Reflecting on the technical development of the Mapping Sculpture Project

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Abstract

This paper explains, evaluates and reflects on the technical challenges and opportunities that underpin both the *Mapping Sculpture* project and its mobile interface. It provides insights into the development process as an integral component of the research methodology, and highlights the importance of meaningful collaboration between researchers and software developers. Just as the project questions the conventional notion of the lone sculpture practitioner, so the technical development needed to mirror the complex web of connections between people, places, objects, organizations and events through enabling large-scale, distributed and collaborative research. Enabling access to these rich resources on mobile devices was a further innovative and challenging development, but one that opens up the possibility for fresh modes of access and development of new audiences. The success of this technical development offers a model for representing complex relationships hidden in multiple sources, enabling innovative research and enhancing access.

Introduction

The use of information technology in art historical research has a history dating back at least 40 years, and like its fellow discipline of history, one of the earliest uses of computer technology was the creation of databases to structure and analyze textual sources. The *Mapping Sculpture* project

continues this tradition, enhanced by recent developments in open source, collaborative and Web accessible technology[1]. This technical innovation, and the new possibilities it brings, can viewed in two ways. First, as a tool; one that brings speed and precision to accessing, querying, sorting and filtering research data. The second view is to see technical innovation as a lens: bringing patterns and relationships into view that had hitherto been obscured, and opening new perspectives and interpretations, which produce fresh questions, and different answers, to those that have been possible before.[2]

These two views of technical innovation are not mutually exclusive, and the development of the *Mapping* project and its subsequent mobile interface should be viewed as both a tool and a lens. What this paper emphasizes, however, is not the particular technologies adopted, important though they are, but the process by which they were created and the research possibilities that they enable. Of particular note is the close collaboration between academic researchers and the technical developers. This may seem an obvious characteristic to emphasize, but as Michael Greenhalgh points out 'some of these [art historians] have been told sententiously that academics should leave such technical matters to programmers'.[3] Doing so would fundamentally undermine, not just this, but any similar project. A close collaboration between researchers and developers is essential, as the creation of any database system requires not only a close understanding of the sources used, but also a level of abstraction of these sources. These are not simply practical technical problems, but represent challenging intellectual questions. What data is to be included, and by implication, what is to be excluded? Can data entries be standardized without losing the nuances of the

original sources? What are the nature and patterns of relationships within and between sources that need to be represented? The latter is particularly important in the context of the *Mapping Sculpture* project. The database model implemented here is a relational one, by far the most common database structure in use. This model sees the database not as a way of structuring data, but of modelling relationships between data. As such it must avoid, consciously or otherwise, pre-interpreting what the relationships should be and represent, as far as possible, all the relationships within the domain.

Mapping the connections underpinning the profession and practice of sculpture can only be achieved by harnessing the power of the database to the research process. This has resulted in a database that has over 360,000 records in 72 tables and 2794 different types of relationships between objects, people, places, organizations, events and sources. This is making explicit what had hitherto been implicit: relationships across a wide variety of dispersed resources that would beyond the capability of any one researcher to harness. This opens up the possibility for new narratives about the sculpture of Britain and Ireland, in its mobile form creates a new relationship between the location-specific, physical context of sculpture, and how it interacts with the reception and interpretation of mobile digital data.

Mapping Sculpture

The *Mapping Sculpture* systems and databases were developed in-house at the University of Glasgow by the Humanities Advanced Technology & Information Institute (HATII)[4]. HATII has been involved in the development of online resources for over 15 years and draws on experience from a wide

range of digital humanities projects, of which *Mapping Sculpture* is one of the largest and most successful.

With project sustainability in mind, a number of technical solutions were adopted which might be applicable to any digital research project. One of the most important was that the *Mapping Sculpture* systems were built using open source software, that is the underlying source code is freely accessible and often developed in an open and collaborative manner. Proprietary software, typically developed by commercial vendors, is usually released as 'closed source', meaning the users and developers have no access to, or understanding of, the underlying code. Support for proprietary software is, therefore, tied directly to the company that created it, which may choose to withdraw support for software in favour of requiring users to purchase the latest version. The specific software used is of little concern here, but the fundamental advantages of using open source solutions are compelling. The Digital Curation Centre (DCC), in which HATII is a partner, recommends the adoption of open source software. In their *Digital Curation Manual*[5], the DCC cites the ubiquity, maturity and transparency of certain open source software as a major strength in terms of the software's expected longevity and availability of support. The popularity of open source ensures that there is an active community of developers supporting the software, unencumbered by the commercial pressures often associated with proprietary offerings.[6] Similar solutions were adopted with regards to embracing open technical standards and data formats to ensure that research data were stored and transmitted in readily reusable and transparent forms.

