exact exhibition characteristics and layout, and the types and sizes of the exhibits present. For a medium-sized museum expenditure would typically range from a few thousands to several hundreds of thousands of dollars.

Tate Modern in the UK has used indoors location-sensing technology since the early 2000s primarily as a means to adapt content presented by its multimedia guide and related mobile apps (Wilson 2004). The system employs the gallery's wi-fi network and has been quite successful with visitors through applications such as the Magic Tate Ball, a location-based game that promotes the exploration of the gallery's collections. However, the technology has severe limitations in that it can only provide room-level accuracy. For this reason it has only been employed in rudimentary ways for audience research primarily to collect app usage and popularity data.

An interesting study using similar indoors coarse-grain technology was carried out at the Louvre in Paris, France during 2011 (Yoshimura *et al* 2012). In this case Bluetooth, a Personal Area Networking technology, was employed to digitally mark a small number of prominent locations in the museum typically gateways between halls. At these locations

Bluetooth scanning stations were installed and were used to identify visitors crossing the gateway through the discovery of their mobile phones. Since the vast majority of mobile phones provide Bluetooth functionality this is generally an effective way to automate the process of visitor tracking. In fact, visitors can be traced across locations because Bluetooth scanning captures the unique identifier associated with the specific mobile phone carried by a particular individual. In this way it becomes possible to follow visitors when entering and exiting specific halls within the museum throughout their visit, information that can be employed to reconstruct the complete pathway they followed across the site. An alternative approach to the system adopted at the Louvre would be to use this technology to identify visitor proximity to specific landmark locations, for example specific exhibits, which have been instrumented with a scanning station. However, this is a less reliable technique in practice due to large timing variations in the device discovery process.

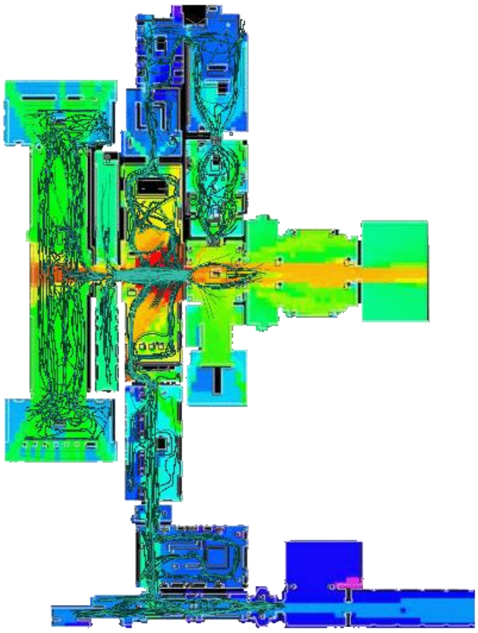

Figure 4: Visitor flow visualisation at the British Museum. The images were constructed using the open source Depthmap software (UCL Space Group 2010).

The Louvre study used a relatively low number of scanning locations but despite this limitation the advantages of this approach against manual data collection are still clear: it is possible to track considerably higher number of visitors thus offsetting the coarse-grain track reconstruction and produce interesting findings relating to visitor flow. The published paper on this study (Yoshimura *et al* 2012) offers few details of its findings from an audience research perspective primarily reporting on the practicalities of recording and the methods used to ensure accurate data capture. This approach is found to be both practical and relatively inexpensive and permits studies of longer duration for example by operating the scanning equipment continuously throughout the year. This would provide unique insights into the temporal dynamics of visiting over an extended period of time and would not have been realistic without the use of technology.

To show how such coarse-grain data can be used effectively to inform analyses of visitor flow, in **Figure 4** we show the results of a feasibility study we conducted using similar Bluetooth technology in 2006 at the British Museum in London, UK. **Figure 4** displays flow maps constructed using gateway counts and provides a visual representation of visitor flow through the site for example quickly identifying congested areas. This visualisation has been generated automatically from tracking data using the Depthmap software (Hillier and Tzortzi, 2006; UCL Space Group 2010), which can also produce animated sequences showing changes for instance in hourly patterns.

Before concluding this section on coarse grain location sensing, we note that there are two very low-cost technologies in current use that could be used for the same purpose namely Radio Frequency Identification (RFID) and QR bar codes. In both of these cases however, it is necessary that the visitors take action in order for their location to be recorded: In the case of RFID they have to bring their mobile phone to close proximity to the RFID tag marking the specific location of interest and in the case of QR they need to scan the bar code with the phone camera. Despite these rather severe limitations RFID has been used successfully to track visitor behaviour in a pioneering project at the Exploratorium (Hsi and Fait, 2005). QR codes have become very common in recent years and although their primary purpose is to provide smartphones with links to supplemental online information relating to exhibits, they can also be used to trace visitors (as long as they scan them) through an exhibition using standard web tracking software.

