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SPATIAL DATA VISUALISATION AND BEYOND

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Introduction

Deformed visions

> The attempt to appreciate the sensory worlds of others, distant in time and place necessitates an unlearning: that we subject to scrutiny our sensory education, of which the prejudice towards vision is only one part.
>
> *(Gosden, 2001, p. 166)*

> I want to propose a theory and practice of a Deformed Humanities. A humanities born of broken, twisted things. And what is broken and twisted is also beautiful, and a bearer of knowledge. The Deformed Humanities is an origami crane – a piece of paper contorted into an object of startling insight and beauty.
>
> *(Sample, 2012)*

Vast computational power promises us that rainbow's-end we've been chasing: the ability to experience, visualise and explore the past *as it was*. Even if we couch that desire in caveats, still, the desire remains. There is nothing wrong with this desire; what is wrong is to pretend that it does not exist.

We have to consider that our digital sense – that extended cognition that overlays and permeates space (knowing what friends are up to miles away because of constant social media updates; the ability to be guided through traffic congestion via constantly updated maps; the sense of loss that occurs when there is no wi-fi signal) is part of the sensorium that archaeologists must now contend with. Let us then begin with this newest sense, and consider the ways it can intersect with physical space *especially* when that sense is dependent on these ephemeral, ghostly, haunted objects that 'send [our] social relations off down a new path, not through any intention on the part of the object, but through its effects on the sets of social relations attached to various forms of sensory activity' (Gosden, 2001, p. 165).

For instance – many Wikipedia articles contain geographic metadata. They are articles about a particular place. What tool would we reach for to understand this geographic coverage? A map, of course, replete with dots or other icons. But Wikipedia exists in its own digital space(s), social and informatic, spaces that overlie real world space. Several years ago we built 'Historical Friction' (Graham & Eve, 2013), a web-toy app extended from Ed Summers' *Ici* (Summers, 2016). Summers' app took the geolocation from a user's device and returned the list of Wikipedia articles geocoded to nearby places. 'Historical

Friction' by contrast *vocalised* that list with several computerised voices from text-to-speech synthesizers. The denser a locale, the greater the cacophony of computers yelling at the listener. The web-toy was not a pleasant experience. It *depended* on the user pulling out the ear-buds, taking off the headphones, and seeing the place with new eyes in the revelatory silence.

Digital data is there for us to reach out and experience. It is not safely confined to a computer in the lab. It permeates space. Experiencing it can be like Sample's origami crane. In this chapter we gesture towards ways we might usefully deform archaeological spatial data, thinking especially about sound and vision.

Archaeological vision

The opening passage of Stephanie Moser's exploration of the birth of archaeological visualisation states:

> It is no surprise that archaeology – a discipline that is centered on the study of material culture – relies heavily on a large suite of visual products to record, interpret, and present its findings to professional and public audiences.
>
> *(Moser, 2012, p. 292)*

She goes on to define visualisation as follows: "On the one hand, it results from the products that result from graphically representing archaeological materials and on the other it refers to the process of interpretation embodied in this visual translation" (Moser, 2012, p. 295). This is also true of spatial visualisations. When one thinks of spatial data visualisation the 'map' is immediately brought to mind. Cartography and map-making have been at the centre of how we visualise the world for millennia (see Andrienko & Andrienko, 2006; Slocum et al., 2008; Kraak & Ormeling, 2013; Tyner, 2014; Gillings, Hacıgüzeller, & Lock, 2019a for overviews). As archaeologists we draw plans, sections and put countless dots on maps (the meditative nature of *manually* drawing such plans has recently been celebrated by Caraher, 2015, as *slow* archaeology). We explore and record an archaeological site horizontally and vertically using complicated (but also familiar) notation such as the hachure or stippling. As well as using this abstract symbology we produce more 'accurate' products like photographs of our trenches and the landscapes in which we are working. We convert the electrical impulses from our geophysical equipment to colours and hues to help us visualise the resistance of the soil to electricity. We capture signals from satellites and convert them to a precise location on the planet which we then represent by a dot or the node in a line on a map. This volume itself is replete with precisely this kind of visualisation.

These techniques are all very familiar to the archaeologist and each one has a vast amount of literature that can be examined, questioned and challenged. There is no space within this short chapter to do justice to a detailed exploration of each of these methods, however, it is fair to say that the majority of spatial visualisations created by archaeologists are currently created using Geographic Information Systems (GIS). These visualisations tend to be presented as 2D plans or maps effectively recreating the drawn record, albeit with clearer symbology and layout. Perhaps as a result of this digital proxy for the hand-drawn record, visualisation of space using GIS has traditionally been seen as a by-product of a deeper spatial analysis, as Ebert puts it, the "read-only mode of GIS" (2004, p. 320). This view has been recently challenged by Gupta and DeVillers, who argue that "visualisation encourages the use of our cognitive abilities (rather than equations and algorithms) to process information and generate new knowledge" (2017, p. 855). The degree to which our orthodox visualization techniques nurture and encourage such an engagement is currently moot.

Archaeological spatial visualisation also has to take account of the temporal dimension. For example, we present results from surveys that took place at specific times, representing artefacts that that were deposited sometimes thousands of years apart. Any spatial visualisation that we create must necessarily deal with both spatial and temporal uncertainty (see Fusco & de Runz this volume). Unfortunately, current GIS software "typically enables navigation of the spatial and thematic dimensions, but it does not offer effective exploration of the temporal dimension" (Gupta & DeVillers, 2017, p. 876). The overwhelming majority of archaeological spatial visualisation is performed through the medium of the cartographic product, be that a set of time-series diagrams, an interactive 2D or 3D GIS interface with a 'time-slider' to explore the temporal aspect or a simple map showing points, lines and polygons. This often means that the data has to be simplified to fit the requirements of the available tools, rather than encouraging an exploration of different forms of visualisation.

As Gillings, Hacıgüzeller and Lock state, "there is nothing wrong with maps that are argumentative, discordant, disruptive, playful, provocative or simply beautiful . . . . if novel connections and relations can only be built [through these methods] then that is how it will have to be" (2019b, pp. 11–12). Beyond the traditional map or plan, other forms of spatial visualisation exist that enable us to approach archaeological data in different ways. These include the novel presentation of statistical analyses, such as Martin Sterry's work (2018) which uses the Hue-Saturation-Value (HSV) colour wheel to visualise results of multi-dimensional correspondence analysis of pottery use in Roman Britain. Recent advances in web-based technology have allowed annotated interactive 3D virtual reality visualisations of LiDAR and other data to be presented through online portals such as SketchFab (see https://sketchfab.com/markwalters). It is now even possible to 3D print scale models of landscapes or artefacts and 'visualise' them haptically (Neumüller, Reichinger, Rist, & Kern, 2014; Di Franco, Camporesi, Galeazzi, & Kallmann, 2015).