The development process itself might be described as unique in several respects. Firstly, it was an unusually collaborative process with the Project Director and the Systems Developer working together closely to design, develop and maintain the systems. On the *Mapping Sculpture* project the Project Director was heavily involved in the technical aspects, as well as overseeing research activity. While there is little need for the researchers on a project to become familiar with the technicalities of the systems being developed to support their work, a willingness to engage with the developers is key to a successful outcome.

Secondly, the Project Director placed the technical aspects of the work at the very heart of the project, rather than treating the development of the database as secondary to the research itself. Thus database development was a fundamental component of the research methodology. The interconnected nature of the data, as well as the sheer number of records generated, meant that the work was made possible only by employing relational database technology. It should go without saying that the research must inform the systems design and not vice versa, but there are countless examples of projects where an inflexible IT system, or an intransigent development team, has had undue influence over the research methodology or other working practices. This sort of scenario benefits neither party: the researcher does not receive the system they require to carry out the work effectively and the developer is regarded as an unhelpful technical hindrance. Indeed, based on the experience of the *Mapping Sculpture* project, there is a strong argument for developers in such projects to be considered as co-investigators or researchers rather than service providers.

Development of the *Mapping Sculpture* system did also present some interesting technical challenges: chief among them was the complex distributed nature of the work. The server hosting the ‘central’ copy of the database was held at HATII, with half a dozen or more researchers working independently of one another on their own local copies of the data. Working in various locations across the UK and Ireland, the researchers enjoyed only intermittent Internet access and could only synchronize with the central database periodically. As and when they had an opportunity to synchronize, the researchers would submit their most recent work for editorial approval and simultaneously receive data submitted by other researchers, already approved and by the Project Director and Editor. These asynchronous database connections, coupled with Internet connectivity of varying quality, required the development of complex workflows that could cope with the researchers’ lack of live access to the central data.

The term ‘synchronization’ came to represent the range of intertwined workflows and software components designed to support the distributed, asynchronous research methodology and, as the project’s most complex technical challenge, the implementation of synchronization might be considered a partial success. In some respects, the elements of synchronization that did not work as well as hoped were those that were simply too ambitious. For example, it was originally intended that a record – say, a person record, made up of many smaller fields such as name, date of birth, and so on – should remain editable by a researcher even after submitting the record for approval. This was to be achieved by tracking changes made to the record at field level, meaning that newly-submitted

fields, maybe date of birth, would be locked until the researcher next synchronized and the field had been approved by the Project Director or Editor. In the meantime, the other fields on the record would remain editable, so that if, in the interim, the researcher uncovered some additional information about the person in question, perhaps their place of birth, they could enter these data without having to wait for the previously-submitted date of birth information to be approved. This extremely granular approach ultimately proved difficult to manage and extremely resource-intensive, meaning that an attempt by a researcher to synchronize with the central database could take a very long time indeed, especially on the often slow public Wi-Fi connections.

In retrospect, despite the obvious advantages afforded by this attempt to track changes to records at field level, there is probably a good argument for simply tracking changes at record level. So, if changes were made to a person record and the researcher submitted these changes, the entire person record would be locked until the data were approved. The disadvantage that the researcher could, for a time, not add to the record would likely be outweighed by the advantages of a much faster, more efficient synchronization process. Even now in 2012, with the mobile Internet apparently so ubiquitous, it is worth noting that researchers working remotely could not be guaranteed constant, reliable access to the central database. Working, as they often were, in the depths of some huge stone-clad museum building or in some remote archive where a mobile phone signal, let alone a 3G signal for mobile Internet access, is by no means a certainty[7].

In spite of the challenges that variable mobile signals posed for data creation and synchronization, the potential to harness mobile technology for end-user

access was a promising one. The amount of data transmitted would be far lower and the need for synchronization would be absent. With this in mind, a second 12 month phase of *Mapping Sculpture*, with additional funding from the Arts and Humanities Research Council was embarked on in 2010 – *Mobilising Mapping*.