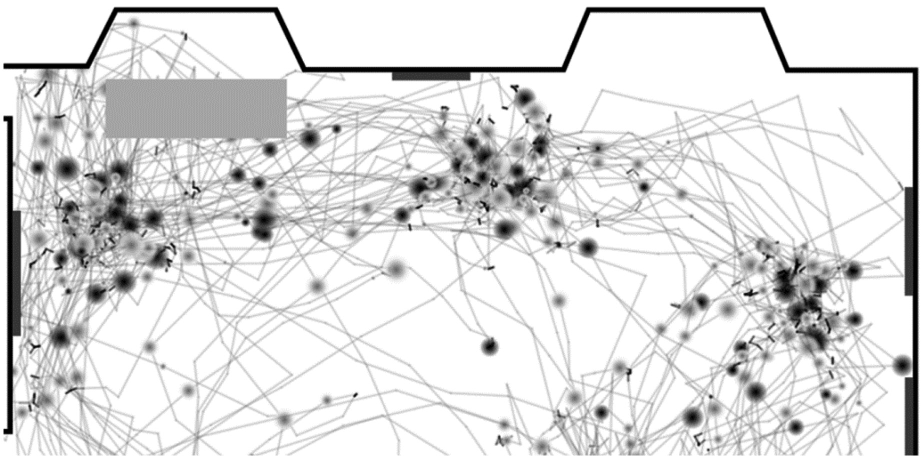

Figure 5: Interior gallery tracks recorded using high accuracy UWB technology at The St Gallen Art Gallery (courtesy Martin Tröndle).

4. Fine-grain Tracking Indoors

The state-of-the-art in mobile location sensing is Ultra Wide Band (UWB) technology, which can provide location estimates with accuracy of a few centimetres as well as detect visitor orientation. Unfortunately, as with many new technologies, the cost of deployment is currently very high and requires the installation of mini-satellites covering the monitored space. Although in the vast majority of cases this technology would be prohibitively high for most museums, it was actually used for a study conducted in 2009 at the Art Museum of St. Gallen, Switzerland. This work was made possible by a research grant and participation by a leading manufacturer of such systems, and was available as a temporary installation rather than a permanent feature of the gallery.

In any case, use of UWB location-sensing technology produced highly accurate tracks of visitors while also correctly identifying orientation within the galleries. **Figure 5** shows several of the tracks recorded in a particular gallery, which reveal a uniquely detailed tracking and timing data set exceeding the capabilities of any alternative indoor or outdoor system (Tröndle *et al* 2013). The data and additional bio-sensed attributes (cf. Section 4 below) have been successfully used to quantify the level of engagement with works of art and explore its relationship to social interaction during the visit. Although clearly this technology is still generally not yet affordable for museums, in the long term the availability of data at very high accuracy and detail opens up distinct opportunities for example, in tracking visitors interactions at the individual artefact level. The National Maritime Museum in Greenwich, UK is one of the sites conducting such experiments with a permanent installation of UWB in a single of its recently redeveloped galleries.

5. Other Sensing Modalities

To be sure, location sensing is the most readily available mobile sensing technology and suitable for extensive use in audience research, but several other sensing modalities currently at different stages of maturity, offer interesting opportunities. Firstly, smartphones typically carry a dozen or so sensors[5] that can be used to capture a variety of personal and environmental information: high quality three- and six-dimensional accelerometers have been used to infer user activities for example distinguishing between periods of standing, sitting and walking in which case the speed and gait can be estimated. Microphones are of course ubiquitous in all phones and have been used to capture fragments of visitor speech which when processed by suitable algorithms can infer the emotional state of the speakers and their levels of stress. These techniques are rapidly reaching maturity and will soon become adequately dependable in audience research.

In our London Zoo study, we employed proximity sensors to measure spatial density, which can be used to provide a good estimate of crowding levels. In other projects we have experimented with a variety of environmental and biological sensors such as those measuring air quality and pollution, noise, ambient radiation, temperature, humidity, heart rate and skin conductance, all of which are widely available at very low price. An interesting use of bio-sensing was employed in the St. Gallen study discussed above, where skin sensors were used to measure skin conductance which is widely believed to indicate the emotional state of the carrier. More recently, mobile electroencephalographs have become affordable as they have been commoditised as game controllers, and can be easily used to measure cognitive activity and responses to particular experiences. This trend is accelerating and it is reasonable to expect mobile sensing devices to become commonplace in the short term, although this is not to say that their use does not pose a challenge for audience research.