Perhaps unsurprisingly, an analysis of the available literature on visualisation suggests that archaeologists are only the tip of the spatial visualisation iceberg (see for instance MacEachren et al., 1998; Slocum et al., 2001; Brewer, MacEachren, Abdo, Gundrum, & Otto, 2000; Crampton, 2002; Howard & MacEachren, 1996, whose work, from a network-theoretic point of view, ties the scholarship of geographic visualisation together).

If we perform the same quick computational reading of the citation knowledge graph (a network analytic reading of the results of a Google Scholar search for 'archaeological + data + visualization', so as to see data visualization beyond archaeological GIS), Figure 24.1, and look for the articles that tie the network together (taking that as a signal that the ideas contained therein bridge scholarship), we find a very strong focus on Virtual Reality work (Acevedo, Vote, Laidlaw, & Joukowsky, 2001; Vote, Acevedo, Laidlaw, & Joukowsky, 2002; Allen et al., 2004; Van Dam, Laidlaw, & Simpson, 2002; Forte, Dell'Unto, Issavi, Onsurez, & Lercari, 2012). If we are not doing GIS and if we are not drawing plans or plotting dots, we are building virtual reality (VR); our debt to archaeological photography and the 'visual' aspect of visualisation seems clear.

Hamilakis (2014, p. 22) has argued that the emergence of photography was *the* medium of capitalism in the 19th century, in that photographs themselves became a kind of currency, a new form of visual economy (citing Sekula, 1981; Poole, 1997). This autonomous and disembodied sense of vision was quickly adopted in archaeology, making archaeology a "device of modernity" (Hamilakis, 2014, p. 9). Archaeology's privileging of the visual therefore is also complicit in the ontological admixture that Hamilakis describes between aesthetics and politics, in that both circle around what is permitted to be sensed, experienced, and appreciated, and by whom: *con*sensus versus *dis*sensus (2014, p. 415). The tools and techniques of computational approaches to archaeology merely replicate this consensus. And yet, archaeology is about that full-bodied sensuous engagement with the *things* and *environments* of the world, at the trowel's edge, from which we craft the past. This tension, Hamilakis tells us, is the wedge with

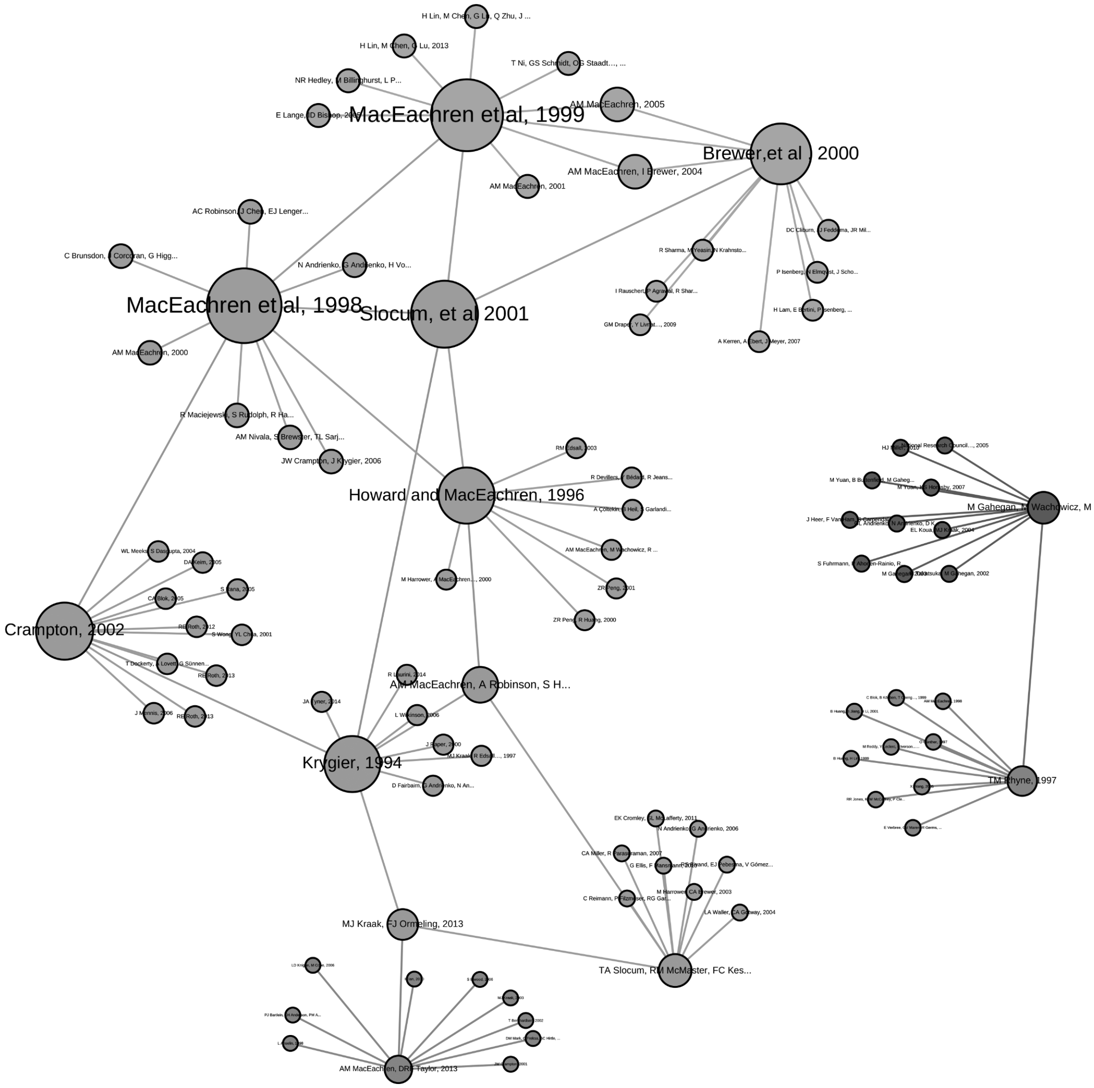

FIGURE 24.1 A citation network of results returned from a Google Scholar search of 'geographic + visualization', using Ed Summers' python package 'Etudier'. "Google Scholar aims to rank documents the way researchers do, weighting the full text of each document, where it was published, who it was written by, as well as how often and how recently it has been cited in other scholarly literature." https://scholar.google.com/intl/en/scholar/about.html. The results give us a sense of the most important works by virtue of these citation patterns. Thus, MacEachren et al. (1998); MacEachren, Boscoe, Hau, & Pickle (1998); Slocum et al. (2001); Brewer, MacEachren, Abdo, Gundrum, & Otto (2000); Crampton (2002); Howard & MacEachren (1996) are most functionally important in tying scholarship together. This is not the same thing as being the most often cited work. Rather, these are the works whose ideas bridge otherwise disparate clumps; they are most central.

which we might insert a more fully sensorial engagement in archaeology (2014, p. 9). "There is no perception which is not full of memories" going on to assert that " . . . it is my conviction that all academic writing should become evocative, merging scholarly discourses with mnemonic and autobiographical accounts" (2014, pp. 9–10). For Hamilakis, the merging of different ways to sense the world (Ingoldian knots, perhaps, of lives lived, Ingold, 2015) means that all sensorial experience is synesthesia (Hamilakis, 2014, pp. 410–411).