Mobilising Mapping

The overarching objective of *Mobilising Mapping* was to develop a web interface, personalization features and social networking tools to the *Mapping Sculpture* database that was optimized for use with a wide range of mobile devices including web-enabled mobile phones (featurephones and smartphones) and tablet devices. The rationale behind this development was that it would facilitate in situ engagement, exploration and research and enable users to collate and share their interaction with *Mapping Sculpture* through personalization features and social networking tools. Additional benefits would come through being able to engage the wider public in an innovative way, particularly new audiences outside academia, for whom mobile phone access is becoming ubiquitous. The latter was a particularly important consideration for the project's museum partners, the Victoria and Albert Museum and the Henry Moore Institute.

These developments took place within an active research area exploring the use of mobile technology in the cultural heritage sector. Broadly speaking, activity can be classified into three areas. Those seeking to use mobile devices loaned to visitors, those exploring the potential of location aware devices, and those seeking to optimize web-based content for viewing on the visitor's own mobile device. The Center for History and New Media at George

Mason University's report 'Mobile for Museums' found that while all genres of museums are very interested in offering content and unique experiences using mobiles, their biggest challenge is working with small budgets and a small staff, limiting their ability to develop content for mobiles.[8]

The supply of mobile hardware to museum and gallery visitors is well established, but requires a significant hardware investment and costly maintenance and upgrades. Nevertheless, this is still an active field of development, for example the Indianapolis Museum of Art (IMA) has launched its first in-gallery mobile tour to coincide with a special exhibition entitled "Sacred Spain" using iPod Touch devices rented from its service desk.[9] However, the supply of mobile devices by galleries and museums ignores the value of the mobile devices the vast majority of visitors carry with them and potentially represents an expensive technological cul-de-sac.

The use of location aware services is potentially one of the most interesting applications for mobile devices. Whilst there are many interesting possibilities, the actual implementation of such services in the cultural heritage sector is currently hindered by technical limitations. For example, Geographic Information Systems (GIS) and Global Positioning Systems (GPS) can quite accurately locate the user in terms of longitude and latitude but less so in terms of elevation. This means the device will not be able to tell whether the user is on the first, second or third floor of a gallery. The use of technologies such as Near Field Communication, Bluetooth and Radio Frequency Identification (RFID) tags can overcome these drawbacks but again require hardware investment and with the exception of Bluetooth, there is limited mobile device support.

Given these issues, the development of a mobile optimized web interface emerges as the preferred technological and resource solution. It does not require any additional hardware investment, is technically tried and tested; being Web browser-based and developed on open standards it is as future proof as possible, easily updated, maintained and scalable (at least to the capacity of the local mobile phone transmitters). Mobile optimized websites are relatively common in the media sector, such as the BBC and *The Guardian*, but relatively rare in the cultural heritage sector, the Vatican Museum being one of the few that have developed its web site with mobile devices in mind.[10] In this context the *Mobilising Mapping* development is something of a pioneer in providing mobile optimized web content in academic research and the cultural heritage sector.

The speed and scale of mobile phone adoption was a crucial context for the *Mobilising Mapping* project. By the first quarter of 2011 mobile phone adoption had virtually reached saturation point, with 91% of the UK population owning a mobile phone,[11] but within this population there was an increasing use of smartphones. Forty eight percent of all phones sold in the first quarter of 2011 were smartphones, resulting in a market penetration of 39%[12] and 27% of UK adults (12 million people) are smartphone users. These trends are important because smartphones are the driving force behind mobile Internet adoption.

This means that by the first quarter of 2011 28% of the UK population claimed to have accessed the Internet from their mobile phone[13] with 59% of total mobile Internet users accessing the Internet at least once per day by the end of 2011.[14] Moreover, mobile as the primary method of Internet access stood

at 12% at the end of 2011[15] and one third of adult smartphone users agreed that their phone is more important for accessing the Internet than any other device, for teens the figure rose to 38%.[16] These figures demonstrate that there is a large and growing user base that not only have the hardware to access Web sites from their mobile, but are demonstrating a preference for this mode of access.