A final point in the current discussion relates to the inference of social interactions in general and through the use of location or proximity data in particular. For example, when two or more visitors are tracked it is possible to deduce that they belong to the same group or that they are interacting at a particular time by observing the duration of their collocation. This heuristic has been successfully used in the study of social networks in a physical setting (Kostakos *et al* 2011) and is directly applicable for audience research. Typically, this requires the specification of a threshold on spatio-temporal co-presence that indicates that contact has occurred. There is further evidence to support this assumption and several related studies report success with this technique (Vu *et al* 2011).

6. Methodological Considerations

The design of any type of audience study is a balancing act whereby alternative methodologies must be weighed against the aims and research questions of the study as well as the time and resources available to complete it. While further practical experience with these technologies is crucial, we anticipate that the ability of mobile sensing technologies to collect Big Data sets from visitors at significantly reduced cost and effort makes large-scale and longitudinal studies decidedly easier to conduct. Technology may finally help overcome the financial barriers in conducting such studies, a long-standing but so far unattainable ambition of the field. The cost advantage of automating data collection and the BYOD approach in particular provide critical support for a shift away from project-based studies as the main research approach, which is limited in that it only captures snapshots of short-term learning benefits while making cross-institution comparisons very difficult. Furthermore, these technologies can accelerate the data collection and analysis cycle thus facilitating evaluation studies where findings be fed back to the project team at very short time frames thus increasing the potential impact of formative evaluation studies especially in cases were rapid prototyping of sections or complete exhibitions is required.

One question that merits further consideration at this stage is the comparative quality of data collected by a person and data collected automatically through technology. An attempt to explore this question specifically has been the work of Baldwin and Kuriakose (2009) that provides encouraging preliminary evidence in favour of the technology. Nevertheless, further studies are required to consider the details especially in fully developed settings that fully account for the realities of museum fieldwork.

From a practical perspective, there are several decisions that must be made for the design of a successful study especially considering the implications of BYOD. First, it is necessary to install recoding software on the visitor's mobile device. This is greatly facilitated by the widespread availability of software distributions mechanisms such as Google Play and the App Store, which allow the seamless and familiar methods for the installation of the required software. However, this process also involves the provision of a privacy and security policy by the research team, which should be in line with guidelines for ethical research, and in any case adds an extra layer of complexity to the project as research need to ensure that it is both sufficient and comprehensive. In particular, the research team should be prepared to address visitor concerns about possible intrusions of their privacy noting that personal devices typically store highly sensitive information that should not be addressed. We discuss this issue further in the following section.

The choice of the specific mobile location-sensing technology employed depends on the particular physical setting for the study, and of course whether tracking will take place outdoors or indoors. For example, the physical attributes of the exhibits displayed have significant bearing on the required accuracy for successful tracking: where exhibits extend over a large area, such as in zoos, lower accuracy systems could work well. Object displays with high item density would require high accuracy location sensing to differentiate between them and at very high densities would stretch the capabilities of any system for questions relating to specific objects rather than the display as a whole. The same factors of physical layout also influence the interpretation of the collected observations, for example assessing the level of engagement with a display meaningful inferring interaction requires proximal presence for a period exceeding a minimum time threshold or confirmation of the visitor orientation.

Similar to other research tools their successful use requires that they serve the exploration of the questions set out the study. We anticipate that in the medium term while the technologies become more usable their most effective use will be in a mixed approach where technology-based data collection can be incorporated into a comprehensive methodology that derives from specific research questions.

7. Implications for Research Ethics

Research ethics are central in any study involving human participants, yet the type and volume of data that is possible to capture and process using these technologies raises distinct issues (see also Raento *et al* 2009 for an extended discussion of this question specifically). Naturally, the first step in ameliorating such concerns is to carefully draft the study information sheet so as to clearly explain what data is collected and how, how it will be processed and anonymized. In particular, at this stage of their development it is more likely that researchers involved in data collection may not be familiar with the full implications of the use of this technology and for this reason it is necessary to incorporate targeted training in understanding data collection in this manner as well as related methods for the effective protection of participant anonymity and dealing with privacy issues.

Personal mobile devices, a core ingredient of BYOD, invariably contain confidential and other sensitive information and despite security measures already in place it is not uncommon that such information can be accessed (maliciously or unintentionally) or that visitors perceive a risk in this possibility. Such concerns are not unfounded and are reinforced by high-visibility incidents widely reported in the public press. Prevention of such incidents requires firstly careful technical development where appropriate and also awareness of these risks by the research team so that appropriate action is taken when necessary. To this end, all research team members must have access to a set of practical measures in the event of visitors experiencing problems as well as appropriate training in troubleshooting common problems or at least taking appropriate action.