Hamilakis also argues that "The human individual, especially as perceived and enacted in Western capitalist modernity, is not the most appropriate unit of analysis for an archaeology of the senses. This is not only because, as anthropological accounts have shown, human persons can be conceptualized and embodied in diverse ways . . . . More important[ly] such an analytical category is inappropriate because sensorial experience is activated at the moment of a transcorporeal encounter; this is an encounter among human bodies, between human bodies and the bodies of other beings, and between human bodies and objects, things, and environments" (Hamilakis, 2014, p. 411). This echoes Ingold in his discussion of the "life of lines" (2015) where he argues not for assemblages, but for *correspondences*. The concept of the 'assemblage' is 'too static' because it does not allow for the frictions or tensions that bind things together. Lines do – for they knot and twist and respond to one another. Meaning is not built from blocks juxtapositioned, but from movement along a line, where it bunches up encountering other lines. As we shall see later, if we cannot use the experienced senses of a human individual of today as a direct proxy for past senses, perhaps we can instead use our present senses to create and experience new things about the past.

Hamilakis only deals with digital media briefly, regarding them as merely another prosthesis for thought. Yet digital media is itself active and has a kind of agency (a way to effect change in the world) in a way other classes of materials genuinely do not. Moreover, digital media bring another actor into the mix, for digital work is a correspondence between user, machine, and programmer. Digital synaesthesia emerges from this knotting. To work in a digital medium, to work with computational tools and semi-autonomous software agents requires the performance of tacit knowledge and experience. We respond to the machine and it in turn responds to us. We may call it a 'black box', which only serves to show that the result is a deformance (portmanteau of 'deform' and 'performance'), a making strange and an estrangement from the sand and dirt and flies of the excavation. But if we recognize that computation is a kind of knotted performance, then we should recognize also that computation returns an emotional connection to this data, to remind us that data is *always* a proxy for human lives lived. And so it is not without ethical consequences. The decisions we take in a digital medium, given the nature of computation (whose fundamental action is to copy), get multiplied in their effects. Copying implies connection, a tangled web of articulations. Hence, the choice of representation (whether visual or aural), or form (or indeed, whom to cite!), when there is a choice to be made (as there always is), is a force multiplier. Computation entangles us, knots us, in networks/meshworks/filigrees of time and space. Computation expands our senses and at the same time our entanglements with the world (c.f. Hodder, 2012).

As archaeologists we are still very much at the edge of exploring the potential of the full sensorium (see Mlekuz, 2004; Frieman & Gillings, 2007; Eve, 2014; Primeau & Witt, 2017) and especially so when attempting to 'visualise' the past and the results of our spatial analyses (for example, see work by Murdoch & Davies, 2017, on whether or not VR reconstructions could be spiritually affective). As the Internet of Things (Xia, Yang, Wang, & Vinel, 2012; Kopetz, 2011) becomes a reality, our concept of what is a computer has also become more complicated. Our laptops, our smartphones, our GPS devices and even our toasters (Engadget, 2018) are connected to the internet at all times and beginning to blur the boundaries between the real world that we inhabit, and the virtual world that we visit via our devices. Currently, however, a paradigm shift is occurring within the computer science sector towards 'spatial computing' (Shekhar, Feiner, & Aref, 2015). Spatial computing recognises this digital kinesthesia, encompassing "the ideas, solutions, tools, technologies, and systems that transform our lives by creating a new understanding of locations – how we know, communicate, and visualise our relationship to locations and how we navigate through them" (ibid., 72). Historically archaeologists have only embraced some aspects of spatial computing, most notably geographic information systems (Conolly & Lake, 2006) and spatial statistics (Wheatley & Gillings, 2000). These technologies and methods are now as familiar to the archaeologist as the trowel – but spatial computing needs to meet the challenges and embrace the opportunities of constantly emerging and evolving technologies. This includes the sheer quantity of data being collected (see Green, this volume; McCoy, 2017; Cooper & Green, 2016, for discussions of [geospatial] Big Data in archaeology), but also the evolving concept of space as represented within the computing environment. Traditional GIS deals with points, lines, polygons and rasters in a very abstracted way, yet there is now a " . . . need for new algorithms, as well as cooperation between users and the cloud, full 3D position and orientation (pose) estimation of people and devices, and registration of physical and virtual things" (Shekhar et al., 2015, p. 77). We are developing the technology to capture human bodies and archaeological objects with full degrees of freedom and can represent them in virtual space (Eve, 2018a). As we will go on to demonstrate, we can now take our GIS objects or the results of our statistical analyses and present and explore them in the real locations of real reality, rather than just on the screen of a computer. The familiar 2D or 2.5D representations of the printed map or illustration can become a real 3D world overlaid on the actual environment with which we can engage and embody.