There has also been significant growth in take-up of mobile broadband. Mobile broadband allows users to access the Web through the mobile phone network on devices other than mobile phones, such as laptops and tablets, using datacards or mobile 'dongles' (typically as plug-in USB device). Interestingly, since the first quarter of 2009 the largest growth sector has been among households in lower socio-economic groups. The largest increase in take-up has occurred in C2 households (where it has increased by six percentage points, to 14% of all C2 households) followed by C1 and DE groups (up four percentage points to 12% of all DE households).[17] So today, more than a quarter of DE households have no fixed connection of any kind and two-thirds of DE households that use mobile broadband do not have fixed broadband.

Take-up is also skewed towards younger consumers, with nearly one in four 15-24 year olds and one in five 25-34 year-olds claiming to use mobile broadband services and half of these using it as their only Internet connection. These two age groups are not only ‘digital natives’ but ‘mobile natives’, they have grown up with mobile communication as the norm and are migrating from mobile voice to mobile data services.[18]

Therefore, if cultural heritage institutions aim to not only increase visitor numbers but broaden their visitor demographics beyond ABC1 socioeconomic groups then mobile-compatible web sites are an important tool in helping to reach these audiences. This change in online access patterns is equally important for the academic partners in the project if they are to fulfill their ambition of making the fruits of their research more accessible to the general public.

The mobile interface to the *Mapping Sculpture* database also enables in situ research, exploration and discovery. This could be a significant paradigm shift in the way all users (academic and non-academic alike), can encounter, explore and interpret the sculpture immediately in front of them. There is a limit to the amount of information that object labels and information boards can contain, if they are provided at all. Even the most comprehensive exhibition catalogue would struggle to convey the multiple and complex relationships in the *Mapping* project. Trying to access this information physically would involve a constant to-ing and fro-ing between object and archives. Even desk-based access to the *Mapping* project from a fixed-line Internet connected PC may dislocate the researcher and information from the object under study.

Therefore, the availability of in situ access to the *Mapping* database has the potential to radically alter the way in which academics conduct their research in relation to material culture on display in museums, galleries and public sites. This will greatly facilitate the handling of large quantities of data and reduce the need to repeat searches. For example, those studying the use of a particular material, such as wax, can investigate its use and store records for

associated practitioners and objects made in this material; academics looking at the professional environment for women sculptors' practice might wish to explore how many were active and where by date range and location; or track the connections of sculptors who were involved with a particular group of art societies or exhibited their work in certain locations.

The *Mobilising Mapping* project also aimed to enhance the functionality for users through the new mobile interface. The interface added personalization functionality that enables users to save information from the database into a personal folder. Users can then build their own 'virtual collection' of records for later research, study or sharing. This service can combine reference to data on the project website with other online resources by providing the facility to share the record links via users existing research, study, social and networking structures such as delicious.com, Facebook, Digg and iGoogle.

Evaluation

The *Mapping Sculpture* project is widely considered to be a great success, both in terms of the volume and quality of the research carried out, and in the scale of the impact the research data have already made. This success is evidenced by the prominence of the *Mapping Sculpture* pages in related Google search results and the multitude of links made to the project by other leading websites, including *The Victorian Web*[19], Wikipedia[20] and the University of Chicago[21]. *Mapping Sculpture* data are also assisting family and local history groups with no links to the project[22]. However, within the confines of the time and resources available, attempts have also been made to evaluate the achievements of the project in a more formal manner. The formal evaluation activity took two forms (user testing during the development of the

project also took place, but is not of concern here): on-site evaluation at the V&A in London and the HMI in Leeds in March 2011 and analysis of the project web site statistics.

The purpose of the on-site evaluations was simply to test the usability of the mobile Web interface in a naturalistic setting by members of the public visiting the exhibitions associated with the launch of the *Mapping Sculpture* project. A simple questionnaire of fourteen questions was used, this had been tested and validated prior to use. Twenty-four valid responses were received, twelve from the HMI and twelve from the V&A. The evaluation did not attempt to be representative of exhibition visitors or have any statistical validity. Visitors were simply approached and asked if they had a mobile phone capable of accessing the Web and if they would be willing to participate in the evaluation. Of the visitors surveyed eleven were female, thirteen male, one was aged 18 or under, seven aged 19-25, eight aged 26-35, seven aged 36-50 and one aged 51 to 66. The purpose of the visit was leisure for sixteen of the respondents, research for three and 'work' for four, the latter all at the HMI.