The feature of Big Data analytics that appears to cause most concerns is the high volume and precision of observations captured over an extended period of time. This issue extends beyond audience research as the availability of mobile location sensing creates wider opportunities for its exploitation and for a more detailed discussion we direct the reader to Duckham (2011). In the short-term visitor tracking is most likely to occur over a single visit, which limits the potential exposure for the visitor, but in case where longer longitudinal studies are attempted these issues directly affect research design and must be carefully considered. Although there are readily available tools that apply strong anonymization algorithms to protect privacy in this context, though it appears that the process can be reversed using newly designed techniques based on data triangulation (Machanavajjhala and Reiter, 2012)

8. Conclusions

In this paper we have attempted to explore the costs and benefits of employing mobile sensing, the BYOD approach and Big Data analytics to audience research. We find that these technologies combined create novel tools that extend the depth and breadth of possible studies while considerably reducing their cost and their demands on specialist human resources. Specifically we discover the following advantages:

- *Reduced effort, time and cost*. Data collection via mobile sensing using the visitors' own mobile phone significantly reduces the need for direct involvement by researchers who can focus on the management and supervision of the process.
- *Increased detail*. Using mobile sensing technology visitor positions are recorded precisely and with undivided attention on each observation for the duration of the visit. Recording captures all behaviors, not only those deemed of relevance at the time of observation. This focus on detail is maintained over prolonged periods of time without fatigue affecting data collectors' performance.
- *Advanced Analytics*. Audience researcher can benefit from a new generation of so-called Big Data technologies that allow the application of advanced machine learning and visualization techniques potentially revealing new patterns and behaviours, especially those evolving over time, that cannot be captured by descriptive statistics.

We consider the collection of tracking data with smartphones as the first step in a comprehensive programme of research in the use of mobile sensing and Big Data analytics for audience research. Several research groups including the authors are currently experimenting with a variety of sensing modalities and in the sort-term we anticipate the use of these technologies to augment the current generation of tracking and timing studies with the presentation of location-specific questionnaires provisioned on the visitor smartphone relating to specific aspects of the exhibition and/or their experience in a highly targeted manner.

The suitability of mobile technologies for audience research is related to their ability to capture the physicality of the experience. Nevertheless, museums are increasingly present online providing experiences beyond simple information related to visiting and increasingly incorporating social media, collaborative authoring and content sharing including audio, video, still images and text captured or published by visitors before, after and during their visit become more influential. The combination of the digital footprint created through participation in online activities and trails followed during visits in the physical setting can potentially be combined to create powerful insights into behaviour across the two settings. This approach can be further extended to incorporate other settings and resources, beyond the museum, that visitors use as they pursue their interests and which can highlight different pathways to interest development and strategies of self-directed learning.

Biographical notes:

Theano Moussouri is Lecturer in Museum Studies at UCL. Her research looks at knowledge construction, visitor experience and meaning-making in museums. Theano is Books Editor of *Curator* and on the Editorial Board of *Museum & Society*. Contact: t.moussouri@ucl.ac.uk.

George Roussos is a Professor of Pervasive Computing at Birkbeck College, University of London. His research interests include human dynamics and the data science of the Internet of Things. Roussos has a PhD in distributed computation from Imperial College. He is a member of ACM, the IEEE Computer Society, and SIGMOBILE. Contact: g.roussos@bbk.ac.uk.

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Notes:

[1] In this paper, we use the term 'audience research' to refer to 'the study of actual and potential audiences of an institution through the use of a variety of methods' (Visitor Behavior, 1998). In this

context, audience research covers different types of studies, ranging from large scale surveys and market research to audience participation and evaluation studies, using a wide range of theoretical and methodological approaches. We use the term 'visitor' to refer to individuals and groups visiting the physical space of the museum.

[2] Sensors are electronic or electromechanical devices that measure some environmental attribute and convert it into an electrical signal. For example an accelerometer, which is present in the vast majority of smartphones and mobile computers, behaves as a damped mass on a spring and uses the piezoelectric effect caused by the displacement of the mass caused by acceleration to produce a current.

[3] GPS is the longest running of all satellite-based location-sensing systems generally referred to as Global Navigation Satellite Systems (GNSS). Other GNSSs include GLONASS, a Soviet era system currently operated by Russia, that using incompatible technology to GPS; Europe's Galileo and China's Beidu are still in early stages of development and are not expected to be fully operational for several years. Neither provides variety of receivers, low cost or coverage comparable to GPS.

[4] The details of using such systems is beyond the scope of this paper and we direct the interested reader to the resources and tutorials published by the Open Source Geospatial Foundation (Open Source Geospatial Foundation 2014)..

[5] The interested reader is referred to Fraden (2010) for more details.