The 'embodied GIS' was first introduced by Stuart Eve (Eve, 2012, 2014, 2017) to formalise the use of Augmented Reality (AR) technology within archaeology. Augmented reality is a form of mixed reality that takes digital data and blends it with the real world. Augmented reality " . . . allows a user to work in a real world environment while visually receiving additional computer-generated or modelled information to support the task at hand" (Schnabel, Wang, Seichter, & Kvan, 2007, p. 4). George Papagiannakis and colleagues produced one of the best-known cultural heritage AR applications, centred on the site of Pompeii (Papagiannakis et al., 2004, 2005; Papagiannakis & Magnenat-Thalmann, 2007) . Using a special see-through video headset along with dynamic modelling of the real and virtual world, Papagiannakis and his team were able to insert virtual characters into various real buildings within Pompeii and guide the visitors through a narrative as they walked through the site. A recent example of the use of AR in archaeology was a 'Pokémon Go' meet up in the city of Chester orchestrated by Big Heritage and Niantic Labs in 2017. Users of the Pokémon Go app were guided around the historical sites in the hope of hunting virtual creatures (Pokémon) while learning more about the history of the city (Zeroghan, 2017). Both of these examples overlay digital data on physical spaces, but in the context of our discussions of Hamilakis' work, it is worth remembering when using AR

> [T]he introduction of the virtual elements should be kept to a minimum and, in contrast, the landscape itself should provide the bulk of the experience – the way in which steep slopes tire you; the shelter gained from standing in the lee of a hill; the smells of the flowers; the sound of the birdsong; and the views and perspectives that open and close as you explore the landscape.
>
> *(Eve, 2017, para. 3.3)*

These are powerful modalities to explore. Yet they depend on proprietary software and hardware, clunky to handle and awkward in the field. The embodied GIS and our entangled digital kinesthetic sense can (and should) involve haptic full-body engagements (TeslaSuit, 2018), olfactory stimulation (Eve, 2018b), gustatory stimulation (Iwata et al., 2004) or even direct electrical stimulation of nerve cells across the body (Delazio et al., 2018). However, without picking the low-hanging fruit of the visual, at present one of the easiest and most accessible way of evoking this digital kinaesthesia, and exploring and

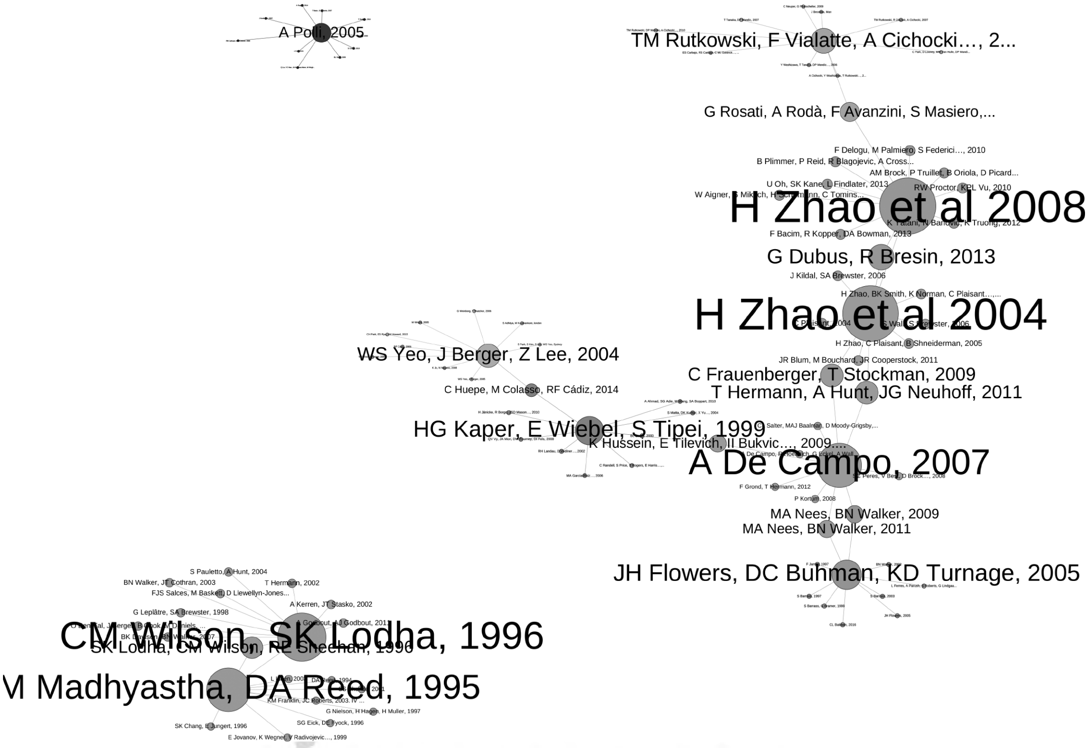

FIGURE 24.2 Citation analysis using Summers' Etudier package, from a Google Scholar Search for 'data+sonification'. Colours are works that have similar patterns of citation; size are central works that tie scholarship together. This is not the same thing as 'most cited'. On this reading, one should begin with Madhyastha and Reed (1995); Wilson and Lodha (1996); Zhao, Plaisant, Shneiderman, and Duraiswami (2004); De Campo (2007); Zhao, Plaisant, Shneiderman, and Lazar (2008).

presenting data is through the creative manipulation of aural data points across and within spaces as we demonstrate in our method and case studies.

As long ago as 1994, John Krygier was arguing for the use of sound and 'auralisation' to represent geographic data, pointing to even earlier work in the 1950s (Pollack & Ficks, 1954) on the use of sound to represent multivariate data. A citation network analysis shows that Krygier's work (Figure 24.2) has not penetrated to any great degree into archaeology, and so we re-introduce ideas of sonification into this space. In particular, he points to the use of sound coupled with animation, to indicate uncertainty:

> Maps tend to be 'totalising' creatures: variations in uncertainty and quality are smoothed over to create an orderly, homogeneous graphic. On one hand, this is why maps are so useful, and it is obvious that maps enable us to deal with our uncertain and messy world by making it look more certain and tidy. Yet it seems important that some sense of the uncertainty or quality of the represented data be available . . . The purpose of maps, remember, is to impose order, not to accurately represent chaos. Further, there is only so much visual headroom on a display: using visual variables to display uncertainty may have the effect of limiting the display of other data variables.
>
> *(Krygier, 1994, p. 161)*

This concern with uncertainty fits well with the 'fuzziness' that a digital synesthesia would promote, and the kinds of 'deformance' or 'brokenness' that digital humanities theoreticians like Mark Sample (2012) argue for. We turn then to sonification as a method and simple ways/case studies that some of this brokenness can be returned to our archaeological geographies.

Method

There is a deep history and literature on archaeoacoustics and soundscapes that tries to capture the sound of a place as it was (see, for instance, Wall, 2018, on the creation of St. Paul's or Jeff Vietch's work on ancient Ostia, 2017). But we are attempting to sonify spatial datasets – to visualise them with sound, *in situ*. This is not so much a recreation of the sounds of the past, but instead a way of exploring our data about the past. For example, where we might look at a graphical representation of a scatter of flints over a field, using the visual devices to distance ourselves from the abstract notion of flint counts – we can instead move through that field wearing headphones, retrieving our location from GPS, and hear the changes in the data, hear the hotspots (and perhaps more importantly notice the absences of sound) as we walk. The resulting aural experience is a literal 'deformance' that makes us hear modern layers of the past in a new way.