All respondents were able to receive a mobile phone signal in the exhibition space, all receiving a 3G signal (the most recent generation of mobile phone signal technology and capable of sustaining the data transfer rates required by mobile Internet sites) and all had a phone contract that included Internet data usage. One of the respondents accessed the site using Wi-Fi. Two of the respondents at the HMI had not used the mobile Web before, rising to seven at the V&A, although all but one respondent had booked something online, a question used to gauge familiarity with use of web sites. One factor the evaluators had not taken into account was the very different visitor profiles at

the two sites. Whilst at the HMI the visitors were British, at the V&A a large number were from overseas. Not wishing respondents to run up expensive overseas data usage they were offered the use of the evaluator's phone to test the site.

All respondents were able to access the mobile *Mapping* site, twenty by typing in the URL and four by using the Quick Response code (a form of bar code that can be read optically by a smartphone). [23] Only two respondents needed help in browsing records and only one was unsuccessful in their attempt to search for records. When asked to register on the site (required to access personalization features) one respondent was unsuccessful, one managed with help and three had too little time to complete this task. When asked if they would use the site again, four reported that they were unlikely to, with the remainder either likely to or definitely would, although five respondents said they were more likely to use the desktop version, pre or post visit.

Although limited in its scope we are able to draw some useful conclusions from this evaluation. Firstly, that the mobile interface to the *Mapping* database posed no serious usability problems for those who have a smartphone. The vast majority of users were able to access the site and use its main functions without assistance. The possibility of large numbers of overseas visitors and the clear recommendation for institutions wishing to provide mobile access is to invest in Wi-Fi connections unless a strong and reliable signal is available. Wi-Fi also brings the benefit of higher bandwidth than 3G and avoids visitors using up their data allocation. Another noteworthy feature is the use of QR codes, although only four visitors used these in the evaluation, the usefulness of them was picked up in follow-on comments. Since the evaluation took place

the use of QR codes across a wide range of print media has become commonplace and greater use of these could provide the crucial link between the physical object and its online records.

The second stage of the evaluation involved the analysis of a variety of statistics from the *Mapping Sculpture* web site collated by Google Analytics. Unlike the qualitative evaluation of users, Google Analytics provides a wide range of quantitative measures of the *Mapping Sculpture* web site use. Over the period 1 March 2011, shortly after the site was launched, to the 30 April 2012, the *Mapping Sculpture* website has received 75,933 visits. 60,413 of these visitors were unique, resulting in over 200,000 page views. The split between new and returning visitors is 80% to 20%. Monthly site use has grown from 1,149 visits in its first month to 7,394 visits during April 2012. On average, users view 2.68 pages per visit with average visit lasting 1 minute and 40 seconds. Perhaps not surprisingly, the vast majority of visitors are from the UK (68%) but the site is also attracting visitors from the USA, Australia, Canada, Ireland, France, Germany, Italy, New Zealand, The Netherlands and beyond. 4,850 of the total number of visits were from mobile phones, with use continually rising to 733 visits per month during April 2012. Interestingly, over 40% of these visits are from the Apple iPad rather than a mobile phone, evidence of the rapid adoption of tablet devices.

In absolute terms these figures are very encouraging, but establishing a benchmark by which to judge them is very problematic. No two web sites are the same and even amongst more specialist academic sites there are few direct comparators with published Web statistics. Looking at some of the trends in more detail reveals the visitor flow within the site. 42% of visitors

arrive on a ‘person’ page, not surprising as it the database was built around people first and foremost. This is followed by organizations at 19%, 15% for places, 6.2% events and 4.6% for references. The remaining percentage is largely taken up by visitors who land at the home page first. As 85% of visitors arrive at the site from a Google search (only 5.8% arrive from a direct link to the Web site) these figures demonstrate that Google is effective in indexing the *Mapping Sculpture* Web pages and returning them as search results.

We can also follow users further through the web site by tracking their interactions following the first page they land on. For users who start on a person page 12% visit an object page next, 9% a reference page, 9% a search page, 8% to browse, 20% go to another type of page, most commonly the about page, but also search pages and pages on organizations and events. Visitors who start on a person page have the highest level of drop-off, with 42% not accessing another page.