As Graham (2016) outlines:

> Sonification is the practice of mapping aspects of the data to produce sound signals. In general, a technique can be called 'sonification' if it meets certain conditions. These include reproducibility (the same data can be transformed the same ways by other researchers and produce the same results) and what might be called intelligibility – that the 'objective' elements of the original data are reflected systematically in the resulting sound.

Last and Usyskin (2015) have undertaken a number of experiments to test how humans react to sonification of datasets and what kinds of tasks this method can achieve. Their results show that even listeners with no formal training in music can perceive useful distinctions on the data. These distinctions included common data visualisation tasks such as classification and clustering.

Because music is sequential and has a duration, Last and Usyskin argue that time-series data is particularly well-suited to sonification (2015, p. 424). Time-series data is also sequential and evolves over time. In many aspects of sonification, 'parameter mapping' is used to match a certain data series to various auditory dimensions (in our flint example, the amount of flint present in a location might be matched to the pitch of the sound – the higher the pitch the greater the concentration of flint). Rasterised GIS datasets, by their very definition, are continuous surfaces of data, and every point of space has a value. Therefore, when we move through the space represented by that raster, physically walking over the field of flint scatters, it can be considered similar to panning the mouse pointer over the raster of flint concentrations. The data is continuous and so sonification of that data is quite appropriate. We journey through the space, at the same time as journeying through the soundscape created by and from that data.

There is also an effect where our expectations of what the sound 'is' or 'represents' causes us to literally hear sounds that are not there. A typical example involves flattening all of the instruments and voices in a pop-song into a midi file, and then playing that midi file as a piano solo. If one is already familiar with the song, one can hear the 'voice' singing. If not, the sound is unintelligible noise. This effect is sometimes called an 'auditory hallucination'(c.f. Koebler, 2015). This example shows how in any representation of data we can hear/see what is not, strictly speaking, there. We fill the holes with our own expectations. The sonification of the flint example is subject to the same spatial resolution issues as a more traditional visualisation, the resulting soundscape will change if we use a 5m pixel resolution (picking up the smaller variations in the data) or a 25m pixel resolution (only playing the broader trends). The same is true of any visualisation; it just is perhaps more apparent as we consider sound. Thus, as with all methods of visualisation, we need to be critically self-aware, and foreground that reflection as part of our analysis.

Case studies

Sonification out loud

We will now present three case studies that represent recent examples of sonifying archaeological spatial data. Each case study has a set of 3D points as its underlying dataset, but each presents the data in a different way – and can be experienced either in situ or via a desktop computer.

Recalling Sample's origami crane – part of the art of origami is to delight in the care and meditation that the process affords. The act of sonification does not always produce pleasing or necessarily immediately intelligible sound. In which case, we need to devote attention to process, to blind alleys, to dead ends. That is, we argue for the 'failure as epistemology' developed for by Croxall and Warnick (2017). The way that things break, the ways our digital tools do not really achieve what we wanted or expected, reveal in their fault lines truths about our ideas about the world, the data, and the past. Surfacing the *process* of digital work is as important as the finished products we make.

York municipal cemetery

As part of the 2014 Heritage Jam organised at the University of York, UK (Laino, 2014) we decided to explore how we could use sound to affect and inform visitors to the 19th–20th century municipal cemetery of York. The resulting application, entitled Voices/Recognition, was "designed to augment one's interaction with York Cemetery, its spaces and visible features, by giving a voice to the invisible features that represent the primary reason for the cemetery's existence: accommodation of the bodies buried underground" (Eve, Hoffman, Morgan, Pantos, & Kinchin-Smith, 2014).

The prototype application is delivered via the speakers or headphones of the user's smartphone. It reads the user's location from the GPS sensor in the smartphone as they walk around the cemetery and then compares that with an underlying spatial database. If the user is in close proximity to a grave that has additional data related to it a sound file is played (the volume of which is determined by the user's distance from the grave itself). The data underlying the application is built from a simple GIS database of the burial register including grave locations along with the names of the people buried. As the application was a prototype, instead of a fully finished product, the grave details were not complete and instead the sound files were created as various whispering voices that were triggered using Apple's Core Location libraries. The use of sonification to explore the grave data raised a number of previously unconsidered questions about the experience of graveyards. For example, while a lot of the graves have markers, there are also a large number of unmarked burial pits – pauper's graves – that contain a large number of skeletons all piled into one pit. These pits tend to be beneath the pathways between the grave markers and in the open spaces, and (being unmarked) are not considered by visitors to the cemetery. As we had no idea how many bodies were interred in each pit, we represented them by a cacophony of different voices telling random stories.

> The areas of the cemetery that are visually empty are suddenly transformed into areas containing a vast number of voices of the dead. There is a common belief that it is bad luck or disrespectful to

> walk over somebody's grave, therefore the 'empty' paths that were previously seen as a 'safe' places to walk, suddenly become areas that are superstitiously liminal.
>
> *(Eve, 2017, para. 4.2)*

The experiment also raised issues about power and control in the cemetery and how that is reflected by the placement of the graves. In contrast to the cacophony produced by the pauper pits, when you move closer to a larger, expensive grave monument the cacophony is reduced to just one or two voices – as the expensive graves have been placed to stand apart from the other graves. The voices of the rich and powerful are heard as clearly in death as they were in life. We would argue that this social stratification and also the affective nature of using sounds and voices to represent the pauper graves would not be so obvious if we were looking at a simple visualisation on a screen or printed on a map.

Listening to Watling Street

Part of the 2015 Heritage Jam, Graham was inspired by the work of the 'Data Drive Dj', Brian Foo, and his piece 'Two Trains – Sonification of Income Inequality on the NYC Subway'. In this piece, Foo takes the US Census data on median wealth along the stops of the subway, and uses this data to generate a piece of music. The length of the piece is scaled against the length of the subway line. The song is generated by running an auction for sound samples at each point along the line. In general, the higher the income, the more sound samples that can be selected and played for the duration until the next subway station is reached. Each station has a 'budget', which is set from the US Census data for average monthly wage at that station; each instrument has a 'price'. The poorer the district, the softer, less complex, the music. Foo's code is open source (Foo, 2018), and well documented and so we can see exactly how the song is generated.

The vision of space in the Roman world, as a sequence of places-that-come-next as depicted on mile-stones and in written itineraries, is readily amenable to Foo's vision for hearing inequality along a subway line. In the case of 'Listening to Watling Street', the data comes from the *Inscriptions of Roman Britain* web site – counts of coins. We take each town in the Antonine Itinerary along Watling Street, and find the relevant number of coins. Then, we set the 'price' for each instrument such that towns with more coins obtain a greater tonal variety. Graham experimented with various combinations of instrument clips, aiming for a tonal composition that would be appropriate for a kind of Roman procession (see Favro & Johanson, 2010).

As we listen to this song, we hear crescendos and diminuendos that reflect a kind of place-based shouting: here are the places that are advertising their Romanness, that have an expectation to be heard (Roman inscriptions quite literally speak to the reader); as Western listeners, we have also learned to interpret such musical dynamics as implying movement (emotional, physical) or importance. The same itinerary can then be repeated using different base data – coins from the Portable Antiquities Scheme database, for instance – to generate a new tonal poem that speaks to the economic world, and, perhaps the insecurity of that world (for why else would one bury coins?).

Foo draws his musical samples from music written by New York artists, music that 'captures the throbbing vibrancy of New York and the movement of its citizens'. In 'Listening to Watling Street' (Graham, 2015) we too are interested in movement, but using these base samples Foo provides (although a small set of these) perhaps unwittingly makes aural comparison to New York. In the first sketches of 'Listening to Watling Street' we slowed down the beats-per-minute to reflect a kind of marching cadence, to subtly introduce the idea of the marching Roman army. In the second version (which was submitted to the Heritage Jam), the tempo was sped up and more instrumentation was used to capture the frenetic motion of the Roman trader. Both versions are true, for a given value of 'truth'.

Ottawa love stories

Tim Ingold directs us to consider the lived life of lines in the landscape (2015). These lines, which humans extend outwards from our experiences entangle with the lines of other humans, other beings, other things. One way Ingold directs us to think about these lines, their knottings, and their co-respondences is to think of them in terms of sound. A vibrating line – a string under tension – makes a noise in the world. If we considered movement through space as a similar kind of noise-making, what would our traces sound like?

Cassandra Marsillo, a student in Carleton University's Public History MA program, has thought about these issues and provides us with another case study. Working with digitised historical newspapers, she was struck by the way the obituaries paid particular attention to spaces and places of these lived lives. She identified a particular genre of these obituaries where a husband or wife died shortly after the death of their spouse, 'of a broken heart'. The emotional impact of the places mentioned in these obituaries seemed clear. She wanted to take the digital representation of the meaningful *affect* of these spaces into the physical locations. It seemed however invasive: the dead had given no permission to have their lives represented this way. Marsillo decided to work with the living, and their memories of emotional spaces. Thus the 'Ottawa Love Stories' project was born (Marsillo, 2018). Marsillo asks her respondents, 'where were/are the places that are important in the shared life of you and your partner?'. The resulting maps inscribe these personal histories as lines on the map within the boundaries of the city of Ottawa.

The map quickly becomes a tangle of knots; but the knots extend also in time. With time comes duration, and with duration comes sound. Marsillo uses simple techniques of parameter mapping to map the changing latitude and longitude and 'amplitude' (intensity of the emotion tied to the location) against the 88-key keyboard. That is to say, she takes a set of values and performs a mathematical transformation against them to scale their relative value within a couple of octaves on the piano. Given that all of these stories are taking place against the map of Ottawa, particular locations appear again and again in these stories. As the songlines are played, those locations form a kind of sonic architecture against which the other notes sound. Unexpected congruences and harmonies emerge, dissipate; lives lived, lines traced.

Each story then takes place inside the same sonic space but altogether certain chords keep happening. Why these chords? Why these places? A sonification of simple point data draws our attention to an Ingoldian conception of lines in the landscape. For readers of this volume, these baselines (bass lines), could be accentuated with other kinds of archaeological data. The archaeological data become the grace notes of a song as a way of approximating an effective approach to the sense history of the place. We cannot recover emic sensations of the past, but we can create new sonic experiences of the past that could redirect our attention.

Conclusion

Within this chapter, we have shown that the visualisation of spatial data is not just limited to dots on a map, or hachures on an archaeological plan – instead we demonstrate that opening up archaeological data to be experienced through other sensory modalities might open our understandings of the past in new ways. The traditional methods of visualising our data have much merit and should not be discarded, they are familiar, and because of that familiarity they are easy to understand and also often easy to produce using modern software. But we would argue that we are now at the point in the development of spatial computing where we can explore our data in parallel using different interfaces and different sensory modalities.

We have used examples of the sonification of data as one way into accessing these different modalities. Whilst the software and hardware to sonify data is still not mainstream, presently it is developed enough to enable researchers to begin to use it (much more so than, for instance, olfactory or gustatory interfaces). Not all data is suitable for sonification, in the same way that not all data is suitable for visualisation in a scatter chart or a raster surface. Nevertheless we have shown that sonification can become another vector for knowledge mobilisation. Just as in a stylised visual map, it is not a passive representation of the archaeological data, but **a performance** of the data that gestures beyond itself, to conjure up other associations, meanings, and emotions.

As available technology and methods progress we are going to be able to move beyond the simple map or distribution chart and begin to experience our data with our bodies, with multiple senses. We are going to be able to experience our datasets in situ, as we walk through an archaeological site or landscape – and we are not going to just *see* the patterns change, we are going to hear, feel, taste and smell them. Spatial data visualisation is no longer visualisation at all, it is an embodied experience that uses multiple sensory modalities to represent the same underlying datasets, each modality telling its own story and revealing its own unique patterns.

References

Acevedo, D., Vote, E., Laidlaw, D. H., & Joukowsky, M. S. (2001). *Archaeological data visualization in VR: Analysis of lamp finds at the Great Temple of Petra, a case study*. Proceedings of the conference on Visualization'01 (pp. 493–496). IEEE Computer Society.

Allen, P., Feiner, S., Troccoli, A., Benko, H., Ishak, E., & Smith, B. (2004). *Seeing into the past: Creating a 3D modeling pipeline for archaeological visualization*. 3D Data Processing, Visualization and Transmission, 2004. 3DPVT 2004. Proceedings. 2nd International Symposium on (pp. 751–758). IEEE.

Andrienko, N., & Andrienko, G. (2006). *Exploratory analysis of spatial and temporal data: A systematic approach*. New York: Springer Science & Business Media.

Brewer, I., MacEachren, A. M., Abdo, H., Gundrum, J., & Otto, G. (2000). *Collaborative geographic visualization: Enabling shared understanding of environmental processes*. Information Visualization, 2000. InfoVis 2000. IEEE Symposium on (pp. 137–141). IEEE.

Caraher, W. (2015). Slow archaeology. *North Dakota Quarterly*, *80*(2), 43–52.

Conolly, J., & Lake, M. (2006). *Geographical information systems in archaeology*. Cambridge: Cambridge University Press.