If we compare this with visitors who start on an organization page, the next most common starting point, 26% go on to view an object page, 19% to search, 19% to view a reference, 17% to browse and 13% to a person page. There is only a 6% visitor drop-off from those who start on an organization page. A possible explanation for the different patterns of drop-off from the people and organization pages is genealogical research. Visitors engaged in genealogical research are perhaps less likely to delve deeper into the data: much of the information they seek is likely to be contained on the page devoted to the person in question. Of course, raw Web statistics can’t confirm this and further qualitative research on visitors information seeking behavior would be required.

If one looks at the second level of interaction (the third page users visit) the most popular are person pages, accounting for 44% of interactions, followed by organizations at 11%, references at 9%, places at 8%, events at 6% and a 22% drop-off rate. Untangling the flows through the *Mapping* Web site suggests a couple of typical routes through. Firstly, Person > Object > Person > Object. Looking at the ID numbers for the pages at each interaction stage suggests visitors are looking at different people and objects at each stage. The second pattern appears to be Organization > Reference > Organization > reference, again with visitors looking at different organizations.

Conclusion

The *Mapping Sculpture* project is a technological and methodological success, indeed the two are intertwined to such an extent that one can suggest that the technology is the methodology and vice versa. Secondly, in developing the mobile interface intriguing possibilities for new forms of engagement and the relationship between physical objects and their histories are opened up. It is too early to tell to what extent these will bear fruit, but there are tantalizing glimpses that this might happen. Thirdly, although further evaluation over a longer period of time would be required to establish the full impact of the project, the accompanying papers in this volume are already good evidence that the *Mapping Sculpture* project is not only an effective tool, but also a good lens through which new research perspectives can be shared.

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[1] M. Greenhalgh, 'Art History', in S. Schreibman, R. Siemens and J. Unsworth (eds.) , *A Companion to Digital Humanities,* Oxford, Blackwell, 2004, p. 31.

[2] S. Berner, 'Digitus Dei ist hic!', *South African Journal of Information Management,* Vol.9(4) December 2007.

[3] Greenhalgh as at note 1, p. 39.

[4] http://www.gla.ac.uk/departments/hatii/

[5] A. McHugh, *DCC Digital Curation Manual, Installment on "Open Source for Digital Curation",* Digital Curation Centre, 2005, http://www.dcc.ac.uk/resource/curation-manual/chapters/open-source/ [accessed 17th May 2012]

[6] The Apache web server, on which the *Mapping Sculpture* sites run, is a prime example of widely adopted open source software, powering an estimated 65.24% of the world's top web servers (*March 2012 Web Server Survey*, Netcraft, http://news.netcraft.com/archives/2012/03/05/march-2012-web-server-survey.html [accessed 16th May 2012])

[7] http://en.wikipedia.org/wiki/3G

[8] S. Leon et al., *Mobile for Museums*, Center for History and New Media, George Mason University, 2009. http://chnm.gmu.edu/labs/mobile-for-museums/

[9] http://www.imamuseum.org/blog/2009/09/01/an-early-look-at-tap/

[10] http://www.allmedia.it/

[11] *The Communications Market Report: UK*, Ofcom, 2011, p. 15. http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr11/UK_CMR_2011_FINAL.pdf

[12] G. Patterson, *Mobile Consumer Trends 2011*, MobileSquared, 2011, p. 3. http://mobilesquared.co.uk/pdfs/mobileconsumertrends2011.pdf

[13] Ofcom as at note 14, p. 8. The small discrepancy with the 27% smartphone ownership is perhaps due to ownership of 'featurephones' which are capable of accessing the Internet, but are not considered smartphones.

[14] Patterson as at note 15, p. 6.

[15] Patterson as at note 17.

[16] Ofcom as at note 14, p. 48.

[17] *The Communications Market Report 2010*, Ofcom, 2010, p. 293.

[18] Ofcom as at note 20.

[19] http://www.victorianweb.org/sculpture/palliser/index.html

[20] http://en.wikipedia.org/wiki/John_Birnie_Philip

[21] http://lucian.uchicago.edu/blogs/vrc/2011/06/07/mapping-the-sculpture-of-britain-and-ireland/

[22] http://www.rootschat.com/forum/index.php/topic,537227.0.html

[23] Quick Response Code - a two dimensional bar code of small black squares on white background that can be read quickly and can store a large amount of information. They are increasingly used to access web sites by users 'scanning' them with their mobile phone.