Cooper, A., & Green, C. (2016). Embracing the complexities of "Big Data" in archaeology: The case of the English landscape and identities project. *Journal of Archaeological Method and Theory*, 23(1), 271–304. https://doi.org/10.1007/s10816-015-9240-4

Crampton, J. W. (2002). Interactivity types in geographic visualization. *Cartography and Geographic Information Science*, 29(2), 85–98.

Croxall, B., & Warnick, Q. (2017). *Failure | digital pedagogy in the humanities | MLA commons*. Retrieved April 29, 2018, from https://digitalpedagogy.mla.hcommons.org/keywords/failure/

De Campo, A. (2007). *Toward a data sonification design space map*. Atlanta: Georgia Institute of Technology.

Delazio, A., Nakagaki, K., Klatzky, R. L., Hudson, S. E., Lehman, J. F., & Sample, A. P. (2018). Force jacket: Pneumatically-actuated jacket for embodied haptic experiences. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (pp. 320:1–320:12). New York, NY, USA: ACM. https://doi.org/10.1145/3173574.3173894

Di Franco, P. D. G., Camporesi, C., Galeazzi, F., & Kallmann, M. (2015). 3D printing and immersive visualization for improved perception of ancient artifacts. *Presence*, 24(3), 243–264.

Ebert, D. (2004). Applications of archaeological GIS. *Canadian Journal of Archaeology/Journal Canadien d'Archéologie*, 319–341.

Engadget. (2018). *The world now has a smart toaster*. Retrieved April 26, 2018, from www.engadget.com/2017/01/04/griffin-connects-your-toast-to-your-phone/

Eve, S. (2012). Augmenting phenomenology: Using augmented reality to aid archaeological phenomenology in the landscape. *Journal of Archaeological Method and Theory*, 19(4), 582–600. https://doi.org/10.1007/s10816-012-9142-7

Eve, S. (2014). *Dead men's eyes: Embodied GIS, mixed reality and landscape archaeology*. BAR British Series 600. Oxford: Archaeopress.

Eve, S. (2017). The embodied GIS: Using mixed reality to explore multi-sensory archaeological landscapes. *Internet Archaeology*, (44). https://doi.org/10.11141/ia.44.3

Eve, S. (2018a). Losing our senses, an exploration of 3D object scanning. *Open Archaeology*, 4(1), 114–122. https://doi.org/10.1515/opar-2018-0007

Eve, S. (2018b). A dead man's nose: Using smell to explore the battle of waterloo. In D. Medway, K. McLean, C. Perkins, & G. Warnaby (Eds.), *Designing with smell: The practices, techniques and challenges of olfactory creation* (In Press). London: Routledge.

Eve, S., Hoffman, K., Morgan, C., Pantos, A., & Kinchin-Smith, S. (2014). *Voices recognition paradata document*. Retrieved February 3, 2016, from www.heritagejam.org/s/VoicesRecognitionParadata.pdf

Favro, D., & Johanson, C. (2010). Death in motion: Funeral processions in the Roman forum. *Journal of the Society of Architectural Historians*, 69(1), 12–37.

Foo, B. (2018). *music-lab-scripts: Scripts for generating music*. Python. Retrieved from https://github.com/beefoo/music-lab-scripts (Original work published 2014).

Forte, M., Dell'Unto, N., Issavi, J., Onsurez, L., & Lercari, N. (2012). 3D archaeology at Çatalhöyük. *International Journal of Heritage in the Digital Era*, 1(3), 351–378.

Frieman, C., & Gillings, M. (2007). Seeing is perceiving? *World Archaeology*, 39(1), 4. https://doi.org/10.1080/00438240601133816

Gillings, M., Hacıgüzeller, P., & Lock, G. (Eds.). (2019a). *Re-mapping archaeology: Critical perspectives, alternative mappings*. New York, NY: Routledge.

Gillings, M., Hacıgüzeller, P., & Lock, G. (2019b). On maps and mapping. In M. Gillings, P. Hacıgüzeller, & G. Lock (Eds.), *Re-mapping archaeology: Critical perspectives, alternative mappings* (pp. 1–16). New York, NY: Routledge.

Gosden, C. (2001). Making sense: Archaeology and aesthetics. *World Archaeology*, 33(2), 163–167.

Graham, S. (2015). *Listening to watling street*. Retrieved from www.heritagejam.org/2015exhibitionentries/2015/9/18/listening-to-watling-street-dr-shawn-graham

Graham, S. (2016). The sound of data (a gentle introduction to sonification for historians). *Programming Historian*. Retrieved from https://programminghistorian.org/lessons/sonification

Graham, S., & Eve, S. (2013). *Historical friction*. Retrieved February 3, 2016, from https://github.com/shawngraham/historicalfriction

Gupta, N., & DeVillers, R. (2017). Geographic visualization in archaeology. *Journal of Archaeological Method and Theory*, 24, 852–885.

Hamilakis, Y. (2014). *Archaeology and the senses: Human experience, memory, and affect*. Cambridge: Cambridge University Press.

Hodder, I. (2012). *Entangled: An archaeology of the relationships between humans and things*. New Jersey: John Wiley & Sons.

Howard, D., & MacEachren, A. M. (1996). Interface design for geographic visualization: Tools for representing reliability. *Cartography and Geographic Information Systems*, 23(2), 59–77.

Ingold, T. (2015). *The life of lines*. Abingdon, UK: Routledge.

Iwata, H., Yano, H., Uemura, T., & Moriya, T. (2004, March). Food simulator: A haptic interface for biting. In *IEEE virtual reality 2004* (pp. 51–57). IEEE.

Koebler, J. (2015, December 18). *The strange acoustic phenomenon behind these wacked-out versions of pop songs*. Retrieved April 29, 2018, from https://motherboard.vice.com/en_us/article/kb7agw/the-strange-acoustic-phenomenon-behind-these-wacked-out-versions-of-pop-songs

Kopetz, H. (2011). Internet of things. In *Real-time systems* (pp. 307–323). New York: Springer.

Kraak, M.-J., & Ormeling, F. J. (2013). *Cartography: Visualization of spatial data*. Abingdon, UK: Routledge.

Krygier, J. B. (1994). Chapter 8: Sound and geographic visualization. In A. M. Maceachren & D. R. F. Taylor (Eds.), *Modern cartography series* (Vol. 2, pp. 149–166). Academic Press. https://doi.org/10.1016/B978-0-08-042415-6.50015-6

Laino, F. (2014). *2014 entries*. Retrieved February 3, 2016, from www.heritagejam.org/2014-entries/

Last, M., & Usyskin, A. (2015). Listen to the sound of data. In *Multimedia data mining and analytics* (pp. 419–446). New York: Springer.

MacEachren, A. M., Boscoe, F. P., Haug, D., & Pickle, L. W. (1998). *Geographic visualization: Designing manipulable maps for exploring temporally varying georeferenced statistics*. In Information Visualization, 1998. Proceedings. IEEE Symposium on (pp. 87–94). IEEE.

Madhyastha, T. M., & Reed, D. A. (1995). Data sonification: Do you see what I hear? *IEEE Software*, 12(2), 45–56.

Marsillo, C. (2018). *Ottowa love stories*. Retrieved from https://ottlovestories.wordpress.com/

McCoy, M. D. (2017). Geospatial Big Data and archaeology: Prospects and problems too great to ignore. *Journal of Archaeological Science*, 84, 74–94.

Mlekuz, D. (2004, November 11). *Listening to landscapes: Modelling past soundscapes in GIS* [text.article]. Retrieved November 16, 2010, from http://intarch.ac.uk/journal/issue16/mlekuz_index.html

Moser, S. (2012). Early artifact illustration and the birth of the archaeological image. *Archaeological Theory Today*, 292–322.

Murdoch, M., & Davies, J. (2017). Spiritual and affective responses to a physical church and corresponding virtual model. *Cyberpsychology, Behavior, and Social Networking*, 20(11), 702–708. https://doi.org/10.1089/cyber.2017.0249

Neumüller, M., Reichinger, A., Rist, F., & Kern, C. (2014). 3D printing for cultural heritage: Preservation, accessibility, research and education. In *3D research challenges in cultural heritage* (pp. 119–134). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-662-44630-0_9

Papagiannakis, G., & Magnenat-Thalmann, N. (2007). Mobile augmented heritage: Enabling human life in ancient Pompeii. *International Journal of Architectural Computing*, 5(2), 396–415.

Papagiannakis, G., Schertenleib, S., O'Kennedy, B., Arevalo-Poizat, M., Magnenat-Thalmann, N., Stoddart, A., & Thalmann, D. (2005). Mixing virtual and real scenes in the site of ancient Pompeii. *Computer Animation and Virtual Worlds*, 16(1), 11–24.

Papagiannakis, G., Schertenleib, S., Ponder, M., Arévalo, M., Magnenat-Thalmann, N., & Thalmann, D. (2004). *Real-time virtual humans in AR sites*. Proceedings of IEE Visual Media Production 2004 (pp. 273–276). Stevenage, Hertfordshire: IEE.

Pollack, I., & Ficks, L. (1954). Information of elementary multidimensional auditory displays. *The Journal of the Acoustical Society of America*, 26(2), 155–158.

Poole, D. (1997). *Vision, race, and modernity: A visual economy of the Andean image world*. Princeton, NJ: Princeton University Press.

Primeau, K. E., & Witt, D. E. (2017). Soundscapes in the past: Investigating sound at the landscape level. *Journal of Archaeological Science: Reports*, 19, 875–885.

Sample, M. (2012). *Notes towards a deformed humanities*. Retrieved April 29, 2018, from www.samplereality.com/2012/05/02/notes-towards-a-deformed-humanities/

Schnabel, M. A., Wang, X., Seichter, H., & Kvan, T. (2007). From virtuality to reality and back. In *Proceedings of the IASDR 2007 conference*. Hong Kong: The Hong Kong Polytechnic University.

Sekula, A. (1981). The traffic in photographs. *Art Journal*, 41(1), 15–25. https://doi.org/10.1080/00043249.1981.10792441

Shekhar, S., Feiner, S. K., & Aref, W. G. (2015). Spatial computing. *Commun. ACM*, 59(1), 72–81. https://doi.org/10.1145/2756547

Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S., & Hedley, N. R. (2001). Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, 28(1), 61–75. https://doi.org/10.1559/152304001782173998

Slocum, T. A., McMaster, R. M., Kessler, F. C., Howard, H. H., & Mc Master, R. B. (2008). *Thematic cartography and geographic visualization*. New Jersey: Prentice Hall.

Sterry, M. (2018). Multivariate and spatial visualisation of archaeological assemblages. *Internet Archaeology*, (50). https://doi.org/10.11141/ia.50.15

Summers, E. (2016). ICI: Edit Wikipedia pages near you. *JavaScript*. Retrieved from https://github.com/edsu/ici (Original work published 2013).

Teslasuit. (2018). *Teslasuit: Full body haptic suit*. Retrieved April 27, 2018, from https://teslasuit.io/

Tyner, J. A. (2014). *Principles of map design*. New York: Guilford Publications.

Van Dam, A., Laidlaw, D. H., & Simpson, R. M. (2002). Experiments in immersive virtual reality for scientific visualization. *Computers & Graphics*, 26(4), 535–555.

Veitch, J. (2017). Soundscape of the street: Architectural acoustics in Ostia. In E. Betts (Ed.), *Senses of the empire: Multisensory approaches to Roman culture*. Abingdon-On-Thames: Taylor & Francis.

Vote, E., Acevedo, F. D., Laidlaw, D. H., & Joukowsky, M. S. (2002). Discovering petra: Archaeological analysis in VR. *IEEE Computer Graphics and Applications*, 22(5), 38–50.

Wall, J. (2018). *Recovering lost acoustic spaces: St. Paul's cathedral and Paul's churchyard in 1622*. Retrieved April 27, 2018, from www.digitalstudies.org/articles/10.16995/dscn.58/

Walters, M. (2018). *Mark Walters on Sketchfab*. Retrieved April 27, 2018, from https://sketchfab.com/markwalters

Wheatley, D., & Gillings, M. (2000). Vision, perception and GIS: Developing enriched approaches to the study of archaeological visibility. In G. Lock (Ed.), *Beyond the map* (pp. 1–27). Amsterdam: IOS Press.

Wilson, C. M., & Lodha, S. K. (1996). *Listen: A data sonification toolkit*. Atlanta: Georgia Institute of Technology.

Xia, F., Yang, L. T., Wang, L., & Vinel, A. (2012). Internet of things. *International Journal of Communication Systems*, 25(9), 1101.

Zeroghan. (2017, July 28). *Interview with Dean Paton, big heritage: Pokemon GO at the chester heritage festival*. Retrieved April 27, 2018, from https://pokemongohub.net/post/interview/interview-dean-paton-big-heritage-pokemon-go-chester-heritage-festival/

Zhao, H., Plaisant, C., Shneiderman, B., & Duraiswami, R. (2004). *Sonification of geo-referenced data for auditory information seeking: Design principle and pilot study*. Atlanta: ICAD.

Zhao, H., Plaisant, C., Shneiderman, B., & Lazar, J. (2008). Data sonification for users with visual impairment: A case study with georeferenced data. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 15(1), 4.